16th European Conference on Antennas and Propagation | 27 March - 01 April 2022 | Madrid, Spain | European Association on Antennas and Propagation

Application Tracks and Acronyms - Legend

T01 LTE and Sub-6GHz 5G	T02 Millimetre wave 5G	T03 Wireless LANS, IoT and M2M	T04 Biomedical and health	T05 Aircraft (incl. UAV, UAS, RPAS) and automotive	T06 Defence and security
T07 Positioning, localization & tracking	T08 Space (incl. cubesat)	T09 EM modelling and simulation tools	T10 Fundamental research and emerging technologies	T11 Industrial Workshops	T12 Scientific Workshops
CS: Convened Session	SW: Scientific Workshop	IW: Industrial Workshop	SC: Short-Course		
A: Antennas	E: Electromagnetics	P: Propagation	M: Measurements		

All times are in local Madrid time (CET)

Time	Auditorium	Paris	Madrid	Berlin	Bogotá	La Paz	Montevideo	Londres	Roma	Amsterdam	Caracas	Buenos Aires
Monday, March 28												
09:30-10:30	*Opening Plenary*											
10:30-11:15	*Keynote 1: Wen Tong*											
11:15-12:00	*Keynote 2: Andrea Alu*											
12:00-12:45	*Keynote 3: Carlos Montesano*											
12:45-14:00	*Lunch / Exhibition*											
14:00-16:00	CS29: *MIMO Antennas for 5G applications*	CS13: *Antennas in severe environments for space and defense applications*	CS09: *Antenna and Beamforming Technology for 5G and Beyond*	CS01: *Advanced RFID Systems and Methods for IoT and Smart Industry*	CS28: *Microwave/millimeter-wave imaging towards real-time medical applications*	A18: *Automotive antennas*	CS27: *Metasurfaces and Reconfigurable Intelligent Surfaces to Tailor Radio Propagation: Modeling, Applications, Prospect*	CS23: *Fundamental challenges and novel methodologies in the next-generation computational electromagnetics*	IW02: *One6G view on propagation models/measurements and antennas for next generation MIMO systems*	CS03: *Advances in Additive Manufacturing/3D Printing; Novel Materials & Metamaterial Structures*	CS19: *COST Session CA18223 (SyMat): Theory and Modeling of Higher Symmetries*	
16:00-16:30	*Coffee Break / Exhibition*											
16:30-17:30	CS42: *Towards-6G Joint Communication and Sensing in Radio Propagation Perspectives*	A01: *Adaptive and reconfigurable 5G Antennas*	CS25a: *IET/IRACON Propagation measurements and modelling for 5G and beyond Part 1*	CS01b: *Advanced RFID Systems and Methods for IoT and Smart Industry (continued)*	M01: *Body and biological tissues propagation measurements*	CS40: *Recent Advances on Propagation Research and Its Impact on Localizations*	CS31: *New Antenna Systems involving Application of Metamaterials and Metasurfaces*	CS23b: *Fundamental challenges and novel methodologies in the next-generation computational electromagnetics (continued)*	IW10: *Recent advances in the design and optimisation of blended rolled edge compact antenna test ranges*	CS03b: *Advances in Additive Manufacturing/3D Printing; Novel Materials & Metamaterial Structures (continued)*	CS33: *Novel Antenna Measurement Techniques and Data Analysis*	*EuCAP 2023 LoC meeting*
17:30-18:30									IW12: *IW12: Dassault*			
18:30-20:00	*Welcome Reception*											

Time	Auditorium	Paris	Madrid	Berlin	Bogotá	La Paz	Montevideo	Londres	Roma	Amsterdam	Caracas	Buenos Aires
Tuesday, March 29												
09:00-10:40		CS17: *Challenges and Solutions of Radio Frequency Testing for advanced 5G Radio Systems*	CS25b: *IET/IRACON Propagation measurements and modelling for 5G and beyond Part 2*	CS30: *Modeling, analysis and design methods for antennas in IoT applications*	CS35: *Preclinical and clinical results of medical microwave imaging systems*	CS04: *Airborne SATCOM on the Move. SOTM*	CS41: *Space-fed antenna systems for SATCOM and high-performance communication systems*	E05: *Modelling and simulation of frequency/polarization selective surfaces and periodic structures*	IW09: *Design of active receiving antennas (AIRBUS)*	CS26: *ISAP session: Recent Advances in Asian Antennas and Propagation Research*	CS39: *Radar Imaging through Obscuring Layers*	IW05: *Simcenter 3D for Electromagnetics: update on new capabilities for antenna design, array design, system integration and environment modelling*
10:40-11:00	*Coffee Break / Exhibition*											
11:00-12:40		CS17b: *Challenges and Solutions of Radio Frequency Testing for advanced 5G Radio Systems (continued)*	CS25c: *IET/IRACON Propagation measurements and modelling for 5G and beyond (Part 2 continued)*	CS30b: *Modeling, analysis and design methods for antennas in IoT applications (continued)*	E02: *Imaging for biomedical applications*	CS05: *AMTA Convened Session: Automotive Performance Testing for Connected and Automated Driving in Simulated Real-World Environments*	CS41b: *Space-fed antenna systems for SATCOM and high-performance communication systems (continued)*	E06: *Modelling and simulation of metasurfaces*	IW01: *Analysis and Design of Advanced Antenna Systems using TICRA Tools*	CS26b: *ISAP session: Recent Advances in Asian Antennas and Propagation Research (continued)*	A20: *Security applications & imaging*	*ROE meeting*
12:40-13:30	*Lunch / Exhibition*											
13:30-14:00		*Poster Session Tuesday*										
14:00-15:00												*AMTA-EurAAP Meeting*
15:00-16:20		*Invited Speakers: Andrea Neto and Natalia Nikolova*							*Invited Speakers: Michael Havrilla & Christian Bornkessel*			
16:20-16:40	*Coffee Break / Exhibition*											
16:40-18:20		P10: *Propagation for LTE and sub 6GHz 5G*	A04: *Antennas for mm-wave 5G*	A30: *Emerging technologies for WLAN, IoT and M2M antennas*	P05: *Propagation for medical applications*	A19: *Aircraft antennas*	E03: *Frequency/polarization selective surfaces for space applications*	E10: *Emerging applications of metasurfaces and metamaterials*	IW04: *Cutting-edge PWG and Applications from VHF to mmWaves Bands*	A11: *Additive manufacturing*	CS11: *Antennas and Propagation for Wireless Power Transfer & Harvesting in Space*	*EurAAP DA meeting*
18:20-18:40												

Time	Auditorium	Paris	Madrid	Berlin	Bogotá	La Paz	Montevideo	Londres	Roma	Amsterdam	Caracas	Buenos Aires
Wednesday, March 30												
09:00-10:40		A03: *Wideband Antennas for 5G*	CS02: *Advancements and Challenges on Measurement Techniques for 5G and Beyond*	A12: *Antennas for Wireless & IoT applications*	CS16: *Biomedical Microwave Techniques and Devices: from Diagnosis to Treatment*	CS07: *AMTA Convened Session: UAV-based Antenna and Field Measurements*	P04: *Satellite propagation I*	A27: *Computational EM for antenna analysis*	IW11: *From antenna design and placement to RF propagation and Co-site interferences: meet the latest challenges with Altair*	CS24: *Future trends in reflectarray synthesis and analysis for communications and sensing*	*Special Session In Memoriam Prof. Jørgen Bach Andersen*	
10:40-11:00	*Coffee Break / Exhibition*											
11:00-12:40		A02: *Antenna design and technologies*	CS02b: *Advancements and Challenges on Measurement Techniques for 5G and Beyond (continued)*	CS10: *Antenna Systems for Wireless Power Transmission and RF Energy Harvesting*	CS16b: *Biomedical Microwave Techniques and Devices: from Diagnosis to Treatment (continued)*	CS07b: *AMTA Convened Session: UAV-based Antenna and Field Measurements (continued)*	P09: *Satellite propagation II - modelling*	E07: *Computational EM in frequency domain*	IW03: *Advanced antenna simulation methods for new communication systems with Ansys*	CS24b: *Future trends in reflectarray synthesis and analysis for communications and sensing continued*	SW01: *First edition of EurAAP Journal: Reviews of EurAAP-RoE*	
12:40-13:30	*Lunch / Exhibition*											
13:30-14:00		*Poster Session Wednesday*										
14:00-15:00												*Characteristic Modes Special Interest Group (CM-SIG)*
15:00-16:20			*Invited Speakers: Juan Mosig and Ke Guan*						*Invited Speakers: Guy Vandenbosch & Sean Victor Hum*			
16:20-16:40	*Coffee Break / Exhibition*											
16:40-17:30		P08: *Experimental methods and campaigns for mm-wave and above*	A05: *Arrays for Millimetre wave 5G*	A14: *Electrically small antennas*	A17: *Implantable antennas*	P07: *Aerial and vehicular propagation*	A25: *Antennas for small satellites*	A26: *EM modelling and simulation of antenna arrays*	IW07: *Outdoor antenna measurements using UASs*	A09: *Reflectarrays and transmitarrays*	SW04: *EurAAP Women in Antennas and Propagation*	
17:30-18:20												*Measurements WG meeting*
18:20-18:30												

Time	Auditorium	Paris	Madrid	Berlin	Bogotá	La Paz	Montevideo	Londres	Roma	Amsterdam	Caracas	Buenos Aires
Thursday, March 31												
09:00-10:40		A10: *Adaptive and MIMO antennas*	CS36: *Progress in sub-THz and THz channel characterization*	CS32: *New trends in small antennas*	A16: *Wearable antennas*	CS37: *Propagation of Smart Mobility empowered by 5G and Beyond*	CS34: *Passive beamforming networks for multi-beam antennas*	CS08: *AMTA Post Processing Techniques in Antenna Measurements*	IW06: *Modern Trends in RF Measurement Range Design*	E08: *Fundamental research in EM theory*	SW03: *Active Array Antennas*	
10:40-11:00	*Coffee Break / Exhibition*											
11:00-12:40		E01: *Metasurfaces for millimeter-wave 5G and 6G*	CS36b: *Progress in sub-THz and THz channel characterization continued*	CS32b: *New trends in small antennas (continued)*	SW05: *General standardisation and the Antenna measurement standards (std1270)*	CS37b: *Propagation of Smart Mobility empowered by 5G and Beyond (continued)*	A23: *Antenna feeds for space reflectors*	CS08b: *AMTA Post Processing Techniques in Antenna Measurements (continued)*	IW08: *Efficient EM design of phased array frontends at IMST*	E09: *Fundamental research in optimization and machine learning*	SW03b: *Active Array Antennas (continued)*	*Active array antennas WG meeting*
12:40-13:30	*Lunch / Exhibition*											
13:30-14:00		*Best Paper Awards - Poster Session*			*Poster Session Thursday*							
14:00-15:00												*Propagation WG meeting*
15:00-16:00		*Invited Speakers: Wonbin Hong & Matthias Geissler*							*Invited Speakers: Alenka Zajic & Danielle Vanhoenacker-Janvier*			
16:00-16:20												
16:20-16:40	*Coffee Break / Exhibition*											
16:40-18:20		P06: *Mm-wave and UWB propagation*	A06: *mm-Wave antennas*	M04: *Material characterization*	SW05b: *General standardisation and the Antenna measurement standards (std149)*	A21: *Antennas for localization and tracking*	A24: *Earth observation antennas*	M03: *Data acquisition, imaging algorithms and measurement post-processing*	CS22: *EuMA-EurAAP joint session: Towards a Smart EM Environment - Network and Hardware perspectives*	A28: *Fundamental research on antennas*	A29: *Emerging Antenna techonologies*	*ESoA meeting*
18:20-18:40												

Time	Auditorium	Paris	Madrid	Berlin	Bogotá	La Paz	Montevideo	Londres	Roma	Amsterdam	Caracas	Buenos Aires
Friday, April 1												
09:00-10:40		P01: *Propagation Modelling*	A07: *Sub-mmWave antennas for B5G & 6G*	CS43: *Unconventional techniques and applications for Inverse scattering problems*	CS15: *Assessment and modeling of antennas and radio channels jointly with increasing complexity/variability*	A22: *GNSS Antennas*	M02: *Satellite and aerospace antenna characterisation*	E04: *Optimization and machine learning in EM and antenna design*	CS14: *Artificial Intelligence for Antennas and Propagation: Current Trends and Emerging Applications*	CS18: *COST CA18223 (SyMat): Applications of artificial materials with higher symmetries*	SW02: *AMTA Scientific Workshop: Expanding the Limits - Antenna Metrology Using UAVs*	
10:40-11:00	*Coffee Break / Exhibition*											
11:00-12:40		P02: *Machine learning for propagation*	A08: *Lenses above 100 GHz*	CS43b: *Unconventional techniques and applications for Inverse scattering problems (continued)*	CS21: *Enhanced Capabilities of Characteristic Mode Analysis for Novel Applications*	P03: *Propagation for radar and sensing*	CS12: *Antennas for Radio Astronomy*	CS06: *AMTA Convened Session: Recent Advances in Test Chamber and Range Modeling, Design, Echo Reduction and Characterizations*	CS14b: *Artificial Intelligence for Antennas and Propagation: Current Trends and Emerging Applications (continued)*	CS18b: *COST CA18223 (SyMat): Applications of artificial materials with higher symmetries (continued)*	SW02b: *AMTA Scientific Workshop: Expanding the Limits - Antenna Metrology Using UAVs*	
12:40-13:40			*Closing Ceremony*									
14:00-18:00		*Short Courses*										

Monday, March 28

Monday, March 28 9:30 - 10:30

Opening Plenary

Monday, March 28 10:30 - 11:15

Keynote 1: Wen Tong

Chairs: Jose A. Encinar (Universidad Politecnica de Madrid, Spain), Manuel Sierra-Castañer (Universidad Politécnica de Madrid, Spain)

10:30 ***Future Massive MIMO Antenna Technologies for 5G and 6G***

Wen Tong (Huawei Technologies Canada Co., Ltd., Canada)

In this talk, we present the development of massive MIMO antenna technologies for the 5G and associated challenges. The overall system performance and antenna design-choice in terms of spectrum and channel propagation properties are discussed. In particular, we further present the novel massive MIMO antenna design to achieve higher capacity with same antenna aperture size and the field trial results. We also discuss the directions for the evolution of massive MIMO antenna for 6G.

Monday, March 28 11:15 - 12:00

Keynote 2: Andrea Alu

Chairs: Jose A. Encinar (Universidad Politecnica de Madrid, Spain), Manuel Sierra-Castañer (Universidad Politécnica de Madrid, Spain)

11:15 ***Extreme Wave Phenomena Based on Metamaterials***

Andrea Alù (CUNY Advanced Science Research Center, USA)

Metamaterials are artificial materials with electromagnetic properties that go well beyond what offered by nature, providing unprecedented opportunities to tailor and enhance the interaction between waves and matter. In this talk, I discuss our recent research activity in this area of technology, with special emphasis on the opportunities offered by metamaterials for wireless, radio-frequency and mm-wave applications. In particular, I will discuss how suitably tailored meta-atoms and careful arrangements of them can open exciting venues to manipulate and control electromagnetic waves in unprecedented ways. I will discuss our recent work on metamaterials for scattering suppression applied to antenna technologies, metasurfaces to control wave propagation and radiation in extreme ways, circulators and isolators that do not require a magnetic bias, and active metasurfaces for next-generation wireless systems. Physical insights into the exotic phenomena underlying these device functionalities, new technologies based on these concepts, and their practical impact will be discussed during the talk.

Monday, March 28 12:00 - 12:45

Keynote 3: Carlos Montesano

Chairs: Jose A. Encinar (Universidad Politecnica de Madrid, Spain), Manuel Sierra-Castañer (Universidad Politécnica de Madrid, Spain)

12:00 ***New Antennas for Satellite Communications and Earth Observation***

Carlos Montesano (EADS-CASA Espacio, Spain)

Antennas are the ears and eyes of the satellites and allows them to communicate and deliver the information to the users. There is an historical trend to improve the efficiency of satellite antennas in all aspects. Larger sizes, more power handling, lower passive intermodulation, more flexibility and adaptability are required and always taking into account the special needs of space applications. Satellite antennas need to keep all performances in a very harsh environment including extreme temperatures, high radiation and launch loads, all with a minimum mass and compact enough to be fitted into the launchers fairing. Satellite antennas have large differences depending on the orbit of the application, from Low Earth Orbit (LEO) to interplanetary missions. A look around different applications and orbits will be presented showing the latest trends in the different solutions that are used.

Monday, March 28 12:45 - 14:00

Lunch / Exhibition

Monday, March 28 14:00 - 16:00

CS29: MIMO Antennas for 5G applications

T01 LTE and Sub 6GHz 5G/ / Antennas

Chairs: Biswajeet Mukherjee (Indian Institute of Information Technology, Design & Manufacturing, Jabalpur, India), Jayanta Mukherjee (Indian Institute of Technology Bombay, India)

14:00 ***Low Profile Three Element Half Cylindrical Dielectric Resonator Antenna for MIMO Application***

Monika Chauhan (IIITDM & Jabalpur, India); Biswajeet Mukherjee (Indian Institute of Information Technology, Design & Manufacturing, Jabalpur, India); Anil Rajput (PDPM IIITDM Jabalpur, India)

A low profile three element half cylindrical dielectric resonator antenna with Multiple Input Multiple Output (MIMO) application is demonstrated. Antenna element and the feeding scheme is arranged orthogonally in space to minimize mutual coupling between antenna elements. This antenna arrangement offers space diversity with radiation pattern diversity. Proposed antenna is fabricated and experimentally verified. Rogers TMM10 (εr = 11.2), a low loss dielectric material is used to fabricate the antenna. Antenna offers a close agreement between simulated and measured results. Proposed antenna element DRA-1 offers 9 - 11.1 GHz, DRA -2 offers 9.2 - 10.6 GHz and DRA -3 offers 8.7 - 11.6 GHz frequency band of operation respectively. It offers 8.3 dBi peak gain at 10 GHz frequency and more than 80% radiation efficiency over the operating frequency range.

14:20 ***Frequency-Bandwidth Dependent Degrees of Freedom as a Bound of Super-Directivity***

Laura Passalacqua, Cristina Yepes, Enrica Martini and Stefano Maci (University of Siena, Italy)

The Degrees of Freedom (DoF) of the radiated field are linked to the MIMO antenna design, since the DoF represent an upperbound for the effective number of degrees of freedom of a MIMO channel and also they represent a limit to the number of users in multi-user MIMO communications. The DoF are normally defined at a certain distance from a minimum surface enclosing the sources, so that the reactive field is negligible. This paper suggests an extension of the DoF concept to include a dependency on the frequency bandwidth, and a process for its calculation. This is done by introducing the ratio between the reactive energy stored in the vicinity of the radiating surface and the radiated power as a measure of the source frequency bandwidth. The problem is here treated analytically for a spherical source region by using spherical wave harmonics.

14:40 ***Triple-Band Quad-Element Polarization/Pattern Diversity Directional MIMO Antenna for Sub-6 GHz Application***

Jogesh Chandra Dash (Indian Institute of Science Bangalore, India); G Shrikanth Reddy (IIT Mandi, India); Nagalakshmaiah Kalva and Jayanta Mukherjee (Indian Institute of Technology Bombay, India)

This paper presents a sequentially rotated quad-element, triple-band MIMO antenna, operating in the sub 6 GHz frequency bands. The individual antenna elements have three resonant frequencies at 3.74, 4.87, and 5.87 GHz, with a frequency separation ratio of 1:1.3:1.56. The three frequency bands are achieved using an inverted F shaped structure connected to a rectangular microstrip patch, with a slot along the width of the patch. The antenna elements have an edge-to-edge gap of 1.9 mm. The achieved isolation between the antenna elements is more than 20 dB and 15 dB respectively at adjacent and diagonal element over all three frequency bands. The proposed quad-element antenna provides a gain of 6.73, 6.06, and 5.83 dBi and efficiency of 84.6%, 80%, and 88% at 3.74,

4.87, and 5.87 GHz, respectively. The ECC, TARC and CCL values are less than 0.05, -10 dB, and 0.5 bits/s/Hz respectively over all three bands.

15:00 ***Multibeam Binomial MSA Array for Sub-6 GHz Application***

Anamika Verma (Indian Institute of Technology, Bombay, India); Mahima Arrawatia (IIT Guwahati, India); Girish Kumar (IIT Bombay, India)

A planar multi-beam microstrip antenna (MSA) array with low SLL is presented in this paper. The beam forming network is integrated with a 11x5 MSA array to form a low profile multi-beam antenna array design. Each linear array is fed by multiple meandered feed lines, which provide desired phase shift for beam-forming. The multi-beam antenna elements are tapered with binomial distribution to suppress SLL below -20dB in E-Plane. The array generates five beams and the individual gain of the beams are 14, 15, 14.5, 14.4, 12 dBi at 3.42 GHz. The |S11| less than equal to -10dB impedance bandwidth of all the ports is from 3.3-3.5 GHz and the isolation between consecutive ports is better than 20 dB for most of the bandwidth.

15:20 ***High Isolation Wideband SICL Excited Compact MIMO Antenna Array for 5G Endfire Applications in Customer Premises Equipment***

Naman Baghel and Soumava Mukherjee (Indian Institute of Technology Jodhpur, India)

This paper presents SICL fed wideband MIMO antenna array for 5G endfire applications. The radiating element in the array is a modified dipole antenna formed by titled at ±45degree to avoid overlapping between successive element in the array configuration. One arm is placed on the top while the other arm is placed on the bottom substrate and are respectively fed by top and middle plate (using a feeding via) of SICL line. The top-bottom arrangement of the arms of dipole antenna enables further compactness in the dimension of the array. SICL technology adds another advantage by reducing the coupling in the other port when one port is excited thereby high isolation is achieved using SICL. A four element MIMO antenna array for 360degree azimuth coverage is proposed to exhibit a gain of 6 dBi with wide impedance bandwidth of 5.6 GHz and cross-polarization level below 13.6 dB at 28 GHz.

CS13: Antennas in severe environments for space and defense applications

T06 Defence and Security/ / Antennas

Chair: Loic Bernard (ISL & IETR, France)

14:00 ***Hybrid Active Antennas for Telecom Applications***

Carolina Tienda, Sonya Amos, Glyn Thomas, Stephen Laws and David Dupuy (Airbus Defence and Space, United Kingdom (Great Britain))

This paper presents some of the last solutions studied to fulfill the flexibility and high capacity demand of complex Very High Throughput and Government Satellites. A description of the concept and two antenna samples have been included.

14:20 ***A Metal-Only Reflectarray Made of 3D Phoenix Cells***

Zhihang AN (INSA Rennes, France); Tony Makdissy (IJL, Université de Lorraine, France); María García-Vigueras (IETR-INSA Rennes, France); Sébastien Vaudreuil (Euromed University of Fes, Morocco); Raphael Gillard (IETR & INSA, France)

This paper presents a metal-only reflectarray antenna made of 3D phoenix cells and its fabrication using additive manufacturing. An electric circuit is proposed for analyzing the behavior and capabilities of the considered cell. The agreement between full-wave simulations and the circuit predictions is very satisfactory when varying the cell geometrical parameters on a large range of values. The simulated gain of the designed reflectarray at 20 GHz is 30.3 dBi with an efficiency of 50.33% and a 1 dB-gain bandwidth of 10.75%. The proposed reflectarray is suitable for working in severe environments due to its metal-only characteristics.

14:40 ***Design of High Gain and High Steering Angle Matrix Antenna for Electronic Warfare Application***

Paul Karmann (XLim & ITHPP, France); Edson Martinod, Joel Andrieu and Mohamad Majed (University of Limoges, France); Mohamad Rammal (ITHPP, France)

This article presents a matrix antenna operating in the L-band and designed for signal jamming applications. The matrix, composed of pixel elements is reduced to 0.31*lambda at 1.2 GHz by filling the cavity with a dielectric. This allows the matrix to achieve a wide bandwidth of 1.21 GHz to 1.6 GHz. The maximum steering angle achieved over the whole band is 70° while maintaining side-lobes levels lower than -9.3 dB and a stable gain.

15:00 ***Evolution of the NISAR Feed Antenna Design Due to Environmental Requirements***

Paolo Focardi (Jet Propulsion Laboratory & California Institute of Technology, USA); Joseph Vacchione (Jet Propulsion Laboratory, USA)

NISAR is an Earth science project currently in its final development phases at NASA Jet Propulsion Laboratory (JPL) and at ISRO. Due for launch in 2023 it will assess how our planet changes over time by measuring differences in the Earth's solid surface due to factors like climate change, movement and melting of glaciers, earthquakes, land-slides, deforestation, agriculture and others. The

enabling instrument for this mission is a dual band radar (L-Band and S-Band) that feeds a 12m deployable mesh reflector. Given the extreme accuracy needed to perform these measurements from Low Earth Orbit (LEO) some of the most stringent requirements were pushed onto the antenna subsystem to control phase and gain stability over time. In this paper we describe how environmental requirements affected the antenna design and what techniques were used to meet these requirements.

15:20 ***UHF Wideband Antenna Design for AUV Applications***

Steven Verwer and Kirill Alekseev (Eindhoven University of Technology, The Netherlands); Robert Engel (Atlas Elektronik GmbH, Germany); Ulf Johannsen (Eindhoven University of Technology, The Netherlands)

Autonomous underwater vehicles (AUVs) gain increasing popularity in the underwater domain. They are particularly suitable for carrying out surveys in areas where manned operation is too dangerous or too expensive, examples being deep sea environments or naval mine clearing operations. However, to make full use of their capabilities, a communication link between AUV and its host platform is necessary. This paper proposes a design for an ultra high frequency (UHF) wideband antenna that can be mounted on mid-sized AUVs. The antenna covers the entire naval UHF frequency band from 225MHz to 400MHz with a reflection coefficient lower than -10dB and an omni-directional radiation pattern. Water effects are taken into account in both, simulations and measurements indicating a stable antenna performance.

15:40 ***Nonlinear Effects of Electromagnetic Pulse on Plasma-Based Electrically Small VHF Antenna***

Adrien Laffont (CEA, DAM, CEA-Gramat, France); Jean-Pierre Adam (CEA, France); Thierry Callegari, Laurent Liard and Olivier Pascal (Université de Toulouse - UPS INPT CNRS, France); Romain Pascaud (ISAE-SUPAERO, Université de Toulouse, France)

Demonstration of the electromagnetic hardening properties of a plasma-based electrically small VHF antenna is presented in this paper. It is shown that when illuminated by an electromagnetic pulse, the maximum voltage collected by the antenna grows linearly with the maximum magnitude of the incident electric field, but beyond a certain threshold around 70 kV/m, the maximum voltage collected ceases to grow linearly and seems to saturate around a value of 200 V.

CS09: Antenna and Beamforming Technology for 5G and Beyond

T02 Millimetre Wave 5G and 6G/ / Antennas

Chairs: Qammer H Abbasi (University of Glasgow, United Kingdom (Great Britain)), Álvaro F. Vaquero (Universidad Politécnica de Madrid & Information Processing and Telecommunications Center, Spain)

14:00 ***Can a mmWave 5G Handset Provide Quasi-Omnidirectional Coverage?***

Cheng Wang, Christopher P Larmour and Vincent Fusco (Queen's University Belfast, United Kingdom (Great Britain)); Muhammad Ali Babar Abbasi (Queen's University Belfast & The Institute of Electronics, Communications and Information Technology (ECIT), United Kingdom (Great Britain))

This paper presents three handset antenna array configurations when each array is 1×4, with a capability of multiple steering angles at an operating frequency of 28GHz. The purpose is to maximize the overall achievable directivity to provide quasi-omni-directional coverage to the handset in millimeter wave (mmWave) 5G frequency bands. Generally, radiation fields from a mmWave antenna suffer high and low directivity regions that severely impact the mmWave 5G service quality. The main objective of this paper is to investigate thoroughly and provide a practical yet simple solution to this problem and ensure close to 100% coverage of a mmWave 5G handset antenna. Antenna array design and investigation around a mobile handset are studied in MATLAB, where combined (resultant) radiation patterns have been numerically calculated as a response of different antenna positions. As commonly used, a standard patch antenna is considered as the handset antenna array unit-cell while cardioid radiation pattern of the single antenna is used for analysis. An overall directivity larger than 0 dB is targeted all around the handset. The result shows that more than 95% of the spherical region can be covered with as low as 6 or 7 steering angle states when used with the proposed antenna array architecture and placement. This investigation focuses only on the handset in free space, while the same investigative approach can be extended for other scenarios like handset in the hand, or handset close of the head, etc.

14:20 ***Phase Reconfiguration via SIW Structures Filled with Liquid Metal***

Shaker Alkaraki (Queen Mary University Of London, United Kingdom (Great Britain)); Alejandro L. Borja (Universidad de Castilla-La Mancha, Spain); James Kelly (Queen Mary University of London, United Kingdom (Great Britain)); Syeda Fizzah Jilani (Aberystwyth University & Queen Mary University of London, United Kingdom (Great Britain)); Raj Mittra (University of Central Florida, Turkey); Yue Gao (University of Surrey, United Kingdom (Great Britain))

This paper presents substrate integrated waveguide (SIW) phase shifter that can be reconfigured using liquid metal. The phase shifter is developed to be used for antenna applications. This digital phase shifter incorporates a series of holes which can be filled or emptied of liquid metal, enabling us to add or remove via connections dynamically, on-the-fly. We employ a switched line approach to achieve course phase control along with reactive loading to achieve fine steps of phase control. By employing both forms of reconfiguration in unison the proposed phase shifter is able to deliver a

phase shift of up to 180° in steps of 10°. The proposed phase shifter operates at 10 GHz and exhibits a measured insertion loss of less than 2.3 dB over its entire operating band.

14:40 ***Path-Loss Modelling and Scalloping Aspects in Intelligent Reflecting Surface Assisted Communication: A Method-Of-Moment Analysis***

Debdeep Sarkar (Indian Institute of Science, India); Yahia Antar (Royal Military College of Canada, Canada)

In this paper, we critically examine the frequency dependent path-loss characteristics and impacts of multiple additional side-lobes in the radiated beams (i.e. scalloping) in an IRS (intelligent reflecting surface) assisted SISO (single-input single-output) communication link. Using Method-of-Moment based MATLAB Antenna Toolbox, we analyze a system of two half-wavelength thin-wire dipoles placed near a planar IRS comprising of circular thin-wire loops. We showcase that, besides the IRS aperture size, the IRS unit-cell dimensions also play a crucial role in shaping the frequency dependent path-loss features. Considering the transmitter and IRS as a unified radiator, we further highlight the importance of properly accounting for multiple additional lobes appearing in the radiating beam due to presence of large reflector, which can cause ripple like variation in the path-loss characteristics. Finally, we demonstrate the significant impact of IRS positioning with respect to the transmit-receive system in altering the frequency dependent pathloss behaviour.

15:00 ***3D Printed Slotted Waveguide Antenna Array for Millimeter-Wave Communication Systems***

Zia Ullah Khan (Queen Mary University of London, United Kingdom (Great Britain)); Shaker Alkaraki (Queen Mary University Of London, United Kingdom (Great Britain)); Qammer H Abbasi and Muhammad Ali Imran (University of Glasgow, United Kingdom (Great Britain)); Tian Hong Loh (UK, National Physical Laboratory, United Kingdom (Great Britain)); Akram Alomainy (Queen Mary University of London, United Kingdom (Great Britain))

This paper introduces a 3D printed slotted waveguide linear antenna array at 28 GHz. The proposed antenna offers the advantages of low fabrication cost and reduced weight compared to the metallic slotted waveguide antenna array. The proposed design can achieve a high gain, low losses, and simplicity with the fabrication. The proposed antenna geometry suggests an operating bandwidth of 15.8% (26.45 GHz - 31 GHz) suitable to fulfil 5G demands with the high gain performance of 12.0 dBi over the operating bandwidth.

15:20 ***Transmitter Considerations for 5G Wireless Powered Sensor Networks***

Adnan Nadeem (Frederick Research Center, Cyprus); David Chatzichristodoulou (RF AND MICROWAVE SOLUTIONS LTD & Frederick Research Center, Nicosia, Cyprus); Hamza Abbas Kiani (Frederick Research Center, Cyprus & National University of Sciences & Technology, Pakistan); Abdul Quddious (KIOS Research and Innovation Center of Excellence, University of Cyprus, Cyprus); Loukia Vassiliou (Agricultural Research Institute, Nicosia, Cyprus); Nosherwan Shoaib (Research Institute for Microwave and Millimeter-Wave Studies (RIMMS) & National University of Sciences and Technology (NUST), Pakistan); Photos Vryonides (Frederick University Cyprus & Frederick Research Center, Cyprus); Symeon Nikolaou (Frederick Research Center & Frederick University, Cyprus)

A two directional scanning conformal array that can be used as transmitter for wirelessly powered sensors, is presented. The array consists of two perpendicular three-element linear arrays that form a cross. Prob-fed square patch antennas form the basic radiating element. The total gain of each array is 9 dBi. Each linear array is conformed around a cylindrical surface and can direct the main beam in three directions; the broadside and two oblique directions that form +/- 37o angle with the broadside direction. In total, the main beam can be directed in 5 distinct directions. The direction can be selected from a microcontroller that provides the DC biasing voltage to the single pole double through (SPDT) switches which are used for the implementation of a phase shifter.

15:40 ***Active, Nonlinear and Time-Varying Metasurfaces for Enhanced Wireless Communications***

Younes Radi and Andrea Alù (CUNY Advanced Science Research Center, USA)

Next-generation wireless communication systems are characterized by stringent requirements in terms of data rates, integrability and reconfigurability. The paradigm of metasurfaces offers an exciting platform to address the associated challenges, especially when considering the opportunity to integrate conventional metasurface elements with active, nonlinear and time-varying components suitably tailored and controlled in real-time to respond to changes in the background. These components can tackle large signal-to-noise ratios, nonreciprocal scattering matrices, real-time reconfigurability and broadband responses, beyond the limitations of conventional communication technologies. By leveraging the latest advances in metasurface technologies and connecting them with the recent progress of the wireless communications and systems community, it may be possible to envision disruptive directions for antenna and beamforming technologies beyond 5G systems.

CS01: Advanced RFID Systems and Methods for IoT and Smart Industry

T03 Wireless LANS, IoT and M2M/ / Antennas

Chairs: Andrea Motroni (University of Pisa, Italy), Smail Tedjini (University Grenoble Alpes, France)

14:00 ***Hyperbolic Positioning and Tracking of Moving UHF-RFID Tags by Exploiting Neural Networks***

Spyros Megalou, Aristidis Raptopoulos Chatzistefanou, Anastasios Tzitzis, Andreana Malama, Traianos Yioultsis and Antonis G Dimitriou (Aristotle University of Thessaloniki, Greece)

In this paper we propose a novel real-time tracking method of a moving UHF-RFID tag. Two antenna pairs fixed at predefined positions monitor the moving tag collecting phase measurements. Phase differences are calculated for each pair and then mapped to distance-differences of the two antennas from the target tag. The intersection of two hyperbolas denotes the position of the tag. Since solving the system of hyperbolas to find the intersection point is not feasible with standard practices, a neural network is exploited to approximate the solution. Compared to prior art, the proposed method does not require knowledge of the tag's initial position or the trace followed (e.g. conveyor belt). Experiments were conducted by placing a tag on a moving robot capable of performing SLAM (Simultaneous Localization and Mapping) to know the ground truth. The results showed a mean error under 0.5m throughout the experimental campaign.

14:20 ***Encoding Strategy to Increase the Data Capacity in Near-Field Chipless-RFID Systems***

Cristian Herrojo (Universitat Autònoma de Barcelona, Spain); Ferran Paredes (Universitat Autonoma de Barcelona, Spain); Ferran Martín (Universidad autónoma de Barcelona, Spain)

In this paper, we propose a novel encoding strategy for chipless-RFID systems based on near-field coupling and sequential bit reading, where the bits are read synchronously. The main purpose of this encoding strategy is to increase the data density per unit length (DPL) and surface (DPS) of the tags, as compared to those data densities achievable with a conventional encoding scheme. Such new encoding uses both the rising and falling edges of a clock signal, generated by the motion of the tag over the sensitive part of the reader. Experimental validation is demonstrated by fabricating and reading two 19-bit tags. Such tags consist of two chains of rectangular metallic patches, whereas the sensitive part of the reader is based on a microstrip transmission line loaded with two different and uncoupled complementary split ring resonators (CSRRs).

14:40 ***Exploiting the Electromagnetic Behavior of UHF-RFID Tags to Improve Worker Safety in Agricultural Workplace***

Andrea Motroni (University of Pisa, Italy); Francesco P. Chietera (University of Salento, Italy); Paolo Nepa and Alice Buffi (University of Pisa, Italy); Riccardo Colella and Luca Catarinucci (University of Salento, Italy); Marco Pirozzi, Luciano Di Donato, Laura Tomassini and Alessandra Ferraro (INAIL, Italy)

This paper presents a safety system based on passive UHF-RFID technology to be applied in agricultural and forest working areas where human workers and remote-control farm machineries operate concurrently. Workers and obstacles are equipped with multiple tags, whereas the machineries carry an on-board RFID reader and an array antenna. An Unscented Kalman Filter, which exploits ranging and Direction of Arrival (DoA) measurements, computes the relative location of worker/obstacle with respect to the machinery. In case of unsafe distance, an alert signal is emitted. The choice of RFID tag typology and configuration has been investigated to guarantee a proper reading accuracy allowing for the best worker/obstacle tracking performance. This smart system is conceived within the SMARTGRID project, in collaboration with INAIL (Italian National Institute for the prevention of accidents at work).

15:00 ***Radio-Frequency Guidance System for Path-Following Industrial Autonomous Guided Vehicles***

Mahmoud Elgeziry, Filippo Costa and Simone Genovesi (University of Pisa, Italy)

Automated Guided Vehicles (AGVs) are mobile robots that are capable of navigating with little or no human intervention. AGVs are found in different fields such as measurements, scanning, and automation. In industry, AGVs are used to improve efficiency and productivity. This growing use of AGVs drives the research towards developing and optimizing navigation accuracy. In this paper, a lateral misalignment radiofrequency sensor for navigation of AGV is presented. The navigation principle is based on laying down a path of resonators that guides the vehicle along the required trajectory. The wireless sensor design presented here can detect deviations from the desired path in the range of 10 cm. However, one of the key features of the proposed sensor is its scalability for different ranges and operating frequencies that may be required in different practical scenarios. The sensing concept was verified using electromagnetic simulations, and finally, a navigation control logic is proposed.

15:20 ***SAW Based Sensing System Coupled to a Thin Flexible Antenna for Biomedical Applications***

Tony Makdissy and Cécile Floer (IJL, Université de Lorraine, France); Omar Elmazria (Université de Lorraine-CNRS, France); Sami Hage-Ali (Université de Lorraine, France)

Herein we present a compact sensing system based on a surface acoustic wave (SAW) device coupled to a thin flexible antenna for health monitoring. The system operates in the 2.4GHz ISM band. It provides interesting radiation characteristics when tattooed on the human skin and preserves a satisfactory behavior even when it is conformed to the deformations of the human body. In addition, the simulations show that the specific absorption rate (SAR) of this system respects the international standards and regulations for RF exposure, which makes it harmless to the human health.

15:40 ***Proof of Concept of Interconnect-Free DRA-SAW RFID Sensing System for Temperature Monitoring***

Tony Makdissy (IJL, Université de Lorraine, France); Omar Elmazria (Université de Lorraine-CNRS, France); Sami Hage-Ali (Université de Lorraine, France)

In this communication, we describe the proof-of-concept for an interconnect-free DRA-SAW high temperature sensing system. The basic concept is the following: a SAW sensor is integrated within the same layer with a DRA antenna's circular slot feed. The DRA ceramic radiator can also serve as package. A 2.48GHz ISM low temperature demonstrator associating a FR-4 substrate and a commercial SAW resonator was simulated and fabricated. Simulations predict a very good impedance matching, 4.7dB gain and a HPBW of 100° in both E and H planes, an attractive feature for practical sensing applications. Sensing measurements were carried out for the first time with heating between 30°C and 100°C. These initial results pave the way for a fully integrated AlN/Sapphire high temperature SAW-DRA sensing system.

16:00 Coffee Break

16:30 ***Target Localization by Mobile Handheld UHF RFID Reader***

Aristidis Raptopoulos Chatzistefanou, Spyros Megalou and Stavroula Siachalou (Aristotle University of Thessaloniki, Greece); Vasiliki Drakaki (Archaelogical Museum of Thessaloniki, Greece); George Sergiadis and Antonis G Dimitriou (Aristotle University of Thessaloniki, Greece)

In this paper we design and implement a mobile handheld human operated device used to guide the user towards the desired RFID target and provide estimations of the distance and the angle from the user to the target. The main components of the device are a UHF RFID reader operating with one antenna, and an IMU used to measure rotation angles. The user is instructed by the device to perform one of three different actions: SCAN, TURN and MOVE. During these actions phase of arrival and rotation angle data are collected by the RFID reader and the IMU respectively. A particle filter algorithm leverages the collected data to estimate the distance and angle of the user, with respect to the user's current pose. Experimental results show a mean angle estimation error of 4 degrees, and distance estimation error less than 0.5m when the user approaches the target.

16:50 ***A Localization System for Autonomous Vehicles Based on TriLateration Tags***

Emidio Di Giampaolo (University of L'Aquila, Italy); Francesco Martinelli (Università di Roma Tor Vergata, Italy); Fabrizio Romanelli (Università Degli Studi di Roma Tor Vergata, Italy)

An indoor global robot localization problem is considered, where the robot is a differential drive kinematics vehicle. It is equipped with an RFID reader which measures phase shift in the RFID signal back-scattered by a set of RFID passive tags, located on the ceiling of the environment in a known position. The main contribution is the introduction of a special kind of tag, including three antennas close one each other (TriLateration Tag), allowing to obtain an estimate of the robot pose even if only one of these tags is detected. An Extended Kalman Filter is used to fuse odometry readings (encoder steps on robot wheels) with phase measurements obtaining a pose estimate which significantly improves results obtained when using standard one-antenna tags deployed with the same density. Simulation results show the effectiveness of the approach, which is particularly suited for large warehouses where RFID tags cannot be deployed too densely.

17:10 ***Performance Assessment of a UHF-RFID Robotic Inventory System for Industry 4.0***

Andrea Motroni and Fabio Bernardini (University of Pisa, Italy); Sacha Vaiani (ACM - Aerospace, Germany); Alice Buffi and Paolo Nepa (University of Pisa, Italy)

In recent years, automatic RFID inventory systems at the UHF band are becoming largely diffused. Therefore, the need to study their effectiveness in terms of inventory accuracy is raising. In this paper, we present a performance assessment analysis of a UHF-RFID robotic inventory system in a real indoor industrial environment. The experimental analysis is conducted at the facilities of Aircraft Cabin Modification - ACM Aerospace GmbH, Memmingen, Germany. In particular, the choice of antenna radiation pattern, distance from the metallic shelving, robot speed, and RFID reader inventory configuration had turned out to be relevant in order to maximize the inventory accuracy. With a proper parameter configuration, a 100\% inventory accuracy can be achieved in the company warehouse with high-density tag deployment, by highlighting the robustness of the proposed robot-based RFID inventory system to multipath effect and electromagnetic coupling among tags.

17:30 ***Ultra Low Power Wireless Epidermal Sensor for Battery-Less pH Monitoring in the Sub-6 GHz 5G Band***

Alessio Mostaccio (University of Rome Tor Vergata, Italy); Cecilia Occhiuzzi, Rocco Giofrè and Paolo Colantonio (University of Roma Tor Vergata, Italy); Gaetano Marrocco (University of Rome Tor Vergata, Italy)

RFID epidermal electronics recently gave us the possibility to connect our body to the external world and gather information about our health and state directly from the skin. To increase the acceptance of the monitoring platforms and overcome the limitations of current technology, i.e. the need of a dedicated reader and a limited bandwidth, new architectures of battery-less backscattering-based communications have been considered. Among them, 5G appears particularly promising thanks to the large bandwidth, the interoperability among devices and the pervasive coverage. In this perspective, this paper proposes the first epidermal chemical sensor for the sampling of the human sweat and the monitoring of the pH. The devices communicate with the external reader through a frequency modulation of the backscattered wave, whose parameters depend on the measured analyte. Early simulations and tests corroborate the feasibility of the approach.

17:50 ***RF Coverage Mapping of Bistatic Radio Links Using the Terrain Integrated Rough Earth Model (TIREM)***

Michael Varner and Thomas A Rodriguez (Georgia Institute of Technology, USA); Gregory Durgin (Georgia Tech, USA)

Boasting low cost, complexity, and energy consumption, scatter-based communications has emerged as a prime technology for real time sensing of spectral and environmental behaviors in

contentious environments. Successful deployment of scatter networks require RF path loss modeling capability that does not readily exist in commercial tools. This work uses the terrain-integrated rough earth model (TIREM) -- a knife-edge diffraction-based propagation engine -- to generate models for bistatic radio links. Using geographical information services (GIS) data, RF prediction maps are generated to determine regions of coverage that will support link establishment and is uniquely focused on smaller scale environment. Prediction maps are generated to observe the effects of realistic environments on bistatic link receive power, SNR, and SIR, illuminating the concerns that face these sensor network topologies and making an argument for the use of tools like TIREM to generate quick, accurate information for researchers and designers.

18:10 ***Flexible RFID Tag for Bottle Labelling***

David C Rodrigues (Instituto Superior Engenharia de Lisboa (ISEL), Portugal); Carlos Mendes (Instituto Superior de Engenharia de Lisboa, Portugal); Pedro Pinho (IT - Instituto de Telecomunicações & ISEL - Instituto Superior de Engenharia de Lisboa, Portugal)

This paper describes the design, manufacturing and range measurement of an UHF (ultra high frequency) RFID (radio frequency identification) tag to apply on a glass bottle filled with water. To achieve this, a free-space matched RFID antenna is studied and modifications are made in order reduce its size drastically and to turn it functional when applied to a bottle with water. Later, range measurement tests are made on the fabricated tag.

CS28: Microwave/millimeter-wave imaging towards real-time medical applications

T04 Biomedical and Health/ / Electromagnetics

Chairs: Sandra Costanzo (University of Calabria, Italy), Natalia Nikolova (McMaster University, Canada)

14:00 ***A Microwave Imaging Technique Based on Artificial Neural Networks for Neck Tumors Detection***

Chiara Dachena and Alessandro Fedeli (University of Genoa, Italy); Alessandro Fanti, Matteo Lodi and Giorgio Fumera (University of Cagliari, Italy); Matteo Pastorino and Andrea Randazzo (University of Genoa, Italy)

A microwave imaging approach for the detection of neck tumors is proposed in this paper. Specifically, a preliminary artificial neural network (ANN) is adopted for the reconstruction of the properties of a cross section of the neck starting from scattered electric fields. To this end, realistic neck phantoms are developed to test the feasibility of the proposed method. Several test cases are performed to evaluate the performance of the ANN to discriminate different size of the tumor and different position in the neck. The preliminary results indicate quite good detection capabilities.

14:20 ***Target Selection in Multistatic Microwave Breast Imaging Setup Using Dielectric Lens***

Daniela M. Godinho (Instituto de Biofísica e Engenharia Biomédica, Faculdade de Ciências, Universidade de Lisboa, Portugal); Joao M. Felicio (Instituto de Telecomunicações, Portugal); Carlos A. Fernandes (Instituto de Telecomunicacoes, Instituto Superior Tecnico, Portugal); Raquel C. Conceição (Instituto de Biofísica e Engenharia Biomédica, Faculdade de Ciências, Universidade de Lisboa, Portugal)

Microwave Imaging (MWI) has been studied to aid early breast cancer detection. Current prototypes in more advanced stages of development include both monostatic or multistatic setups. However, multistatic configurations usually include a high number of antennas which consequently require complex and computationally-intensive signal processing algorithms to ensure a good target detection. We previously presented a novel approach using a dielectric lens which reduces the signal processing burden of multistatic setups, while ensuring good spatial resolution. In this paper, we evaluate this novel setup using an anatomically realistic breast phantom and its capability of selecting targets inside the breast. We show a successful detection of the targets using an artefact removal algorithm based on singular value decomposition when the Bessel beam is centered at the target location.

14:40 ***Slot-Loaded Antipodal Vivaldi Antenna for a Microwave Imaging System to Monitor Liver Microwave Thermal Ablation***

Mengchu Wang (National Research Council-Institute for Electromagnetic Sensing of the Environment, Italy); Sandra Costanzo (University of Calabria, Italy); Lorenzo Crocco (CNR - National Research Council of Italy, Italy); Marta Cavagnaro (Sapienza University of Rome, Italy)

This study presents the design and the experimental validation of a slot-loaded antipodal Vivaldi antenna for to monitor liver microwave thermal ablation through microwave imaging techniques. The antenna's overall dimension is equal to 40mm×65mm, and its working bandwidth goes from 600 MHz up to 3 GHz, with the possibility to operate at a higher frequency. The antenna is designed to operate inside a coupling medium that allows to scale down the antenna dimensions, as well as to improve the coupling of the electromagnetic power to the tissue. The antenna's S-parameters well agree with the simulation result. Finally, the antenna proposed in this work shows the most compact aperture dimension, as compared with other similar antennas designed for biomedical applications, working within the same bandwidth.

15:00 ***Preliminary Development of Anatomically Realistic Breast Tumor Models for Microwave Imaging***

Ana Catarina Pelicano (Instituto de Biofísica e Engenharia Biomédica, Fac. Ciências Un. Lisboa & FCiencias ID, Portugal); Nuno Araújo (Centro de Física Teórica e Computacional, Fac. Ciências Un. Lisboa, Portugal); Raquel C. Conceição (Instituto de Biofísica e Engenharia Biomédica, Faculdade de Ciências, Universidade de Lisboa, Portugal)

In this work, we present a preliminary study of three classifiers - Linear Discriminant Analysis (LDA), Support Vector Machines (SVMs) and k-Nearest Neighbors (kNN) - to differentiate between malignant and benign tumors extracted from Magnetic Resonance (MR) images, based on their morphological features. The dataset in this study comprises 24 tumors: 12 malignant and 12 benign. Twelve morphological features were initially considered for tumor classification. The Mann-Whitney test was employed for feature selection, and the performance of the classifiers was evaluated with accuracy, sensitivity, specificity, F1-score and Matthew's Correlation Coefficient (MCC) metrics. kNN (with k=6 and Chebyshev distance) outperformed the other classifiers with an accuracy, sensitivity, and specificity of 87.5%, 83.3% and 91.7%, respectively.

15:20 ***Package-PCB Near-Field Antenna Co-Design for K-Band Radar-Based Breast Cancer Detection***

Martin Maier (Technische Universität Braunschweig, Germany); Duy Hai Nguyen (Goethe University Frankfurt, Germany); Jochen Moll (Goethe University Frankfurt am Main, Germany); Viktor Krozer (Goethe University of Frankfurt am Main, Germany); Vadim Issakov (Technische Universität Braunschweig, Germany)

This paper presents considerations on co-design and co-optimization of a chip-package to a near-field PCB antenna transition operating at K-Band frequencies. The transition and the on-PCB antenna are intended for use with a stepped FMCW radar chipset, operating in the frequency range from 16 GHz to 24 GHz. The target application is the realization of a large MIMO imaging array for breast cancer imaging. In this paper we first present the system level considerations. We describe the intended system itself, system partitioning, as well as the arrangement of antennas and radar transceivers. Next, we discuss in detail the antenna design. Unlike the classical free-space scenario, in this case the antenna radiates into the skin and fat tissue. Secondly, we show the package transition design considerations. The transition is realized in the embedded wafer level ball grid array (eWLB) packaging technology.

15:40 ***Towards Real-Time Monitoring of Pulsed Microwave Ablation Using Thermoacoustic Signals: A Study of Signal Characteristics as a Function of Salinity***

Audrey L Evans, Chu Ma and Susan Hagness (University of Wisconsin-Madison, USA)

Tracking the characteristics of microwave-induced thermoacoustic (TA) signals is an emerging method for real-time monitoring of microwave ablation (MWA) performed with microsecond-duration microwave pulses. Extensive understanding of how tissue properties impact TA signal characteristics is necessary to enable the effective use of TA signals to monitor the evolution of an ablation zone. In this study, we investigate the impact of salinity content in water on TA signal characteristics that are generated as a result of pulsed microwave absorption. Experimentally measured TA signals are compared to computed TA signals using known salinity-dependent dielectric, thermal, and acoustic properties in a multi-physics simulation model. The predicted and observed trends with saline content are in agreement, and demonstrate the potential for monitoring a changing tissue environment during microwave heating by exploiting the thermoacoustic effect.

A18: Automotive antennas

T05 Aircraft (incl UAV, UAS, RPAS) and automotive/ / Antennas

Chairs: Daniel N Aloi (Oakland University, USA), Stefan Lindenmeier (Universität der Bundeswehr, Germany)

14:00 ***Transfer Function Analysis and Vehicle Models for Investigation of Coupling Between a Multi-Antenna System and Wires***

Emanuel Panholzer (University of the Federal Armed Forces Munich & Mercedes-Benz AG, Germany); Stefan Lindenmeier (Universität der Bundeswehr, Germany)

New technologies in a vehicle increase the effort for the safeguarding of electromagnetic interaction between novel bus-/communication systems (e.g. Automotive Ethernet 100Base-T1 and 1000Base-T1) and vehicle antennas. Characteristic transfer functions measured in the real vehicle environment with a vector network analyzer can be used as an approach to determine the electromagnetic interaction of wiring harnesses and antennas in the vehicle. In this contribution, several antenna structures and vehicle models are analyzed with respect to the induced emission signal at the antennas. The analysis thus allows a first insight into the electromagnetic interaction of a multi-antenna system in the application of a 100Base-T1 communication system. The advantage of different antenna structures for the multiantenna system in terms of the interaction with a wire harness is discussed.

14:20 ***A Wideband Automotive 4x4-MIMO 5G Antenna System with Single-Stage Decoupling Circuit for a Double Shark Fin Cover***

Mirco Hardman (Universität der Bundeswehr München, Germany); Stefan Lindenmeier (Universität der Bundeswehr, Germany)

An automotive 4x4 MIMO Antenna set for 5G mobile communication with decoupling- and matching circuit is presented which can be integrated in a symmetrical double shark fin. The antenna system with circuit is well performing in a low 5G-frequency band from 617 MHz up to 960 MHz as well as in a high band from 1.7 GHz up to 6 GHz. The decoupling circuit yields a transmission factor between adjacent antennas of about -10dB in the low band and less than -15dB in the high band. Matching is achieved with less than -6dB in the low band and less than -10dB in the high band. Measured and simulated scattering-parameter values are shown in comparison with each other. The decoupling and matching circuit yields low losses which can be shown by the total efficiency of

the antennas depending on the frequency.

14:40 ***A Compact Wideband Circular Polarized Antenna for Automotive GNSS Applications***

Zafer Toprak (Universität der Bundeswehr München, Germany); Stefan Lindenmeier (Universität der Bundeswehr, Germany)

This paper presents a new wideband right-hand circular polarized antenna with a homogenous high Gain (4 dBiC) and a good-cross polar discrimination (XPD) over a bandwidth of 85 MHz. The proposed antenna is optimized for the L1-Band of the global navigation satellite service. The return loss between 1.525GHz and 1.61GHz is lower than -15 dB without the need of any matching circuit. The compact antenna structure is made of panel and can be fabricated easily by an industrial punch bending process.

15:00 ***Metasurface Antenna System for Pedestrian to Vehicle Communications Based on IEEE 802.11p: Design and Evaluation***

Narimane awada Mislmani (University of Gustave Eiffel & IFSTTAR-LEOST, France); Divitha Seetharamdoo (IFSTTAR, LEOST & Univ Lille Nord de France, France)

Vehicular communication systems can be used for enhancing the safety level of road users by exchanging safety/warning messages. In this paper, we propose an antenna for a pedestrian-to-vehicular (P2V) device which provides safety service to road workers on the highway or road environment. A metasurface antenna system was fabricated and tested in the anechoic chamber. The device is worn close to the body of the road worker and at a distance of less than 200 mm. In this framework, the SAR has to be evaluated and compared to the threshold values recommended by standards. Experimental results showed that the proposed antenna, backed by a metasurface reflector, is an excellent candidate for P2V communications based on IEEE802.11p systems with desirable radiation pattern, polarisation, and safety limits. Finally, a comparison between our antenna system performance in terms of full coverage direction and other systems is done.

15:20 ***Low-Profile Automotive Antenna Systems for MIMO 5G and L1/L5 GNSS Communications***

Ahmad Yacoub and Daniel N Aloi (Oakland University, USA)

This paper presents fully integrated low-profile antenna systems for multiple-input multiple-output (MIMO) 5G and global navigation satellite system (GNSS) for L1/L5 frequency bands. The designs can be used on the vehicle's roof inside a low-profile housing due to its physical parameters and performance. Two samples are presented using HFSS simulation. The first sample shows the 5G MIMO integration performance with the L1 GNSS band while the second sample is integrated with the L5 GNSS band. The measurement results are discussed and plotted in terms of VSWR, passive isolation, and radiation patterns.

15:40 ***Towards Holographic Antenna Systems for MIMO Radar and Communication Applications***

Thomas Frey (University Ulm - Institute of Microwave Engineering, Germany); Maximilian Döring (University Ulm, Germany); Christian Waldschmidt and Tobias Chaloun (University of Ulm, Germany)

A novel synthesis method using an incident angle dependent impedance mapping for holographic multi-feed antennas is presented. In the proposed multi-beam synthesis, a individual merged impedance hologram for each feeding point is determined, which has the lowest impedance error to the corresponding analytical holograms. Subsequently, a non pixel-based genetic optimization is used to account for global error minimization across all feeds. The antenna is going to be realized on glass due its lower loss and dispersive properties compared to Teflon-based materials at mm-wave frequencies. In addition to the incident angle dependent hologram synthesis method, an appropriate sub-wavelength pixel has been design and optimized with enhanced anisotropic properties. The implemented holographic multi-feed antenna design has an antenna gain of 23.3 dBi and 23.0 dBi, a polarization purity of 23.0 dB and 20.3 dB and a side-lobe level of -18.5 dB and -19.0 dB with 2 feeds at 77 GHz.

CS27: Metasurfaces and Reconfigurable Intelligent Surfaces to Tailor Radio Propagation: Modeling, Applications, Prospect

T10 Fundamental Research and Emerging Technologies/ / Propagation

Chair: Vittorio Degli-Esposti (University of Bologna, Italy)

14:00 ***Metagratings with Advanced Scattering Features***

Andrea Alù (CUNY Advanced Science Research Center, USA)

In the framework of reconfigurable intelligent surfaces, it is of key importance to be able to tailor spatially and temporally with large flexibility the impinging radio-wave signals. In this context, conventional metasurfaces relying on spatial gradients to manipulate the optical wavefront are fundamentally limited on their overall efficiency to reroute the impinging waves towards arbitrary directions in reflection and transmission. In addition, due to their fastly varying profiles of surface impedance, metasurfaces usually require high-resolution fabrication processes, limiting their applicability and bandwidth of operation. Metagratings, i.e., periodic or locally periodic arrays operated in the few-diffraction order regime, on the contrary can manipulate electromagnetic waves

with unitary efficiency even in the limit of extreme responses. In this talk, we will review the physical mechanisms behind the functionality of metagratings and provide an outlook of the recent progress in this field of science and technology, of particular relevance to reconfigurable intelligent surfaces.

14:20 ***Modeling and Measurements for Multi-Path Mitigation with Reconfigurable Intelligent Surfaces***

Ruya Zhou, Xiangyu Chen, Wankai Tang, Xiao Li and Shi Jin (Southeast University, China); Ertugrul Basar (Koc University, Turkey); Qiang Cheng and Tie Jun Cui (Southeast University, China)

A reconfigurable intelligent surface (RIS) is capable of manipulating electromagnetic waves with its flexibly configurable unit cells, thus is an appealing technology to resist fast fading caused by multi-path in wireless communications. In this paper, a two-path propagation model for RIS-assisted wireless communications is proposed by considering both the direct path from the transmitter to the receiver and the assisted path provided by the RIS. The proposed propagation model unveils that the phase shifts of RISs can be optimized by appropriate configuration for multi-path fading mitigation. In particular, four types of RISs with different configuration capabilities are introduced and their performances on improving received signal power are compared through extensive simulation results. In addition, an RIS operating at 35 GHz is used for experimental measurement. The experimental results verify that an RIS has the ability to combat fast fading and thus improves the receiving performance.

14:40 ***Huygens' Metasurfaces for Antenna Beamforming and Beamsteering***

Vasileios G. Ataloglou (University of Toronto, Canada); Minseok Kim (University of North Dakota, USA); George V. Eleftheriades (University of Toronto, Canada)

Huygens' metasurfaces provide a platform for realizing low-profile antennas without sophisticated feeding networks. In particular, they can synthesize radiating apertures by passively transforming the incident fields. In this paper, we summarize recent progress on the field of beamforming and beamsteering with Huygens' metasurfaces. Several strategies to overcome the limitations posed by the passivity of Huygens' metasurfaces and to achieve arbitrary beamforming are explored. Furthermore, ways to integrate tunable metasurfaces with leaky-wave antennas are discussed with the purpose of obtaining electronically steerable far-field patterns.

15:00 ***From Physics to Reconfigurable Intelligent Surfaces: A Pioneers' Point of View***

Geoffroy Lerosey (Greenerwave, France)

In this paper we review our works on reconfigurable intelligent surfaces over the past 10 years, summarize our main results, and underline the problems we have faced while trying to push this idea towards applications. This allows us give a pioneer's point of view of the future of RIS, that we foresee as a technology that should be as autonomous as possible.

15:20 ***Ray-Field Scattered by Polygonal Reflecting Intelligent Surfaces***

Stefano Maci, Ernest Ofosu Addo, Matteo Albani and Enrica Martini (University of Siena, Italy)

A method is presented here for ray-representation of the scattered field from polygonal, metasurface (MTS)-based Reflective intelligent Surfaces (RIS). The method is based on the use of an infinite periodic problem for finding the current distribution over the RIS aperture, which is eventually windowed for calculating the radiated field. Stokes theorem is used on the windowed radiating aperture for finding a closed form radiated field in terms of rays. The formulation is developed here in the far zone; it is however suggested how it can be extended in Fresnel region by introducing proper Fresnel transition functions.

15:40 ***Analytical Models of Link Budget in the Presence of Reflection-Shaping Metasurface Panels***

Sergei Kosulnikov and Sergei Tretyakov (Aalto University, Finland); Ana Díaz-Rubio (Universitat Politècnica de València, Spain)

The use of reconfigurable intelligent surfaces (RIS) for optimization of propagation channels is one of the currently actively studied techniques for improving the efficiency of the next generation of communications systems. In this work, we combine the physical optics approximation and the theory of diffraction gratings to derive simple analytical formulas for far-zone fields reflected and scattered by anomalously reflecting metasurface panels mounted on walls. In the talk, we will present numerical examples, illustrating the difference in performance of conventional phase-gradient reflectors (reflectarrays) and optimized nonlocal metasurface reflectors.

CS23: Fundamental challenges and novel methodologies in the next-generation computational electromagnetics

T09 EM Modelling and Simulation tools/ / Electromagnetics

Chair: Francesca Vipiana (Politecnico di Torino, Italy)

14:00 ***Closed Form Solutions for Stochastic Green Functions in Non Dissipative Chaotic Cavities***

Luis Landesa (Universidad de Extremadura, Spain); Lucia Bautista, Inmaculada Castro, Javier Losada and Jose M. Taboada (University of Extremadura, Spain)

We introduce a closed form for the solution of the Stochastic Green functions in closed chaotic environments. The solution is an alpha-stable random distribution whose parameters (stability, skewness, scale and location) depend on the distance between source and observation, frequency and dissipation in low dissipative problems. Excellent comparisons with infinite-sum stochastic Green function and numerical problems is shown, which will allows, in the future, the use of simple stochastic expressions in Surface Integral Equation methods for chaotic environments.

14:20 ***A Unified Nyström/Galerkin Method for for Multiscale Problems***

Felipe Vico (Universidad Politécnica de Valencia, Spain); Miguel Ferrando-Bataller and Eva Antonino-Daviu (Universitat Politècnica de València, Spain); Marta Cabedo-Fabrés (Universidad Politécnica de Valencia, Spain)

Integral equation methods are widely used in computational electromagnetics (CEM). Galerkin and Nyström are two possible schemes to discretize any integral equation. Among the CEM community, Galerkin is by far the most common scheme used. Nyström has some advantages when dealing with second kind integral equations, nevertheless it has some disadvantages when dealing with multiscale geometries. In this paper we propose a fix for that and apply this to the Charge-current integral equation.

14:40 ***Efficient Combination of Scalar-Potential Representations of Solenoidal Functions and Quasi-Helmholtz Projectors***

Bernd Hofmann (Technical University of Munich, Germany); Thomas F. Eibert (Technical University of Munich (TUM) & Chair of High-Frequency Engineering (HFT), Germany); Francesco Andriulli (Politecnico di Torino, Italy); Simon B Adrian (Universität Rostock, Germany)

Among the most mature approaches to stabilize the EFIE for low frequencies are quasi-Helmholtz projectors. In this work, we show how to adapt these projectors such that the right-hand side can be discretized in a stable manner on multiply-connected geometries, preventing otherwise occurring catastrophic round-off errors. To this end, an approach to combine the quasi-Helmholtz projectors with a scalar-potential representation of solenoidal functions is presented. Furthermore, we provide a strategy to efficiently compute the corresponding projectors via the Schur complement, all of which is corroborated by numerical results.

15:00 ***Fast Eigenmode Mapping in Printed Periodic Structures***

Denis Tihon and Modeste Bodehou (Université Catholique de Louvain, Belgium); Shambhu Nath Jha (Thales Belgium SA, Belgium); Christophe Craeye (Université Catholique de Louvain, Belgium)

We use the Method of Moments to study the iso-frequency dispersion curve of conducting patches of general shape printed on a grounded dielectric substrate. To accelerate the method, we use a specialized interpolation technique to rapidly evaluate the periodic impedance matrix of the system for many different phase shifts between consecutive unit cells. The interpolation procedure is based on the extraction of an easy-to-compute rapidly varying term and the interpolation of the smooth remainder. Using the proposed method, computing the periodic impedance matrix for a new phase shift is a matter of milliseconds without sacrificing the accuracy. To validate the method, we reproduced results that are available in the literature.

15:20 ***Numerical Aspects of the Application of Ray-Tracing to Geodesic Lenses***

Sarah E Clendinning and Shiyi Yang (KTH Royal Institute of Technology, Sweden); Qingbi Liao (Ericsson AB, Sweden); Pilar Castillo-Tapia (KTH Royal Institute of Technology, Sweden); Francisco Mesa (University of Seville, Spain); Nelson Fonseca (European Space Agency, The Netherlands); Oscar Quevedo-Teruel (KTH Royal Institute of Technology, Sweden)

This paper presents a model developed to numerically determine the radiation pattern presented by a given geodesic lens. A simplified model describing the trajectory of a TEM-mode wave through the lens was required as a time-efficient alternative to commercial software. Geometrical optics have been used to approximate the ray trajectory from the source to the aperture of the lens. The power conservation in ray tubes is then used to evaluate the amplitude of the electric field in the aperture, knowing the distribution at the source. The Kirchhoff diffraction formula is finally numerically approximated to evaluate the far-field. Three examples have been simulated with our algorithm and compared with full-wave simulations. We demonstrate that our assumptions provide a good agreement with full-wave simulation while reducing significantly the computation time, thus providing an efficient method for design optimization. Most notably, this more general formulation may be extended to non-rotationally symmetric lenses.

15:40 ***Solving Electromagnetic Scattering in Dielectric Bodies by Monte Carlo Sampling***

Hector Lopez-Menchon (Universitat Politecnica de Catalunya (BarcelonaTECH), Spain); Juan M. Rius (Universitat Politècnica de Catalunya, Spain); Eduard Ubeda (Universitat Politècnica de Catalunya (UPC), Spain); Alexander Heldring (Polytechnical University of Catalunya, Spain)

In this work, we propose Monte Carlo sampling as a technique to avoid communication overhead in the numerical solution of complex electromagnetic scattering problems. The method is based on statistically sampling a formal representation of the solution of the scattering problem, based on a modified Born series. The sampling process can be independently carried out in different processors with no need for communication between them. This lack of communication makes the algorithm suitable for massively parallel computational environments.

16:00 Coffee Break

16:30 ***Evaluation of near Singular Integrals for Computational Electromagnetics by Dimensionality Reduction***

Donald Wilton (University of Houston, USA); Michael Khayat (NASA Johnson Space Center, USA); William Johnson (Private Consultant, USA); Javier Rivero and Francesca Vipiana (Politecnico di Torino, Italy)

With the need for ever faster codes, a limiting factor that must be dealt with is the accurate yet efficient evaluation of interaction integrals between the more problematic near-field elements. Several recent works have together shown that all evaluations of source potential integrals and their derivatives for the most common bases and elements can be reduced to the evaluation of boundary line integrals; these can be evaluated by Gauss-Legendre quadrature, though integrand-smoothing transforms are often needed to accelerate their computation. In this paper, we modify the reported approach to eliminate cancellation errors in the line integral integrand, reinterpret the integral as a vertex function, and study the scalar potential integral form under the sinh transform and static subtraction acceleration methods.

16:50 ***Analytic Treatment of Galerkin Matrix Elements Involving Normal Derivatives of Green's Function***

Elizabeth Bleszynski (Monopole Resesarch, USA); Marek Bleszynski, Dr (Monopole Resaearch, USA); Thomas Jaroszewicz (Monopole Research, USA)

We consider a method of evaluating Galerkin matrix elements of surface integral equations involving the normal derivative of Green's function, for basis functions supported on parallel planes. Our method uses the previously introduced representations of integral-equation kernels as Laplacians of non-singular auxiliary functions, and Gauss's theorem resulting in conversion of surface integrals to integrals over triangle perimeters. However, unlike in the previously considered kernels, the discontinuity (across the plane of the basis function support), of the normal derivative of Green's function affects also the corresponding auxiliary functions. We examine their behavior and its effects on the numerical evaluation of the line integrals. Our analysis allows us to improve the accuracy of the numerical line integration and avoid instabilities associated with cancellation of large terms in the line integrals. The derived Laplacian representation is also used to obtain analytic expressions for the double line integrals, in terms of elementary functions.

17:10 ***Discontinuous Galerkin JMCFIE Formulation for Solving Multimaterial Composite Objects***

Víctor Martín, David Larios and Luis Landesa (Universidad de Extremadura, Spain); Fernando Obelleiro (University of Vigo, Spain); Jose M. Taboada (University of Extremadura, Spain)

In this work we present the combination of the JMCFIE formulation in synergy with the discontinuous Galerkin surface integral equation method for the electromagnetic analysis of piecewise homogeneous objects. The interfaces between different materials can be independently modeled, without need to add restrictions at the junctions between them. The proposed scheme avoids the need to joint and delete extra coefficients to enforce the boundary conditions at the multi-material junctions. Numerical experiments will be shown to illustrate the great flexibility of this approach for the solution of composite objects with multiple high contrast materials in contact.

17:30 ***Quantum Metamaterials and Metasurfaces***

Andrea Alù (CUNY Advanced Science Research Center, USA)

In this talk, I will review our latest progress towards the design and implementation of metamaterials and metasurfaces that can manipulate electromagnetic waves in exotic ways by operating at the quantum limit. I will discuss various examples of opportunities enabled by quantum engineering metasurfaces, discussing coupled nanocavities supporting embedded eigenstates that enable single-photon trap-and-release mechanisms, nonlinearity-based isolators for guided light and free-space radiation, and giant nonlinearities in tailored metasurfaces. I will also discuss polaritonic systems that enhance light-matter interactions through quantum phenomena. During the talk, I will discuss opportunities, potentials, challenges enabled by metamaterial approaches to manipulate quantum and classical electromagnetic waves.

17:50 ***Quantum-Assisted Combinatorial Optimization of Reconfigurable Intelligent Surfaces***

Qi Jian Lim (University of Illinois Urbana-Champaign, USA); Charles Ross (University of Illinois at Urbana-Champaign, USA); Gabriele Gradoni (University of Nottingham, United Kingdom (Great Britain)); Zhen Peng (University of Illinois at Urbana-Champaign, USA)

Recently, we have seen an extensive and growing interest in leveraging reconfigurable intelligent surfaces towards smart radio environments. One key question arises on how to efficiently select the phase configuration that produces a desired reflective wavefront. In this work, we proposed a physics-based optimization approach inspired by the quantum mechanical physics of correlated spins. The new idea is grounded on the isomorphism between the electromagnetic scattered power and Ising Hamiltonian. Thereby, the problem of optimizing phase configuration is converted into finding the ground state of the target Ising Hamiltonian. Under this framework, we successfully demonstrated the feasibility of combinatorial optimization for weighted beamforming and diffusive scattering applications.

18:10 ***A Boundary Element Method Modeling the Multiple Scattering from Hydrodynamic Metallic Nanoparticles***

Xuezhi Zheng (Katholieke Universiteit Leuven, Belgium); Christos Mystilidis (KU Leuven, Belgium); Guy Vandenbosch (Katholieke Universiteit Leuven (KU Leuven), Belgium)

In this work, within the Boundary Element Method (BEM), we present a novel modeling scheme that considers the multiple scattering of light by metallic nanoparticles. Different from the classical treatments where the optical properties of metals are captured by the local response model, we describe the metals by a nonlocal model, i.e., the hydrodynamic model. This nonlocal model is important for the cases where the nanoparticles are of deep-nm sizes or the nanoparticles have a deep-nm feature, e.g., a dimer with a gap size of a few nm's. To fully consider the nonlocal effects, we write down the boundary integral equations and implement the BEM for the following three different interface configurations: the local - local interface, the local - nonlocal interface, and the nonlocal - nonlocal interface. The results from our BEM implementation are compared to the analytical ones from the Mie theory, and a good agreement is demonstrated.

IW02: One6G view on propagation models/measurements and antennas for next generation MIMO systems

Industrial Workshop

CS03: Advances in Additive Manufacturing/3D Printing; Novel Materials & Metamaterial Structures

T10 Fundamental Research and Emerging Technologies/ / Electromagnetics

Chair: William Whittow (Loughborough University, United Kingdom (Great Britain))

14:00 ***3D Printed Metaparticles Based on Platonic Solids for Isotropic, Multimode Microwave Scattering***

Alex W Powell, James Capers, Simon Horsley, John Sambles and Alastair Hibbins (University of Exeter, United Kingdom (Great Britain))

Advances in additive manufacturing techniques and materials have enabled the fabrication of complex 3D microwave scatterers that until very recently were beyond the reach of experimental science. These show powerful isotropic scattering behaviour, with negligible dependence on incident angle or polarization for several resonant modes. These scatterers have applications in enhancing the radar signature of small objects such as drones and satellites and in controlling the radiation pattern of antennas.

14:20 ***Adjoint Optimization of 3D Printed RF GRIN Lenses***

Eric B Whiting, Sawyer D Campbell, Galestan Mackertich-Sengerdy, Saber Soltani and Douglas H Werner (The Pennsylvania State University, USA); Pingjuan Werner (The Pennyslvania State University, USA)

Additive manufacturing makes possible the rapid design and testing of gradient index (GRIN) lenses. GRIN lenses, whose refractive index profiles are spatially-varying, have been shown to improve the gain of antenna systems while in more compact forms. However, optimization of the GRIN lens profiles is difficult because the lenses can be many wavelengths wide, and the simulations slow to compute. Furthermore, the large number of design variables makes solving the GRIN lens profile a challenging problem. However, these problems can be remedied using adjoint sensitivities to compute the gradient for every design variable in only two simulations. Then local optimization approaches can follow these gradients to rapidly converge to a good candidate solution. To demonstrate the efficacy of the approach, a GRIN lens design was optimized to have the same measured broadside gain as a 20 dB standard gain horn.

14:40 ***Disposable 3D Printed Liquid Sensor***

Peter M. Njogu, Benito Sanz-Izquierdo and Steven Gao (University of Kent, United Kingdom (Great Britain)); Zhijiao Chen (Beijing University of Posts and Telecommunications, China)

A device for detecting liquid chemicals of various permittivity using a 3D Printed frequency selective surface (FSS) is proposed. The sensor is an array of square loops on a square unit cell with trenches dug in the dielectric material around the loops. The trenches allows deposition of the liquid chemicals to be detected. The variation in the dielectric characteristics of the liquids in the trenches produces a change in the resonance frequency of the FSS. Transmission coefficient is measured to evaluate the resonance frequency due to each liquid chemical. Butan-1-ol, Propan-2-ol, Ethanol and Methanol were added to demonstrate the sensing technique. Good agreement was found to exist between simulated and measured results. The envisioned detector could be used in a laboratory or in chemical industry where liquids can fall into the trenches for detection purpose. 3D printing allows for the rapid fabrication of the structure which can be disposable.

15:00 ***Fused Filament Fabrication Additive Manufacturing and Characterisation at Loughborough University for RF Applications***

Athanasios Goulas, Tom Whittaker and William Whittow (Loughborough University, United Kingdom (Great Britain))

This paper discusses the research related to 3D printed radiofrequency (RF) devices, using fused filament fabrication, carried out at Loughborough University. Different multidisciplinary aspects include the ability to 3D print unique shapes, the ability to tailor the infill to make functionally graded and heterogeneous substrates, characterizing the dielectric properties and how these materials can be used for antennas and other RF designs.

15:20 ***3D Printed Millimetre-Wave and Sub-Terahertz Devices: Prospects, Challenges, and Solutions***

Yang Yang, Mengze Li, Karu Esselle and Dush Thalakotuna (University of Technology Sydney, Australia)

Advanced 3D printing technology enjoys the advantages of fast-prototyping, low-entry-cost, and in-house short-run manufacturing, which empowers millions of start-ups and companies with demanding confidentiality and accelerated innovation. The advancement of AM technology will circumvent the limitations of traditional 3D printed microwave circuits and antennas. This talk aims to present the fundamental knowledge about AM technology and its capability in microwave/millimeter-wave/terahertz circuits and antenna designs. This article presents an overview of state-of-the-art 3D printing technologies and their applications in the millimeter-wave, and sub-terahertz designs, including meta lenses, frequency selective surfaces, waveguides, and antennas.

15:40 ***High Aperture Efficiency 3D-Printed Radial GRIN Lens***

Anastasios Paraskevopoulos, Ilir Gashi, Matteo Albani and Stefano Maci (University of Siena, Italy)

In this article, the experimental verification of a 3D-printed radial GRIN lens operating in the Ku-band between 12 to 18 GHz is presented. The GRIN lens can be found useful in high directivity and beamforming antenna applications. The design of the radial GRIN lens is based on a new closed form expression for the refractive index which is derived by geometrical optics. The GO-based formula is proved to achieve a minimum phase error that can lead to an increased lens aperture efficiency. The challenges that arise from the practical realization using 3D printing technology are discussed. Measurement results of the 3D printed lens are presented and compared with simulations, showing good agreement. Two antennas of low-medium gain are used, a 5 dB open-ended waveguide antenna and a 15 dB horn antenna. A maximum gain of 25 dB is achieved with a lens aperture of 7.2λ diameter at the highest frequency.

16:00 Coffee Break

16:30 ***Design of Compact Resonant Cavity Antennas Using Ultra Low-Cost Customized 3D-Printed Superstrates***

Touseef Hayat (Macquarie University, Australia); Muhammad Usman Afzal, Foez Ahmed and Karu Esselle (University of Technology Sydney, Australia)

The Far-field radiation performance of quintessential compact resonant cavity antennas (CRCAs) is compromised because of even transmission through uniform superstrate resulting in nonuniform aperture phase distribution. Phase varying superstrate (PVS) can be used to improve phase non-uniformity and even achieve wideband directional characteristics with small footprint. This paper presents three different PVSs using customization ability of additive manufacturing (AM) and distinct fabrication approaches for CRCA. These three approaches are based on height variation, infill variation and perforation size variation in the radio-frequency graded acrylo-butadiene sterene (ABS) material. Each PVS comprises three dielectric regions with different transmission characteristics for local phase variation. Uneven transmission through PVSs remarkably improves aperture phase of CRCAs subsequently increasing peak directivity (>17 dB) and 3dB directivity bandwidth (>50%) whilst maintaining small footprint of radius ≈0.84λL. All three PVSs can be developed at a cost less than US$ 1.25 without compromising antenna performance.

16:50 ***Multi-Material Additive Manufacturing of Microwave Devices***

Benjamin Vial (Queen Mary, University of London, United Kingdom (Great Britain)); Henry Giddens (Queen Mary University London, United Kingdom (Great Britain)); Yang Hao (Queen Mary University, United Kingdom (Great Britain))

In recent years, additive manufacturing has evolved to become a key method of prototyping devices across many industrial sectors including electromagnetic systems such as antennas. The range of materials that can now be deposited by 3D printers has expanded the suite of devices that can be rapidly manufactured. In this paper we will present two electromagnetic lenses that demonstrate the advantages of multi-material 3D printing, where a number of different dielectric materials are used to design functional devices with interesting properties. The first example is a frequency dependent dual focusing lens design through topology optimization, using two different dielectric filaments. The second is a compressed Luneburg lens that theoretically requires a continuous permittivity gradient from 7.8 in its centre down to 1 on the surface, and is realised by printing with a total of five different dielectrics.

17:10 ***3D-Printed Wide Beamwidth Lens Antennas for Beamforming Coverage Improvement***

Vitor Coelho, Tiago Varum and João Matos (Instituto de Telecomunicações, Universidade de Aveiro, Portugal)

Phased arrays are increasingly used in communication systems to benefit of their full beamforming capabilities. However, some of its limitations are related to the limited coverage, due to the antenna elements that are used today present some directivity. In this paper, two radiating structures with enlarge beamwidth are presented, using principles of lens antennas that can be produced with the support of 3D printing, and its most popular materials. Both solutions start from a microstrip antenna, and a multilayer structure operating as a lens and validating the principle at 7.8GHz, allowing to increase beamwidths by 80% for the ϕ=0° plane and 40% for the ϕ=90° plane.

17:30 ***A Fully-Screen Printed, Multi-Layer Process for Bendable mm-Wave Antennas***

Zubair Akhter (King Abdullah University of Science and Technology, Saudi Arabia); Weiwei Li (KAUST, Saudi Arabia); Yiyang Yu and Atif Shamim (King Abdullah University of Science and Technology, Saudi Arabia)

In the era of the Internet of Things and wearable electronics, printing techniques, such as screen printing, are becoming popular because of their lower costs and mass manufacturing abilities. However, most of the previous work has been done on printing metallic patterns and not the substrates. In this paper, we introduce a custom screen printable dielectric ink, which provides lower loss even at millimeter-wave bands. With the help of dielectric ink and a custom silver nanowires-based metallic ink, a multilayer fully screen-printed fabrication process has been developed. To demonstrate the efficacy of the proposed inks and the multilayer printing process, a stacked patch antenna is designed and fabricated for the mm-wave band. Despite a new fabrication process, the measured results show a decent antenna performance for flat and bent positions where the input impedance is matched from 26.5-30 GHz and a maximum gain of ~8dBi has been achieved.

17:50 ***3D Printed Discrete Dielectric Lens with Improved Matching Layers***

Juan Andrés Vásquez Peralvo and José Manuel Fernández González (Universidad Politécnica de Madrid, Spain); Thomas T Y Wong (Illinois Institute of Technology, USA)

This paper presents a non-zoned discrete dielectric lens comprising two or three matching layers to reduce the 50-110 GHz frequency range reflections. Based on Chebyshev and binomial multi-section transformers, the designed models use matching layers at the top and bottom. In addition, the presented designs use pins instead of the conventional slots for the matching layers, thus easing the manufacturing process. The results show that the broadband realized gain obtained using the proposed design is higher for both the two- and three-layer design than the commonly used quarter-wave transformer. A Binomial lens with two matchings layers using 38 unit cells is fabricated and illuminated by an open-ended waveguide to validate the simulation results obtained using CST Microwave Studio. The fabrication process uses stereolithography additive manufacturing.

18:10 ***3D-Printed Half-Maxwell Fish-Eye Dielectric Lens Antenna with Integrated DRA Feed***

Jose-Manuel Poyanco (University Carlos III of Madrid, Spain); Francisco Pizarro (Pontificia Universidad Catolica de Valparaiso, Chile); Eva Rajo-Iglesias (University Carlos III of Madrid, Spain)

The design of a Half-Maxwell Fish-Eye lens antenna fully made with 3D printing, including its feed, is presented. For the feed, a dielectric resonator antenna with a symmetrical radiation pattern was specifically designed. This antenna is also made with 3D printing technology and it is integrated with the lens. The lens has 10 layers with different permittivities that are implemented with two commercial filaments by varying the infill percentage. The design was made for a 28 GHz central frequency and has the capability for scanning or multibeam performance.

CS19: COST Session CA18223 (SyMat): Theory and Modeling of Higher Symmetries

T10 Fundamental Research and Emerging Technologies/ / Electromagnetics

Chair: Guido Valerio (Sorbonne Université, France)

14:00 ***Multimodal Transfer Matrix Approach for the Analysis and Fundamental Understanding of Periodic Structures with Higher Symmetries***

Pilar Castillo-Tapia (KTH Royal Institute of Technology, Sweden); Francisco Mesa (University of Seville, Spain); Oscar Quevedo-Teruel (KTH Royal Institute of Technology, Sweden)

The Multimodal Transfer Matrix Method (MMTMM) is a hybrid approach that efficiently computes the dispersion relation of a periodic structure. It is able to retrieve both the phase shift and attenuation constant of any arbitrary structure susceptible to be analyzed by means of commercial simulators. Here, we propose the use of this method in order to get a physical insight of periodic structures possessing higher symmetries. The MMTMM is here explained and corroborated with two different structures: a glide-symmetric dielectric-filled corrugated rectangular waveguide and a three-fold twist-symmetric bricks embedded in a dielectric waveguide. The first structure allows for the propagation of backward modes below the hollow waveguide cut-off frequency, whereas the second one has handedness selection.

14:20 ***Exceptional Points of Degeneracy in Electromagnetic Periodic Waveguides and the Role of Symmetries***

Tarek Mealy, Mohamed Y Nada, Ahmed F. Abdelshafy, Ehsan Hafezi and Filippo Capolino (University of California, Irvine, USA)

We show the relation between reflection and glide symmetry in periodic lossless waveguides and the existence of various orders of exceptional points of degeneracy (EPDs). We use an equivalent circuit network to model each unit-cell of the waveguide. Assuming that a coupled-mode waveguide supports N modes in each direction, we derive the following conclusions. When N is even, we show that a periodic waveguide with reflection symmetry may exhibit EPDs of maximum order N. To obtain a degenerate band edge (DBE) with only two coupled waveguides, reflection symmetry must be broken. For odd N, N+1 is the maximum EPD order that may be obtained, and an EPD of order N is not allowed. We present an example of three coupled microstrip transmission lines and show that breaking the reflection symmetry by introducing glide symmetry enables the occurrence of a stationary inflection point (SIP) which is an EPD of order three.

14:40 ***Wideband Characterization of Holey Glide-Symmetric Parallel-Plate Waveguides***

Boris Fischer and Guido Valerio (Sorbonne Université, France)

Glide symmetry is a low-cost design change that enhances many properties of metallic waveguides, such as the achievable stopband, the frequency and spatial dispersion, or the effective density. But the multi-modal coupling in glide-symmetric waveguides makes it difficult to model them efficiently. This paper presents a wideband homogenization technique based on a quasi-static approximation. It yields a closed-form formula for the effective refractive index of holey glide-symmetric parallel- plate waveguides. This formula enables fast analytic studies for the properties of these waveguides, such as maximum density, isotropy, or effective constitutive parameters.

15:00 ***Implementation of an Open Ended PTD-Symmetric Edge Waveguide***

Iram Nadeem, Enrica Martini, Alberto Toccafondi and Stefano Maci (University of Siena, Italy)

This paper demonstrates the practical feasibility of an open-ended parity, time-reversal, duality symmetric edge waveguide structure. This includes perfect electric and perfect magnetic based parallel plate waveguides. For practical implementation, a mushroom structure is used to emulate the perfect magnetic boundary conditions. Two kinds of edge waveguides are implemented and numerically analyzed. Results concerning the return loss and the ability to confine the EM field near the edge waveguide at the open-end are shown and compared.

15:20 ***Periodic Integral Equation Formulation for the Numerical Analysis of Glide Structures***

Jorge A. Tobon Vasquez and Javier Rivero (Politecnico di Torino, Italy); Guido Valerio (Sorbonne Université, France); Francesca Vipiana (Politecnico di Torino, Italy)

In this paper, we propose a technique based on integral equations, the periodic Green's function, and the method of moments discretization to analyze the dispersion diagram of non-canonical glide-symmetry unit cells. The technique is combined with a root finder approach to automatically identify the values of the wavevector that make the unit cell resonant. The proposed technique is tested on a glide fully metallic implementation of a Luneburg lens.

15:40 ***Glide-Symmetric Periodic Structures with Enhanced Isotropic Properties***

Marko Bosiljevac and Zvonimir Sipus (University of Zagreb, Croatia); Eva Rajo-Iglesias (University Carlos III of Madrid, Spain)

Periodic structures with higher symmetries have the potential to unlock many enhanced properties of microwave components and enable the development of novel components. The dispersion properties of these structures, however, are often not spatially isotropic which limits their application in some cases. For this reason, we focus on the analysis of holey structures with glide symmetry and their isotropic properties. Through analysis of typical holey structures and different lattices we demonstrate which design directions are to be used when one of the priorities are good isotropic properties and where are the limits of considered structures.

Monday, March 28 16:00 - 16:30

Coffee Break / Exhibition

Monday, March 28 16:30 - 18:30

EuCAP 2023 LoC meeting

CS42: Towards-6G Joint Communication and Sensing in Radio Propagation Perspectives

T03 Wireless LANS, IoT and M2M/ / Propagation

Chairs: Minseok Kim (Niigata University, Japan), Yang Miao (University of Twente, The Netherlands), Stefano Savazzi (Consiglio Nazionale delle Ricerche CNR, Italy)

16:30 ***Wireless LAN Sensing with Smart Antennas***

Marco Santoboni (Adant Technologies Inc., Università di Padova, Italy); Riccardo Bersan (Adant Technologies, Italy); Stefano Savazzi (Consiglio Nazionale delle Ricerche CNR, Italy); Alberto Zecchin (Adant Technologies, Italy); Vittorio Rampa (National Research Council of Italy (CNR), Italy); Daniele Piazza (Adant, Italy)

The paper targets the problem of human motion detection using Wireless Local Area Network devices (WiFi) equipped with pattern reconfigurable antennas. Motion sensing is obtained by monitoring

the body-induced alterations of the ambient WiFi signals originated from smart antennas supporting the beam-steering technology, thus allowing to channelize the antenna radiation pattern to pre-defined spots of interest. We first discuss signal and Channel State Information (CSI) processing and sanitization. Next, we describe the motion detection algorithm based on Angle-of-Arrival (AoA) monitoring. Proposed algorithms are validated experimentally inside a large size smart home environment.

16:50 ***Device-Free Localization Using Millimeter-Wave Double-Directional Channel Sounding Measurements***

Minseok Kim, Yuto Miyake, Togo Ikegami, Keiichiro Kumakura and Hibiki Tsukada (Niigata University, Japan)

The authors have developed the Multipath-RTI (radio tomographic imaging) technique based on millimeter-wave (mm-wave) radios such as 5G mobile and WiGig LAN systems. Mm-wave radios can realize a highly accurate device-free localization (DFL) for smart home/smart building applications by utilizing the features that mm-wave radios usually have high delay and angle resolution, and thus is capable of separating the multi-path components (MPCs). The Multipath-RTI can drastically reduce the number of sensor nodes by using the virtual nodes created by multipaths. However, there are technical challenges to handle the multipaths and corresponding pathways. This paper proposed a practical data processing scheme for Multipath-RTI and presented some actual imaging results for DFL using double-directional channel sounding measurements.

17:10 ***Validation of Propagation Delay on the Development of Wi-Fi CSI Based Channel Sounder for Passive Motion Sensing***

Nopphon Keerativoranan (Tokyo Institute of Technology, Japan); Kentaro Saito (Tokyo Denki University, Japan); Jun-ichi Takada (Tokyo Institute of Technology, Japan)

Wi-Fi channel state information (CSI) has been widely utilized in various motion sensing applications such as motion detection, recognition, localization and tracking. Comparison with Doppler frequency, propagation delay is unreliable due to a non-synchronization between two Wi-Fi stations, thus it is hardly utilized for motion sensing. Since the CSI B2B calibration in the previous work introduced a form of synchronization via a cable channel, the propagation delay has become utilizable. In this paper, a performance and reliability of the CSI propagation delay will be validated as well as addressing the source of delay offset due to B2B calibration. In addition, applicability of utilizing propagation delay in a person falling scenario will be demonstrated as one of the motion sensing application.

17:30 ***Effects of Human Body on Characteristics of a Reverberation Chamber for Microwave Frequencies***

Masaru Numano and Takahiro Aoyagi (Tokyo Institute of Technology, Japan)

In this paper, several posture models is set up in the reverberation chamber, and the effects of human body on the electric field distribution is quantitatively evaluated by numerical simulation at 2.45 GHz. Specifically, 12 observation points are set up, and the simulation is performed by changing posture models and stirrer angles. The simulation results show that the electric field amplitude becomes less than 1/100 and the electric field homogeneity deteriorates with posture models. Also, the results of the analysis of variance show that the influence of the observation points is smaller compared to the previous study simulated at 403.5 MHz. Furthermore, it is found out that the electric field homogeneity deteriorates as the number of observation points increased. Future studies includes evaluating the effects of various postures and comparing them with actual measurements.

17:50 ***Widely Linear Beamforming for Full-Duplex Joint Communications and Sensing: An Investigation on Virtual Displacement of Array Elements During Local Optimization***

Hadi Alidoustaghdam, Yang Miao and Andre Kokkeler (University of Twente, The Netherlands)

We have a closer look at widely linear beamforming (WLB) for full-duplex Joint Communication and Sensing (JCAS). WLB is a powerful method for mitigating the effect of IQ imbalances in array radiation. In full-duplex JCAS, the transmitting aperture radiates multi-beams focusing towards the communication user and the sensing target, while simultaneously the receiving aperture receives sensing signals. When applying WLB intended for interference mitigation between the transmitting and receiving apertures, mirror beams often occur and degrade the mitigation effect. In this paper, we propose to use virtual displacement of array elements during local optimization in WLB to further reduce the mirror beams. The virtual displacement is to deviate the antenna elements virtually in WLB optimization process and, in the numerical analysis, we show that this can be a solution for interference mitigation while we use uniform arrays in practice. This approach can facilitate the usage of modular hardware for JCAS.

18:10 ***Polarization Conversion from a Two-Port Impedance Loaded Tag***

Luis Felipe Fonseca Dias (University of Toulouse & CEA LETI, France); Camille Jouvaud (CEA LETI, France); Christophe Delaveaud (CEA-LETI, France); Hervé Aubert (Laboratory of Analysis and Architecture of Systems & Institut National Polytechnique de Toulouse, France)

The electromagnetic clutter mitigation is increasingly demanded for achieving the indoor identification and long-range reading of wireless and passive sensor tags. In this paper, a new Polarization Diversity scheme is proposed to reduce the clutter and consequently, to increase the reader-to-tag separation distance. The proposed wireless tag is a two-port patch antenna loaded by proper passive impedances. When illuminated by a circular polarized electric field, the proposed tag backscatters a linear or circularly polarized electric field, depending on the choice of four passive load impedances. This polarization conversion is then easily controlled, and could be advantageously implemented to improve the existing RFID systems by increasing reader-to-tag separation distance in cluttered environments.

A01: Adaptive and reconfigurable 5G Antennas

T01 LTE and Sub 6GHz 5G/ / Antennas

Chair: Daniel N Aloi (Oakland University, USA)

16:30 ***A New Weighting Method for Antenna Clusters***

Yunfeng Dong (vivo Mobile Communication Co., Ltd, China); Shen Wang (vivo Mobile Communication co., Ltd, China)

This paper presents a new weighting method that can be used for designing antenna clusters. The proposed weighting method performs a compromise, which provides a moderate and practical way of taking into account both the scattering parameters of the antenna cluster and the efficiencies of the individual antenna elements. Meanwhile, it does not require the detailed information nor the volume integral of far-field radiation patterns at each frequency point. In order to validate the proposed weighting method, an antenna cluster consisting of four inverted-F antenna (IFA) elements for mobile handset devices operating at 700-960 MHz is designed. The total active reflection coefficient (TARC) and the total efficiency of the antenna cluster are compared with the existing methods.

16:50 ***High-Gain Wideband and Superdirective Electronically-Beam-Switchable Antenna for Smart Communication Objects***

Lotfi Batel (CEA-Leti, France); Antonio Clemente (CEA-LETI Minatec, France); Christophe Delaveaud (CEA-LETI, France)

This paper proposes the design of a high-gain, wideband, directive, and compact circular array composed of 5 symmetrical radiating elements (1 fed and 4 parasitic elements). The possibility to implement an electronically beam-switching capability over the horizontal plane is studied. Thanks to the superdirectivity principle, the proposed closely spaced parasitic antenna array achieves a maximum gain of 10 dBi steered in four directions on the horizontal plane and a minimum gain of 9 dBi in the whole horizontal plane. The proposed antenna achieves a stable gain > 9dBi in the frequency band 758-803 MHz, which is interesting for sub-GHz 5G applications.

17:10 ***Substrate Integrated Waveguide Pedestal Filtenna for Sub-6 GHz 5G Radio Frequency Front-Ends***

Elmine Meyer and Niels Vertegaal (Eindhoven University of Technology, The Netherlands); Leanne Johnson (Stellenbosch University, The Netherlands); Petrie Meyer (Stellenbosch University, South Africa); Ulf Johannsen (Eindhoven University of Technology, The Netherlands)

This paper presents the design, manufacturing, and measurement of a novel substrate integrated waveguide (SIW) pedestal filtering antenna solution for use in 5G New Radio sub-6 GHz communications. Miniaturization is achieved through the use of SIW pedestal resonators and integration of the radiating element into the filter design, resulting in higher order suppression. The design generates a third order filtering response utilizing SIW pedestal resonators and a patch antenna element. The manufactured SIW pedestal filtenna achieves a 10 dB return loss bandwidth of 4.29 % about a centre frequency of 3.63 GHz, and a boresight gain of 3.66 dBi. Additionally a 1x4 linear array is measured, demonstrating the applicability to 5G radio frequency front-ends.

17:30 ***Simulation and Measurement for Sidelink Communication Between Cars and Bicycles***

Simon Hüsges and Michael Meuleners (Hochschule Niederrhein University of Applied Sciences, Germany); Niloufar Bateni (University of Duisburg-Essen, Germany); Christoph Degen (Hochschule Niederrhein University of Applied Sciences, Germany)

Vulnerable road users such as cyclists and pedestrians are now being increasingly integrated into connected driving issues. The focus of this paper is on cyclists with pedelecs as one group of vulnerable road users. Direct sidelink communication between cyclists and cars is also examined. In this study we present measurements obtained with commercially available on-board units operating at 5.9 GHz and based on LTE V2X. The antennas are connected to the OBU in different constellations using transmit and/or receive diversity. Simulations are used to support the measurements. For the intersection example scenario we observed reliable communication between a car with a distance of 25 m and a pedelec with a distance of 60 m towards the intersection. In a rural scenario, the communication range can be more than 400 m. However, the results depend highly on the antenna position on the pedelec.

17:50 ***Monte-Carlo Method for EMF Exposure Distribution Assessment in 5G Base Station***

Jiang Tingyong (Northwest Institute of Nuclear Technology, China & Microwave Lab, China); Anja K. Skrivervik (EPFL, Switzerland)

This paper studies the EMF (electromagnetic field) exposure distribution for a specific deployment scenario. This developed novel approach based on a Monte-Carlo (MC) approach took into account

the non-uniform user distribution and its corresponding projection to provide a realistic EMF exposure assessment for a particular coverage area of the 5G base station. A suburban area with relatively complex user distribution was selected to study the exposure distribution by the proposed method. The simulated results derived by the MC method show that considering the user distribution will reduce the user-related E-field exposure distribution under the given configuration by more than one half when compared to the traditional conservative deterministic approach. Moreover, the MC method demonstrates a more detailed exposure distribution feature corresponding to the specific active user distribution. It presents a reliable basis for power control when considering the trade-off between exposure evaluation and service quality.

18:10 ***Phased Array Antenna Design with Improved Radiation Characteristics for Mobile Handset Applications***

Naser Ojaroudi Parchin (Edinburgh Napier University, United Kingdom, United Kingdom (Great Britain)); Ahmed S. I Amar (Ain Shams University, Egypt); Atta Ullah and Raed A Abd-Alhameed (University of Bradford, United Kingdom (Great Britain))

This paper presents a low-profile 5G phased array with improved radiation properties for smartphone applications. By modifying the structure of antenna elements from conventional slots to air-filled slot-loop resonators (with the same thickness of the substrate), the array is capable to provide high-performance radiation beams at different scanning angles, even though it is designed on an FR-4 substrate. The array contains eight slot-loop radiators. The employed elements have low profiles with discrete-feeding ports and they operate at 21-23.5 GHz. Moreover, the coupling of the radiators is less than -15 dB at the centre frequency. Well-defined and quasi end-fire radiation, good efficiency and gain levels, wide beam-steering wide operation band are the promising characteristics of the introduced array which make it suitable for smartphone applications.

CS25a: IET/IRACON Propagation measurements and modelling for 5G and beyond Part 1

T02 Millimetre Wave 5G and 6G/ /Propagation

Chairs: Marina Barbiroli (University of Bologna, Italy), Sana Salous (Durham University, United Kingdom (Great Britain))

16:30 ***Path Loss Measurements and Modelling in a Citrus Plantation in the 1800 MHz, 3.5 GHz and 28 GHz in LoS***

Leandro Juan-Llacer and Jose-Maria Molina-Garcia-Pardo (Universidad Politécnica de Cartagena, Spain); Alain Sibille (Telecom Paris, France); Saúl Torrico (Comsearch & The George Washington University, USA); Luis Martínez Rubiola (Universidad Politécnica de Cartagena, Spain); Maria Teresa Martinez-Ingles (University Centre of Defence at the Spanish Air Force Academy, MDE-UPCT, Spain); José-Víctor Rodríguez and Juan Pascual-García (Universidad Politécnica de Cartagena, Spain)

Agriculture 4.0 is going to represent a massive deployment of sensors, so efficient planning of radiocommunication systems in this type of environment will be necessary. In this work, the measured path loss in a LoS condition, with the transmitter and receiver heights below the trees height, at a citrus plantation in the 1800 MHz, 3.5 GHz and 28 GHz frequency bands using a two-ray model in the vertical plane and the FI (Floating Intercept) and the CI (Close-In reference) slope models is analysed. Results show that, in the 28 GHz band, the direct and reflected-from-soil contribution may be enough to estimate the path loss for all the measure distance range, however, in the 1800 MHz and 3.5 GHz bands the multiple-scattering contributions from trees need to be considered after some distance between the transmitter and receiver. Furthermore, a guiding effect has been observed only in the 1800 MHz band.

16:50 ***Off-Grid Compressive Sensing Based Channel Estimation with Non-Uniform Grid in Millimeter Wave MIMO System***

You You (Purple Mountain Laboratories, China); Li Zhang (University of Leeds, United Kingdom (Great Britain))

Channel estimation is challenging for millimeter-wave communications because of the use of hybrid architecture and massive multiple-input multiple-output technology. By utilizing the sparsity in the angular domain, conventional on-grid compressive sensing methods can efficiently recover the channel state information. However, the channel estimation accuracy is severely affected by the off-grid errors and the selection of grid angles. The off-grid compressive sensing methods and the non-uniform grid angles can improve the channel estimation accuracy. In this paper, we investigate the impact of the non-uniform grid angles for the off-grid compressive sensing methods and the on-grid compressive sensing methods. We propose to employ the orthogonal matching pursuit algorithm with interior point method based off-grid error mitigation to implement the channel estimation using the selected angle design. The simulation results demonstrate the advantages of the proposed off-grid compressive sensing method and show the impact of the non-uniform grid angles.

17:10 ***Reflection and Penetration Loss Wideband Measurements of Building Materials at 28 GHz and 39 GHz***

Saied El-Faitori and Sana Salous (Durham University, United Kingdom (Great Britain))

This paper presents, the results of wideband measurements of several common building material conducted at 28 GHz, and 39 GHz in co-polar and cross-polar alignments to investigate the reflection and penetration loss at different incident angles using the wideband channel sounder developed at Durham University and narrow-beam lens antennas with 4.5 degrees beamwidth. The results show that, the lowest value of penetration loss was when the transmitter and receiver antennas are perpendicular on the material, and it was more than 30 dB (co-polar) and 20 dB (cross-

polar) at angles greater than 10 degrees on either side from the zero angle for most of the tested materials.

17:30 ***Deep Learning-Based Path Loss Prediction Using Side-View Images in an UMa Environment***

Nobuaki Kuno, Minoru Inomata, Motoharu Sasaki and Wataru Yamada (NTT, Japan)

Several models using DNN have been proposed to estimate the path loss characteristics in the UMa environment, most of which use the height of buildings around Tx and Rx as input images to the CNN part. However, buildings between Tx and Rx affect the path loss characteristics more than the buildings surrounding Tx and Rx, since the over-rooftop propagation becomes dominant when a Tx antenna is installed higher than the surrounding buildings. In other words, the DNN in these models does not consider the propagation paths over rooftops. If such paths were considered, it would be possible to improve the estimation accuracy. In this work, we propose a new model that uses the side-view image of a building on the straight line between Tx and Rx as input, in addition to the conventional top-view image. We then evaluate the effect using measurement data.

17:50 ***MIMO Measurements at 25 GHz in Factory Environment***

Mohamed Abdulali and Sana Salous (Durham University, United Kingdom (Great Britain))

This paper presents eight by eight MIMO measurements in a factory environment for both line of sight (LoS) and non-line of sight (NLoS) scenarios at 25 GHz using eight directional antennas at the transmitter and at the receiver with the custom-designed channel sounder developed at Durham University. The data were analysed to estimate the Rician the K-factor, angular spread, root mean square (rms) delay spread. The 50% and 90% values of the rms delay spread values for a 20 dB threshold are presented for both scenarios. The MIMO channel capacity is also estimated for different signal to noise ratios.

18:10 ***Angular Characteristics Prediction of Radio Propagation Channel from Point Cloud Data by Aperture Field Integration Method***

Kentaro Saito (Tokyo Denki University, Japan); CheChia Kang and Jun-ichi Takada (Tokyo Institute of Technology, Japan)

With the recent growth of computing resources, the construction of large-scale cyber-physical systems (CPS) becomes feasible, and they are expected to be an indispensable infrastructure. Because wireless communication is now an essential function in many systems, the simulation technique of the propagation channel becomes quite important to realize the CPS. There are several types of research that utilize the point cloud data of the environment for the radio propagation simulation. However, the usage of the point cloud data is not so straightforward because it generally includes large noise, and points are not taken at constant spacing. In this paper, we propose the channel prediction method by the aperture field integration method (AFIM) approach. In the proposed method, the spatial spectrum of the surface electric current is calculated, the scattering waves are represented by the superposition of several plane waves. The noise of point cloud data can be eliminated by filter.

M01: Body and biological tissues propagation measurements

T04 Biomedical and Health/ / Propagation

Chairs: Agostino Monorchio (University of Pisa & CNIT, Italy), Mauricio D Perez (Uppsala University, Sweden & National Technological University, Argentina)

16:30 ***Dielectric Characterization and Chemical Concentration Sensing Using T-Shaped Antenna***

Muhammad Usman Ejaz (Antenna Group, EECS, Queen Mary University of London, United Kingdom (Great Britain)); Tayyaba Irum and Akram Alomainy (Queen Mary University of London, United Kingdom (Great Britain))

A multifunctional, cost-effective, and easy to fabricate T-shaped patch antenna is presented, resonating in the frequency range of 18 - 25 GHz when evaluated without sample and resonant frequency in a range of 2.5 - 9 GHz when sample layer is introduced as superstrate, having a broad range of applications in the field of chemical and biomedical sensing. The sensor layer is the topmost layer with a T-shaped patch antenna underneath with substrate and ground plane, respectively. Ethanol, Methanol, and edible fat solution samples are investigated for concentration sensing. The design demonstrated consistent behaviour of increase in resonant frequency by the value of at least 150 MHz with an increase in the concentration of Ethanol and methanol. In the case of edible fat, the resonant frequency increased by a value of 10 MHz with an increase in the concentration of edible fat in the sample layer.

16:50 ***A Feasibility Study of a Radio-Frequency Theranostic Device for Tumor Localization and Treatment***

Sabrina Rotundo and Danilo Brizi (University of Pisa, Italy); Agostino Monorchio (University of Pisa & CNIT, Italy)

In this paper, we present a feasibility study of an innovative theranostic system for non-invasive detection and treatment of malign neoplasms by using a radio-frequency magnetic field. The proposed hardware system, operating at 3 MHz, consists in a resonant spiral coil coupled to an unloaded concentric probe loop. The tumor detection is achieved by measuring the amplitude shift of the probe input impedance while scanning the region of interest. This hardware configuration has the main purpose to produce a focused and homogeneous field distribution, which improves the

device resolution during the imaging procedure; conversely, in the ablation treatment, it produces a focused heating precisely directed towards the previously detected tissues, preserving the surrounding healthy regions. The main advantages of the proposed system, beside the relatively low-complexity instrumentation, also include the possibility to reducing the time of diagnosis and the invasiveness for the patient, to increase the therapy effectiveness.

17:10 ***Muscle Analyzer System: Exploring Correlation Between Novel Microwave Resonator and Ultrasound-Based Tissue Information in the Thigh***

Viktor Mattsson (Uppsala University, Sweden); Mauricio D Perez (Uppsala University, Sweden & National Technological University, Argentina); Leanne Ackermans, Maud Vesseur, Julia Bels and Marcel van de Poll (Maastricht University Medical Centre+, The Netherlands); Bappaditya Mandal (Uppsala University, Sweden); Patricia Sánchez-González (Universidad Politécnica de Madrid, Spain); Alexander Seiffert (Universidad Politécnica de Madrid); Enrique Gómez (Universidad Politécnica de Madrid, Spain); Paul Meany (USA); Jan Ten Bosch (Maastricht University Medical Centre+, The Netherlands); Taco Blokhuis (University Medical Center Maastricht, The Netherlands); Robin Augustine (Uppsala University, Sweden)

A microwave sensor to safely measure quality of muscle tissue for diagnosis and screening of diseases and medical conditions characterized by fat infiltration in muscle is presented. Fat infiltration in muscle may be seen by a lower dielectric constant of muscle at microwave frequencies corresponding to the large contrast between fat and muscle tissues. A planar resonator based on a bandstop filter and optimized to noninvasively interrogate muscle in the thigh on tissue quality is proposed. Currently, a study based on clinical trials is carried out, and, here, we present a preliminary correlation between skin and fat thicknesses and rectus femoris cross sectional area (CSA) measured with ultrasound and the proposed sensor's resonance frequency. CST simulations based on the ultrasound information guide the analysis. We see that although there are signs of a potential correlation between CSA and resonance, skin and fat variability is still an issue to overcome.

17:30 ***Bessel Beam Radiating System for Focused Transcranial Magnetic Stimulation***

Sabrina Rotundo and Danilo Brizi (University of Pisa, Italy); Agostino Monorchio (University of Pisa & CNIT, Italy)

In this paper, we present an innovative radiating system able to produce a focused treatment for transcranial magnetic stimulation applications. The proposed configuration is based on a non-diffractive Bessel Beam launcher as radiating device. The launcher consists in five concentric planar spiral coils, working at 3 kHz, singularly fed with a proper current amplitude and phase. In this way, a Bessel-like non-diffractive magnetic field distribution can be recreated so that a focused induced electric field inside tissues can be generated. Such peculiar field distribution can find interesting applications for Transcranial magnetic stimulation (TMS), since extremely focused and accurate stimulation can be performed. The numerical results obtained through full-wave simulations show a good spatial resolution and focalization, in term of induced electrical field inside brain tissues at different depths. Such preliminary results suggest the possibility to overcome the single coil performance, encouraging further analysis.

17:50 ***Impact of Drug Treatment on the Electromagnetic Properties of Basal Cell Carcinoma Cancer in the Terahertz Band***

Shohreh Nourinovin, Muhammad Rahman, Robert Jones, Mike Philpott and Akram Alomainy (Queen Mary University of London, United Kingdom (Great Britain))

Terahertz (THz) radiation has remarkable potential in the medical area as a non-ionizing, non-invasive, and label free method, especially in the early detection of cancer. Skin tumors typically have a higher water portion than healthy tissues, and this can be reflected in the electromagnetic parameters. In this work, we have investigated artificial human tissue with basal cell carcinoma (skin cancer) and explored the functionality of the anti cancer drug in the treatment process. The measurement is done in frequency range of 0.2 to 1.5 THz. In comparison with the artificial normal tissue, the results are in adaption with previous works and enriches the database of THz characterisation of cancer cells. Obtained THz electromagnetic properties of treated cancer can open new windows to boost the precision of diagnose and prevent skin tumours at the early stage

CS40: Recent Advances on Propagation Research and Its Impact on Localizations

T07 Positioning, Localisation and tracking/ /Propagation

Chairs: Christian Gentner (German Aerospace Center (DLR), Germany), Wei Wang (Chang'an University, China)

16:30 ***Simultaneous Localization and Antenna Calibration***

Robert Pöhlmann, Siwei Zhang, Emanuel Staudinger and Armin Dammann (German Aerospace Center (DLR), Germany); Peter A. Hoeher (University of Kiel, Germany)

Cooperative localization fills the gap in scenarios where global navigation satellite system (GNSS) reception is denied or impaired. Position and orientation information is then often provided based on signal round-trip time (RTT) and direction-of-arrival (DoA). Obtaining a meaningful RTT requires calibrated transceiver group delays, and accurate DoA estimation requires antenna calibration. Usually, such calibrations are performed once before operation. However, calibration parameters can change over time, e.g. due to varying temperature of RF components or reconfigurable antenna surroundings. To cope with that, we propose to estimate antenna responses and ranging biases simultaneously with positions and orientations by simultaneous localization and calibration (SLAC).

We derive a SLAC algorithm based on Bayesian filtering, which is suitable for arbitrary antenna types. The algorithm is evaluated with measurement data from robotic rovers. We show, that ranging and DoA performance is improved considerably, leading to better position and orientation accuracy with SLAC.

16:50 ***Correlation Levels for Measured Indoor 21.5 GHz Channels with a User-Held Handset***

Jesper Ø Nielsen and Gert Pedersen (Aalborg University, Denmark)

Adaptive beamforming (BF) is essential when mm- wave bands are utilized for mobile communications, where it is important that the channel experienced when BF is applied is as similar as possible to the estimated channel. This work investigates the similarity of the channel at different time-instants using estimates of auto-correlation functions for the instanta- neous channel coefficients, based on 21.5 GHz measurements with a smartphone-like mock-up in different indoor corridor scenarios, with and without a user holding the mock-up. The correlation is found to be relatively independent of the location and orientation, with a reduced correlation with a person present. Further, BF is studied based on the 7-element handheld array with a 8.8-24.6 dB gain found for the 1st amplitude percentile obtained with ideal channel state information (CSI). Non-ideal CSI typically reduces both the correlation and the BF gain.

17:10 ***Multipath-Enhanced Device-Free Localization Using Low-Cost Ultra-Wideband Devices***

Martin Schmidhammer and Christian Gentner (German Aerospace Center (DLR), Germany)

Multipath propagation can improve device-free localization (DFL). In this work, we therefore provide an overview of the required signal processing for multipath-enhanced device-free localization (MDFL) and introduce a possible sequential Bayesian approach. Furthermore, we demonstrate that low-cost ultra-wideband devices can be used for MDFL. Specifically, we use the Qorvo (DecaWave) DWM1000 module, for which we describe how to access the channel impulse response in detail. Based on a sparse network of ultra-wideband devices, we evaluate the localization performance of both DFL and MDFL for an indoor scenario. Thereby, MDFL is shown to clearly outperform DFL in terms of localization performance.

17:30 ***A Learning-Based NLOS Mitigation Method for Single-Anchor SLAM***

Tianyu Wang, Yuxiao Li, Junchen Liu and Yuan Shen (Tsinghua University, China)

Location-awareness has playing an increasingly important role in wireless networks. Indoor radio frequency-based simultaneous localization and mapping (SLAM) can be enabled through ultra-wide bandwidth systems due to its ability to provide accurate channel information. In this paper, we provide a deep learning approach to improve the localization accuracy of users and reflection points based on a single-anchor ultra-wide bandwidth system in indoor complex environments. In the proposed approach, we propose a deep generative model to mitigate the distance and the angle-of-arrival estimation errors introduced by non-line-of-sight propagation. Instead of manually extracting features, we make full use of the amplitude and phase information in the channel impulse response to obtain more location-related information. Our work is validated by an indoor sufficient measurement campaign with self-built FCC-compliant ultra-wide bandwidth transceivers, and the results show that our approach outperforms conventional machine learning approaches in practical scenarios.

17:50 ***Multipath-Based Localization and Tracking Considering Off-Body Channel Effects***

Thomas Wilding, Erik Leitinger and Klaus Witrisal (Graz University of Technology, Austria)

This paper deals with multipath-based positioning and tracking in off-body channels. An analysis of the effects introduced by the human body and the implications on positioning and tracking is presented based on channel measurements obtained in an indoor scenario. It shows the influence of the radio signal bandwidth on the human body induced field of view (FOV) and the number of multipath components (MPCs) detected and estimated by a deterministic maximum likelihood (ML) algorithm. A multipath-based positioning and tracking algorithm is proposed that associates these estimated MPC parameters with floor plan features and exploits a human body-dependent FOV function. The proposed algorithm is able to provide accurate position estimates even for an off-body radio channel in a multipath-prone environment with the signal bandwidth found to be a limiting factor.

18:10 ***Opportunistic Navigation Using Sub-6 GHz 5G Downlink Signals: A Case Study on A Ground Vehicle***

Ali Abdallah and Zaher Kassas (University of California, Irvine, USA)

A user-based navigation framework that exploits 5G signals is developed. The proposed framework exploits the "always on" 5G downlink signals simultaneously in a time- domain-based receiver to navigate a ground vehicle. To do so, a so-called ultimate synchronization signal (USS) is proposed to utilize the time-domain orthogonality of the orthogonal frequency division multiplexing (OFDM)-based 5G signals. This approach simplifies the complexity and enhances the perfor- mance of the 5G opportunistic framework. An experimental results was performed in a suburban environment to evaluate the proposed framework on a ground vehicle platform while sub-6 GHz 5G signals from two gNBs corresponding to two U.S. cellular providers. It is shown that over a trajectory of 2.17 km traversed in 230 seconds, the position root mean-squared error (RMSE) was 9.71 m compared to 14.93 m achieved using the state-of-the-art frequency-based 5G opportunistic navigation framework.

CS31: New Antenna Systems involving Application of Metamaterials and Metasurfaces

T10 Fundamental Research and Emerging Technologies/ / Antennas

Chair: Rafael R. Boix (University of Seville, Spain)

16:30 ***A Single Metasurface Plate Excited by a Patch Antenna for Large Tilt Angle Formation***

Tomoki Abe, Junji Yamauchi and Hisamatsu Nakano (Hosei University, Japan)

An antenna system composed of a single metasurface plate and a feed patch antenna is proposed. First, for inclusions of the metasurface plate, a double L-shaped metaatom is investigated, where the metaatom has inner and outer conducting arms. The change in the inner arm length creates a desired transmission phase for plane wave incidence on it. Next, the metasurface plate is placed above the feed patch antenna. As an example, a tilt beam of 60 degs is designed. The gain in a fixed direction of theta = 60 degs is approximately 18 dBi, which is approximately 11 dB higher than the gain of the patch antenna. The 3-dB gain drop bandwidth is approximately 12%. The VSWR at the feed point of the patch antenna is less than two.

16:50 ***Ultrathin Metamaterial-Inspired Huygens Dipole Antenna and Rectenna Arrays for Wireless Power Transfer Enabled IoT Applications***

Wei Lin (University of Technology Sydney, Australia); Richard Ziolkowski (University of Technology Sydney, Australia & University of Arizona, USA)

Ultrathin metamaterial-inspired Huygens dipole antenna and rectenna arrays are presented for wireless power transfer (WPT) enabled IoT applications. The fundamental array element is the electrically small Huygens dipole antenna (HDA) that consists of two metamaterial-inspired structures: an Egyptian axe dipole (EAD) and a capacitively loaded loop (CLL). The EAD and CLL are designed on both sides of a single PCB substrate functioning as the in-phase and orthogonal electric and magnetic dipoles. A short-driven dipole close to the CLL excites the two radiators. Based on the single element HDA, an ultrathin, beam-steerable Huygens dipole antenna array (HDAA) with wide area coverage and small gain variation has been developed as a long distance WPT transmitter for battery-free applications. Experimental verifications of the simulated results are presented.

17:10 ***Space-Time-Coding Digital Metasurfaces for New-Architecture Wireless Communications***

Lei Zhang, Xiao Qing Chen, Qiang Cheng and Tie Jun Cui (Southeast University, China)

Space-time-coding (STC) digital metasurfaces have attracted great research interests due to their outstanding capabilities of manipulating electromagnetic (EM) waves and modulating information in various domains, which have been extensively studied to control the spatial and spectral distributions of EM waves. In this paper, we present a compact review of some new-architecture wireless communication systems based on the STC digital metasurfaces, which have the advantages of low cost, low complexity, low power consumption and high efficiency, and provide candidate technologies for future 6G wireless communication networks.

17:30 ***Multifunctional Metasurface for Broadband Reflect-Transmit-Array Antenna at 5G Millimeter-Wave Band***

Weixu Yang, Ke Chen and Yijun Feng (Nanjing University, China)

In this paper, a high-efficiency multifunctional full-space metasurface is proposed to independently control the reflection and transmission wavefront. As a proof of concept, a broadband reflect-transmit-array antenna with bidirectional high-gain beams is designed in the 5G millimeter-wave band around 26.8 GHz. The finally assembled antenna achieves 1-dB gain bandwidths of 21.2% (16.2%) and 3-dB axial ratio bandwidths of 35.5% (36.5%) for reflectarray (transmitarray) operations. Moreover, a total aperture efficiency of 55.8% is realized by considering the two radiation operations. The proposed reflect-transmit-array antenna with the advantages of broad bandwidth, high aperture efficiency, and high polarization purity maybe a promising candidate for bidirectional wireless communication applications.

17:50 ***High-Directivity Ultra-Sparse Antenna Arrays Using Multielement Metagratings***

Ariel Epstein and Yaniv Kerzhner (Technion - Israel Institute of Technology, Israel)

We present a rigorous analytical model utilized to design highly-sparse antenna arrays, taking advantage of the recent concept of metagratings (MGs). The proposed semianalytical methodology, avoiding full-wave optimization, enables replacement of the generally-large number of active radiating elements with passive capacitively-loaded wires (meta-atoms), without sacrificing array directivity. Contrary to common techniques to dilute arrays, relying mostly on optimization of active element distribution and excitation, our modular solution utilizes a standard array configuration with linearly-phased elements; grating-lobe suppression is achieved by proper engineering of the passive MG, harnessing Floquet-Bloch formalism to control power partition into diffraction orders. To facilitate dramatic dilution and comply with printed-circuit-board (PCB) design requirements, we extend our previous work, enabling inclusion of multiple meta-atoms per period within a multilayered dielectric substrate. This concept, verified via full-wave simulations, is expected to facilitate the development of low-cost, planar, low-loss, and highly-directive antenna systems for future cellular and satellite communication.

18:10 ***Direct Inversion Approach with Gaussian Ring Basis Functions for MTS Antennas Synthesis***

Marco Faenzi (University of Siena, Italy); David González-Ovejero (Centre National de la Recherche Scientifique - CNRS, France); Enrica Martini and Stefano Maci (University of Siena, Italy)

Design of modulated metasurface antennas has been recently treated as an inverse problem stemming from the discretization of an EFIE equation. Fourier-Bessel basis functions have been used for representing the currents and the IBC. We explore a similar formulation of synthesis taking advantage of the use of a set of quasi-orthogonal sub-domain Gaussian-Ring basis functions. Representation of the MTS equivalent impedance in terms of this base allows to invert the EFIE problem and, therefore, to directly define the boundary conditions suitable to generate a rather arbitrary radiation pattern. The technique combines the possibility of directly designing the aperture IBCs with advantages coming from GRBF adoption. Such a base offers the power of sub-domain functions spatial resolution and the possibility to define the unknown impedance on a customary interval. Furthermore, the analytical expression of the basis functions allows for quick closed or semi-closed form evaluation of matrices in EFIE inversion procedure.

Monday, March 28 16:30 - 17:30

IW10: Recent advances in the design and optimisation of blended rolled edge compact antenna test ranges

Monday, March 28 16:30 - 18:30

CS33: Novel Antenna Measurement Techniques and Data Analysis

T09 EM Modelling and Simulation tools/ /Measurements

Chair: Dennis Lewis (Boeing, USA)

16:30 ***High-Performance Processing with Equivalent Currents: Results on a Very Large Measured Antenna***

Lucia Scialacqua (Microwave Vision Italy, Italy); Francesca Mioc (Consultant, Switzerland); Francesco Scattone (Microwave Vision Group (MVG), Italy); Lars Foged (Microwave Vision Italy, Italy); Giorgio Giordanengo (LINKS Foundation & Politecnico di Torino, Italy); Marco Righero (LINKS Foundation, Italy); Giuseppe Vecchi (Politecnico di Torino, Italy)

The method of the equivalent currents for antenna diagnostics has been widely demonstrated over the years on a large set of measured data. Its key advantage is to provide a complete 3D representation of the antenna by a direct post processing, without any additional testing, like probing. Recently, the method has been equipped by a technique based on a Nested Skeletonization Scheme (NSS) for post processing of very large antennas. In a previous investigation the post-processing with NSS has been applied to a prototype of an array antenna. Only a portion of the array geometry has been considered in the investigation for the limitation imposed by RAM constraint. In this paper we will show a new technique that enhances the NSS method for processing of large problems and that makes possible a complete diagnostics investigation where previously this was not feasible.

16:50 ***Examination of Antenna Calibration Methodologies in an Extrapolation Range***

Zhong Chen and Yibo Wang (ETS-Lindgren, USA); Dennis Lewis (Boeing, USA)

Antenna measurements using an extrapolation range have been used for accurate far-field gain calibrations since the 1970s. It is still considered one of the most accurate methods for obtaining the absolute far-field gain of an antenna. The method is based on curve fitting the scalar antenna responses to the generalized transmission equation, which is in the form of a polynomial equation. It is much more common today to use vector network analyzers in an extrapolation range. The vector data provides experimentalists additional processing tools to further improve measurement accuracy and reduce effects from extraneous reflections in the chamber. In this paper, we explore the use of angular spectrum filtering for removing chamber multipath effects from the response data. Specifically, we demonstrate the benefits by applying the technique on a set of measurement data obtained in a 30'x30'x70' fully anechoic extrapolation range.

17:10 ***Alternate Methods for Computation of Higher-Order Modal Scattering of Anechoic Absorbers at mm-Wave Frequencies***

Anoop Adhyapak (ETS-Lindgren, USA); David Rolando (Ansys, USA)

Prediction of chamber reflectivity levels based on the geometry-optics based ray-tracing method by considering only the specular modes is accurate at microwave frequencies but fails at mm-wave frequencies. Previous research laid out methods on the extraction of higher-order modal reflectivity of the anechoic absorber at mm-wave frequencies. The higher-order modal scattering were translated to chamber modelling and a cumulative reflectivity heat-map was generated. This paper explore an alternate approach based on Design of Experiments analysis to reduce the simulation time while maintaining the simulation accuracy. In addition, another approach based on PML boundary condition and plane-wave excitation is explored to overcome the 100-mode limit of the Floquet based model results.

17:30 ***Characterization of 5G k-Band Array Antennas***

Thomas Harz (PTB Braunschweig, Germany); David Ulm and Thomas Kleine-Ostmann (Physikalisch-Technische Bundesanstalt, Germany)

The use of active antenna arrays in mobile radio applications such as 5G New Radio has made it necessary to define new metrics to evaluate these antenna systems. The guidelines in the mobile radio network are regulated by 3GPP and require conformity testing. The legal rules, which serve for the protection of persons against electromagnetic fields, have to be fulfilled as part of the approval procedure for a base station. In this paper, requirements are presented regarding the definition of radiation patterns. It also shows a measurement method for measuring the envelope curve, which is the basis for calculating the electromagnetic field exposure in the approval procedure in Germany. Applying this method, the measurement results of a millimeter-wave antenna are presented.

17:50 ***Exponential Correlation Model for Electric Field Intensity in Reverberation Chambers***

Carlo Carobbi (University of Florence, Italy); Ramiro Serra (Eindhoven University of Technology, The Netherlands)

The role of field correlations in the intrinsic measurement uncertainty in reverberation chambers (RC) is a topic of great interest for many electromagnetic compatibility as well as over-the-air measurement techniques. This paper investigates the applicability of an exponential correlation model to measured electric field intensities in a RC under different loading conditions. The exponential model allows for a robust estimation of the average correlation in measured data, which is a key parameter for quantifying measurement uncertainty.

18:10 ***Salient Features of Eulerian and Quaternion Formalisms in Antenna Applications***

Yahya Rahmat-Samii (University of California Los Angeles (UCLA) & UCLA, USA); Tianjian Huang (UCLA, USA)

This paper revisits the formalisms of coordinate system and rotation transformations encountered in diverse antenna analysis and measurement scenarios in a unified fashion. Both Eulerian angles and quaternion constructions are applied and relevant details are presented. The advantages and disadvantages of both constructions are discussed, and appropriate formulas are developed to demonstrate how these two formalisms could be interrelated.

Monday, March 28 17:30 - 18:30

IW12: IW12: Dassault

Monday, March 28 18:30 - 20:00

Welcome Reception

Tuesday, March 29

Tuesday, March 29 9:00 - 10:40

IW05: Simcenter 3D for Electromagnetics: update on new capabilities for antenna design, array design, system integration and environment modelling

Industrial Workshop

CS17: Challenges and Solutions of Radio Frequency Testing for advanced 5G Radio Systems

T01 LTE and Sub 6GHz 5G/ / Measurements

Chairs: Wei Fan (Aalborg University, Denmark), Pekka Kyösti (Keysight Technologies & University of Oulu, Finland)

9:00 ***Large DUT Testing in FR2 MIMO OTA***

Jukka-Pekka Nuutinen (Spirent Communications, Finland); Doug Reed and Alfonso Rodriguez-Herrera (Spirent Communications, USA)

This paper discusses the limited test volume of FR2 MIMO OTA test systems according to 3GPP specifications. The current FR2 MIMO OTA test system supports a 20 cm diameter UE size. However, 5G services are expected to include larger devices, such as tablets and small-scale monitors, as well. We show that the best way to improve the performance of the FR2 MIMO OTA system is to increase the chamber size to support a 1.75m range length instead of the current 0.75m range length. We also discuss the error factors inside the test volume, showing how the boundary of the test volume dominates the error.

9:20 ***Polarization of BS Array in FR2 Deployments***

Doug Reed and Alfonso Rodriguez-Herrera (Spirent Communications, USA); Jukka-Pekka Nuutinen (Spirent Communications, Finland)

The impact of selecting a BS array with a two different polarization options are compared using several different performance characteristics. A V&H polarized array utilizing Plus (+) elements is compared to an array with slant 45° (X) elements using standardized models to evaluate potential differences in PDP, Autocorrelation, eigenvalues, and Capacity estimates. Comparisons are made and discussed.

9:40 ***Analysis of Instantaneous and Maximal RF Exposure in 4G/5G Networks with Dynamic Spectrum Sharing***

Lisa-Marie Schilling, Christian Bornkessel and Matthias Hein (Technische Universität Ilmenau, Germany)

Dynamic spectrum sharing (DSS) was introduced in the 2100 MHz band since 2020, which allows a parallel operation of 4G and 5G. There is an increasing need of public information with regard to a possible change in human RF exposure associated with 5G and DSS. Hence, investigations were carried out to study the instantaneous and maximal exposure of persons to base stations in the 2100 MHz band. Our study shows, that the instantaneous exposure has remained comparable before and after the introduction of 4G/5G with DSS. Regarding the maximal RF exposure, code-selective measurements of 3G and 4G with DSS show no significant change in exposure. To analyze the maximal exposure to 5G with DSS, code-selective measurements have been applied for the first time and compared with the 4G exposure in the same band. The results show no significant difference in maximal exposure between 4G and 5G.

10:00 ***Multi-Probe Linear Matrix Inversion Method in Sub-Array Internal Element Calibration***

Yusheng Zhang, Zhengpeng Wang and Jungang Miao (Beihang University, China)

This paper presents a sub-array internal element calibration method using linear matrix inversion method. Multi-probe is employed to detect the E-field distribution of the sub-array under test in the near field. A transmission matrix between the sub-array and probes is built. The key point of this method is getting low condition number transmission matrix. Furthermore, optimization strategy based on genetic algorithm is introduced to obtain more stable matrices. Simulation results show only 4 probes are needed for a 4-element array testing. Finally, a 4-element sub-array composed of rectangular waveguide antennas operating at 3.5 GHz was measured to validate the effectiveness of the proposed method, and the results show a high accuracy - the error between the proposed method and the reference test is less than ±0.2dB, ±2°.

10:20 ***Mobile Network Testing of 5G NR FR1 and FR2 Networks: Challenges and Solutions***

Christoph Hausl (Rohde & Schwarz, Germany); Julian Emmert, Manuel Mielke, Benjamin Mehlhorn and Corbett Rowell (Rohde & Schwarz GmbH, Germany)

This paper considers mobile network testing for 5G NR (both sub-6GHz and millimeter wave frequency bands) with a passive RF receiver. Methods for the measurement of network coverage, network synchronization, channel impulse response, and the strength of the electromagnetic field with a code selective procedure are proposed and implemented. An approach for automatic channel detection is presented in order to find the relevant carrier frequencies for 5G mobile network testing in networks with an unknown configuration. Finally, the proposed methods are applied for deployed 5G networks, demonstrating the effectiveness of the equipment.

10:40 Coffee Break

11:00 ***Fast Array Diagnosis Based on Measured Complex Array Signals with Short Measurement Distance***

Mengting Li, Fengchun Zhang and Wei Fan (Aalborg University, Denmark)

Fast array diagnosis method is of great importance for ensuring reliable array performances in the fifth generation(5G)communication systems. In this paper, a fast array diagnosis method is presented for antenna arrays composed of several subarrays. The objective is to detect the failures based on the measured complex array signals in short measurement distance. A single probe is required to record the array response in the near-field of the array. All the array elements are excited simultaneously, and only phase shift states of 0 and 180 degree are required in the measurements. For a base station(BS)antenna array with N subarrays, N+1 measurements are required, resulting in a fast diagnosis process. Finally, the proposed method was validated in an antenna array composed of 4 subarrays with 3 antenna elements in each subarray and successful diagnosis results (both for the faulty subarray and faulty single antenna element in subarray cases) can be observed.

11:20 ***EMF Exposure of Human Head by Handset mmWave Phased Antenna Array***

Stanislav Stefanov Zhekov and Ming Yao (Aalborg University, Denmark); Ondřej Franek (Aalborg University & APMS Section, Denmark); Kun Zhao and Shuai Zhang (Aalborg University, Denmark)

Deployment of the fifth-generation (5G) mobile communications at the millimeter-wave (mmWave) part of the electromagnetic spectrum comes with concerns related to exposure of the human to electromagnetic field (EMF). The irradiation of the human body from phased antenna arrays, integrated into handsets operating at mmWave frequencies, is evaluated in terms of power density (PD). This paper presents a study on the local incident power density (IPD) on a surface made of vacuum and having the shape of the specific anthropomorphic mannequin (SAM) head phantom. The employed array consists of four off-ground half-wavelength dipoles. Two different orientations of the mobile terminal with respect to the phantom - cheek and tilt position are studied, as the goal is to find test exclusion possibilities. According to the results, the lower exposure in the tilt position (regardless of the frequency, inter-element spacing, and array excitation) allows tests for this handset orientation to be omitted.

11:40 ***Radio Channel Emulation for Virtual Drive Testing with Site-Specific Channels***

Allan Mbugua and Yun Chen (Huawei Technologies Duesseldorf GmbH, Munich Research Center, Germany); Wei Fan (Aalborg University, Denmark)

Virtual drive testing (VDT) with measured or ray tracing (RT) simulated channels requires the simplification of the channel to match the hardware specification of radio channel emulators. That is, reduction of the number of multipath components (MPC)s and adjustment of the arbitrary delays of the MPCs to the sampling grid of the radio channel emulator. In this paper, a fractional delay (FD) filter approximated by a general least square (GLS) finite impulse response (FIR) filter is used for band-limited interpolation to align the delay of the MPCs to the sampling grid of the radio channel emulator. A dominant power selection strategy is then employed to reduce the taps to match a given hardware specification. The GLS FIR method is shown to have superior performance in preservation of the channel frequency response (CFR) compared to rounding delays to the nearest integer multiple of the sampling time.

12:00 ***Study of Channel Model Validation in Millimeter Wave MIMO OTA Test***

Shangbing Qiao and Xiang Zhang (China Academy of Information and Communications Technology, China); Ying Zhu, Feilong Wang and Hao Sun (China Academy of Information and Telecommunications Technology, China)

Millimeter wave (mmWave) technology is one of the key technologies introduced in 5G new radio(NR). Abundance of spectrum resource allows the mmWave 5G NR to achieve higher rates, greater capacity and lower latency. Performance test is a powerful means to help develop mmWave technology. Particularly, over-the-air (OTA) test is the only practical method for mmWave technology due to the lack of accessible antenna port on mmWave devices. The Third Generation Partnership Project (3GPP) has started the studies on mmWave MIMO OTA performance test methodology for which channel model validation is crucial. This paper investigates the impact of test antenna pattern under near-field condition on mmWave channel model validation. Simulation shows that different models have different requirements for the test antennas of which omnidirectional antennas are not always needed.

12:20 ***Validating FR2 MIMO OTA Channel Models in 3D MPAC***

Usman Tahir Virk (Keysight Technologies & Aalto University, Finland); Lassi Hentila (Keysight Technologies, Finland); Pekka Kyösti (Keysight Technologies & University of Oulu, Finland); Jukka Kyröläinen (Keysight Technologies Finland oy, Finland)

Fifth Generation (5G) technology is about to set its global footprint. Its success relies heavily on the standardization process, which is rapidly progressing to specify verification metrics and test methodologies for 5G New Radio (NR) device certifications. For this purpose, three-dimensional (3D) multi-probe anechoic chamber (MPAC) has been selected as a reliable reference solution for creating an accurate test environment. This paper reports first ever FR2 MIMO over-the-air (OTA) channel models validation measurements according to 3GPP specified verification procedure. The evaluated validation metrics include power-delay profile (PDP) and power-angular spectrum (PAS) similarity percentage (PSP). The measurement results closely follow the simulated and theoretical references, thereby demonstrating the feasibility of FR2 MIMO OTA channel models validation procedure adopted by 3rd Generation Partnership Project (3GPP).

CS25b: IET/IRACON Propagation measurements and modelling for 5G and beyond Part 2

T02 Millimetre Wave 5G and 6G/ /Propagation

Chairs: Marina Barbiroli (University of Bologna, Italy), Sana Salous (Durham University, United Kingdom (Great Britain))

9:00 ***Omnidirectional Millimeter-Wave Propagation Characteristics of Corridor Environments Based on Measurements at 28, 38, 71 and 82 GHz***

Juyul Lee, Kyung-Won Kim, Jae-Joon Park, Myung-Don Kim and Heon Kook Kwon (ETRI, Korea (South))

This paper investigates measurement-based omni-directional millimeter-wave propagation characteristics for an indoor corridor environment. The omnidirectional characteristics were obtained with actual omnidirectional antenna measurements both at TX and RX, and not by synthesizing directional antenna measurements. With wideband sounding at 28, 38, 71 and 82 GHz, we analyzed path

loss, shadow fading, excess loss and delay spread characteristics. In the path loss and the excess loss analyses, evident differences between the LOS and the NLOS were observed due to the waveguide effects. In the excess loss and the delay spread analyses, gaps were observed between the relative lower mmWave frequencies (28 and 38 GHz) and the upper frequencies (71 and 82 GHz).

9:20 ***An Introduction to Dimensionality Reduction for Propagation Measurements***

Alejandro Ramírez-Arroyo and Luz Garcia (University of Granada, Spain); Antonio Alex-Amor (Universidad CEU San Pablo, Spain); Juan Valenzuela-Valdés (Universidad de Granada, Spain)

This paper presents the dimensionality reduction of a propagation channel dataset created through a measurement campaign. The scenario knowledge is essential for the signal processing prior to the transmission and the application of these techniques allows a quick scenario differentiation. The measurement campaign, which has been performed in the SWAT research group's facilities at the University of Granada, includes propagation channels from three different scenarios: anechoic, reverberation and indoor. t-SNE, a Machine Learning technique that performs a non-linear dimensionality reduction, has been applied to the propagation channels. The results show the separability of the three scenarios in a low-dimensional space for an optimal election of the t-SNE hyperparameters. The most relevant hyperparameters in the performance of the technique are the distance metric and the perplexity.

9:40 ***RMS Delay Spread Model for 60 GHz Band for Offices and Conference Rooms***

Monika Drozdowska (The Polytechnic University of Valencia, Spain); Amar Al-Jzari and Sana Salous (Durham University, United Kingdom (Great Britain)); Narcis Cardona (The Polytechnic University of Valencia, Spain)

The performance of indoor wireless systems depends on the deployment scenario, so proper parameterization and planning of the local area network (LAN) are crucial, in particular in the millimeter wave band which suffers from blockage. Two of the key performance indicators for wireless LANs are the packet delay and the end-to-end latency, which are related to the amount of redundancy added at the PHY and MAC layers, aimed to compensate the dispersive effect of the radio channel, usually represented by the root mean square delay spread (RMS-DS). This paper proposes a model that helps to predict RMS-DS in 60 GHz band based on room's geometry and compares the results with the ITU model. The work is based on measurements and results previously presented in the literature, especially focuses on offices and conference rooms.

10:00 ***A Low Cost Dual-Branch Q-Band 39.4 GHz I/Q Satellite Beacon Receiver for Atmospheric Propagation Studies***

Patrick Eggers and Igor Syrytsin (Aalborg University, Denmark); Johannus Kristmundsson (Fiskaaling P/F, Faroe Islands)

A satellite beacon receiver is designed for research and educational purposes. To provide data to investigate possible weather induced scattering processes, a complex valued dual branch architecture is chosen, operating in the Q-band. The construction is based on mostly readily available components and instruments at Aalborg University radio laboratory. The paper describes the beacon receiver and its features.

10:20 ***Multi-Band Outdoor-To-Indoor Propagation Measurements Using a Drone***

Franco Fuschini, Marina Barbiroli, Enrico M. Vitucci and Vittorio Degli-Esposti (University of Bologna, Italy)

Outdoor-to-indoor propagation path-loss measurements have been carried out at 27 and 38 GHz, two of the frequencies allocated for 5G networks, for two different buildings: an office glass, steel and concrete building and a brick-wall residential house. The outdoor station has been mounted on a drone in order to have more placement flexibility and reach the desired height above ground without the use of a crane truck. Overall outdoor-to-indoor loss seems to depend primarily on the window surface and on the construction material. While loss is higher at 38GHz with respect to 27 GHz for the office building, brick-walls of the residential house appear to be less frequency selective.

10:40 Coffee Break

11:00 ***SDR-Based Communication Sniffing for Determining the Proliferation of ITS-G5***

Golsa Ghiaasi (Silicon Austria Lab, Austria); Thomas Blazek and Fjolla Ademaj (Silicon Austria Labs GmbH, Austria); Julian Karoliny (Silicon Austria Labs GmbH & Johannes Kepler University, Linz, Austria); Stefan Marksteiner, Markus Wolf and Peter Priller (AVL List GmbH, Austria); Hans-Peter Bernhard (Johannes Kepler University Linz, Austria)

This paper describes the measurement setup for the proliferation of the vehicular communication systems in operating cars. The setup builds on a communication sniffer which detects cooperative awareness messages broadcast from ETSI ITS-G5 systems, decodes them and records the public information in these messages. The experimental characterization of the setup in an outdoor scenario is presented in order to verify the sniffer's performance with respect to transmit power and communication range. The setup is deployed for measurements on a busy road with slow moving traffic in the center of the city of Linz, Austria. The number of active users as well as their transmit power, duration of the transmission and packet length have been recorded.

11:20 ***Statistical Modelling of Short-Range Interference Paths***

Richard Rudd (Plum Consulting Ltd, United Kingdom (Great Britain))

There is a frequent requirement in spectrum sharing studies (e.g. in relation to frequency assignment for 5G systems) to assess the basic transmission loss on short (typically less than 1 km) outdoor paths in a variety of environments. In most sharing studies, it is required that the results of the modelling are generic (i.e. no site specific inputs to the model are necessary) and are presented in statistical terms (typically path loss not exceeded for a given probability). A useful model must also be suitable for computer implementation, often within a Monte Carlo framework. Many existing models are deterministic in the sense that they apply to specific geometries or environments which makes it impossible to apply such models in the general case where statistics covering all path geometries are required. This paper proposes a new, unambiguous, method for the prediction of the statistics of basic transmission loss in such cases.

11:40 ***Multibeam Leaky-Wave Antenna for Mm-Wave Wide-Angular-Range AoA Estimation***

Julien Sarrazin and Guido Valerio (Sorbonne Université, France)

The design of a periodic leaky-wave antenna for angle-of-arrival (AoA) estimation is presented. Thanks to multiple radiating space harmonics, a multibeam operation is achieved in order to scan a large angular range with a limited fractional frequency bandwidth. The matching and radiation efficiency issues raised by the large spatial period involved with multibeam operation is addressed by using a dedicated unit-cell to control both the leakage constant and the Bloch impedance. Simulations confirm that a MUSIC processing enables the system to perform AoA estimation without ambiguity among the multiple beams. This allows for AoA estimation over the 180°-angular range with a bandwidth of only 3.7% at 27 GHz.

12:00 ***A Reference Model for Channel Sounder Performance Evaluation, Validation and Comparison***

Sven Wittig (Fraunhofer Heinrich Hertz Institute, Germany); Michael Peter (Fraunhofer Institute for Telecommunications, Heinrich Hertz Institute, Germany); Wilhelm Keusgen (Technische Universität Berlin, Germany)

In this paper, we propose a detailed generic reference plane model for performance evaluation and system validation of radio channel sounders. It allows to abstractly describe a broad variety of channel sounder implementations and architectures in a common framework, thus facilitating systematic evaluations and comparisons. To illustrate the utility of the concept, we present the mapping of two practical channel sounder realizations - one time domain and one frequency domain - to the model, along with selected performance metrics defined on its reference planes. For the two presented channel sounders, we give measurement examples for these metrics.

12:20 ***Challenges for 5G and Beyond***

Jelena Senic, Anmol Bhardwaj, Camillo Gentile, Derek Caudill and David Lai (NIST, USA); Damir Senic (ANSYS, USA); Sung Yun Jun (National Institute of Standards and Technology, USA); Jack Chuang and Jian Wang (NIST, USA); Anuraag Bodi (National Institute of Standards and Technology, USA); Raied Caromi (National Institute of Standard and Technology, USA); Nada Golmie (NIST, USA)

In this paper, we discuss some challenges for 5G-and-beyond communications systems based on our measurements conducted with millimeter-wave (mmWave) channel sounders. One study analyzes path loss at 28 GHz vs. 83 GHz and in line-of-sight conditions vs. non-line-of-sight conditions and finds it to depend much more heavily on the latter than the former. A significant factor of path loss is penetration loss; in fact, another study focuses on obstructions that are typical in wireless environments: building walls, human bodies, and trees. Finally, in addition to investigating how power is distributed over distance through path loss, we also investigate how power is distributed over delay and angle per distance, otherwise referred to as channel dispersion. In particular, we discuss the importance of diffuse multipath to the total received power at mmWave and the foregone conclusion of wide-sense stationarity, which we show will often not apply to mmWave small-scale fading.

CS30: Modeling, analysis and design methods for antennas in IoT applications

T03 Wireless LANS, IoT and M2M/ /Antennas

Chairs: Jaume Anguera (Fractus Antennas & Universitat Ramon Llull, Spain), Martijn van Beurden (Eindhoven University of Technology, The Netherlands)

9:00 ***Bandwidth Enhancement of Microstrip Antennas Using Crossing Avoidance of Characteristic Modes***

Bashar Bahaa Qas Elias (Universiti Malaysia Perlis (UniMAP), Malaysia); Azremi Abdullah Al-Hadi (University Malaysia Perlis, Malaysia); Ping Jack Soh (University of Oulu & Katholieke Universiteit Leuven, Finland)

In this paper, a method of designing antennas by avoiding crossing between the modes is presented. This is aimed at enhancing antenna bandwidth using ground fragmentation techniques based on the characteristic modes analysis (CMA) approach. A compact and flexible Saxophone antenna and a conventional rectangular microstrip antenna both dimensioned at 30 × 30 mm2 (0.66λg × 0.66λg) are designed to operate at 5.8 GHz to validate the proposed method. The proposed saxophone structure with a full ground enhances the bandwidth up to 170 MHz (2.97%) relative to the

conventional antenna. This is then improved up to 890 MHz (14.67%) and 794 MHz (13.58%) when integrated with a fragmented and a partial ground plane, respectively. In comparison, the conventional antenna exhibited a bandwidth of 360 MHz (6.38%) and 410 MHz (7.25%) for these cases. Modeling is performed using FEKO software based on two approaches: the method of moments (MoM) and CMA.

9:20 ***Plantenna: Using Plant Leaves to Increase Antenna Performance***

Lieke A. M. Geubbels, Gabriele Federico and Vojkan Vidojkovic (Eindhoven University of Technology, The Netherlands); Jaume Anguera (Universitat Ramon Llull, Spain); L. A. (Sander) Bronckers (Eindhoven University of Technology, The Netherlands)

In agricultural applications, it is becoming ever more important to be able to send sensor data in an energy-efficient way, possibly from each plant. This study investigates the possibility to excite a plant leaf using an Antenna Booster to enhance antenna performance. A PCB including a Matching Network is designed to accommodate the Antenna Booster. This PCB is placed in a simulation environment on material emulating the electrical properties of a plant. It is shown that the Antenna Booster uses the PCB and the leaf it is placed upon to radiate. The simulations show that it is possible to increase the radiation efficiency of the antenna structure from 9.6% up to 15% at a frequency of approximately 2 GHz by attaching the Antenna Booster to a leaf-like plane, and that using the leaf thus should be considered in the Internet of Plants (IoP).

9:40 ***Multi-Standards Slot-Based Antenna Design for NB-IoT and LTE-M Applications***

Rifaqat Hussain (KFUPM, Saudi Arabia); Mohamed A Abou-Khousa (Khalifa University of Science and Technology, United Arab Emirates); Muhammad Umar Khan (National University of Sciences and Technology (NUST), Pakistan); Mohammad S. Sharawi (Polytechnique Montreal, Canada)

In this paper, a highly miniaturized folded slot-based antenna is presented for internet of things (IoT) applications. It consists of meandered slot with folded structure along with varactor diode loading. Miniaturization is obtained using a unique combination of meandered slot with folded structure that is reactively loaded with varactor diode. The antenna exhibits dual-bands operation covering frequency bands from 730-965 MHZ and 1250-1940 MHz. A single varactor diode is used to obtain a continuous frequency sweep over both bands. The proposed antenna is best suited for next generation 5G IoT applications. The proposed antenna design has a total board dimensions of 2727 mm2.

10:00 ***Embedding Antenna Booster in Smart-Metering Platforms***

Alejandro Fernández (Ignion, Spain); Jussi Rahola (Optenni Ltd, Finland); Jaakko Juntunen (Optenni Ltd., Finland); Aurora Andújar (Ignion, Spain); Joan Pijoan (Universitat Ramon Llull, Spain); Jaume Anguera (Fractus Antennas & Universitat Ramon Llull, Spain)

The growth of the Internet of Things (IoT) requires that a large number of devices need wireless connectivity. For this reason, a simple and fast method capable of designing multiband antenna systems, utilizing a very simple antenna element is proposed. In this method the antenna is seen as an impedance box where a multiband matching network with lumped components is the one that fixes the number of frequency bands. The multiband matching network was designed in Optenni Lab based on the measured antenna input impedance and the EM-simulated radiation efficiency. To validate the procedure, a multiband antenna system operating at 824MHz-960MMHz and 1710-2690MHz is implemented. The matching network has been obtained through a fully automated process without human intervention and without any type of adjustments. This enables the design of multiband antenna systems in a quick, easy, and systematic way.

10:20 ***Approximate and Full-Wave Analysis for Efficient Antenna Design***

Hubregt J. Visser (imec The Netherlands, The Netherlands)

Antenna design, starting from scratch, using full wave analysis software can become a very time consuming task. Using analytical (approximate) antenna models, especially at the initial stage, can reduce the overall design time considerably, as is shown in this paper. To help antenna designers, a list of common antenna types and the accompanying models is given. Two of the models have not been published, in the current form, before.

10:40 Coffee Break

11:00 ***Antenna De-Embedding in FDTD Using Spherical Wave Functions by Exploiting Orthogonality***

Leonardo Mörlein (Leibniz Universität Hannover, Germany); Lukas Berkelmann (Leibniz University Hannover, Germany); Dirk Manteuffel (University of Hannover, Germany)

De-embedding antennas from the channel using Spherical Wave Functions (SWF) is a useful method to reduce the numerical effort in the simulation of wearable antennas. In this paper an analytical solution to the De-embedding problem is presented in form of surface integrals. This new integral solution is helpful on a theoretical level to derive insights and is also well suited for implementation in Finite Difference Time Domain (FDTD) numerical software. The spherical wave function coefficients are calculated directly from near-field values. Furthermore, the presence of a near-field scatterer in the de-embedding problem is discussed on a theoretical level based on the Huygens Equivalence Theorem. This makes it possible to exploit the degrees of freedom in such a way that it is sufficient to only use out-going spherical wave functions and still obtain correct results.

11:20 ***Multi-Band Antenna System for IoT from Space Applications***

Fabien Ferrero (Université Cote d'Azur, CNRS, LEAT & CREMANT, France); Le Huy Trinh (University of Information and Technology & Vietnam National University, Vietnam)

This article presents a multi-band antenna system covering LP-WAN, GNSS and WiFi bands. The 868MHz and 1575MHz bands have a right-hand circular polarization with a wide aperture beamwidth. The 2400MHz band provides an omnidirectional pattern with linear polarization. The complete system is built using two FR4 substrates connected through vertical wires. The overall system has a size of 72*72*12mm. A total efficiency higher than -3dB is measured for the three bands.

11:40 ***Wearable Harmonic Transponder for IoT Applications***

Milan Polivka (Czech Technical University in Prague, Czech Republic); Vaclav Hubata-Vacek (Intriple Corp., Czech Republic); Milan Svanda (Czech Technical University in Prague, Czech Republic)

The paper presents a novel compact wearable harmonic transponder, composed of a dual-band patch-type antenna loaded by an HSMS-2820 Schottky diode, operated at 869 MHz and 1 734 MHz frequencies. The antenna itself is optimized for a minimum ground plate size. The transponder performance was evaluated both in free space and when attached to a human muscle phantom. The total harmonic transponder conversion loss is 6.2 dB for an excitation power of –25 dBm at the antenna-diode interface, outperforming state-of-the art solutions. The measured reading distances are 9.0 m and 8.8 m for EIRP = 20 dBm when the transponder is placed in free space and on the human body, respectively. As a means of machine-to-person communication, the transponder is suitable for Internet-of-Things concept.

12:00 ***A CRLH-Resonant Small Antenna for Earphones and Testing the BLT Received-Signal Sensitivity***

Sungtek Kahng (University of Incheon, Korea (South)); Yejune Seo (Inchoen National University, Korea (South)); Munsu Jeon, Junghyun Cho, Ji Yeon Jang and Ye jin Lee (Incheon National University, Korea (South)); Jaume Anguera (Fractus Antennas & Universitat Ramon Llull, Spain); Changhyeong Lee (Korea Institute of Machinery & Materials, Korea (South))

In this paper, a novel chip antenna and its function in wireless connectivity are presented for Bluetooth(BLT) earphones. The chip antenna is a CRLH-metamaterial so compact as the size of 4.9×13.0×2.0 mm3 that when it is mounted on the PCB, it can sit in the enclosure of the BLT earphone. This setting does not degrade the resonance of the proposed antenna. As two earphones in a pair are demanded to communicate with each other, one shares an RF signal with the other and they take turns as the master and slave. The received signal sensing indicator(RSSI) is observed for that pair of the chip antenna-mounted earphones. Electromagnetic simulation of the antenna is done and verified by fabrication and measurement. Especially, a good RSSI is obtained as -67.5 dBm, larger by 50 dB than the threshold.

12:20 ***3D Printed DRA for S-Band IoT from Space Applications***

Fabien Ferrero (Université Cote d'Azur, CNRS, LEAT & CREMANT, France); Le Huy Trinh (University of Information and Technology & Vietnam National University, Vietnam); Romain Faye, Julien Sourice and Guillaume Calan (Nanoe, France)

In this paper, the design of a 3D printed Dielectric resonator for S-Band application is studied. A dual-band structure is targeted in order to support uplink and downlink satellite communication. A partial filling of some specific part of the DRA is used to optimize the antenna input impedance. The designed DRA exhibit a compact dimension of 0.25*0.25*0.1 wavelength with a 5dBi realized gain.

CS35: Preclinical and clinical results of medical microwave imaging systems

T04 Biomedical and Health/ / Electromagnetics

Chairs: Marta Guardiola Garcia (MiWEndo Solutions, Spain), Tommy Henriksson (EMTensor GmbH, Austria)

9:00 ***MammoWave Breast Imaging Device: Path to Clinical Validation, Results and Implications in Future Population-Based Breast Screening Programs***

Gianluigi Tiberi (London South Bank University, United Kingdom (Great Britain) & UBT - Umbria Bioengineering Technologies, Italy); Navid Ghavami (UBT - Umbria Bioengineering Technologies, Perugia, Italy); Daniel Álvarez Sánchez-Bayuela (UBT - Umbria Bioengineering Technologies, Italy); Lorenzo Sani, Alessandro Vispa and Alessandra Bigotti (UBT - Umbria Bioengineering Technologies, Perugia, Italy); Mario Badia (UBT - Umbria Bioengineering Technologies, Italy); Lorenzo Papini (UBT - Umbria Bioengineering Technologies, Perugia, Italy); Giovanni Raspa (UBT - Umbria Bioengineering Technologies, Italy); Cristina Romero Castellano and Lina Marcela Cruz Hernandez (Hospital Virgen de la Salud, Toledo, Spain); Daniela Bernardi (Humanitas Research Hospital, Milan, United Kingdom (Great Britain));

Alberto Tagliafico (University of Genoa, Italy); Massimo Calabrese (IRCCS Ospedale Policlinico San Martino, Genoa, Italy); Mohammad Ghavami (London South Bank University, United Kingdom (Great Britain))

Microwave imaging for breast cancer detection has attracted growing global attention with a small number of prototypes advancing to the clinical trial stage. This investigation aims to provide an overview of MammoWave, a novel microwave-based imaging system for breast lesion detection and to assess its introduction into the clinical routine and its potential role in future breast screening programs. As a key focus of this work, we will describe in detail the various aspects of the clinical protocol procedure that has enabled us to perform a successful clinical trial. Obtained preliminary results indicate the ability of our device to distinguish breasts with no radiological finding and those with radiological findings, with a sensitivity of 89.6%.

9:20 ***Human Brain Imaging by Electromagnetic Tomography: A Mobile Brain Scanner for Clinical Settings***

Tommy Henriksson, Sahar Sahebdivan and Ramon Planas (EMTensor GmbH, Austria); Cornelia Brunner (University Clinic Tulln, Austria); Lukas Kellermair and Michael Guger (Med Campus III, Kepler University Hospital GmbH, Austria); Walter Struhal (University Clinic Tulln, Austria); Peter Fuchs (Med Campus III, Kepler University Hospital GmbH, Austria); Andreas Stelzer (Johannes Kepler University Linz, Austria); Serguei Semenov (EMTensor GmbH, Austria); Stephen Pearce (EMTensor Inc., USA); Milan Vosko (Med Campus III, Kepler University Hospital GmbH, Austria)

A mobile electromagnetic tomography brain scanner prototype was developed, with the aim of the first mobile bed-side application of the technology for human brain imaging in a clinical setting. The usability and safety of the scanner was ensured to fulfill the requirements for clinical study operation. The mobile electromagnetic scanner was successfully put through its first pilot feasibility clinical study on healthy volunteers and real stroke subjects. The goal was to prove safety and feasibility of the technology for operation in the clinical setting, as well as gathering the first indication of its ability to detect and differentiated between ischemic and hemorrhagic strokes. The outcome is a significant step towards a safe and clinically viable EMT solution, where the scanner was proved to be safe and usable in healthy volunteers and real patients and first indications of its ability to detect brain pathology in stroke patients.

9:40 ***MiWEndo: Microwave Endoscopy System for Early Detection of Colorectal Cancer. Challenges in the Industrialization and Preclinical Phase***

Roberto Sont and Sergi Marcoval (MiWEndo, Spain); Jordi Romeu (Universitat Politècnica de Catalunya, Spain); Marta Guardiola Garcia (MiWEndo Solutions, Spain)

Colorectal cancer is one of the most common diagnosed tumors. The cancer is prevented with an early detection of polyps that may appear on the colon wall. This paper presents a microwave system for colonoscopy application. The goal is to improve the polyp detection rate by combining microwave information with the current optical video. It presents the main challenges on the prototype design, facing regulatory, industrialization and clinical acceptance requirements. Finally, the system is validated with ex vivo measurements to analyze its performance.

10:00 ***Spatial Domain Indirect Holography for Phaseless Microwave Imaging***

Sandra Costanzo, Giuseppe Lopez and Giuseppe Di Massa (University of Calabria, Italy)

The solution of inverse scattering problem arising in microwave imaging generally requires the knowledge of the incident field distribution inside the imaging domain. This task can be accomplished by sampling the whole imaging domain, but resulting into an inconvenient strategy. Alternatively, the incident field can be collected on the measurement domain, by subsequently retrieving the required field distribution. In this contribution, a two-step phaseless strategy for the prediction of the incident field is presented. Starting from the intensity knowledge of the incident field on the measurement domain, the corresponding phase is retrieved by applying a SDIHT. The retrieved complex field is then exploited within a ME formulation for the incident field reconstruction inside the imaging domain. The validity of the approach is tested within a phaseless strategy, where intensity-only data are assumed to be sampled. The effectiveness of the proposed solution is demonstrated through validation on a breast imaging scenario.

10:20 ***Wireless Capsule Video Endoscopy for Population-Based Colon Cancer Screening Using 5G Network***

Ali Khaleghi (Norwegian University of Science and Technology (NTNU) & Oslo University Hospital, Norway); Hemin Ali Qadir (University of Oslo & OmniVision Technologies Norway As, Norway); Per H. Lehne (Telenor Research, Norway); Ilangko Balasingham (Norwegian Institute of Science and Technology, Norway)

We develop a battery-free communication system for wireless-capsule endoscopes with video streaming at a rate of up to 15 Mbps. We apply our innovative approach using backscatter for implants-a RADAR approach that remotely reads the information from the deep implants, such as the video capsule endoscope. We use the 5G deployed network with edge computing and slicing to transmit the video data from the capsule to a high-performance computing platform in a secure way with guaranteed end-to-end latency to perform polyp detection and localization. This way, the energy-intensive inference using deep learning neural networks for polyp detection and localization can be performed in the edge where control signals are sent back to the pill to increase the spatial and temporal resolution of the video, to obtain high-quality images for further analysis. The paper provides a system-level description, with a demonstrated setup for the capsule data streaming to the network.

CS04: Airborne SATCOM on the Move. SOTM

T05 Aircraft (incl UAV, UAS, RPAS) and automotive

Chair: Gonzalo Expósito-Domínguez (Airbus DS & Military Transport, Spain)

9:00 ***Flight Test Campaign of Embedded Electronically Steerable SATCOM Aero Antenna for Clean Sky 2 Project***

Gonzalo Expósito-Domínguez (Airbus DS & Military Transport, Spain); Francisco Jiménez-González (Airbus, Spain); Avi Gal (Gilat Satellite Networks Ltd, Israel); Alex Volodarsky (GILAT Satellite Networks, Spain); Borislav Marinov (RaySat, Bulgaria)

This paper presents the ground test and flight test campaign of the electronically steerable SATCOM aero antenna (E2S2A2) developed under Clean sky 2 project (717164-E2S2A2-H2020-CS2-CFP02-2015-01). The antenna is installed in an AIRBUS 295 prototype aircraft completely embedded without modifying the aerodynamic shape of the aircraft. Ground test and Flight test campaigns are planned and carried out in order to demonstrate connectivity under specific satellite coverage.

9:20 ***Conformal Structural Integration of Airborne Satellite Communication Antennas***

Jaco Verpoorte and Harmen Schippers (National Aerospace Laboratory NLR, The Netherlands)

The paper describes the conformal and structural integration of a Ku-band phased array antenna in the fuselage of an aircraft. A novel fuselage panel with an orthogrid stiffened structure has been developed. The cells of the orthogrid structure are used for the embedding of the Ku-band antenna tiles.

9:40 ***Tapered Continous Transverse Stub Antenna in Hybrid Technology for SatCom Applications***

Adham Mahmoud (Institut d'Électronique et de Télécommunications de Rennes, France); Ronan Sauleau (University of Rennes 1, France); Mauro Ettorre (University of Rennes 1 & UMR CNRS 6164, France)

A very high-gain continuous transverse stub (CTS) array targeting K/Ka band for SatCom applications is presented. The CTS array is fed by a tapered corporate feeding network (CFN) to reduce its sidelobe level to -20 dB over the full intended band (17 GHz - 31 GHz). A new pillbox coupler is introduced to illuminate the CTS array, with a reflection coefficient better than -10 dB over a 200% relative bandwidth. Multiple sources in the focal plane of the pillbox coupler allows steering of the antenna main beam in elevation up to ±65°. The fabrication technology used is hybrid. The pillbox coupler is designed by classical milling while the rest of the antenna is in multi-layer printed circuit board (PCB) technology. The size of the antenna is 62.2×62.2×2.2 λ_0^3, where λ_0 is the free space wavelength at 31 GHz. The minimum calculated gain is 38.5 dBi at 17 GHz.

10:00 ***Simultaneous X/Wide-Band-Ka Feed System for SATCOM Reflector Antenna Applications***

Christophe Granet (Lyrebird Antenna Research Pty Ltd, Australia); John Kot (Young & Kot Engineering Research, Australia)

A simultaneous X-band and wide-band Ka-band horn is designed for reflector antenna satellite communication applications. The theoretical performance of a 2.4m offset parabolic reflector, a 13.5m shaped Cassegrain reflector and a compact 1.3m dual reflector antenna are calculated as a proof of concept.

10:20 ***Wideband Phased Array Design for Ku/Ka SatCom Applications***

Alexander J van Katwijk and Andrea Neto (Delft University of Technology, The Netherlands); Giovanni Toso (European Space Agency, ESA ESTEC, The Netherlands); Daniele Cavallo (Delft University of Technology, The Netherlands)

The design of a dual-polarized broadband array that simultaneously covers the Ku- and Ka- satellite communication transmit bands is presented. The array element is a connected slot backed by a ground plane and loaded with artificial dielectric layers. The design includes the detailed feeding structure for the two polarizations and accounts for realistic manufacturing constraints in the definition of the layer stack-up. A conical scan volume of up to 60 degrees is achieved with active voltage standing wave ratio (VSWR) below 2 in the Ku-band and below 3 in the Ka-band. An efficient numerical method to analyze the finite-by-finite array is also presented and can be used to estimate the edge effects.

CS41: Space-fed antenna systems for SATCOM and high-performance communication systems

T08 Space (incl. cubesat)/ /Antennas

Chairs: Antonio Clemente (CEA-LETI Minatec, France), Carolina Tienda (Airbus Defence and Space, United Kingdom (Great Britain))

9:00 ***Recent Developments of Wideband and Multi-Band Dual-Circularly-Polarized Reflect-Arrays***

Zhi Hao Jiang, Xuanfeng Tong, Yuan Li, Fan Wu and Wei Hong (Southeast University, China)

The recent developments of dual-circularly-polarized (dual-CP) reflect-arrays (RAs) at microwave and millimeter-wave frequencies are reported. In the first part, dual-CP RAs with a wide operational bandwidth are described through several demonstrating examples. Two strategies are employed - one utilizing only Berry phase with two functional layers and the other exploiting both dynamic and Berry phases for dual-CP beamforming with a single functional layer. In the second part, by incorporating shared-aperture techniques into the RA cell alignment, dual-band dual-CP RA cell designs are described, which have four degrees of freedom in terms of reflective phase control. The designs are numerically validated by diffraction analysis of a linear gradient array of dual-band dual-CP RA cells, exhibiting reflective beam bending with both simultaneous polarization and frequency diversities.

9:20 ***Huygens' Metasurfaces for Extending the Scan-Range of Phased Arrays***

Jaemin Kim, George V. Eleftheriades and Gleb A. Egorov (University of Toronto, Canada)

In this overview paper we summarize our results regarding the problem of extending the angular scan range of antenna arrays using Huygens' lens-like metasurfaces. Existing theory of scan enhancement using lenses is summarized, where various devices are discussed. This includes the single-lens far-field enhancer, the single-lens near-field enhancer and finally the two-lens near-field enhancer. An important addition to existing work is that physical metasurface structures are full-field simulated. Extremely close agreement between simulated and theoretical results is observed despite non-idealities such as losses which are present in the simulations.

9:40 ***Evaluation of Multi-Faceted Reflectarray Configurations on SmallSats***

Borja Imaz-Lueje, Manuel Arrebola and Marcos R. Pino (Universidad de Oviedo, Spain)

In this paper, different configurations of multi-faceted reflectarrays for small satellite platforms are evaluated. The reflectarrays are designed in a SATCOM band to generate a directive beam in dual-linear polarization. The performance and physical characteristics of both antennas are compared with a flat reflectarray of a similar aperture. The proposed multi-faceted configurations improve the in-band performance antenna without an increase in the complexity of manufacture, satellite storage, and in-orbit deployment.

10:00 ***Preliminary Results of a Multibeam Reflectarray Antenna in Ka-Band for LEO Satellites Constellations***

Daniel Conde-Parraga (Universidad Politecnica de Madrid, Spain); Daniel Martinez-de-Rioja (Universidad Politécnica de Madrid, Spain); Jose A. Encinar (Universidad Politecnica de Madrid, Spain)

This contribution presents preliminary results of a reflectarray antenna to generate a multi-spot coverage from a LEO satellite for 5G and Beyond-5G communications. The reflectarray is proposed to generate the complete multi-spot coverage at 18.2 GHz for the user's downlink. The phase distributions on the reflectarray surface have been optimized to broaden the beams at the same time as reducing the distortion of the beams at the edge of the coverage. The antenna performance of a standard reflectarray (with a conventional phase distribution to focus pencil beams) and the proposed reflectarray have been compared by simulated results. The simulations show that the proposed reflectarray can generate a continuous coverage of 36 beams with an End-Of-Coverage level of 26 dBi.

10:20 ***Space-Fed Antenna Based on Dielectric-Only Transmitarray***

Andrea Massaccesi and Paola Pirinoli (Politecnico di Torino, Italy)

In this work, preliminary results on the design of a dielectric transmitarray (TA) antenna are presented. The unit-cell consists in two circular cylinders located on the two sides of a thin square slab, with size 0.3λ at the central frequency, realized with the same dielectric material of the cylinders. The amplitude and phase of the transmission coefficient are controlled varying the diameter of the cylinders, while their height is kept constant. In order to minimize the unit-cell thickness, but at the same time assuming that 3D printing techniques will be used for the TA manufacturing, a dielectric material with εr=10 is considered. The results obtained from the simulation of a transmitarray working in Ka-band with size 15λx15λ are presented and discussed.

10:40 Coffee Break

11:00 ***Wideband, Electronically Reconfigurable Reflectarrays with 1- and 2-Bit Phase Quantization***

Mohammad Mahdi Honari, John Booske and Nader Behdad (University of Wisconsin-Madison, USA)

In this paper, we present an approach to realize wideband, 1-bit (2-bit), reflectarray unit cells using only one (three) single-pole-single-throw switch(es). The proposed reflectarray unit cells consist of an antenna and a reflecting circuit with a switchable phase shift response that is controlled using PIN diodes. The reflecting circuit entirely reflects the incident wave received by the antenna with a phase shift that can be adjusted electronically by controlling the PIN diodes. The proposed reflectarray unit cells offer two primary improvements over state-of-the-art in electronically tunable reflectarray antenna designs: significant bandwidth enhancement; and reduced implementation complexity. As a proof-of-concept, we designed reflectarray unit cells with 1-bit and 2-bit phase quantization. Our approach enabled us to achieve wide bandwidths of 78% and 50% for the 1-bit and 2-bit reflectarray unit cells, respectively.

11:20 ***Phase Gradient Metasurface for Wide Angle Beam Scanning Antennas with Highly Reduced Sidelobes***

Francesco Caminita (Wave-Up SRL, Italy); Massimo Nannetti (Wave Up Srl, Italy); Giuseppe Labate (Wave Up S. R. L., Italy); Cristian Della Giovampaola (Wave Up srl, Italy); Gabriele Minatti (Wave Up S. r. l., Italy); Enrica Martini (University of Siena, Italy); Giovanni Toso (European Space Agency, ESA ESTEC, The Netherlands); Stefano Maci (University of Siena, Italy)

We present a metasurface based planar deflector that can be used to realize a low-profile antenna with mechanical beam steering capability in a wide angular range, within a large bandwidth. The deflector exploits a Pancharatnam-Berry phase effect to steer the beam and allows to maintain low side lobe levels within the whole antenna field of view. Numerical results are provided as support to the discussion. The device has been conceived for next generation satcom communication in the Ka-band from user terminals on board of moving platforms.

11:40 ***An Active True Time Delay Transmit/Receive Antenna for Satellite Communications Based on a Discrete Lens and Magnifying Reflectors***

Gianfranco Ruggerini (Space Technology for Innovation); Pasquale Nicolaci (TICRA); Giovanni Toso (European Space Agency, ESA ESTEC, The Netherlands)

The aim of this paper is to present the design of a Ku band, active multibeam antenna working both in transmission and reception. The dual band antenna system is constituted by an active discrete lens magnified by two confocal paraboloidal reflectors. The novelty and the main challenging aspects are associated to the combined transmit and receive functionalities of the active discrete lens. In order to guaranty the dual band operation, an innovative RF building block chain working in dual polarizations has been introduced. In addition, the magnifying reflector system permits to mimic an active array of larger dimensions.

12:00 ***Dual-Band, Dual-Linearly Polarized Transmitarrays for SATCOM Applications at Ka-Band***

Reda Madi (CEA-LETI, France); Antonio Clemente (CEA-LETI Minatec, France); Ronan Sauleau (University of Rennes 1, France)

We propose here a 40×40-element shared-aperture dual-band dual linearly-polarized transmitarray with 1-bit phase resolution and fixed beam at Ka-band. The design is based on a stacked approach where the unit-cell size is compact and is equal to only 0.48×l0 and 0.32×l0 at 29 GHz and 19 GHz, respectively. The beam-scanning performances of this array are compared to those of an array with the same number of elements and same illumination but comprising unit-cells based on the interleaving approach (lattice size of 0.72×l0 and 0.47×l0, respectively). The shared-aperture unit-cells include four printed U-slotted patch antennas and a connecting metallized via; the desired 180° phase shift is obtained by rotating one of the patches around its corresponding via. Our simulation results demonstrate that the transmitarray based on the stacked approach exhibits excellent beam scanning performance up to ±70°. A prototype pointing at broadside is optimized and fabricated to validate the numerical simulations

12:20 ***Unit Cell Polarizability and Sheet Impedance Extraction in Aperiodic Environments***

Jordan Budhu (University of Michigan, USA); Anthony Grbic (University of Michigan, Ann Arbor, USA)

A technique for the extraction of the polarizability of a particle or equivalent sheet impedance of printed circuit elements in aperiodic metasurface environments is presented. The technique does not rely on local periodic assumptions that are commonly made in metasurface sheet impedance extraction techniques. Instead, the local electric field and induced surface current on each of the homogenized sheet impedance elements in the aperiodic array is extracted from a solved linear system representing the electromagnetics problem. The ratio of local electric field to induced surface current density defines the element impedance in the true aperiodic environment. This impedance is used to find a printed circuit element which generates the same current when excited by the local electric field. Geometrical parameters are varied until agreement between the homogenized sheet impedance and the printed circuit element is observed. An example of an aperiodic 10-element metasurface is provided.

E05: Modelling and simulation of frequency/polarization selective surfaces and periodic structures

T09 EM Modelling and Simulation tools/ / Electromagnetics

Chairs: Buon Kiong Lau (Lund University, Sweden), Carlos Molero (University of Granada, Spain)

9:00 ***Eigenstate Equivalent Circuit for Bi-Periodic Surfaces: Application to Three Parallel Dipoles***

Alberto Hernández-Escobar (Universidad de Málaga, Spain); Elena Abdo-Sánchez (University of Málaga & E. T. S. I. Telecomunicación, Spain); Jaime Esteban (Universidad Politécnica de Madrid, Spain); Teresa María Martín-Guerrero and Carlos Camacho-Peñalosa (University of Málaga, Spain)

An equivalent circuit for the unit cell of bi-periodic surfaces is proposed. The equivalent circuit is general and simple. It is based on the decomposition of the eigenmodes of the structure and it takes into account the polarization of the incident wave. It consists of the interconnection of two different admittances and two transformers. The model of a unit cell composed of three parallel dipoles is extracted. The transformer models the rotation of the dipoles, while the admittances model their resonances. This equivalent circuit provides physical insight and, at the same time, it separates the contribution of the rotation from the resonances. The model is able to replicate the simulation result with great accuracy.

9:20 ***Active Unit Cell with Continuous Transmission Phase for a Radome-Periodic Structure in S-Band***

Pablo Camacho and Mohammad S. Sharawi (Polytechnique Montreal, Canada)

This work presents the methodology of design and the characteristics of an active, three layer unit cell embedded in a radome. The structure covers a phase range of 330 degrees with a transmission magnitude better than -3 dB. The design of the proposed active unit cell utilizes 2-port network theory to estimate the port impedance of each layer and the transmission coefficient of the complete structure.

9:40 ***On the Design of Unit Cells with Diagonal Symmetry for Wideband Polarization Converters***

Salvador Moreno Rodriguez (University of Granda, Spain); José Luis Medrán del río (University of Sevilla, Spain); Angel Palomares-Caballero (Universidad de Granada, Spain); Antonio Alex-Amor (Universidad CEU San Pablo, Spain); Armando Fernández (Universidad de Sevilla, Spain); Carlos Molero (University of Granada, Spain)

This paper presents a theoretical study of diagonal-symmetric metasurfaces based on very simple transmission-line models in order to achieve wideband polarization converters. The approach profits from the decomposition of the incident-field vector in field components directed along the diagonal-axis, decoupling the problem into two different, individual and independent subproblems. This issue reduces considerably the complexity of the problem, and allows for a better understanding of the physical insight of the structures. Practical examples of wideband rotators/circular polarizers based on very simple metasurface-cells are implemented with the aim of supporting the theoretical conclusions. Experimental prototypes have successfully been manufactured and will soon be tested.

10:00 ***Comparison of Capacitive and Inductive Partially Reflective Surface Antenna Using Ray-Tracing***

Qiuyan Liang (Lund University, Sweden & Xidian University, China); Buon Kiong Lau (Lund University, Sweden)

A partially reflective surface (PRS) antenna is a low-cost high gain antenna, which is often classified by the capacitive or inductive nature of the PRS. It has been shown that, for a given reflection magnitude, capacitive PRS facilitates a larger antenna gain than inductive PRS, based on leaky-wave model and practical design examples. In this paper, we extend the classical ray-tracing approach to derive analytically that the superior gain is primarily due to the greater height of the capacitive PRS from the ground plane, which leads to a smaller phase delay and a more uniform magnitude distribution across the PRS. To verify the analytical study, the simulated phase and magnitude distributions of a capacitive and an inductive PRS antenna are produced and shown to agree with the predicted trends of the phase and magnitudes distributions from ray-tracing.

10:20 ***Fast and Accurate Modeling and Optimization of Large Metasurface Considering near Couplings***

Zixuan Ma and Yuchenxi Zhang (Nanjing University of Science and Technology, China); Mengmeng Li (Nanjing University of Science and Technology & Communication Engineering, China)

When considering near couplings, the design and optimization of metasurfaces would consume huge time and memory costs. Deep neural networks provide unprecedented computational efficiency and accuracy for solving complex electromagnetic calculation problems. In this paper, two deep neural networks (DNN) are designed to solve the fast design and optimization problems of surface-enhanced Raman scattering (SERS) and focusing with metasurface respectively. The numerical calculation results prove the effectiveness of the work in this paper.

IW09: Design of active receiving antennas (AIRBUS)

CS26: ISAP session: Recent Advances in Asian Antennas and Propagation Research

T10 Fundamental Research and Emerging Technologies/ / Antennas and Propagation

Chair: Kunio Sakakibara (Nagoya Institute of Technology, Japan)

9:00 ***Metantennas: Opportunities and Challenges in Future Microwave Metasurface Antenna Research and Applications***

Zhi Ning Chen, Qun Lou and Wei E. I. Liu (National University of Singapore, Singapore)

Metantennas have triggered enormous opportunities in antenna designs but along with arduous challenges. The views and overviews of critical issues, such as ohmic losses, of metamaterials and metasurfaces-based antenna designs at microwave bands are shared. The opportunities and challenges in future metantenna research and applications are predicted and proposed hopefully to pave future ways to enhance performance and introduce more functions of microwave antennas.

9:20 ***Millimeter-Wave Antenna Arrays for 5G Mobile Handset***

Chao Yu, Xiaoyue Xia, Yunli Li, Xuanfeng Tong, Fan Wu and Zhi Hao Jiang (Southeast University, China); Yu Yao (Huawei Technologies, China); Wei Hong (Southeast University, China)

In this paper, three compact dual-polarized millimeter-wave antenna array designs for 5G mobile handset are presented, including an end-fire antenna array, a broadside antenna array and a tilted-beam antenna array. The environmental effects are also considered in the antenna designs. In the validation, these three designed antenna arrays can effectively cover 5G N257 (26.5 GHz -29.5 GHz) and N258 (24.25 GHz -27.5 GHz) frequency bands for both polarizations with different radiation directions. Especially, for the tilted-beam antenna array, the beams of dual polarization show consistent and tilt to 45°. For better demonstration, measurement results in the actual environment of mobile handset are provided to effectively validate the proposed designs.

9:40 ***Large Scale Channel Parameters Estimation by Utilization of Reflected Rays Information for an Urban Environment***

Inocent Calist, Zhiqiang Li and Minseok Kim (Niigata University, Japan)

This paper presents a development of a machine learning (ML) based prediction model for large scale channel parameter (LSCP) estimation by analyzing the interaction of the multipath ray's information with the propagation environment. Utilizing the robustness of ML, a dynamic LSCP predictive model can be realized. The input parameters to the prediction model are transmitter (TX) and receiver (RX) positional coordinates, and the reflected rays' information such as the delay, angle of arrival, angle of departure, elevation angle of arrival, elevation angle of departure, and power gain. The proposed model was implemented using Random Forest. Ray tracing (RT) simulation was performed to calculate the input dataset of the LSCPs, and also the input datasets of the reflected rays. Cross validation was utilized to validate the model.

10:00 ***A Wideband Magneto-Electric Dipole Transmitarray for Linear to Circular Polarzation Conversion***

Jun Hu (Shenzhen University, China); Hang Wong (City University of Hong Kong, Hong Kong)

In this paper, the design and implementation of a wideband circularly polarized (CP) transmitarray are reported. The receiving/transmitting unit cell is designed by using magneto-electric (ME) dipole with polarization conversion from linearly polarized (LP) to CP. In addition, a full 360-deg geometric phase tuning range can be provided by rotating the transmitting CP element. As a demonstration, a single beam transmitarray is developed by utilizing geometric phase compensation technique. The results verify that the axial ratio performance can be improved within the whole operating frequency band due to the opposite phase response for the dual CP components. Moreover, this methodology can be easily extended to the design of multi-beam CP transmitarray with a cluster of LP feeds.

10:20 ***Design of a Linearly Dual-Polarized and Dual-Wideband Multi-Ring Microstrip Antenna Fed by Two L-Probes for a Small Ground Plane***

Yuki Kimura, Sakuyoshi Saito and Yuichi Kimura (Saitama University, Japan)

This paper presents design of a linearly dual-polarized and dual-wideband multi-ring microstrip antenna (MR-MSA) fed by two L-probes for a small ground plane. Two circular ring patches with a different size are printed on the top and middle dielectric substrates and two L-shaped probes arranged orthogonally are placed in the bottom substrate with a large thickness for dual-polarized and dual-wideband operation. Furthermore, the MR-MSA is surrounded by a cavity structure for stable gain characteristics. In this paper, the dual-band and wideband MR-MSA fed by two L-probes for a small ground plane is considered by using numerical simulation. The simulated results reveal that the cavity provides stable gain characteristics for a side of the ground plane more than 0.85 wavelengths at the center frequency of the lower band. It is also confirmed that better performance is obtained by the MR-MSA without the cavity for a smaller size of the ground plane.

10:40 Coffee Break

11:00 ***Design of Dual-Polarized Display-Integrated Antenna Arrays for mmWave Communications***

Jin Myeong Heo and Gangil Byun (Ulsan National Institute of Science and Technology (UNIST), Korea (South))

This paper proposes, a design of optically transparent antenna arrays with dual polarization for mmWave communications. The proposed antenna is consisting of three radiating patches resonating at slightly different frequencies and has two ports to excite dual polarizations. The individual patch is fed by a 'T'-shaped probe in proximity. For display-integration, the antenna is modeled as thin-metal meshes, whose shape is rhombus with equal edge lengths to provide optical transparency. Antenna characteristics such as impedance bandwidth, gain, and polarization isolation are simulated. The optically transparent antenna shows fractional bandwidth of 17.2% and peak gain of greater than 8 dBi from 25.5 GHz to 30.1 GHz. It is confirmed that the proposed design is effective to broad 10-dB matching bandwidths with high gain of greater than 8 dBi.

11:20 ***An Embedded Dual-Band Base Station Antenna Array Employing Choked Bowl-Shaped Antenna for Cross-Band Scattering Mitigation***

Yi He, Can Ding and Gengming Wei (University of Technology Sydney (UTS), Australia); Y. Jay Guo (University of Technology Sydney, Australia)

An embedded dual-band dual-polarized base station antenna (BSA) array is proposed in this paper consisting of two low-scattering bowl-shaped antenna elements working at the lower band (LB) and five cross-dipoles operating at the higher band (HB). Such an array configuration naturally has an ability to mitigate the negative effect on the HB antennas' radiation pattern caused by the presence of adjacent LB antennas. In this paper, a new LB antenna loaded with metal chokes is proposed to reduce its scattering to the HB radiation. The results obtained with conventional bowl-shaped LB antenna and with choked LB antenna are compared to demonstrate the superiority of this de-scattering method. The simulation results show that the HB performance is significantly

improved with the help of metal chokes while the LB performance remains nearly unchanged.

11:40 ***Highly Efficient and Wideband Millimeter-Wave Slotted-Array Antenna Technology for 5G Communications***

Mst Nishat Yasmin Koli (University of Technology Sydney, Australia); Muhammad Usman Afzal (School of Electrical and Data Engineering University of Technology Sydney, Australia); Karu Esselle and Dush Thalakotuna (University of Technology Sydney, Australia); Md Zahidul Islam (Teleaus: Serveno Australia Pty Ltd, Australia)

The 5G, 6G of future wireless technology has brought a growing demand for different types of electrically small or large antennas, which are highly efficient, directive, and provide wideband coverage. We have presented here a compact and highly efficient slotted-array antenna technology operating at a millimeter-wave frequency range to be used for the emerging applications of 5G wireless backhauling and mobile radio services. The antenna consists of two conducting plates, with the upper plate having a slotted array in the form of a spiral. A waveguide forms between these plates and supports outward traveling TEM waves. The antenna was simulated using CST to validate the design mechanism. The proposed antenna achieved an extremely high gain of 27.2 dBic. The antenna has shown a high 3dB gain bandwidth of 4.6 GHz, ranging from 33.2 GHz to 37.8 GHz, and an overall wide bandwidth of 13%.

12:00 ***Thermographic Investigation of Frequency-Reconfigurable Wearable Antennas***

Quoc Hung Dang (The University of Adelaide & Australia, Australia); Shengjian Jammy Chen (Flinders University, Australia & The University of Adelaide, Australia); Christophe Fumeaux (The University of Adelaide & School of Electrical and Electronic Engineering, Australia)

The thermal behavior of a frequency-reconfigurable wearable textile antenna is investigated in this paper through infrared thermography. The relationship between the temperature of the textile antenna and the input power is experimentally considered to identify the antenna hot spots. It is found that, the highest temperature point is mainly at the tuning component location, which is consistent with the loss predictions from electromagnetic simulation tools. A clear correlation is confirmed between the radiation efficiency and temperature of the varactors used as tuning elements. It is also observed that tuning frequency remains stable despite the antenna input power variations within the range from 21 to 521 mW. The presented preliminary results demonstrate the use of infrared thermography as a valuable tool for characterization of thermal safety margins of wearable devices and for imaging of losses in reconfigurable antenna technology.

12:20 ***Design of an Ultra-Wideband Antenna for Ambient Radio Frequency Energy Harvesting in 10.88-33.66 GHz***

Samar Ahmed Elbendera (Egypt Japan University of Science and Technology & Suez Canal University, Egypt); Ahmed Sayed Ahmed Abdelhamid Allam (Egypt-Japan University of Science and Technology (E-JUST), Egypt); Ahmed Magdy Mohamed (Suez Canal University, Egypt); Ramesh K. Pokharel (Kyushu University, Japan); Adel Bedair (Egypt-Japan University of Science and Technology, Egypt)

This paper aims at exploiting the expected massive deployment of RF signals by proposing a low-cost ultrawideband (UWB) planar antenna with a bandwidth of approximately 23 GHz ranging from 10.9 to more than 33.66 GHz. Using different slots on patch and ground plane and through feedline transitions the UWB requirements are achieved. Simulation results show that a proposed antenna with optimized dimensions can enhance the impedance matching and increase the bandwidth without a much effect on the antenna performance. The antenna is fabricated, and the simulated results are validated by the experimental measurements.

CS39: Radar Imaging through Obscuring Layers

T06 Defence and Security/ / Electromagnetics

Chairs: María García Fernández (University of Oviedo, Spain), Carey Rappaport (Northeastern University, USA)

9:00 ***A Hybrid Lebesgue-Space Inverse-Scattering Technique for Microwave Imaging of Objects Hidden Behind a Wall***

Andrea Randazzo (University of Genoa, Italy); Cristina Ponti (Roma Tre University, Italy); Alessandro Fedeli and Matteo Pastorino (University of Genoa, Italy); Giuseppe Schettini (Roma Tre University, Italy)

A hybrid through-the-wall imaging method is presented in this paper. It is based on the use of an iterative technique performing a regularization in the framework of the variable-exponent Lebesgue spaces. The exponent function is computed using a preliminary image obtained through the singular value decomposition method. The effectiveness of the approach has been tested by means of experimental data acquired in a laboratory environment.

9:20 ***Using 3D Soil Surface Profile to Predict and Remove the Surface Response in Stripmap SAR***

Brian Burns (DEVCOM C5ISR Center, USA); Nader Namazi (The Catholic University of America, USA)

It is desirable to detect buried objects such as land mines at standoff distances and Ground Penetrating Synthetic Aperture Radar (GPSAR) is one technology that has potential to detect some buried objects. One challenge with using GPSAR is that responses from the surface of the ground can be similar in magnitude to the buried objects. To try and remove some to these responses, the surface profile of the ground was measured with high resolution optical sensors. This surface profile was used to model the radar response of the ground using gprMax. The modelled response was then subtracted from the measured radar response to reduce the response from the ground and better reveal the responses of the buried objects.

9:40 ***Automatic Classification of Low-Loss and Lossless Materials in Wideband Radar Images for Millimeter- Wave Personnel Screening Systems***

Mahshid Asri, Mohammad M. Tajdini, Elizabeth Wig and Carey Rappaport (Northeastern University, USA)

Fast and accurate characterization of concealed threats and benign objects is of great importance for increasing the efficiency of mm-wave imaging radar personnel screening systems in airports. Correctly classifying low-loss and lossless materials is essential in detecting threats. Previous work developed a real-time, fully automatic algorithm for characterizing lossy vs. lossless materials. This paper extends the mm-wave image-processing-based method to distinguish low-loss media, such as paper vs. lossless materials, that include explosives. The developed method is verified experimentally by applying it to experimentally measured radar data generated by a 10-40 GHz wideband laboratory airport screening prototype.

10:00 ***Impact of the Number of Transmitting-Receiving Channels on the Quality of the Images Obtained by a Millimeter-Wave Freehand Imager***

Guillermo Alvarez Narciandi (University of Oviedo, Spain); Jaime Laviada (Universidad de Oviedo, Spain); Fernando Las-Heras (University of Oviedo, Spain)

This contribution assesses the impact on the image quality of the number of transmitting (TX) and receiving (RX) channels of a freehand millimeter-wave imaging system. The freehand imaging system comprises a compact radar module that can be moved by hand while its position is tracked. This enables the use of synthetic aperture radar techniques to obtain high-resolution images with a compact handheld scanner. The employed radar module, capable of capturing data from 400 TX-RX channels per acquisition, was used to scan a test target and the reflectivity image of the area under scan was generated considering several TX-RX configurations. Results show that, as expected, the higher the number of considered TX-RX channels, the better the quality of the retrieved image. However, the target can be accurately reconstructed with configurations that employ a reduced number of TX-RX, reducing the computational cost of the imaging system and increasing the acquisition speed.

10:20 ***SAFEDRONE Project: Development of a UAV-Based High-Resolution GPR System for IED Detection***

María García Fernández, Guillermo Alvarez Narciandi, Yuri Alvarez-Lopez and Fernando Las-Heras (University of Oviedo, Spain)

This contribution presents the main objectives and achievements of the SAFEDRONE project, devoted to the development of airborne-based high-resolution Ground Penetrating Radar (GPR) systems for the detection of buried landmines and Improvised Explosive Devices (IEDs). The overall goal of the project is to take advantage of the ability of Unmanned Aerial Vehicles (UAVs) to enable a contactless, safe, and fast scanning of the area of interest, together with the capability of Synthetic Aperture Radar (SAR) systems to provide high-resolution radar images. Down-Looking and hybrid Forward-Looking/Down-Looking architectures have been tested throughout the project in order to determine which of them provides the best detection results (depending on the scenario, and geometry, composition, and depth of the buried targets). To achieve the required accuracy to enable GPR-SAR processing, precise positioning and geo-referring subsystems have been integrated within the UAV. Results of the validation tests conducted in realistic scenarios are presented.

Tuesday, March 29 10:40 - 11:00

Coffee Break / Exhibition

Tuesday, March 29 11:00 - 12:40

ROE meeting

E02: Imaging for biomedical applications

T04 Biomedical and Health/ / Electromagnetics

Chair: Jaime Laviada (Universidad de Oviedo, Spain)

11:00 ***Fast Microwave Screening of Breast Tumors with a System-By-Design Inversion Strategy***

Francesco Zardi (ELEDIA Research Center, Italy); Lorenzo Poli (ELEDIA Research Center, University of Trento, Italy); Marco Salucci (ELEDIA Research Center, Italy)

The quantitative imaging of breast tumors through microwave measurements is addressed. An innovative solution approach based on the System-by-Design (SbD) paradigm is proposed to achieve a highly accurate reconstruction with limited computational resources. Towards this end, the inverse scattering problem (ISP) at hand is reformulated in terms of the differential electromagnetic (EM) quantities with respect to a reference/healthy scenario, enabling the exploitation of prior knowledge regarding the breast composition. The performance of the developed approach is investigated in numerical simulations considering realistic breast phantoms. The results indicate that highly accurate reconstructions are achieved even under a significant noise level. Furthermore, the developed approach only requires few minutes of processing, hinting at its applicability to real-world scenarios.

11:20 ***Application of Supervised Descent Method to MRI Electrical Properties Tomography***

Sabrina Zumbo (Università Mediterranea di Reggio Calabria, Italy); Stefano Mandija (University Medical Center Utrecht, The Netherlands); Ettore Meliadò (Computational Imaging Group, The Netherlands); Nico van den Berg (University Medical Center Utrecht, The Netherlands); Tommaso Isernia (University of Reggio Calabria, Italy); Martina Teresa Bevacqua (Università Mediterranea di Reggio Calabria, Italy)

Electrical properties, conductivity and permittivity, of biological tissues are widely investigated because they provide crucial knowledge in different biomedical applications, for example in electromagnetic dosimetry and hyperthermia treatment planning, where is very important to quantify the induced specific absorption rate by a radiofrequency field. In this framework, a possibility is to retrieve the electrical properties starting from the measurements of the radiofrequency field collected inside a magnetic resonance scanner. To this end, in this paper, a learning approach based on supervised descent method is proposed in order to improve the efficiency of the reconstruction methods typically used in the literature. The approach is tested in the case of a 2D scenario mimicking a human head.

11:40 ***Preliminary Phantom-Based Dynamic Calibration Techniques Assessment for Microwave Colonoscopy Systems***

Alejandra Garrido (Universitat Politècnica de Catalunya, Spain); Walid Dghoughi (MiWEndo Solutions, Spain); Jordi Romeu (Universitat Politècnica de Catalunya, Spain); Marta Guardiola Garcia (MiWEndo Solutions, Spain)

Early detection and resection of colon polyp is the best way to reduce colorectal cancer (CRC) mortality. The current method for early detection is colonoscopy, which has a limited field of view, and its efficacy is highly dependant on the endoscopist's experience and colon preparation. This work presents a device for combining microwave imaging with optical colonoscopy. The challenges of this new microwave imaging system are presented, such as the unknown distance to the colon mucosa, which leads to undesired scattered fields and, the antenna size limitations. Four dynamic calibration techniques are proposed to remove the effects of the undefined distance from the imaging region to colon mucosa. These calibration methods are based on averaging the colonoscopy trajectory frames and subtracting the calibration set from the current frame. The phantom preliminary results evidence that these calibration methods delete the undesired scatters satisfactorily.

12:00 ***Systematic Analysis of Microwave Breast Imaging Detection of Different-Sized Malignant and Benign Tumors***

Raquel A. Martins (Instituto de Telecomunicações/Instituto Superior Técnico, Portugal); Joao M. Felicio (Instituto de Telecomunicações, Portugal); Jorge R. Costa (Instituto de Telecomunicações / ISCTE-IUL, Portugal); Carlos A. Fernandes (Instituto de Telecomunicacoes, Instituto Superior Tecnico, Portugal)

Microwave Imaging (MWI) has been explored as an alternative to conventional breast tumor screening methods. It is acknowledged that benign and malignant tumors can be distinguishable by their architectural features: benign tumors are often round with well-defined margin, while malignant tumors have an ill-defined margin and are micro-lobulated or spiculated. We present a MWI-based systematic analysis of malignant and benign breast tumors of different sizes, to evaluate if its characteristics allow differentiating the images. To this end, we performed measurements on a dry MW setup, using a slot-based antenna in the 2-5 GHz frequency range to scan an anthropomorphic breast phantom. We placed inside eight malignant and benign tumors with 3, 4, ...10 mm average radius, one at a time. This study shows that both types of tumors can be detected, but not distinguishable only via MWI. Smaller tumors become harder to detect, the 3 mm tumor being unreliably caught.

12:20 ***Experimental Evaluation of Thin Bone Fracture Detection Using Microwave Imaging***

Kesia Santos (Instituto Federal de Educação, Ciência e Tecnologia da Paraíba, Brazil); Carlos A. Fernandes (Instituto de Telecomunicacoes, Instituto Superior Tecnico, Portugal); Jorge R. Costa (Instituto de Telecomunicações / ISCTE-IUL, Portugal)

Microwave imaging is a promising candidate modality for the detection of fractures in superficial bones. We propose a simple dedicated experimental setup and use it to evaluate experimentally the feasibility of detection and location of thin transversal fractures in an animal bone. A single small Vivaldi antenna scans the bone along its length in two longitudinal planes, and collects the monostatic scattered fields in the 8.3-11.1 GHz frequency range. The image is reconstructed using a wave migration algorithm. Tests were carried on an ex-vivo animal leg bone with an induced transversal fracture. The results showed that transversal bone fractures can be detected down to 0.35 mm thickness. The system is attractive for a practical application because it is contactless, operated in air, non-ionizing, simple and comfortable for the patient. It can be used e.g. by first responders in the field, or in low-income settings.

CS05: AMTA Convened Session: Automotive Performance Testing for Connected and Automated Driving in Simulated Real-World Environments

T05 Aircraft (incl UAV, UAS, RPAS) and automotive/ /Measurements

Chair: Christian Bornkessel (Technische Universität Ilmenau, Germany)

11:00 ***Advances in the ICV EMC Test Standardization in China-SAE***

Yuanliang Peng (China Automotive Engineering Research Institute Co., Ltd, China)

The automotive industry, especially smart, intelligent connected vehicles (ICV), is evolving towards more intelligent and electrified systems. Vehicles equipped with autonomous driving assistance systems are becoming increasingly popular, and the functions and performance have significantly improved. However, the examination of autonomous driving assistance systems and wireless telematics systems are not included in the existing standards for automotive electromagnetic compatibility. A method proposed by China Automotive Engineering Research Institute Co., Ltd (CAERI) is introduced in this paper. The aim of the paper is to discuss the electromagnetic safety test method of intelligent connected vehicles equipped with wireless telematics systems and/or advanced driver assistance systems, which further specifies the electromagnetic immunity test conditions, technical requirements, and evaluation methods for intelligent networked vehicles.

11:20 ***Automotive Performance Tests Based on Machine Learning Algorithms***

Matthias Geissler (IMST, Germany); Jürgen Kunisch, Christos Oikonomopoulos-Zachos and Aline Friedrich (IMST GmbH, Germany)

This paper suggests an innovative approach to define and perform tests of communication systems in cars. The test concept requires the placement of the vehicle under test on a planar turntable in an anechoic chamber. Software-defined multimode transceiver modules, referred to as radio heads, are placed in a quarter circle or half circle around the car at an adequate distance. This setup allows flexible, realistic, reproducible and dynamic over-the-air testing of the cars communication systems in the sense of a virtual drive test. One key topic is the definition of sufficiently realistic test scenarios based on real outdoor scenarios. The full description of those scenarios requires a large number of parameters and performance indicators, making it impractical to perform this derivation following a classical straight-forward approach. Therefore, our concept foresees the use of machine learning algorithms.

11:40 ***Experimental Validation of Automotive OTA Measurements at Close Distance***

Francesca Mioc (Consultant, Switzerland); Alessandro Scannavini (Microwave Vision Italy, Italy); Kim Rutkowski (Microwave Vision Group, Satimo Industries, France); Mathieu Mercier (Microwave Vision Group, Hong Kong); Francesco Saccardi and Lars Foged (Microwave Vision Italy, Italy)

Given the advancement of technologies related to automotive communications, working groups have been formed to define the methodologies for Automotive Over the Air (OTA) Measurements. The 5GAA test plan [1] defines two methods for OTA radiated power and sensitivity measurements, Direct-OTA and Combinational Method. In this paper the OTA measurement results performed on a full vehicle at near field distances are reported. The results are presented using the metrics which are relevant to automotive technologies. Direct-OTA results and estimated Baseline far field results are compared. The feasibility of measuring at a distance closer than far field is examined. Measurement time reduction for alternative measurement methodologies is evaluated.

12:00 ***Virtual Drive Testing Based on the Identification of Challenging V2X and LTE Link Scenarios***

Philipp Berlt (Technische Universität Ilmenau, Germany); Berk Altinel (Technische Universitat Ilmenau, Germany); Christian Bornkessel (Technische Universität Ilmenau, Germany); Matthias Hein (Ilmenau University of Technology, Germany)

Virtual drive tests using the over-the-air/vehicle-in-the-loop method are becoming an essential part of testing vehicular radio systems. Different approaches address the question which link scenarios and channel environments are relevant, and should be tested. Up to now, this question has not been fully answered. This paper deals with the identification of challenging scenarios for the wireless transmission standards LTE and ITS-G5 based on jointly performed drive tests, and how these can be transferred into a virtual test concept. In the case of LTE, the focus is on the transition region between different mobile radio cells (cell edge). We have reproducibly observed that the achievable data throughput drops significantly at cell edges compared to the cell centers. For ITS-G5, the communication limit was examined as a function of the distance and visibility conditions between two communicating vehicles.

12:20 ***Chamber Design for Automotive EMC and ADAS Testing***

Garth D'Abreu and Zhong Chen (ETS-Lindgren, USA)

EMC testing is typically performed in shielded absorber lined enclosures, and the design of these chambers have evolved over the years to take advantage of improvements in the material technology, and changes in the way tests or measurements are performed. Other RF measurements like antenna pattern or over the air (OTA) communication measurements are also performed in shielded absorber lined enclosures for many of the same reasons. This paper looks at one of the options available for an extended EMC chamber that also supports antenna and ADAS feature testing.

E06: Modelling and simulation of metasurfaces

T09 EM Modelling and Simulation tools/ / Electromagnetics

Chairs: Enrica Martini (University of Siena, Italy), Francesco Vernì (Politecnico di Torino, Italy)

11:00 ***Dynamic Metasurface for Holographic Imaging***

Rui Feng (Xidian University, China); Badreddine Ratni (Univ Paris Nanterre, France); Jianjia Yi (Xi'an Jiaotong University, China); Hailin Zhang (Xidian University, China); Gérard-Pascal Piau (Airbus, France); Alexandre Piche (Airbus Defence and Space, France); André de Lustrac (C2N, Université Paris-Saclay, France); Shah Nawaz Burokur (LEME, France)

Multi-functional metasurfaces have attracted considerable attention over the recent years. However, the passive multi-functional metasurface is subjected to fixed functionalities. In this work, we propose the design of a two-dimensional dynamic metasurface where the meta-atom is individually addressable by an elaborately designed bias system. Three different kinds of holographic imaging containing focusing spots, numbers, and letters are fulfilled at different working frequencies.

11:20 ***Experimental Validation of Camouflaging a High-Index Dielectric Scatterer with Metasurfaces***

Riccardo Cacocciola (Paris Nanterre University & Saint-Gobain Research, France); Badreddine Ratni (Univ Paris Nanterre, France); Nicolas Mielec and Emmanuel Mimoun (Saint-Gobain Research, France); Shah Nawaz Burokur (LEME, France)

A high-index dielectric scatterer is camouflaged with respect to a low-index dielectric reference by incorporating buried metasurfaces within the scatterer's volume. The metasurface-tuned scatterer is analytically modeled with transmission lines and a proof-of-concept prototype is fabricated and measured in the X-band. Experimental results of the scattering suppression phenomenon is presented in the near-field and far-field regions for both normal and oblique incident illuminations. This study presents metasurface-tuning as a frequency adjustable, polarization insensitive alternative tuning solution to efficiently camouflage dielectric scatterers, such as mechanical joints in seamed-radome structures.

11:40 ***An Integral Equation Approach Towards the Design of Compact Metasurface Pairs***

Mario Phaneuf and Puyan Mojabi (University of Manitoba, Canada)

Herein, we propose a method for the design of compact metasurface pairs which is based on an integral equation formulation. The novelty of this method is the ability to be used for metasurface pairs with arbitrary shape and orientation. The validity of the method will be shown for a fundamental case.

12:00 ***FMM IE-GSTC Simulation of Metasurfaces with Complete Dyadic Surface Susceptibilities***

Jordan R. Dugan, Tom Smy and Shulabh Gupta (Carleton University, Canada)

An accelerated Integral Equations (IE) field solver for determining scattered fields from electrically large electromagnetic metasurfaces, with both normal and tangential susceptibilities, utilizing Fast Multipole Method (FMM) is proposed and demonstrated in 2D. In the proposed method, practical general metasurfaces are modeled as a zero thickness sheet model described with surface susceptibilities, and where the total fields around it satisfy the Generalized Sheet Transition Conditions (GSTCs). While the standard IE-GSTC offers fast field computation compared to other numerical methods, it is still computationally demanding when solving electrically large problems, with a large number of unknowns. Here we accelerate the IE-GSTC method using the FMM technique. Using a numerical example, the speed improvement of the FMM IE-GSTC method O(N^(3/2)) over the standard IE-GSTC O(N^3) method is confirmed, when both tangential and normal surface susceptibilities are present.

12:20 ***Toward Fast Machine Design of Metasurface Antennas***

Andrea Scarabosio (LINKS Foundation, Italy); Francesco Vernì (Politecnico di Torino, Italy); Marco Righero (LINKS Foundation, Italy); Giorgio Giordanengo (LINKS Foundation & Politecnico di Torino, Italy); Giuseppe Vecchi (Politecnico di Torino, Italy)

Machine design of metasurface antennas concerning relevant figures of merit, such as the realized gain, typically requires 3D computationally intensive full-wave simulations due to the more or less complex feeding structure. However, via domain decomposition analysis, we show here that the modelling of the feed and the antenna itself can be effectively decoupled in many, if not all, relevant conditions. We then propose an accelerated design and optimization scheme in which the electrically large antenna is only simulated with well-known 2.5D fast algorithms, significantly reducing the design complexity.

IW01: Analysis and Design of Advanced Antenna Systems using TICRA Tools

Industrial Workshop

A20: Security applications & imaging

T06 Defence and Security/ / Antennas

Chairs: Daniele Cavallo (Delft University of Technology, The Netherlands), Luis Jofre (Universitat Politecnica de Catalunya, Spain)

11:00 ***Multibeam Directional Transmission with Multiport Compact Antenna***

Edith Annette Cabrera-Hernández and Josep Parrón (Universitat Autònoma de Barcelona, Spain); Alan Tennant (University of Sheffield, United Kingdom (Great Britain))

Directional modulation (DM) using multiport compact antennas shows some limitations when transmitting multiple independent beams. In this communication, we propose adding a monopole to a multiport compact stacked patch antenna in order to gain an extra degree of freedom in the transmission of DM. The improvement in security that can be achieved with the resulting antenna will be evaluated through bit error rate (BER) simulations for different configurations with two independent beams.

11:20 ***Directional Analysis of Jamming Attack for Connected Vehicular Platoons***

Rocío Valiente Casas and Christian Ballesteros Sanchez (Polytechnic University of Catalonia, Spain); Luis Jofre (Universitat Politecnica de Catalunya, Spain); Luca Montero Bayo (Polytechnic University of Catalonia, Spain)

Nowadays, one of the most promising developments for a safer and more sustainable mobility is the Connected and Autonomous Vehicle (CAV), where the Advanced Driving Systems (ADAS) and connectivity cooperate and take advantage of each other. The Cooperative Adaptive Cruise Control (CACC)might be one of the beneficiaries of such collaboration, being in turn the key enabler of platooning. While this cooperation improves safety and driving efficiency, it also opens the door to increasingly sophisticated cyberattacks. This paper analyses aCACC based platoon model approach in which communication is vulnerable to jamming attack. Jamming attack refers to to an unwanted signal radiated by a malicious device intended to impair the quality of an operating link. Two different platooning variants are compared taking diverse scenarios into account. The presented approach shows how platooning can be susceptible to cyberattacks and some directional measures to mitigate it are proposed.

11:40 ***Diffraction-Limited Imaging Using a Silicon Integrated Array at Submillimeter Wavelengths***

Martijn Hoogelander (Delft University of Technology, The Netherlands); Sven L van Berkel (NASA-JPL, Caltech, USA); Satoshi Malotaux (Tusk IC, The Netherlands); Maria Alonso-delPino, Marco Spirito, Andrea Neto, Daniele Cavallo and Nuria LLombart (Delft University of Technology, The Netherlands)

In this paper, the diffraction-limited imaging capabilities are presented of a focal plane array (FPA) of antenna-coupled direct detectors at submillimeter wavelengths. The FPA prototype is a tightly sampled, 12-pixel array that was developed in a 22nm CMOS technology and covers a relative bandwidth of 3:1, from 200 GHz to 600GHz. We are currently developing a quasi-optical (QO) setup to perform imaging using active illumination of the FPA. The images created by this QO setup and FPA will be the first demonstration of achieving diffraction-limited angular resolution, making this FPA

12:00 ***Fourier-Based Radar Processing for Multistatic Millimetre-Wave Imaging with Sparse Apertures***

Vasiliki Skouroliakou, Amir Masoud Molaei and Vincent Fusco (Queen's University Belfast, United Kingdom (Great Britain)); Okan Yurduseven (Queen's University Belfast & Duke University, United Kingdom (Great Britain))

Fourier-based radar processing algorithms have attracted a lot of interest among imaging techniques mostly because they are extremely fast. Moreover, such techniques can be integrated with a Multiple-Input Multiple-Output (MIMO) effective aperture to form a cost-effective imaging system that can retrieve an estimation of the scene in real-time. The proposed technique leverages the phase center approximation and a multistatic-to-monostatic data conversion to render the back-scattered measurements compatible with fast Fourier processing. Whereas the phase center approximation is applicable for imaging in the far-field of the synthesized aperture, in the near-field, a more sophisticated aperture design should be considered to reduce the distortion in the reconstructed images. This paper presents a theoretical study for a sparse aperture design and the optimization of the aperture layout for near-field imaging. Furthermore, it proposes a GPU accelerated reconstruction algorithm able to form 3D images in a few milliseconds with low-cost hardware.

Tuesday, March 29 12:40 - 14:00

Lunch / Exhibition

Tuesday, March 29 13:30 - 15:00

Poster Session Tuesday

Passive and Modular Surface Design for Tailoring EM Propagation in Urban Scenarios

Pietro Da Rù (ELEDIA Research Center, Italy); Nicola Anselmi (University of Trento, Italy); Paolo Rocca (University of Trento & ELEDIA Research Center, Italy); Andrea Massa (University of Trento, Italy)

Modular, passive and static metasurfaces are employed for the realization of a smart electromagnetic skin, a device embedded in the facade of buildings aimed at improving the communication performances through the intelligent reflection of the signal towards otherwise "blind" areas. The proposed design methodology considers an admissible surface area on the building facade and divides it into tiles (i.e., the minimal sized building blocks of the smart skin). A binary multi-objective genetic algorithm is then paired to the analytical model of the smart skin to optimize its layout (i.e., the tiles position and number), in order to satisfy a desired field threshold inside specific areas under consideration in the urban scenario. The final result is a Modular Reflecting Smart-Skin (MRSS) design methodology capable of providing an entire set of solutions, each one offering a trade-off between the complexity of the MRSS and the coverage of the blind area.

Enhancing mmWave Devices with Custom Lenses

Konstantin Koslowski (Fraunhofer Heinrich Hertz Institute, Germany); Felix Baum (Research Associate, Germany); Michael Peter (Fraunhofer Institute for Telecommunications, Heinrich Hertz Institute, Germany); Wilhelm Keusgen (Fraunhofer Heinrich Hertz Institute, Germany)

The demand for higher data rates and stability in wireless communications is increasing steadily. The mmWave band offers higher bandwidths and therefore increased data rates compared to sub-6 GHz bands, however drawbacks such as limited range and vulnerability to blockage remain a challenge. In this paper, we take off-the-shelf mmWave devices in the 60GHz band and combine them with self-developed lenses. The results show a focused beam in one dimension, while offering full coverage in the other, resulting in increased ranges with constant, high data rates. This allows applications for industrial communication or wireless backhaul networks and use cases such as platooning with autonomous vehicles.

High-Gain Fractal Antenna with Wide Range Operation for 5G Applications over V-Band Spectrum

Mohammad Alibakhshikenari (Universidad Carlos III de Madrid, Spain); Syed Muhammad Rizvi Jarchavi (Beijing Jiaotong University, Beijing, China); Akash Hussain (University of Engineering and Technology, Pakistan); Francisco Falcone (Universidad Publica de Navarra, Spain); Ernesto Limiti (University of Rome Tor Vergata, Italy)

In this paper, a double T-shaped fractal antenna operating in V-band spectrum is presented. The fractal antenna technique was exploited to achieve an Wideband antenna. The radiator consists of three fractal structure and was designed on Roger RT/duroid 5880 having an overall dimension of 16 mm × 18 mm × 0.79 mm. The presented antenna covers V-band that from 59 GHz to 68 GHz with an average gain of > 6.5 dBi. The proposed antenna was designed using HFSS and compared with CST results to verify various performance parameters. Simple geometrical configuration with low profile and high gain makes the proposed work a protentional candidate for 5G applications operating in V-band.

Wideband Co-Polarized Antenna System for In-Band Full-Duplex Applications

Di Wu (Shenzhen University, China); Ruina Lian (Henan University, China); Bing Xiao (The University of Hong Kong, Hong Kong); Bo Wang (City University of Hong Kong, Hong Kong); Min Li (The Hong Kong University of Science and Technology, Hong Kong); Yujiang Wu (University of Electronic Science and Technology of China, China); Lawrence K. Yeung (the University of Hong Kong, Hong Kong)

A wideband, monostatic, co-horizontally polarized (Co-HP) antenna system with omnidirectional radiation patterns for in-band full-duplex applications is presented. The proposed antenna consists of a printed four-element dipole array and two groups of parasitic strips for impedance bandwidth and omnidirectional performance enhancement. To achieve high isolation, the four ports of the proposed antenna are excited with two orthogonal phase modes for TX and RX using a well-designed beamforming network (BFN). The BFN is a six-port microstrip circuit, which consists of two 180° hybrid couplers, one 90° hybrid coupler, and a Wilkinson power divider. The measured TX/RX overlapping impedance bandwidth (IMBW) of the proposed STAR antenna system is from 4.71 to 6.2 GHz, and the TX/RX isolation is more than 40 dB from 4.81 to 5.88 GHz.

High Gain Broadband Stacked Filtering Antenna with Stable Radiation Pattern

Rinkee Chopra (IIITDM Kancheepuram, India & NA, India); Rahul Lakhmani (Skiify Solutions, India)

A broadband and high gain filtering antenna is designed by embedding two symmetrically oriented tapered slots. Broad bandwidth is achieved by using electromagnetically coupled stacked configuration. Tapered slots generate nulls in upper and lower bands of the antenna gain response. The designed antenna provides 35.6% BW with an average gain of 9.3 dBi. Null depth of lower and upper frequency bands is greater than 22.8 and 29.2 dB, respectively. The antenna provides a stable boresight pattern with cross and back radiation of better than 16 dB. The antenna is suitable for wireless communication in 2G, 3G, 4G-LTE and 5G applications.

Microstrip Radiating Element with High Polarization Purity for Weather Observations

Francesco Zardi (ELEDIA Research Center, Italy); Paolo Rocca (University of Trento & ELEDIA Research Center, Italy)

Next-generation weather radars are expected to be implemented with electronically-scanning planar phased arrays. Their scan agility could enable higher update rates and improved forecasts. However, application requirements on the polarization purity are hard to satisfy with a planar structure. Previous works in the literature have indicated a requirement of -22 [dB] on the Cross-Polarization Level (CPL) on scan under Ludwig's 2nd definition. This work presents a novel radiating element that approximates a magneto-electric dipole and has a printable planar structure. Preliminary numerical results show that the radiating element satisfies the CPL requirement in more than 98% of the scan directions of interest.

Analysis of Arrays Composed of Quarter-Cylinder Dielectric Resonator Antennas

Gabriel P Paulena (Federal University of Pampa, Brazil); Juner M. Vieira (Aeronautics Institute of Technology, Brazil); Marcos V. T. Heckler (Universidade Federal do Pampa, Brazil)

This paper presents the study of arrays composed of quarter-cylinder dielectric resonator antennas (QCDRA). The proposed antenna array has been optimized to operate at 1.575 GHz (L1-band of GPS). Initially, the design of the single antenna is presented. Then, the array performance using four different arrangements of elements is discussed for broadside radiation. In order to assess the performance of the proposed array, a study on the beam steering capabilities has been carried out and the resulting radiation patterns are shown and discussed. It is demonstrated that the proposed antenna design allows obtaining good performance in terms of axial ratio in the analyzed beamforming cases and, due to its compactness, it is a good candidate for multi-antenna high-precision GPS receivers.

A High-Gain Fabry-Perot Antenna Based on Partially Reflecting Surfaces and Polarization Conversion Surfaces

Yang Cai and Peng Mei (Aalborg University, Denmark); XianQI Lin (University of Electronic Science and Technology of China, China); Shuai Zhang (Aalborg University, Denmark)

A high isolation and high gain antenna designed with polarization-dependent partially reflective surface (PRS) and polarization conversion surface (PCS) is described in this paper. It is observed that no matter what polarized source is employed, the final polarizations of the proposed antenna are identical. For demonstration, a dual-polarized square patch antenna operating at 9.0 GHz is simply employed as a TE- or TM-polarization source. The simulated results demonstrate the peak gains for two polarizations are all up to 14.4dBi, and the isolation between the two ports are more than 15 dB at 9.0 GHz. The experimental measurement results match well with the simulated ones verifying the effectiveness of the proposed antenna.

Cell-Free Massive MIMO Deployments: Fronthaul Topology Options and Techno-Economic Aspects

Lucas Furtado and André Fernandes (UFPA, Brazil); Aline A Ohashi and Fabricio Farias (Federal University of Pará, Brazil); Andre Mendes Cavalcante (Ericsson, Brazil & Ericsson Research, Brazil); Joao Weyl Costa (Universidade Federal do Pará - UFPA, Brazil)

Cell-free (CF) massive multiple-input multiple-output (MIMO) networks are an alternative to achieve a higher a more uniform signal-to-interference-plus-noise ratio (SINR) over a mobile coverage area. Most of the literature for these networks considers a star fronthaul topology. This topology may lead to a non-scalable complex and costly fronthaul network. Some works proposed serial interconnection among several access points (APs) to a Central Processing Unit (CPU) to solve this problem, an alternative we call cell-free with segmented fronthaul. However, there is a lack of studies investigating if this alternative is cost-saving. This work explores the technical-economic feasibility of cell-free with segmented fronthaul based on bus, star, ring, and tree topologies. Moreover, evaluations are made in terms of multiple levels of serialization, which are the number of APs connected serially. Results show that the best overall topology is tree-based with a low serialization level.

A Novel PIFA Antennas Design with Capacitive Load for Glacier Monitoring Applications

Martina Lodigiani, Nicolò Delmonte and Marco Pasian (University of Pavia, Italy)

In glaciology, Ground Penetrating Radar (GPR) are frequently used to characterize electrical and physical properties of glaciers and snow coverages. An application is the estimation of the snow water equivalent of glaciers, coming from the knowledge of internal features of the glacier itself, such as its depth and density. For glacier monitoring, the usual frequencies space from few MHz to hundreds of MHz. Depending on the compromise between the penetration depth and the spatial resolution, the working frequency was determined. In this work, we designed, developed and measured a 300 MHz antenna used for this purpose. The shape and size were modeled in order to be used in portable systems; therefore, it was important to have light and small radiators. For this reason, we implement a novel planar inverted-F antenna (PIFA) design with capacitive load, reaching small dimensions compared to the wavelength.

Optimal Planning of Passive Reflective Skins for Next-Generation Smart EM Urban Environments

Arianna Benoni (ELEDIA Research Center, Italy); Baozhu Li (Tsinghua University, Italy); Marco Salucci (ELEDIA Research Center, Italy); Andrea Massa (University of Trento, Italy)

The optimal planning of passive reflective skins installed on the building facades for implementing next-generation smart electromagnetic environments (SEEs) is addressed. Towards this end, a

customized System-by-Design (SbD) strategy is exploited to yield the best trade-off solutions between maximum coverage enhancement within selected regions of interest (RoIs) and overall cost/environmental impact. A suitable binary coding strategy is adopted to define the degrees-of-freedom (DoFs) of the planning problem at hand, which is solved by means of a customized binary genetic algorithm (BGA) integrated with a learning-by-examples (LBE) prediction tool for the computationally-efficient evaluation of the urban wireless coverage. An illustrative numerical example is shown to assess the effectiveness and potentialities of the proposed planning strategy in a realistic scenario.

Gain Improvement of Wideband Patch Antenna at Millimeter-Wave Band Using Novel Metamaterial Superstrate

Abubakar Hamza (King Fahd University of Petroleum and Minerals, Saudi Arabia); Abdelhalim Chaabane (Université 8 Mai 1945 Guelma, Algeria); Hussein Attia (King Fahd University of Petroleum and Minerals (KFUPM), Saudi Arabia)

A new design of a patch antenna with a broad bandwidth and high gain is demonstrated in this work. The 32 GHz wideband highly-directive patch antenna is covered with a novel single layer metamaterial-based superstrate to attain a significant gain improvement over a wide bandwidth. A new multi-resonant dual face unit cell with four asymmetrical patches and apertures is used as a building block of the superstrate. The superstate performing as a frequency selective surface (FSS) offers a partial reflection that is based on the positive phase gradient concept. The results show a 10.5 dB increase in the gain which is about 210% enhancement over the single antenna gain at 32 GHz. The proposed antenna attains a broad impedance bandwidth of 32-43.1 GHz (29.6%), and a 3-dB radiation bandwidth of 12.6%.

A New Method for Gain Prediction of Superdirective End-Fire Arrays

Alessio Tornese (Université Grenoble Alpes & CEA Leti, France); Antonio Clemente (CEA-LETI Minatec, France); Christophe Delaveaud (CEA-LETI, France)

The problem of gain estimation of a superdirective end-fire dipole-based array is discussed. The current method to compute the gain, for a given element radiation efficiency, is based on the array factor (AF) theory. This work is intended to show that an equivalent formulation can be done using the Spherical Wave Expansion (SWE) theory. Besides the interest in validating the theory, the main objective is a better understanding of the radiation and attenuation phenomena that occur in compact and superdirective arrays. The limits in their practical implementations are imposed by the high sensitivity of the system. The SWE theory provides more information in the expression of the radiated field, thus unfolding the possibility to address the problem with lower sensitive solutions.

Evaluation of the Active Impedances in Large Interleaved Parasitic Arrays Antennas (IPAAs)

Remy Lamey (Xlim ; Thales Land & Air Systems, France); Marc Thevenot and Cyrille Menudier (University of Limoges, CNRS, XLIM, UMR 7252, F-87000, Limoges, France); Olivier Maas and Faycel Fezai (Thales Land & Air Systems, France)

This paper explores the performances of finite antenna arrays optimized using the Interleave Parasitic Arrays Antenna (IPAA) concept. A prototyped IPAA of 36 elements is used to compare the simulated performances obtained using the scattering matrix extraction from the periodic model method and measurements with great accordance. Then, two large arrays composed of 1024 and 4096 elements are studied using the same simulation method. The results show that the IPAA concept is particularly suited for large arrays, with only a few edge elements showing degraded performances.

Triple-Band Dual-Antenna Decoupling System for Mobile Handset

Jesús de Mingo, Pedro Carro, Paloma Garcia, Antonio Valdovinos and Juan Ernesto García (University of Zaragoza, Spain)

A low profile, triple band standard coverage, and multiple-input-multiple-output (MIMO) antenna system is proposed for mobile application in this work. The main objective of the study presented in the article is to reduce the coupling between the different access ports of the antennas to reduce the correlation between the signals received by them in a MIMO scheme. The MIMO antenna system consists of two Inverted F Antenna (IFA) multiband elements for 4G standard, covering different bands between 1720 and 2690 MHz, reused in 5G standards. This integrated MIMO antenna system is fabricated on a FR4 substrate with εr equal to 4.5. The dimensions of the board are equal to 130x60x1.54 mm3, which is a typical backplane of a mobile handset. The study includes two different distributions of the MIMO antennas in a handset, one of them with the antenna located in a co-polar configuration and the other in cross-polar configuration.

Design of Multiband Stub Loaded Oval Ring Patch Antenna with Serpentine Shaped EBG for C- and Ku-Band Communications

Karteek Viswanadha (Delhi Technological University & India, India)

Electromagnetic Bandgap structures (EBG) are used along with patch antennas due to their ability to reduce the size of the antennas and enhance the performance parameters of the patch antennas. Many shapes of EBG are proposed in the recent times to meet the needs of wireless technologies in the future. This paper proposes a stub loaded oval ring patch antenna mounted on a serpentine shaped EBG ground. The patch antenna possesses dimensions of 18 x 18 x 0.8mm3. Miniaturization of 89.1% is achieved with the proposed antenna structure. The proposed patch antenna resonates at 4.28GHz, 6.15GHz, 6.78GHz and 12.15GHz. Peak gains of 1.1dBi, 1.3dBi, 2.8dBi and 2dBi are observed at 4.28GHz, 6.15GHz, 6.78GHz and 12.15GHz respectively. Bidirectional radiation patterns are observed at 4.28GHz, 6.15GHz, 6.78GHz and 12.15GHz. The radiation patterns are observed to be stable at the resonant frequencies.

Compact, Multiband, Flexible Decagon Ring Monopole Antenna for GSM/LTE/5G/WLAN Applications

Jayshri S Kulkarni (Vishwakarma Institute of Information Technology, India); Abdullah G. Alharbi (University of Missouri - Kansas City, MO, USA); Chow-Yen-Desmond Sim (Feng Chia University, Taiwan); Jaume Anguera (Fractus Antennas & Universitat Ramon Llull, Spain)

The design of linearly polarized, flexible, multi-band decagon ring monopole antenna is proposed. The decagon ring monopole antenna incorporates a decagon ring having a thickness of 5 mm encircling a chamfered patch to generate multiband linear polarized waves. These radiators are excited by coplanar waveguide (CPW) fed based technique to induce two resonances at 2.20 GHz and 4.10 GHz covering bandwidth requirement of Global System for Mobile (GSM) 1800, Long Term Evolution (LTE) 2300/2600, Fifth Generation (5G) and WLAN bands. The simulated outcomes confirm the -10 dB impedance bandwidth of 48.84% (1.64 - 2.70 GHz) and 43.01% (3.65 - 5.65 GHz) at resonating frequency of 2.20 GHz and 4.10 GHz, respectively. Further, the bending analysis validates that the impedance matching and radiation performance of decagon ring antenna have minimal impact on the operating bands.

Dual-Linearly Polarized Wideband Printed Planar Monopole Antenna

Pedro Falcão (University of Lisbon, Portugal); Custodio Peixeiro (IST-University of Lisbon, Portugal)

Design, fabrication and test of a dual-linearly polarized wideband, printed planar monopole antenna is presented. The proposed configuration consists of two orthogonal CPW-fed modified octagonal monopoles with low mutual coupling. It is developed to be used in a wearable antenna system application to probe the electromagnetic field, with frequency in the range 0.7-3.5 GHz (5:1 bandwidth), incident on a professional user. The reasonable agreement obtained between simulated and experimental results has validated the proposed design approach and provided the proof of concept.

Inset Feed Impedance Matching Technique for Rectennas

Erik Farias da Silva (Instituto Federal da Paraiba, Brazil); Alfredo Gomes Neto (Federal Institute of Paraíba & Grupo de Telecomunicações e Eletromagnetismo Aplicado - GTEMA, Brazil); Custodio Peixeiro (IST-University of Lisbon, Portugal)

The rectenna is the basic fundamental element for RF energy harvesting. The development of efficient rectennas requires the implementation of some impedance matching technique between the rectifying circuit and the antenna element. An impedance matching technique inspired by the inset feeding of microstrip patches is proposed in this work. The technique keeps the size of the rectenna unchanged and does not require any additional components. An application example operating at 5.8 GHz and using a cheap FR4 substrate is presented.

Spectrum Sensing by Wideband Antenna for Cognitive Radio Applications

Shirin Aghabeiki and Adel Belkacem (Capgemini Engineering, France); Imad Adjali (Capgemini Engineering); Mouna Ben Mabrouk (Capgemini-Altran Engineering, France)

This paper investigates the design and practical implementation of wideband antennas along with the application of cognitive radio. Three planar antennas, having omnidirectional radio pattern and limited size, are designed to respect the signal detection priorities in a shared environment: the frequency bands of GSM, LTE and Wi-Fi networks. They are fabricated on 1.6-mm-thick FR4 with permittivity ε_r = 4.4. The simulation and measurement results confirm their compliance with the requested specifications. Their performance in a spectrum sensing scenario are also evaluated according to a machine-learning based signal detection algorithm. A comparison between their performance in practice is realized by computing Receiver Operating Characteristics (ROC) curves.

A Pattern Reconfigurable Compact Antenna Structure Based on Shorted Microstrip Patches

Feza Turgay Çelik (Middle East Technical University, Turkey); Lale Alatan (METU, Turkey); Ozlem Aydin Civi (Middle East Technical University, Turkey)

A compact pattern reconfigurable antenna structure is proposed. The proposed antenna structure is composed of two shorted quarter-wave microstrip patch antennas placed side by side to share a common shorting plane. Therefore, the total length of the antenna is a half wavelength. Pattern reconfiguration is achieved by exciting two antennas with different phases and consequently steering the main beam. With such a compact antenna, beam steering up to 350 is demonstrated.

Microfluidically Frequency & Polarization Reconfigurable Patch Antennas

Hamza Abbas Kiani (Frederick Research Center, Cyprus & National University of Sciences & Technology, Pakistan); David Chatzichristodoulou (RF AND MICROWAVE SOLUTIONS LTD & Frederick Research Center, Nicosia, Cyprus); Adnan Nadeem (Frederick Research Center, Cyprus); Abdul Quddious (KIOS Research and Innovation Center of Excellence, University of Cyprus, Cyprus); Nosherwan Shoaib (Research Institute for Microwave and Millimeter-Wave Studies (RIMMS) & National University of Sciences and Technology (NUST), Pakistan); Photos Vryonides (Frederick Research Center and Frederick University, Cyprus); Dimitris E. Anagnostou (Heriot Watt University, United Kingdom (Great Britain)); Symeon Nikolaou (Frederick Research Center & Frederick University, Cyprus)

Microfluidically frequency reconfigurable and polarization reconfigurable probe-fed patch antennas are presented in this paper. For the frequency reconfigurable antenna, a frequency tuning bandwidth of 14% (4.35-4.5 GHz) can be achieved by continuous loading of liquid metal inside the additively manufactured microfluidic channels on top of patch slots. During the frequency reconfigurability, the bandwidth remains greater than 5%, the gain remains higher than 7.5 dBi and there is polarization consistency over the complete tuning range. For the second antenna, switching between left-hand and right-hand circular polarization is demonstrated by alternatively inserting or removing metallic ink inside 3D printed Polylactic Acid (PLA) channels. For both

polarization states stable reflection coefficient with -10 dB S11 bandwidth of 9.6% (4.48-4.93 GHz) and 3-dB axial ratio bandwidth (ARBW) of 5.2% (4.48-4.72 GHz, are achieved.

Receive Antenna Selection for Time-Reversal Receive Antenna Shift Keying Systems

Mingyue Wang (Aalborg University, Denmark); Fangwei Li (Chongqing University of Post and Telecommunications, China); Jing Xiaorong (Chongqing University of Posts and Telecommunications, China)

Time-reversal receive antenna shift keying (TR-RASK) technology, which effectively facilitates designing a simplified receiver. However, it limits the number of receive antennas to be a power of two and the diversity gain of receive diversity cannot be utilized since only one receive antenna is selected in each time instant to receive information bits. The Euclidean-distance-based receive antenna selection (EDRAS) algorithm and the autocorrelation-based receive antenna selection (ACRAS) algorithm are proposed based on minimizing the bit error rate (BER) criterion. Simulation results verify that the proposed algorithms outperform the traditional scheme without receive antenna selection. Furthermore, the results also reveal that the EDRAS algorithm achieves optimal BER performance with enormous complexity, while the ACRAS algorithm attains the sub-optimal BER performance but offers a significant reduction in complexity.

Analysis of a Semitransparent PIFA Element for MIMO Applications

Luis Inclan-Sanchez (University Carlos III of Madrid, Spain)

This paper analyzes the design of a semi-transparent Planar Inverted-F Antenna (PIFA) to operate in the 5G band. The proposed antenna consists of a set of metallic wires that form a grid which configures the conductive parts of the antenna. This new radiant element offers an adequate response in terms of gain and impedance matching. On the other hand, it can be easily manufactured using 3D printing techniques. The semitransparent element has been integrated into a 2x2 subarray to analyze its application in MIMO systems. The subarray has been tuned to provide port isolation, good impedance matching, envelope correlation coefficient and radiation characteristics which are desired for MIMO applications. The proposed element offers utility to implement large antennas in array configuration and, at the same time, allows visible light to pass through it.

A Comparison Between Different Approaches to Wireless Power Transfer

Rafael González Ayestarán, Marcos R. Pino and Borja Imaz-Lueje (Universidad de Oviedo, Spain); Paolo Nepa (University of Pisa, Italy)

The equivalence and differences between some different approaches to efficient Wireless Power Transfer are explored analytically. Design methods for transmitting arrays intended to wirelessly feed a receiving device can be found in the scientific literature under different framworks such as Near-Field Focusing, microwave device design or MIMO communications. However, those apparently different approaches result in equal or at least very close solutions. In this communication, the advantages, drawbacks or equivalences of these techniques are analyzed, and some simulations are carried out to support the conclusions. Some interesting future research lines are also highlighted.

Co-Design of Dual-Purpose Heatsink Antenna for Multi-Source Ambient Energy Harvesting

Azamat Bakytbekov and Atif Shamim (King Abdullah University of Science and Technology, Saudi Arabia)

IoT infrastructure involves billions of devices that must be self-sustainable. Using ambient energy sources to power IoT devices is a promising solution. Ambient RF and thermal energy (diurnal temperature fluctuations) harvesters have great potential since both are available continuously. Smart integration is required for these two harvesters to create synergy and collect more energy. Here, a dual-purpose triple-band heatsink antenna for multi-source ambient energy harvesting is presented. Heatsink antenna serves as a receiving antenna for the RF energy harvester and serves as a heatsink for the thermal energy harvester (TEH). Co-optimization of the heatsink antenna is performed in Ansys HFSS and Ansys Fluent simultaneously. Heatsink antenna operates at GSM900, GSM1800, 3G bands with measured gains of 3.8dB, 4dB, 5.3dB respectively. Antenna gain is doubled (~3dB) and the TEH performance is tripled (200%) when the heatsink fins are integrated, emphasizing the benefit of the co-design and smart integration via heatsink antenna.

Experimental Demonstration of Bessel-Beams Self-Healing at W-Band

Srđan Paković (Université de Rennes 1, France); Alvaro J Pascual (University of Rennes 1 & IETR, France); Walter Fuscaldo (Consiglio Nazionale delle Ricerche (CNR), Italy); Mauro Ettorre (University of Rennes 1 & UMR CNRS 6164, France); David González-Ovejero (Centre National de la Recherche Scientifique - CNRS, France)

We present the experimental validation of the self-healing property of Bessel-beams at W-band. The capacity of Bessel-beams to heal after an obstruction is validated experimentally by placing a circular metallic obstacle within the nondiffractive region of the generated Bessel-beam. In particular, the near-field radiated by a broadband launcher with and without obstacles is measured, and its profile is compared in both cases. It appears that the Bessel profile after the obstacle is preserved. The results show the resilience of Bessel-beams to obstacles over a broad bandwidth and their robustness in near-field links with applications in wireless power transfer and near field wireless communications.

Optically Controlled Circularly Polarized-Reconfigurable Millimeter-Wave Rectangular Dielectric Resonator Antenna Using Photoconductive Switches

Akrem Soltan (Sheffield University, United Kingdom (Great Britain)); Abdulmajid Abdulmajid (The University of Sheffield, United Kingdom (Great Britain)); Salam

Khamas (University of Sheffield, United Kingdom (Great Britain))

A circularly polarized (CP)-reconfigurable rectangular dielectric resonator Antenna (RDRA) is proposed for mm-wave applications. By utilizing two photoconductive switches, the antenna can be switched to radiate either a linearly polarized (LP) field, left-hand CP (LHCP) field, or right-hand CP (RHCP) field. The structure requires a simple fabrication process. The simulated results demonstrate reconfigurable polarization characteristics with an impedance bandwidth of 31.8% for both LHCP and RHCP radiations as well as an impedance bandwidth of 9.5% for the LP radiation. This is achieved in conjunction with a maximum gain of 7 dBi. The axial ratio (AR) bandwidth is ~11% for both LHCP and RHCP radiations.

Dual-Band Multi-Polarization Metallic Cavity Antenna Design for Satellite Communications

Jorge Calatayud-Maeso (Universidad Politecnica de Madrid, Spain); Alfonso-Tomás Muriel-Barrado (Universidad Politécnica de Madrid, Spain); Adrián Tamayo-Domínguez and Pablo Sanchez-Olivares (Universidad Politecnica de Madrid, Spain); José Manuel Fernández González (Universidad Politécnica de Madrid, Spain)

A highly reconfigurable dual band cavity structure for satellite communications at K/Ka band is proposed. The key of the presented structure lies on a compact dual stacked cavity system. By modifying the radius of each cavity and the dimensions of the feeding slot, both cavities have been matched at the center frequency of their respective band. Correctly enabling and phasing each input port allows to generate any desired polarization scheme. Cavity radius were carefully chosen to prevent any coupling of the K band cavity with the Ka band one. For demonstration purposes, this structure has been integrated with a Turrin horn antenna that operates as a multimode horn for the Ka band. Monomode operation at the lower band was ensured by limiting the horn aperture radius. In this configuration a directivity of 10.3/12.4dB in K/Ka band was achieved.

Broadband Circularly Polarized Reconfigurable Single Layer Metasurface Antenna

Ahmed El Yousfi (Universidad Carlos III De Madrid, Spain); Abdenasser Lamkaddem (Carlos III University of Madrid, Madrid, Spain); Kerlos Atia Abdalmalak and Daniel Segovia-Vargas (Universidad Carlos III de Madrid, Spain)

A low profile wideband circularly polarized reconfigurable metasurface antenna is proposed. The proposed antenna consists of a 3 × 4 rectangular metasurface (MTS) and a rotated coplanar waveguide feeding line (CPW). Four PIN diodes (D1, D2, D3 and D3) are utilized to realize circular polarization reconfigurability. The antenna could operate in left handed circular polarization (LHCP) and right handed circular polarization (RHCP) depending on the state of the diodes. The simulated results show an impedance bandwidth (IBW) of 16% and a 3-dB axial ratio band (ARBW) of about 13% in both RHCP and LHCP radiation modes, while the gain for both polarizations is higher than 6 dBi in the operating band.

Beam-Steerable Helical Antenna Using Plasma Reflectors

Fatemeh Sadeghikia (Aerospace Research Institute, Iran); Mahsa Valipour (Iran); Mohamed Himdi (Université de Rennes 1, France); Theodore Anderson (Haleakala Research and Development, USA); Ali K. Horestani (The University of Adelaide, Australia)

The aim of this paper is to investigate the steering mechanism of the beam pattern of a helical antenna using a half-cup plasma reflector. To this end, variations of the radiation characteristics and also the direction of the main beam of the antenna due to changes in the dimensions of the half-cup plasma reflector, including its diameter and height, are numerically computed and analyzed. The simulation results show that using this structure, the beam direction can be altered in 3-D space within a solid angle of ±10o. Also, it is highlighted that the half-cup plasma reflector may adversely affect the polarization of the helical antenna. Therefore, a trade-off between polarization and performance of an antenna based on a parametric study has to be made. Good agreement between the numerically calculated and measured results validates the presented study.

Low-Noise Amplifier-Antenna Co-Design Overview

Kirill Alekseev (Eindhoven University of Technology, The Netherlands); Marcus Hasselblad (Gapwaves AB, Sweden); Klas Eriksson (Ericsson AB, Sweden); Martin Johansson (Ericsson Research, Sweden); A. B. (Bart) Smolders and Ulf Johannsen (Eindhoven University of Technology, The Netherlands)

Antenna and low-noise amplifier (LNA) co-design is a promising method for increasing the sensitivity of millimeter-wave (mmWave) receiver systems. Co-design involves several individual steps which usually do not intersect with each other in one design flow, but this method combines all of them together and allows to obtain mutual benefits for all components. This paper gives an overview of several different mmWave engineering tasks like antennas and monolithic microwave integrated circuit (MMIC) design together with RF interconnection solutions like wirebonding, flip-chip and packaging technology. The suggestion of the mmWave receiver co-design for achieving minimum noise figure at low costs is also provided.

Eigenanalysis-Based Port Synthesis of Multifeed Antenna for Power Combining

Sirous Bahrami (Pohang University of Science and Technology, Korea (South)); Wonbin Hong (Pohang University of Science and Technology (POSTECH), Korea (South)); Ho-Jin Song (POSTECH, Korea (South))

In this paper, a method for synthesizing multi-feed antennas is proposed. The Eigenvalue analysis of the scattering matrix of a multi-feed antenna has been used to synthesize different types of excitations. We have shown that the eigenvectors in the null space of the scattering matrix act as the building blocks of the excitation vectors for optimum power combination. To bring more flexibility, we propose two different scenarios to fit the design restrictions: (A) antenna ports with different input power levels and equal input impedances, and (B) equal input power levels and

different input impedances. Based on simulation results of a four-port half-wavelength dipole both scenarios yield the same power combining for the multi-feed antennas. Also, we studied the effect of the feeds' weighting vector on equivalent isotropic radiated power (EIRP). It can be concluded that the EIRP in the multi-feed antenna is not a linear function of input power.

Millimeter-Wave Gap-Waveguide Interconnect for Launcher in Package Technology

Qiannan Ren (Chalmers University of Technology, Sweden); Carlo Bencivenni (Gapwaves AB, Sweden); Ashraf Uz Zaman and Jian Yang (Chalmers University of Technology, Sweden); Giorgio Carluccio (NXP Semiconductors, The Netherlands); Harshitha Thippur Shivamurthy (Delft University of Technology, The Netherlands)

Highly integrated systems in package with waveguide interfaces are of high interest recently. To investigate the connections between the integrated system and waveguide based antennas, an interconnect based on gap-waveguide technology is presented in this paper. The dispersion properties of gap-waveguide pin texture adopted by the interconnect is demonstrated. The simulated results show that the proposed interconnect has low loss and provides high isolation regardless the air gap variation. In addition, the performance degradation due to the misalignment between the blocks is checked and the simulated results show that the interconnect is robust in terms of insertion loss and isolation. As a result, the presented interconnect is able to ensure robust system level integrations while requiring non-galvanic contact.

Design of Fully Planar Cost-Effective Metamaterial-Enhanced SIW Antennas for 5G Applications

Michalis Nitas, Vasileios N. Salonikios, Savvas Raptis and Traianos Yioultsis (Aristotle University of Thessaloniki, Greece)

We present fully planar, low-cost and easy to fabricate metamaterial-based Substrate-Integrated Waveguides (SIWs) and Slot Antennas for 5G Communications. The SIW is entirely planar since it is designed using series of side-by-side broadside-coupled complementary split-ring resonators (BC-CSRRs) etched on top and bottom metal ground surfaces of a dielectric substrate. This metamaterial-inspired structure replaces the vias of a classical SIW by providing a negative dielectric effective material parameter behavior which results to the block of the wave propagation to the direction perpendicular to the axis of propagation. Using this structure as a waveguide, slot antennas are consequently designed, by the proper etching of slots on the substrate. Coaxial cable excitation perpendicular to the circuits' plane is applied, avoiding the design of complex in-plane matching circuits.

Narrow Band Rejection in UltraWideband Pixel Antennas

Mohamad Majed (University of Limoges, France); Mohamad Rammal (ITHPP, France); Hussein AbouTaam (Lebanese University, Lebanon); Mayank Mayank (XLIM, France); Joel Andrieu (University of Limoges, France); Bernard Jecko (XLIM, France)

In order to meet the growing demand for new services, airborne or satellite platforms must integrate more and more radio systems while the space available for the integration of these elements is increasingly reduced. Particularly, the use of ultra wideband (UWB) Radar, Electronic Warfare devices or wide band telecommunication systems increases the difficulty to share the allowed frequency band on a platform. Then, the introduction of a narrow forbidden band in these UWB structures is a challenge today. This narrow band can be used for localization, voice, internet, communications using for example another antenna located nearby on the platform, but also inside the UWB antenna itself building a Multifunction Antenna. Agile Radiating Matrix Antennas (ARMA) (Fig1) built with wide band pixels are a good candidate to perform this multi-functionality as shown in this paper.

Substrate Integrated Waveguide Based Compact Multiband and Broadband Antennas at X / Ku-Bands

Soumik Dey and Sukomal Dey (Indian Institute of Technology Palakkad, India)

This paper presents two novel miniaturized substrate integrated waveguide (SIW) cavity backed slot antennas (CBSAs) with multiband and broadband characteristics. The first antenna combines the modified non-resonant rectangular slot with two pairs of symmetrically placed shorting pins and fed with tapered coplanar waveguide (CPW) to SIW transition for obtaining three resonances at 8.8, 12.25, and 14.35 GHz. The 10 dB return loss bandwidths (BWs) correspond to three resonances are 4.78, 3.11, and 1.82 % with peak realized gain of 6.41, 6.31, and 7.26 dBi respectively. Later for the second antenna, an indigenous method of splitting the SIW cavity is incorporated using shorting vias to obtain broadband impedance matching. Lower and high order modes (half TE110 and TE210) of the SIW cavity are coupled together to achieve broad BW with S11<10 dB from 12.34 14.54 GHz (16.4 %) and a flat gain > 6.4 dBi over the operating range.

A Compact, Tri-Band and Circularly Polarized Patch Antenna Using a Ferrite Material

Sarra Jemmeli (University of Limoges, France); Laure Huitema (Xlim Laboratory, France); Thierry Monediere (XLIM-University of Limoges, France); Eric Arnaud (XLIM, France)

A single fed, compact and circularly polarized patch antenna operating in three frequency bands is proposed in the present paper. This patch antenna uses a polarized ferrite substrate which therefore has the property of naturally generating circularly polarized waves. The modelling process of a compact antenna having dimensions of λ0/10×λ0/9.5×λ0/27 at 3 GHz and presenting three circularly polarized modes is exhibited. A prototype measurement has been carried out for an experimental validation of the simulated results.

A Dually-Polarized Leaky-Wave Antenna Based on Polarization-Selective Coupling Mechanisiam with Fixed Beams Capability

Mohammad reza Rahimi (Polytechnique Montréal, Canada); Mohammad S. Sharawi (Polytechnique Montreal, Canada); Ke Wu (Polytechnique Montréal, Canada)

In this work, we investigate the effect of polarization diversity for the higher-order space harmonics (HSH) of periodically-loaded leaky-wave antennas, i.e., TE10 and TE01. A hybrid form of nonradiative dielectric (NRD) waveguide and substrate integrated waveguide (SIW) is used to explore the inherent diversity feature for our antenna. The radiation properties of HSH in different passbands are examined where we investigate the behavior of scanning range variation of different HSH of n ϵ [-1, -2, -3, -4]. Furthermore, the effect of the unit-cell geometry on the propagation constant, and beam alignment of the TE10 and TE01 modes is studied and we show how the concept of HSH can be utilized for achieving a dually-polarized leaky-wave antenna (DP-LWA) with fixed beam operation. The proposed work is validated by showing an experimental prototype of DP-LWA in which a good agreement is achieved between the simulation, analysis, and measurement results.

Bidirectional Periodic Leaky-Wave Antennas Using Side-Fire and Slot-Pair Configurations

Mohamed K. Emara and Shulabh Gupta (Carleton University, Canada)

Two different bidirectional periodic leaky-wave antennas (LWAs) are presented for the millimeter-wave (mm-wave) band with suppressed stopbands and orthogonal radiation directions: a bidirectional side-fire antenna with left/right in-plane radiation and a bidirectional slot-pair antenna with top/bottom out-of-plane radiation. The operations of these antennas are confirmed using full-wave simulations, with a broadside frequency of approximately 28 GHz. These antennas can be individually engineered to form various radiation patterns in each of their radiation planes, and can further be combined to design a tetra-directional periodic LWA.

Beam Scanning Leaky-Wave Antenna with a Reconfigurable Impedance Plane

Lucia Teodorani and Francesco Vernì (Politecnico di Torino, Italy); Giorgio Giordanengo (LINKS Foundation & Politecnico di Torino, Italy); Rossella Gaffoglio and Giuseppe Franco (Fondazione LINKS, Italy); Giuseppe Vecchi (Politecnico di Torino, Italy)

An electronically-reconfigurable leaky-wave antenna based on metasurfaces is designed and implemented. This innovative antenna consists of a multilayered structure with two (metasurface) impedance planes. The beam scanning at fixed frequency is achieved by electronically tuning the surface impedance of the lower plane using voltage-controlled varactor diodes. The rationale of this solution is that a variation in the impedance profile of the antenna in the direction transversal to propagation affects the phase velocity of the leaky wave and therefore the beam direction.

A Single-Layer Center-Feed Slotted Antenna Array with Reflection Canceling Stairs in 38-GHz Waveband

Wenbo Liu (Graduate School of Engineering, Takushoku University, Japan); Yasuhiro Tsunemitsu (Takushoku University, Japan)

We design and estimate the performance of a single-layer center-feed slotted waveguide antenna array. First, we optimize the matching waveguide, the feed waveguide, and the radiation waveguide based on finite-element-method (FEM) calculation. Perfect impedance matching condition is realized by optimizing the length width and height of the matching waveguide. As a result, we obtain > 800-MHz bandwidth for input port (with < -20 dB S11). Besides, we successfully design a 1×5 feed waveguide with an S11 of -19.9 dB at 38 GHz. The responding conductive wall strongly suppresses the reflection of each unit. In addition, we present the analysis of a radiation waveguide with ten pairs of slots and stairs. Finally, we compare the directive gain and the aperture efficiency between the 10×10 slots antenna arrays with designed feed waveguide and an ideally feeding condition.

New Reconfigurable HMSIW Associated to Horn Antenna

David René--Loxq (Université de Rennes 1, France); Olivier Lafond (IETR - Université de Rennes 1, France); Mohamed Himdi (Université de Rennes 1, France); Langis Roy (Ontario Tech University, Canada); Farhan Ghaffar (Lakehead University, Canada)

This paper concerns the design of a beam steerable Leaky Wave Antenna (LWA) based on integrated electronic devices. The design uses a Half-mode Substrate Integrated Waveguide (HMSIW) where the short circuited wall (via holes) is modified to integrate Varactor diodes. Thanks to the behavior of these varactor diodes, the wave number and the phase shift of the propagating signal can be controlled. To narrow the beam in E plane, the HMSIW antenna is used as feeder of a horn like structure. This antenna allows to have a beam steering of 25° for a fixed center frequency in H plane and a 24° beamwidth in E plane.

Continuous Leakage from Slow-Wave Structure for Integrated All-Dielectric Uniform Leaky Wave Antenna

Daniel Headland (University of Adelaide, Australia); Withawat Withayachumnankul (The University of Adelaide, Australia)

We propose a concept to achieve continuous leakage from a slow-wave through a combination of wave tunneling and anti-reflection structures, and the result is a metal-free uniform leaky-wave antenna that is entirely composed of intrinsic silicon. This holds potential to realize terahertz-range radar and non-contact sensing applications with no Ohmic loss.

Study on the Series Arrangement of One-Dimensional Leaky-Wave Antennas

Miguel Poveda-García and Eloy Andreu-Garcia (Technical University of Cartagena, Spain); Alejandro Gil Martinez (Technical University of Cartagena Cartagena, Spain); David Cañete Rebenaque and Jose-Luis Gómez-Tornero (Polytechnic University of Cartagena, Spain)

The radiation characteristics of a series-fed array of 1D Leaky-Wave Antennas (LWA) are reported. A study of the proper transition between antennas, as well as the antenna design is performed,

showing how to reach an optimum overall performance to keep the desired radiation pattern with good efficiency. Theoretical examples are shown for the 900 MHz UHF band. Finally, simulated results are obtained for a practical design in planar Half-Width Microstrip Leaky-Wave technology.

On the Use of Leaky-Wave Antennas for Amplitude Monopulse Comparison

Alejandro Gil Martinez (Technical University of Cartagena Cartagena, Spain); Miguel Poveda-García (Technical University of Cartagena, Spain); David Cañete Rebenaque and Jose-Luis Gómez-Tornero (Polytechnic University of Cartagena, Spain)

The performance of a single bidirectionally-fed scanning leaky-wave antennas for low-cost amplitude monopulse synthesis, is compared to the most conventional use of two tilted antennas. The main advantages and drawbacks are demonstrated in detail with a practical design for direction finding in the 2.4 GHz ISM band. It is demonstrated that leaky-wave antennas offer a much more compact and low-cost design, which reduces the near-field zone for proximity sensing. However, the frequency beam-squinting must be considered for accurate operation in the entire bandwidth.

Handmade Microstrip Leaky-Wave Antenna in UHF Band for Educational Purposes

María Campo-Valera (Universidad Politécnica de Cartagena, Spain); Miguel Poveda-García and Joaquin Garcia-Fernandez (Technical University of Cartagena, Spain); David Cañete Rebenaque and Jose-Luis Gómez-Tornero (Polytechnic University of Cartagena, Spain)

The design, manufacture and testing of a micro strip leaky-wave antenna in the UHF band is reported. The antenna is fabricated using low-cost materials and handmade techniques. This activity is intended for educational purposes and hands-on training of antenna engineering and related applications. Particularly, the proposed antenna can be used for localization of passive RFID tags and DVB-T base stations.

Branch Line Coupler Inspired Circularly Polarized Leaky-Wave Antenna with Broadside Scanning

Ayaz Ahmad (Indian Institute of Technology Bombay, India); Vishakha Pandey (Indian Institute of Technology, Bombay, India); Mahesh Kumar Busineni and Jayanta Mukherjee (Indian Institute of Technology Bombay, India)

In this work, a new microstrip circularly polarized leaky-wave antenna is presented for X-band applications. The design of the proposed leaky-wave antenna is inspired by the conventional 3 dB branch-line coupler. The geometry of the unit cell of the proposed leaky-wave antenna is realized by removing the two collinear feed lines of the branch-line coupler. The open stopband is eliminated by optimizing the geometry. The proposed leaky-wave antenna provides impedance bandwidth with $|S11| < -10$ dB between 8.2-11.1 GHz. The bandwidth corresponding to axial ratio < 3 dB is 9.4-10.3 GHz. The antenna radiates in the broadside at 9.9 GHz with 14.1 dBic gain.

A Planar Leaky-Wave Antenna with Dual Circular Polarization in Continuous Backward and Forward Scanning

Xiaowen Li (Beijing Jiaotong University, China); Lei Wang (Heriot-Watt University, United Kingdom (Great Britain)); Jun Hong Wang (Beijing Jiaotong University, China); George Goussetis (Heriot-Watt University, United Kingdom (Great Britain))

A planar leaky-wave antenna (LWA) with flexible circular polarization (CP) characteristic is proposed in this paper, which is promising for satellite communication applications. A novel fan-blade shape slot is utilized to achieve left- or right-handed circular polarizations by manipulating the wave propagating directions in the waveguide. Moreover, a two-LWA array is further investigated to obtain dual CPs in both the backward and forward scanning. In addition, the proposed LWA overcomes the open stopband, which is a problem frequently plaguing LWAs. As a result, the proposed LWA scans continuously from backward to forward. An example LWA is designed in the Ka band using the substrate integrated waveguide (SIW) technique with coaxial connector feedings. The main radiation beam steers continuously from $-45°$ to $45°$ in dual CPs when the operating frequency varies between 28 and 37.3 GHz. A prototype has been fabricated and tested to demonstrate the design idea and application scenario.

Parallel-Plate Waveguide with a Bed of Nails for Radial-Line Slot Array Antennas

Jose I Herranz-Herruzo (Universitat Politècnica de València & APL - iTEAM, Spain); Alejandro Valero-Nogueira (Universidad Politécnica de Valencia, Spain); Miguel Ferrando-Rocher (Universidad de Alicante & Universitat Politècnica de València, Spain)

This communication explores the use of a parallel-plate waveguide with a bed of metallic nails on its bottom plate with the aim to design all-metal radial-line slot array antennas (RLSAs). This kind of antennas would provide a highly-efficient directive radiation of circularly-polarized waves at millimeter-wave band, adopting a very simple power distribution scheme. Specifically, in this communication, the radial propagation of the fundamental mode within this pinned waveguide is explored and the coupling to the slot array is studied and modeled. This study will enable an efficient analysis and design of all-metal RLSAs.

Non-Homogeneous Fabry-Perot Antenna Design Process to Improve Aperture Efficiency

Pablo Mateos-Ruiz (University of Malaga, Spain); Elena Abdo-Sánchez (University of Málaga & E. T. S. I. Telecomunicación, Spain); Carlos Camacho-Peñalosa

(University of Málaga, Spain)

A novel technique to design Fabry-Perot antennas with non-homogeneous PRS is described. It uses a transmission line circuit model to efficiently obtain all necessary unit cell designs that satisfy the cavity resonance condition. This method allows an increase in directivity without reducing the bandwidth for a given footprint. Some design examples in the Ku-band are presented, showing the evolution from a simple single-layer PRS to a non-homogeneous two-layer one. The latter achieves an increase of about 3 dB in directivity while maintaining the bandwidth in electromagnetic simulations. This way, the gain-bandwidth product is improved from a value of 5 to almost 9, effectively raising the antenna efficiency.

The Way One Defines Specification Matters: On the Performance Criteria for Efficient Antenna Optimization in Aggregated Bi-Objective Setups

Adrian Bekasiewicz and Michal Czyz (Gdansk University of Technology, Poland)

Design of antenna structures for real-world applications is a challenging task that often involves addressing multiple design requirements at a time. Popular solution approaches to this class of problems include utilization of composite objectives. Although configuration of such functions has a significant effect on the cost and performance of the optimization, their specific structure is normally determined based on engineering experience and does not involve auxiliary investigations oriented towards adjustment of process efficiency. In this work, the effects of used functions and their composition on performance and cost of the bi-objective optimization process are investigated. The analyses are performed on a case study basis using a planar, multi-parameter antenna optimized for minimization of footprint and reflection within the 3.1 GHz to 10.6 GHz range. The numerical results show significant differences between the performance of the obtained solutions, as well as the computational cost of the optimization.

Inverse Design of Rectangular Microstrip Patch Antenna Using Neural Network Combining with Time-Domain Representation of S-Parameters

Yue Su (Southeast University, China); Zhiguo Su (China); Hongtai Chen and Hongxin Zhao (Southeast University, China); Xiaoxing Yin (State Key Laboratory of Millimeter Waves, China)

In this study, a multilayer perceptron (MLP) neural network is utilized to inversely design a rectangular microstrip patch antenna. The MLP network maps the input features, including the resonant frequency, directivity, realized gain, and time-domain representation of the S-parameters, to the output that is the antenna geometrical parameters. Especially with the time-domain representation of S-parameters added into the input features, the prediction error of the antenna geometrical parameters can be decreased dramatically. The mean square error (MSE) and mean absolute error (MAE) are 0.00432% and 0.484% for the test dataset, respectively. The promising results verified that incorporating the time-domain representation of S-parameters into the features could effectively improve the prediction accuracy of the MLP network for inverse antenna design.

Gradient-Based Topology Optimization in Method of Moments with Black & White Material Elements

Jonas Tucek, Miloslav Capek and Lukas Jelinek (Czech Technical University in Prague, Czech Republic)

A topology optimization technique based on exact reanalysis is proposed within method-of-moments formalism. The optimization is formulated over a fixed discretization grid by performing general block structural modification. The procedure is based on an inversion-free evaluation of topological sensitivities, constituting a gradient-based local step that is iteratively restarted by the genetic algorithm. The proposed method sacrifices structural resolution at the expense of lower computational time and direct manufacturability. The method's validity and effectiveness are demonstrated in two examples.

Using the Convolutional Neuron Network for Target Localization and Wall Characterization in the Through the Wall Imaging Problem

Behzad Ashrafi Nia (University of California, Irvine, USA); Sajjad Sadeghi (University of Tehran, Iran); Franco De Flaviis (University of California, Irvine, USA)

This paper investigates through the wall imaging (TWI) problem via machine learning. To solve the TWI problem in presence of the wall, a Convolution Neuron Network (CNN) is proposed. The detection of the scatterers behind the wall when there is a strong reflection from the front wall is very challenging. Several microwave imaging algorithms have been introduced to extract the unknown parameters of the wall and mitigate the wall clutter to predict the location of the target. This process is very time consuming even though it has accurate results. In this paper we developed a method for exploiting the complex information for TWI problem by using a CNN that accepts complex numbers from receiver to predict wall thickness, material, and location of the target behind the wall at the same time. We show that our proposed model can predict these parameters with an accuracy of 92.6%.

Application of Field Intensity Shaping Paradigm in a Biological Scenario for MRI Shimming

Sabrina Zumbo, Martina Teresa Bevacqua and Giada Maria Battaglia (Università Mediterranea di Reggio Calabria, Italy); Tommaso Isernia (University of Reggio Calabria, Italy)

A fundamental problem in electromagnetics is the shaping of the field intensity distribution in a given region of interest. Several strategies have been designed to address such issue in several and different applications, ranging from hyperthermia to wireless power transfer. In this contribution, we focus our attention on MRI shimming. Usually the shimming (or leveling) of the radiofrequency field B1+ can be performed by using particular materials characterized by high permittivity values or by acting directly on the primary sources (i.e., the excitations of the radiofrequency coil). Herein, the proposed procedure exploits the field intensity shaping paradigm to design the primary sources in such a way to ensure a uniform field and to control the specific absorption rate inside the biological region under investigation

Optimization of Uniform Amplitude Periodic Linear Phased Arrays for Grating Lobe Reduction

Yanki Aslan and Nehir Berk Onat (Delft University of Technology, The Netherlands)

The optimization of mode excitation coefficients in linear periodic arrays of multi-mode antenna elements is studied for grating lobe reduction. A novel beamforming architecture is proposed with a new optimization problem based on equi-amplitude element excitations for optimal power efficiency. The capabilities of the proposed synthesis approach on suppressing the grating lobe for wide scan angles, and on maintaining the peak gain at the steering angle are analyzed. A 16-element 0.7-wavelength spaced array of dual-mode circular patch antenna elements is used for demonstration purposes. It is shown that a good performance trade-off is achieved when the excitation amplitude of the high order mode is restricted to a sufficiently large value. The ratio of the peak gain outside the main lobe to the gain at the angle of steering is reduced up to about -15 dB and -14 dB for scanning towards 30 and 45 degrees off-broadside, respectively.

Minimum Q-Factor for Microstrip Antennas

Ben A. P. Nel (Lund University, Sweden); Anja K. Skrivervik (EPFL, Switzerland); Mats Gustafsson (Lund University, Sweden)

Microstrip patch antennas are generally narrowband and therefore their Q-factor is an important design parameter. To minimize Q-factor, current optimization has been successful in obtaining bounds for arbitrary shaped antennas. This formulation relies on a method of moments implementation. Here, current optimization is extended to microstrip antennas. Allowing antenna designers to obtain minimum Q-factor for given constraints. Further, the bound can provide a trade-off of several parameters when considering Q-factor.

Analysis of Dielectric Post-Wall Waveguide-Based Passive Circuits Using Recurrent Neural Network

Saba Kobakhidze and Elguja Archemashvili (Free University of Tbilisi, Georgia); Vakhtang Jandieri (General and Theoretical Electrical Engineering (ATE), Faculty of Engineering, Germany); Hiroshi Maeda (Fukuoka Institute of Technology, Japan); Wonbin Hong (Pohang University of Science and Technology (POSTECH), Korea (South)); Douglas H Werner (Pennsylvania State University, USA); Daniel Erni (University of Duisburg-Essen, Germany)

The dielectric post-wall waveguide-based passive circuits are analyzed using a surrogate model represented by an attention-based recurrent neural network. The predicted results from this much simpler, trained model show a good agreement with those obtained by a corresponding full-wave computational electromagnetics analysis with a fully independent EM commercial software package.

Design of Double-Reflector Objective for Corneal Sensing in the 220-330 GHz Band

Mariangela Baggio, Aleksi Tamminen, Juha Ala-Laurinaho and Zachary D Taylor (Aalto University, Finland)

An all-reflective, Schwarzschild objective design for corneal reflectometry is evaluated in the WR 3.4 (220-330 GHz) frequency band. The shadow created by the 60-mm diameter secondary mirror is sufficiently large to mount a standard, OCT system to enable concomitant data acquisition with both modalities while avoiding beam obscuration. The system was fed with a bottle beam comprised of a $p = 0$, $\ell = 4$ Laguerre-Gaussian mode with a 12.5 mm beam waist radius for increased throughput. The 50 mm focal length system was checked with ray tracing and simulated with an in-house physical optics code using a PEC sphere as a test target. The coupling coefficient between the feed beam and scattered beam varied from 0.25 at 220 GHz to 0.36 at 330 GHz. While the system demonstrated a clear phase center < 1λ from the focal point, significant edge diffraction prevents the formation of a spherical phase front.

Cross Polarization in Swept Beam THz Imaging Systems Using Off-Axis Parabolic Mirrors

Pouyan Rezapoor, Aleksi Tamminen, Irina Nefedova and Juha Ala-Laurinaho (Aalto University, Finland); Nuria LLombart (Delft University of Technology, The Netherlands); Jan Stake and Helena Rodilla (Chalmers University of Technology, Sweden); Zachary D Taylor (Aalto University, Finland)

The optical behavior of a terahertz imaging system employing a train of four identical off-axis parabolic mirrors with oblique incidence angle illumination is investigated in this work. The aperture filling and aberrations of a single off-axis parabolic mirror when illuminated by a Gaussian terahertz beam at its focus point is measured and simulated. The amplitude of E-field in transverse electric (TE) and transverse magnetic (TM) polarizations at target plane reveals a significant cross polarization, even when there is zero cross polarization at the source beam, amplitude of which is ~ 33% of TE polarization. The investigation of the E-field on the detector plane reveals that this ratio is ~ 1.5% at the detector plane, and the cross polarized E-field at the target plane is rotated back to co polarization. Although its amplitude is negligible, the TM distribution at detector plane is bimodal and tilted about the optical axis.

On the Modelling of a Quasi-Optical Link Between Two Photoconductive Antennas Under Pulsed Laser Illumination

Huasheng Zhang, Andrea Neto, Juan Bueno, Paolo Sberna and Nuria LLombart (Delft University of Technology, The Netherlands)

Photoconductive antennas (PCAs) are promising candidates for millimeter-resolution imaging applications. In the past, our group investigated their properties under pulsed laser illumination only in transmission, with the receiver being a power detector. Here we consider a second PCA as the receiver and develop a quasi-optical (QO) time-domain link for investigating the coupling between the transmitter and the receiver. Specifically, a field matching technique is used to evaluate the short-circuit current of the receiver. Based on this current, the spectral mutual coupling between the two PCAs, including the QO link can be evaluated. Moreover, a time-domain Norton circuit in reception is proposed to quantify the detection. A marching-on-time technique is used to evaluate the response of the receiver. As an example, a bow-tie antenna feed is simulated to show the coupling and the device response.

Coherence Factor Based Methods for Improving the Image Quality of the Advanced Imaging System

Guanying Sun, Mohammad Hossein Nemati and Carey Rappaport (Northeastern University, USA)

Three coherence factor based methods are analyzed and then incorporated into the imaging procedure of our near-field millimeter-wave radar security scanning system. The performance of these methods is verified by multiple simulations and experiments. The simulation and experimental results show that these methods are effective in decreasing the side lobe levels of the reconstructed images by Advanced Imaging Technology, hence improving the image quality of our imaging system.

Multi-Resolution Strategies for Microwave Inverse Scattering - Challenges, Solutions, and Future Trends

Francesco Zardi and Marco Salucci (ELEDIA Research Center, Italy); Lorenzo Poli (ELEDIA Research Center, University of Trento, Italy); Andrea Massa (University of Trento, Italy)

This work deals with the retrieval of the electromagnetic properties of two-dimensional (2D) and three-dimensional (3D) domains starting from microwave scattered data. Within this context, multi-resolution (MR) methods can yield accurate, robust, and computationally-efficient solutions, overcoming single-resolution (SR) inversion strategies. As a matter of fact, they reduce the degree of non-linearity of the inverse scattering (IS) problem, providing at the same time an effective regularization of its solution. The aim of this work is to (i) highlight the main concepts and principles of MR strategies, (ii) provide an overview of the most recent advances in this field, and (iii) introduce an innovative overconstrained (OC-MR) solution strategy for solving fully non-linear IS problems.

Direction Finding with Time-Modulated Digital Metasurface

Gang Ni, Lening Zhang, Anjie Cao, Chong He and Ronghong Jin (Shanghai Jiao Tong University, China)

A novel direction-finding method for digital metasurface is proposed and verified. Considering the phase-control capability of the digital metasurface and the limit of only a single receiving channel, time modulation technique is introduced herein to modulate the phase of incident wave periodically from phase 0 to π. Multiple harmonics are thus generated and carry the angle information in the single-channel signal. With the discrete Fourier transform (DFT) and harmonic characteristic analysis, the direction of arrival can be easily estimated from the harmonics. Simulation and experiment results are provided to verify the feasibility of the proposed method.

Study of Feasability for 2D and 3D Innovative Jet Printed RF Devices

Camille Delfaut (Grenoble INP, France); Tan-Phu Vuong (IMEP-LAHC Grenoble, France); Alejandro Niembro-Martin (Schneider Electric, France); Nadège Reverdy-Bruas (LGP2, France); Thierry Lacrevaz (Imep Lahc, France); Cécile Venet (Schneider Electric, France); Jean-Emmanuel Broquin (University Grenoble Alpes, CNRS, Grenoble INP, IMEP-LAHC, France); Quoc-Bao Duong and Damien Paulet (Université Grenoble Alpes, France)

This work presents a radiofrequency (RF) performance review of a conductive ink dispensing process for RF applications. This innovative process allows to functionalize existing objects like plastic cases for adding a RF function. It can print devices on a substrate placed horizontally or in a tilted position. The main purpose of this work consists in showing the feasibility of this process. First, Coplanar transmission lines are printed with silver ink on horizontal substrate by a simple configuration. It exhibits a performant attenuation coefficient: α4GHz=0.021±0.007 dB/mm. In a second part, a 6-axis robot is used for improving the 3D process, coplanar transmission lines are also printed and exhibit a performant attenuation coefficient: α4GHz=0.060±0.009 dB/mm. Finally, coplanar lines are printed on tilted plastic substrate and then measured. The scattering parameters of horizontal and tilted substrates are similar and exhibit a good performance in the range of 0 to 4 GHz.

Line-Of-Sight Probability for Urban Microcell Network Deployments

Dave Townend (BT & University of Essex, United Kingdom (Great Britain)); Stuart D Walker (University of Essex, United Kingdom (Great Britain)); Adrian Sharples (BT Labs, United Kingdom (Great Britain)); Andy Sutton (BT Technology, United Kingdom (Great Britain))

In this paper we present a new line-of-sight probability model for the urban micro cellular deployment scenario. This study utilises a high resolution 3D model of central London to conduct large scale ray-tracing of direct propagation paths between neighbouring lamp posts. These serve as a representation of mmWave self-backhauling small cells such as 3GPP integrated access and backhaul nodes. The statistical properties of the propagation paths are assessed against recognised line-of-sight probability models as a function of the distance between transmitter and receiver. Contributions as outlined in this paper have application in analytical studies aiming to understand the statistical characteristics of unobstructed high frequency `access' links between microcell sites and end users as well as `transport' backhaul links between neighbouring microcell sites.

Dog IoT: Path Loss and Link Budget Analysis for Canine Wireless Body Area Network

Jasper Goethals (Ghent University & IMEC, Belgium); Gunter Vermeeren (Ghent University, Belgium); Margot Deruyck (Ghent University - IMEC, Belgium); Luc Martens (Ghent University - imec, Belgium); Wout Joseph (Ghent University/IMEC, Belgium)

Internet of Animal Health Things is an upcoming domain in animal welfare monitoring. WBAN represent a large allotment in the realization of these applications. Characterization of the path loss between on-body nodes in various surroundings is required when deploying such network. In this paper, the path loss between various on-body transmitting sensors and an on-body receiver is investigated at 2.45 GHz. Simulations using the FDTD method are performed using a representative, homogeneous canine model on which two half-wavelength dipoles are placed at short distance from the body of the dog. All path loss results are fitted to a log-normal path loss model with path loss exponent n ranging from 2.7 to 3.5. A link budget is composed with the wireless technologies ZigBee. The ZigBee device XB24CAPIT-001 assures 237 days without recharging when using a battery capacity of 5000 mAh with an awake time period of 25%.

Comparison of Statistical and Deep Learning Path Loss Model for Motherboard Desktop Environment

Jinbang Fu, Prateek Juyal, Erik Jorgensen and Alenka Zajic (Georgia Institute of Technology, USA)

In this paper, the path loss of the THz channel in motherboard desktop environment has been characterized and modeled by both statistical (mixture distributions) and deep learning (MLP) models. The performance of the two different model classes are compared and results show that mixture models captures the randomness of the channel by matching the PDF of measured path loss, which means that the statistical model can adapt to the changing environment. However, for the complex yet static motherboard desktop environment, the deep learning model outperforms the statistical models since it can also precisely describe the hidden patterns due to resonant modes and signal propagation in the static environment.

Outdoor Line-Of-Sight Path Loss Modeling at 140 GHz

Brecht De Beelde (Ghent University & IMEC, Belgium); Emmeric Tanghe, David Plets and Wout Joseph (Ghent University & IMEC, Belgium)

This paper presents outdoor radio channel measurements at 140 GHz using a spectrum analyzer-based channel sounder operational in the D-band, ranging from 110 to 170 GHz. We measure directional Line-of-Sight (LOS) path loss (PL) in a suburban environment for distances ranging from 2 m to 95 m, using an omnidirectional transmit antenna and directional receive antenna. Every 10 m, a full angular scan is performed by physically rotating the receive antenna in steps of 12◦, which corresponds to the antenna's half-power beamwidth. A floating-intercept PL model is created, resulting in a fitted intercept P L0 at 1 m of 80.7 dB, and PL exponent n 1.9. The azimuthal angular spread varies between 7◦ and 45◦, with a mean angular spread of 19.7◦.

Capacity Analysis and Improvement for OAM-MIMO in Typical Multipath Scenarios

Kuo Zhao and Tao Hu (Chongqing College of Electronic Engineering, China); Yang Wang and Xi Liao (Chongqing University of Posts and Telecommunications, China)

Orbital angular momentum (OAM) can provide an additional multiplexing degree in wireless communications. However, it suffers large propagation loss in the misalignment and rich-multipath scenarios. In this paper, the joint iterative power allocation and average phase compensation (IPA-APC) scheme is proposed to improve the performance of OAMMIMO in street scenarios. On the one hand, the average phase compensation scheme improves the channel capacity as well as the phase deviations caused by misalignment and multipath; on the other hand, compared with the optimal power allocation (OPA) scheme, the proposed iterative power allocation scheme reduces the running time of the algorithm and ensures the capacity performance. Simulation results verify the superiority of the proposed scheme.

Radar-Based Refractivity Estimation: A New Calibration Approach Relying on Reanalysis Data

Brais Sánchez-Rama, Rubén Nocelo López and Veronica Santalla del Rio (University of Vigo, Spain)

The radio refractivity is a valuable parameter to model radio communication links and it is widely used in numerical weather prediction (NWP), since it is closely related to temperature and relative humidity. Recently, a method to estimate this parameter from radar phase measurements was proposed. However, the accuracy of the estimates largely depends on the calibration stage, which is based on measurements performed by ground-based weather stations. Due to the high cost of installing and maintaining an automatic weather station network, looking for alternative calibration procedures has become interesting for radar operators. This paper discuses the reliability and performance of a new calibration method based on the European Centre for Medium-range Weather Forecast (ECMWF) reanalysis data.

Two Co-Linear Transitions for Q-Band Horn Waveguide Dense Cluster

Marco Simone (Univerity of Cagliari, Italy); Matteo Lodi and Giacomo Muntoni (University of Cagliari, Italy); Nicola Curreli (Italian Institute of Technology, Italy); Alessandro Fanti (University of Cagliari, Italy); Tonino Pisanu (INAF - OAC, Italy); Giuseppe Valente (Italian Space Agency (ASI), Italy); Giorgio Montisci and Giuseppe Mazzarella (University of Cagliari, Italy)

This paper presents the design of two in-line transitions operating in Q-band for radioastronomy or satellite applications. Both employ the WR-22 rectangular waveguide. The first transition involves as end-launcher a microstrip line, the second a coaxial cable. Focus of the works is to obtain a design which simplifies the geometrical configuration by keeping a reasonable compactness and

without affecting the transversal space occupation, while ensuring a good matching (return loss higher 24 dB in both cases). The performance are evaluated in terms of scattering parameters.

Propagation Models Trials for TV White Spaces in Colombian Rain Forest

Andres Navarro and Leonardo Vargas (Universidad Icesi, Colombia); Dinael Guevara (Francisco de Paula Santander University, Colombia); Diego Parada (Federal University of Minas Gerais, Brazil); Christian Amu (Universidad ICESI, Colombia); Cássio Rego (Federal University of Minas Gerais, Brazil)

TV White Spaces (TVWS) is an attractive technology for rural wireless broadband, because of the frequencies used and the available bandwidth. Some successful trial has been carried out in different countries, with promising results, although the business model is still confusing. Colombian pacific coast is a vast region of tropical rain forest, with disperse afro and indigenous communities, with a complex geography and lack of connectivity. In this work, we show simulations with different propagation models, which includes multiple diffractions, to estimate radio coverage for a TVWS system, intended to provide broadband service in the pacific region. At the moment of writing this paper, the network is in the pilot stage, to verify the simulations and adjust the models; therefore, we only show the simulation results and some very initial results with three operating sites and simulation results for one projected site.

Outage Performance of Cooperative Satellite Diversity System Using Two Aerial Regenerative Relays

Konstantinos Psychogios and Athanasios D. Panagopoulos (National Technical University of Athens, Greece)

Cooperative Diversity Systems are used in current generation networks for improving the reliability and the quality of service of wireless networks. Cooperative diversity techniques have been proposed offering significant values of diversity gain and increase the of system's availability. In this paper, the outage performance of a Selection Relaying cooperative system with two aerial regenerative relays is evaluated in terms of easily calculated integrals. Rician fading is assumed for the satellite to aerial relays, while shadowed Rician fading is assumed for the relays to destination links. Extended numerical results show the importance of the cooperative diversity systems and finally, the effect of different shadowing conditions on the performance of the cooperative diversity system is presented.

A Harmonic-Free Wilkinson Power Divider Using Lowpass Resonators

Gholamhosein Moloudian (Tyndall National Institute, Ireland); Ali Lalbakhsh (Macquarie University, Australia); Sirous Bahrami (Pohang University of Science and Technology, Korea (South))

This paper presents a Wilkinson power divider (WPD) capable of suppressing unwanted bands up to 16th harmonic with high isolation. In this WPD, a lowpass filter composed of a main resonator and three bended stubs are used to guarantee a wide stopband. The presented WPD illustrates suitable performance at 0.85 GHz for GSM applications. Isolation between of output ports, input return loss and insertion loss are better than 24 dB, 20 dB and 3.4 dB, respectively.

Low-Cost Over-The-Air Testing Method to Create a 3D Spatially Dynamic Environment to Evaluate the Performance of 5G Millimeter Wave Devices

David Reyes Paredes (Silicon Austria Labs GmbH, Austria); Mark Beach (University of Bristol, United Kingdom (Great Britain)); Moray Rumney (Rumney Telecom, United Kingdom (Great Britain))

To deliver the high capacity and throughput goals for 5G, the effective use of millimeter-wave spectrum is necessary. These high frequencies incur in greater attenuation due to path loss and blockages when compared to sub-6 GHz, necessitating the use of directional antennas at both ends of the communications link. These are most likely to be implemented by means of antenna arrays and beamformers in a highly integrated form within the RF-transceiver. The radio environment at these frequencies is known to be highly dynamic in both spatial and temporal domains. Hence, Over-the-Air conformance testing of such systems will be necessary, since traditional conducted non-spatial test methods will not predict the radiated performance in space. This paper presents a novel OTA test method that facilitates the excitation of a device under test from multiple dynamic angles of illumination in azimuth and elevation planes, thus representing realistic operating propagation conditions

Using a Conical Horn as Compact Antenna Test Range Feed in Millimetre Bands

Sergiy Pivnenko (Antenna Systems Solutions, Denmark); Ashraf Uz Zaman and Marianna Ivashina (Chalmers University of Technology, Sweden)

Using a conical horn as a feed for a single offset-fed Compact Antenna Test Range (CATR) is described. Although such horn has larger variation of the phase centre with frequency and slightly different beamwidth in the E-plane and H-plane within the used field of view, as compared to a specially designed corrugated horn feed, good results were obtained for the measured amplitude and phase variations in the Quiet Zone at mm-band. Some details of application of conventional conical horns as CATR feeds are also explained.

Investigation of Material and Scattering Losses in Antennas in Transmitting and Receiving Mode

Mohamed K. Emara and Shulabh Gupta (Carleton University, Canada)

This paper investigates material and scattering loss from a general two-port leaky-wave antenna (LWA) in transmit and receive modes using scattering parameters. It is demonstrated that the total material and scattering losses depend on the LWA orientation and whether the LWA is used as a transmitter or a receiver, leading to a different radio frequency (RF) environment in each scenario.

First, full-wave simulations are used to demonstrate this behavior for a patch-to-horn configuration. Then the behavior is experimentally demonstrated for two-port LWAs in different orientations with respect to a horn antenna.

A New Design of RF Medium Power Calorimeter Based on Water Calorimetric Method

Jinwen Liu and Wenze Yuan (National Institute of Metrology (NIM), China); Yang Zhao (China Jiliang University, China); Wei Zhao and Xiaohai Cui (National Institute of Metrology, China)

A new design of microwave medium power calorimeter is introduced in this paper, based on principle of water calorimetry. Calorimeter is designed to measure coaxial radiofrequency (RF) power 1 W -100 W in power range, and 10MHz - 7.5GHz in frequency range. Whereas in this paper, only 1W - 10W power level and 2GHz - 3GHz frequency range are investigated, due to current power amplifier limitation. Comparing to conventional medium power measurement based on coaxial attenuator, proposed method displays explicit traceability chain from RF DC medium power. In proposed calorimeter system, thermopile is designed with clinging brass blocks. Water temperature is homogenized in block and transient calorimetric results are investigated, showing that 5 minutes rest time is needed to reach system thermal equilibrium. Effective efficiency between RF and DC power is investigated for 1W and 10W power levels, with less than 2.4% and 2.8% respectively in relative standard deviation.

Platform for Multi-User Channel-Based Encryption of Speech Communication with AES on 2.45 GHz

Victor Van der Elst, Ruben Wilssens and Jelle Jocqué (Ghent University, Belgium); Joryan Sennesael (Ghent University & Imec, Belgium); Jo Verhaevert (Ghent University - imec, Belgium); Patrick Van Torre and Hendrik Rogier (Ghent University, Belgium)

This paper outlines a hardware platform for half-duplex, real-time encrypted digital speech communication on 2.45 GHz. The platform is based on a STM32F415 MCU with a low power ADF7242 transceiver for wireless communication. The Advanced Encryption Standard (AES) Electronic Code Book encryption scheme is performed on the transmitted packets with symmetrically generated channel-based keys. Encryption keys of 128-bit are obtained, based on the unique reciprocal channel characteristics of the employed link. Key reconciliation is applied by means of a Hamming code and a cyclic redundancy check (CRC) to correct key mismatch. A multi-user system is introduced by splitting voice key distribution and speech communication into different abstraction layers. Measurements reveal a maximum communication range of 400 m without significant packet loss. A high key entropy of 0.94 bit is established with a packet rate of 167 packets/s and a key bit generation delay of four received signal strength (RSS) measurements.

Tuesday, March 29 14:00 - 15:00

AMTA-EurAAP Meeting

Tuesday, March 29 15:00 - 16:20

Invited Speakers: Andrea Neto and Natalia Nikolova

15:00 ***On the Modelling, Design and Characterization of Pulsed Photo-Conducting THz Front Ends***

Andrea Neto (TNO, The Netherlands)

The power available from Photoconductive Antennas (PCA) by exploiting pulsed Optical-to-THz up/down conversions was so far only sufficient for localized spectroscopy. This has been a bottle neck for the wider use of these type of sources in sensing. However, recently reproducible m-watt power sources in the THz spectrum have been demonstrated by the THz Sensing Group. This talk will address some of the difficulties that hindered the progress for many years. The most important were likely associated to wide band modelling of short Electromagnetic pulses in complex active passive environments. Also the difficulties in manufacturing and interpretation of the measurements will be addressed.

15:40 ***Microwave and Millimeter-Wave Imaging in Real Time***

Natalia Nikolova (McMaster University, Canada)

Real-time microwave and millimeter-wave imaging methods are the workhorse in applications ranging from synthetic aperture radar, which operates with far-field data, to nondestructive testing and medical imaging, which employ near-field measurements. Research in this field is intensifying due to the rapid expansion of the wireless technologies beyond communications and into imaging and sensing. This expansion is fuelled by the advances of on-chip millimeter-wave to sub-THz electronics and the envisioned integration of communication and sensing in the future (beyond-5G)

wireless networks and devices. This paper is an attempt to explain, categorize, compare and contrast the real-time imaging methods and algorithms within a common mathematical framework so that this interdisciplinary subject is rendered more comprehensible and accessible to the wider research community.

Invited Speakers: Michael Havrilla & Christian Bornkessel

Chair: Fernando Las-Heras (University of Oviedo, Spain)

15:00 ***Nondestructive Material Measurements***

Michael J Havrilla (Air Force Institute of Technology, USA)

Nondestructive measurements are often employed for characterizing electromagnetic materials, especially in non-laboratory environments. Nondestructive techniques are fairly well established for simple media (i.e., materials that are linear, isotropic, homogeneous and time-invariant). However, the past decade or two has seen considerable interest in materials that are non-linear, non-isotropic (e.g., hyperbolic and bianisotropic media), spatially varying & dispersive (e.g., wire media), time varying (e.g., spacetime metamaterials) and non-reciprocal (e.g., topological insulators). What types of nondestructive techniques can be utilized for these materials? What new theory must be developed and what new measurement devices need to be invoked? What are the future challenges of nondestructive material characterization? How has 3D printing shifted the paradigm of the meaning of nondestructive evaluation? This talk will provide an overview of modern nondestructive material measurement techniques and will address the many questions and challenges one encounters when dealing with nondestructive evaluation of contemporary materials.

15:40 ***Current Research Aspects in the Automotive Antenna Measurement Chamber VISTA at the TU Ilmenau***

Christian Bornkessel (Technische Universität Ilmenau, Germany)

The Thuringian Center of Innovation in Mobility (ThIMo) under the roof of the Technische Universität Ilmenau operates an automotive antenna measurement chamber VISTA, equipped with a multi-probe measurement system covering the frequency range from 70 MHz ... 6 GHz including the sub-6-frequencies for 5G mobile radio. In this talk, several current application-oriented research topics are presented and illustrated with examples. These research topics include: Fast car antenna measurements in the installed state with various boundary conditions beneath the car. Extension to antenna measurements installed on other electrically large objects like locomotives. Emulation of LTE and V2X links as well as automotive radar in virtual environment. Characterization of small cell antennas with regard to their RF exposure to humans by using a hybrid measurement-numerical method.

Tuesday, March 29 16:20 - 16:40

Coffee Break / Exhibition

Tuesday, March 29 16:40 - 18:40

EurAAP DA meeting

Tuesday, March 29 16:40 - 18:20

P10: Propagation for LTE and sub 6GHz 5G

T01 LTE and Sub 6GHz 5G/ / Propagation

16:40 ***Frequency Dependence of Fire-Induced Signal Level Variability***

Manuel García Sánchez, Iñigo Cuiñas, Luis A López-Valcárcel, Miguel Riobó Prieto and Isabel Expósito (AtlanTTic Research Center, Universidade de Vigo, Vigo, Spain)

In this paper we present the results of an experiment carried out to assess the signal level variability induced by propagation through fire. It extends preliminary results carried just for the 200 MHz -

400 MHz frequency band to de 200 MHz - 4 GHz frequency band. Results show that signal level variability increases with frequency, reaching values that are significantly higher than the ones we report previously. Such variation should be taken into account as an additional fade margin when planning radio networks that should be resilient to fire effects.

17:00 ***Wave Scatterer Localization in Outdoor-To-Indoor Channels at 4 and 14 GHz***

Pasi Koivumäki, Aki Karttunen and Katsuyuki Haneda (Aalto University, Finland)

In this paper, we present the results of wave scatterer localization at 4.65 and 14.25 GHz in an outdoor-to-indoor scenario at a traditional office building in Finland. The localization is based on a single-bounce model of interaction with a scatterer to localize the sources of measured multipath components. The estimated scatterer locations were mapped to an aerial photograph of the site and classified according to their location. We found that approximately two thirds of paths originate from higher order interactions with the environment. In contrast, one third of paths can be attributed to single-bounce interactions, with interior walls of the building being twice as strong sources of single-bounces as walls outside both in terms of power and number of paths.

17:20 ***RF Performance of USRP TwinRX Daughterboard Under Influence of Strong Interferers***

Maximilian Engelhardt (Fraunhofer Institute for Integrated Circuits IIS, Germany); Carsten Andrich (Technische Universität Ilmenau, Germany); Alexander Ihlow (Ilmenau University of Technology, Germany); Giovanni Del Galdo (Fraunhofer Institute for Integrated Circuits IIS & Technische Universität Ilmenau, Germany)

In this paper, we investigate the sensitivity of the software-defined radio USRP X310 with a TwinRX daughterboard to strong interferers. In a conducted test setup, the signal-to-interference-plus-noise ratio (SINR) is measured under the influence of a mock-up Long-Term Evolution (LTE) base station. The frequency of the interferer is varied to analyze the effects over a wide frequency band, whereby a distinction is made between signals inside and outside the intermediate frequency (IF) band. The former can cause clipping at the analog-to-digital converter (ADC), while the latter are to be suppressed in the analog part of the software-defined radio. Here, leakage and higher-order mixing products make the receiver sensitive to spurious frequencies, whereby the performance degradation is particularly noticeable near the first intermediate frequency (IF1) of 1.25 GHz. At this point, even an interference signal with -28 dBm PEP causes an SINR loss of 3 dB.

17:40 ***Analysis of MIMO Performance in Complex Indoor Scenarios at 3.7 GHz Band for Future 5G Deployments***

Luis Lenin Trigueros (Universidad Publica de Navarra and Institute of Smart Cities, Spain); Peio Lopez Iturri (Universidad Publica de Navarra, Spain); Leyre Azpilicueta (Tecnologico de Monterrey, Mexico); Carlos del-Río (Universidad Publica de Navarra & Institute of Smart Cities, Spain); Francisco Falcone (Universidad Publica de Navarra, Spain)

The evolution in wireless communication systems aims to provide adequate parameters in terms of higher transmission rates and increased spectral efficiency. Physical layer functionalities such as MIMO can increase throughput and provide higher coverage/capacity relations. However, its performance is directly affected by radio channel characteristics defined in the radio channel matrix, as well as in the employed antenna spacing. In this work, the performance of a MIMO system operating within a 5G NR FR1 capable band is analyzed, by considering volumetric channel analysis in frequency/power as well as in time domain and the impact of variable antenna spacing. The results show a clear benefit in received power level as antenna spacing is increased from 1λ to 3λ in the case of a complex indoor scenario.

18:00 ***Measurement Trials of Radiowave Propagation Through Pinus Pinaster Fuel Bed Under Fire***

Stefânia Faria (Instituto de Telecomunicações, Portugal); Mario Vala (Instituto de Telecomunicações de Portugal, Portugal); Nuno R. Leonor and Joao M. Felicio (Instituto de Telecomunicações, Portugal); Carlos A. Fernandes (Instituto de Telecomunicacoes, Instituto Superior Tecnico, Portugal); Carlos Salema (I.S.T. - Technical U. Lisbon / IT Lisbon, Portugal); Rafael F. S. Caldeirinha (Polytechnic Institute of Leiria & Instituto de Telecomunicações, Portugal)

This paper presents results of a measurement campaign conducted to evaluate the impact of forest fires on radiowave propagation. A total mass of 3.4 kg of Pinus Pinaster needles was used as fuel heap and it was uniformly placed in a triangular shape bed, above a metallic table. The ignition sources were two wool yarns soaked in diesel, allocated in two sides of the triangle, with different incident angles, in order to generate two independent fire fronts that will suffer a junction after some seconds. The excess loss introduced by fire was evaluated for a 5 GHz bandwidth, from 3 to 8 GHz. A multipath analysis is also presented in order to detect the variations on signal level, for the dominant components during transmission.

A04: Antennas for mm-wave 5G

T02 Millimetre Wave 5G and 6G/ / Antennas

Chairs: Ramón Martínez (Universidad Politécnica de Madrid, Spain), Paolo Rocca (University of Trento & ELEDIA Research Center, Italy)

16:40 ***Enhanced Data Throughput Using 26 GHz Band Beam-Steered Antenna for 5G Systems***

Muhammad S Rabbani and James Churm (University of Birmingham, United Kingdom (Great Britain)); Sohail Payami (University of Surrey, United Kingdom (Great Britain)); Mohsen Khalily (University of Surrey & 5G Innovation Centre, Institute for Communication Systems (ICS), United Kingdom (Great Britain)); Pei Xiao and Rahim Tafazolli (University of Surrey, United Kingdom (Great Britain)); Tian Hong Loh (UK, National Physical Laboratory, United Kingdom (Great Britain)); James Kelly (Queen Mary University of London, United Kingdom (Great Britain)); Alexandros Feresidis (University of Birmingham, United Kingdom (Great Britain))

A high gain (20 dBi) Leaky-Wave Antenna (LWA) is presented at 26 GHz with beam steering capabilities (44°) for high data throughput in millimeter-wave (mm-wave) 5G systems. A tunable phase shifting High Impedance Surface (HIS) exhibiting low loss (<0.1 dB), is employed for the antenna's beam steering. A Piezo-Electric Actuator (PEA) is employed to electromechanically tune the HIS. The employed PEA exhibited fast (milliseconds) and continuous displacement variation of up to 500 µm. The LWA has been demonstrated by deploying it within a 5G testbed operating within the 26GHz band. It was observed that the channel performance can significantly be improved utilizing the beam steering capability of the antenna in the case when the line-of-sight (LOS) is blocked by an obstacle.

17:00 ***SbD-Based Propagation Contouring Through 1-Bit Dual-Polarization Reconfigurable Intelligent Surfaces***

Giacomo Oliveri (University of Trento & ELEDIA Research Center, Italy); Andrea Massa (University of Trento, Italy)

The possibility to achieve advanced beam contouring capabilities with single-bit dual-polarization reconfigurable intelligent surfaces (RISs) is addressed in this contribution with reference to their application in the Smart Electromagnetic Environment (SEE) framework. The discrete multi-scale RIS reconfiguration problem is firstly recast in terms of a phase-only inverse source one. The RIS discrete descriptors are then optimized through a customized System-by-Design (SbD) strategy. Preliminary numerical results are presented to illustrate the wave manipulation capabilities and efficiency enabled by the proposed strategy.

17:20 ***Array Antenna Power Pattern Analysis Through Quantum Computing***

Luca Tosi and Nicola Anselmi (ELEDIA Research Center, Italy); Alessandro Polo (ELEDIA Research Center, University of Trento, Italy); Paolo Rocca (University of Trento & ELEDIA Research Center, Italy)

The analysis of the power pattern generated from a uniform linear array is here carried in the Quantum Computing (QC) framework. The formulation and the analysis method based on the quantum Fourier transform (QFT) algorithm and the values observable at the output of the quantum computation are presented. A preliminary proof-of-concept result is reported and analyzed to point out the peculiarities and the advantages of the proposed method.

17:40 ***On the Design of HAPs High Throughput and Flexible 5G Communication Payloads***

Miguel Salas-Natera and Gonzalo Lázaro (Universidad Politécnica de Madrid, Spain); Antonio Abad (C/Anabel Segura 11 - Edificio Albatros 4 floor & Hispasat, Spain); Ramón Martínez (Universidad Politécnica de Madrid, Spain)

This work presents a technical analysis and a proposal of the payload architecture including a 5G antenna design. The analysis covers the comparison with terrestrial networks and satellites, and the frequency bands and service area limitation versus available power and payload technology onboard actual High-Altitude Platforms (HAP). For this, a review of the HAP system capacity and payload requirements is done. Furthermore, the definition of the payload architecture is based on actual and mature state of the art of the technologies and the antenna aperture has dual-band and dual-circular polarization operation capacity.

18:00 ***Design of an Amplitude-Tapered Corporate-Feed Slot Array Antenna with Reduced Side-Lobe Level for Silicon Micromachining***

Armin Karimi and Joachim Oberhammer (KTH Royal Institute of Technology, Sweden)

This work proposes a novel unbalanced corporate-feed network antenna design with amplitude tapering of the radiated power to get a reduced sidelobe level. The phase imbalance of the asymmetric power dividers is compensated by integrated delay lines which maintain the aperture efficiency. The 10 dB beamwidth is reduced by 8.5% in E-plane and 10.2% in H-plane after the phase compensation. A 16×16 and a 32×32 array antenna have been designed for 230-290 GHz, i.e., a 23% fractional bandwidth. The 16×16 and 32×32 antenna's realized gain is between 29.4-32.1 dBi and 34.6-37.6 dBi, with sidelobe levels better than 21.2 dB and 20.5 dB, respectively. The design is optimized for being implemented by silicon micromachining. To the best of the author's knowledge, this is the first amplitude tapered corporate feed slot array antenna with delay lines for phase compensation that has been proposed in this frequency range with this wide operational bandwidth.

A30: Emerging technologies for WLAN, IoT and M2M antennas

T03 Wireless LANS, IoT and M2M/ / Antennas

16:40 ***Liquid Metal Enabled SIW Vias and RF Blocking Walls for Reconfigurable Antennas***

Shaker Alkaraki (Queen Mary University Of London, United Kingdom (Great Britain)); Zhishu Qu and James Kelly (Queen Mary University of London, United Kingdom (Great Britain)); Alejandro L. Borja (Universidad de Castilla-La Mancha, Spain); Raj Mittra (University of Central Florida, Turkey); Yi Wang (University of Birmingham, United Kingdom (Great Britain))

This paper presents a method for designing reconfigurable microwave devices based on substrate integrated waveguides (SIW) technology. The method involves forming walls from drill holes that can be filled with liquid metal to form vias. Furthermore, the proposed method is validated by designing and testing several reconfigurable radio frequency (RF) switches. The switches are intended to be used for reconfigurable antenna applications. The measured results for the proposed devices are in good agreement with the simulated results and they show wideband operating bandwidth with highly efficient performance. The proposed method will find application within a wide range of different reconfigurable microwave devices and circuits.

17:00 ***ClothFace: Battery-Free On-Body Interface Platform for Future Human-Machine Interaction***

Xiaochen Chen, Han He, Adnan Mehmood and Pasi Raumonen (Tampere University, Finland); Mirka Leino and Sari Merilampi (Satakunta University of Applied Sciences, Finland); Johanna Virkki (Tampere University, Finland)

Smooth communication between people and machines plays an important role in the intelligent environments of the future, where the best sides of both people and machines are to be exploited in the name of efficiency and flexibility. This requires a functional human-machine interface that allows the necessary control actions but does not require any use of robot-specific devices. In this paper, we further introduce a passive ultra-high frequency (UHF) radio frequency identification (RFID)-based platform, which is an attractive solution for on-body interfaces, as it is passive and maintenance-free, does not require a line-of-sight to function, and has reading distances of several meters. The unique aspect of this study is the established fully textile-based battery-free touchpad for writing digits, which can be integrated into everyday clothing and worn on body. Further, the paper presents various use cases for the developed technology.

17:20 ***Robust Antenna Composed of Metal Box with a Slot and Inner Folded Dipole Element***

Yukiko Wada and Naobumi Michishita (National Defense Academy, Japan); Atsushi Yamamoto (Panasonic Corporation, Japan); Kazuhiro Matsumoto and Tetsuya Hishikawa (Panasonic, Japan); Hisashi Morishita (National Defense Academy, Japan)

From the viewpoint of heat resistance and reduction of the influence of the surrounding environment, an antenna system which is configured a metal box with a slot including small transceivers and a power supply device has been put into practical use. In this study, a robust antenna consisting of a metal box with a slot and a folded dipole element is proposed and their operation mechanism is clarified. Based on this operation mechanism, miniaturization of the metal box and enhancement of operating bandwidth are realized. As a result, the width of the metal box could be reduced from 0.22λ0 to 0.03λ0 and the relative bandwidth is improved from 7.6% to 18.9%.

17:40 ***Wideband Circularly Polarized Antenna with Enhanced Gain and Wide Beamwidth for Energy Harvesting Applications***

Yassmeen Mohammad Afify (Egypt-Japan University of Science and Technology & Electronics Research Institute, Egypt); Ahmed Sayed Ahmed Abdelhamid Allam (Egypt-Japan University of Science and Technology (E-JUST), Egypt); Tanemasa Asano (Kyushu University, Japan); Adel Bedair (Egypt-Japan University of Science and Technology, Egypt)

This paper presents a high gain wideband circularly polarized antenna. The antenna is a small single-element antenna that radiates over a wide frequency band (from 4.8 to 6 GHz), covering 5.2 GHz (Wi-Fi) and 5.8GHz (ISM).A metallic reflector is placed behind the ground plane. The proposed structure achieves a wide beamwidth which ensures a flat-top angular coverage from -50° to +50° throughout a high gain of a range from 4 to 8.1 dBi. As a result, that antenna is proposed as a rectifying antenna (rectenna), as it guarantees good rectification efficiency. The antenna can be utilized to harvest RF energy from Wi-Fi and ISM bands.

18:00 ***Performance Analysis of Indoor Distributed Massive MIMO Based on Channel Measurements at 3.5 GHz***

Abla Bedoui (National Institute of Posts and Telecommunication, Morocco); Mohamed Et-tolba (National Institute of Posts and Telecommunications, Morocco); Óscar Fernández (Universidad de Cantabria, Spain); Jesús Ramón Pérez and Luis Valle (University of Cantabria, Spain); Rafael Torres (Universidad de Cantabria, Spain)

Massive multiple-input multiple output (MIMO) is among the potential technologies to meet the expected performance of future wireless communication systems. There are two configurations of massive MIMO deployment: centralized and distributed configurations, called Cm-MIMO and Dm-MIMO respectively. The second configuration is shown to be the best choice of massive MIMO deployment when the antenna arrays are properly arranged. In this paper, we present an experimental analysis of uplink Dm-MIMO performance in an indoor environment considering maximum ratio combining (MRC), zero forcing (ZF), and minimum square error (MMSE) combining methods. Performance evaluation has been carried out in terms of the spectral efficiency and the user fairness based on indoor channel measurements.

P05: Propagation for medical applications

T04 Biomedical and Health/ / Propagation

Chairs: Simona Di Meo (University of Pavia, Italy), Mauricio D Perez (Uppsala University, Sweden & National Technological University, Argentina)

16:40 ***A Quantitative Analysis of the Plastic Shell Effects in 3D-Printed Breast Phantoms for Microwave Imaging***

Tyson Reimer, Spencer Christie and Stephen Pistorius (University of Manitoba, Canada)

3D-printed breast phantoms have been used to evaluate methods in breast microwave sensing (BMS). These phantoms use 3D-printed shells from MRI images to hold liquids that mimic the dielectric properties of breast tissues. The MRI-derived shells allow the phantoms to mimic the morphology of in vivo tissues and the liquids mimic the microwave properties of the tissues. The use of low-permittivity 3D-printable plastics in the shells poses a potential challenge, as the plastics do not mimic the properties of breast tissues. This work quantitatively investigated the effects of eight plastic fibroglandular shells. The statistical analysis in this work indicated that three of the eight phantom shells did not produce significant reflections. These results indicate that, depending on the specific phantom shell design, the utility of 3D-printed phantoms may be limited by using low-permittivity plastics, and further examination of the role of plastics in 3D-printed phantoms should be performed.

17:00 ***On-Body Path-Gain Investigation for Body-Centric Wireless Communications for Hearing Instruments***

Jonas Ørnskov Nielsen and Kristina Josefine Würden Kammann (Technical University of Denmark, Denmark); Søren Helstrup Kvist (GN Hearing A/S, Denmark); Kaj Bjarne Jakobsen (Technical University of Denmark, Denmark)

The on-body path gain is investigated for four different link configurations. The height and width of the body torso is varied for each link configuration to determine the influence on the path gain. To prevent that waves propagate from one side of the body to the other, absorbers are positioned on the torso. It is found that the path gain (in decibels) appears to be linearly dependent on the torso height and width. A realistic smooth convex stomach is added to the model which is comprised of mainly straight and flat surfaces. The thickness of the stomach layer is varied and the impact on the path gain is studied. Ear-to-front pocket links are seen to be influenced by the stomach size, whereas there are no apparent impact on ear-to-back pocket links. The simulations are performed in HFSS.

17:20 ***Anatomical and Dielectric Tissue Mimicking Phantoms for Microwave Breast Imaging***

Eliana Canicattì and Giulia Monacelli (University of Pisa, Italy); Daniel Álvarez Sánchez-Bayuela (UBT - Umbria Bioengineering Technologies, Italy); Alessandro Vispa (UBT - Umbria Bioengineering Technologies, Perugia, Italy); Lorenzo Sani (UBT - Umbria Bioengineering Technologies, Italy); Agostino Monorchio (University of Pisa & CNIT, Italy); Gianluigi Tiberi (London South Bank University, United Kingdom (Great Britain) & UBT - Umbria Bioengineering Technologies, Italy)

Nowadays, the application of microwave imaging for breast cancer diagnosis has expanded as an alternative method to traditional mammography. In fact, the use of electromagnetic fields in the microwave range allows determining the dielectric contrast between healthy and malignant tissue for the detection of breast lesions. Special phantoms are used to evaluate the diagnostic capability of these devices. In this work, a prototype that replicates both the anatomy of the breast and its dielectric properties has been designed. A heterogeneous, multilayers, realistic phantom of the pathologic breast has been designed using cheap commercially available materials with low production costs. Furthermore, the preservation of the prototype without any means of degradation has been tested. All the samples have been electromagnetically characterized by means of an already presented open-ended coaxial probe.

17:40 ***Numerical Quantitative Evaluation of the Skin Impact in Breast Cancer Imaging at mm-Waves***

Simona Di Meo, Arianna Fava and Marco Pasian (University of Pavia, Italy)

In this paper, a quantitative evaluation of the skin impact on mm-wave imaging systems for breast cancer detection is presented. Different scenarios, considering both homogeneous (skin + fat) and heterogeneous (skin + fat + fibro glandular) breast, were evaluated in a frequency range from 26.5 to 40 GHz. To take into account the dielectric and propagation losses, together with the reflection at the interfaces, the simulated results for both planar and full- wave scenarios were compared. All simulations were performed by using the software Ansys HFSS. The link budget was evaluated considering several constraints, together with the possible improving factor due to the expected utilization of a multi-static radar configuration in the final system. Results show that a target up to 4 cm in fat under a 2-mm skin is reachable with a standard VNA, while a dedicated electronic is required in presence of fibro-glandular tissue.

18:00 ***End-To-End Transmission of Physiological Data from Implanted Devices to a Cloud-Enabled Aggregator Using Fat Intra-Body Communication in a Live Porcine Model***

Johan Engstrand (Uppsala University, Sweden); Mauricio D Perez (Uppsala University, Sweden & National Technological University, Argentina); Bappaditya Mandal (Uppsala University, Sweden); Johan Liden (Intel Sweden, Sweden); Christian Rohner (Uppsala University, Sweden); Thiemo Voigt (Swedish Institute of Computer

Science & Uppsala University, Sweden); Robin Augustine (Uppsala University, Sweden)

This article presents, for the first time, the end-to-end transmission of physiological data from implanted antennas mimicking sensors to a cloud-enabled aggregator device using fat intra-body communication (fat-IBC). The experiment was performed on a live porcine model in full accordance with ethical standards. Measurement data from two different sensors were collected and sent through a fat-IBC network. The fat-IBC network consisted of three nodes, of which two used antennas implanted in the fat tissue of a live porcine model and one used an on-body antenna placed on the skin. The sensor data was forwarded via Bluetooth Low Energy to an Intel Health Application Platform device, which in turn forwarded the encrypted data to a web server. The experimental results demonstrate that the fat channel can be used in an end-to-end communication scheme, which could involve relaying of sensor data from an implanted device to an external web server.

A19: Aircraft antennas

T05 Aircraft (incl UAV, UAS, RPAS) and automotive/ / Antennas

Chairs: José Manuel Fernández González (Universidad Politécnica de Madrid, Spain), Alicja Schreiber (German Aerospace Center, Germany)

16:40 ***Equiangular Spiral Antenna Design Embedded in a Launcher Fuselage for S-Band Communications***

Sergio García (Universidad Politécnica de Madrid, Spain); Pablo Sanchez-Olivares (Universidad Politecnica de Madrid, Spain); José Manuel Fernández González (Universidad Politécnica de Madrid, Spain); Adrián Tamayo-Domínguez (Universidad Politecnica de Madrid, Spain)

An improved equiangular spiral antenna with circular polarization is proposed as the radiating element for a phased array antenna intended for new generation space launchers. The spiral has been designed in printed technology to achieve a low-profile configuration capable to be embedded in the launcher fuselage. The bidirectional radiation of the spiral is converted into unidirectional by introducing the antenna in a metallic cavity. Furthermore, an absorber ring is added inside to maintain the radiation characteristics of the antenna without increasing its size as well as to adjust the axial and impedance ratio produced by the cavity. The antenna has been simulated and fabricated to validate its performance. Besides the array will operate from 2.0 to 2.3 GHz, wideband results of the spiral antenna have been obtained. The antenna, with a diameter of 0.6 wavelengths at 2.0 GHz, provides a 52% relative bandwidth (2.0-3.4 GHz) with a pure circular polarization.

17:00 ***Horizontally Polarized Antenna Array for an Airborne Ka-PolInSAR System***

Alicja Schreiber (German Aerospace Center, Germany); Markus Limbach, Bernd Gabler and Andreas Reigber (German Aerospace Center (DLR), Germany)

This paper presents a design of a horizontally polarized antenna array for a new DLR airborne Ka band synthetic aperture radar system with the maximum gain of 24 dB, low cross-pol level of - 40 dB and a shaped radiation pattern with low sidelobe level in both azimuth and elevation planes below -18 dB. It has been designed using the slotted waveguide antenna (SWA) technology for the center frequency equal to 35.5 GHz. A suitable feeding network consisting of a conventionally H-plane T-junction power divider and a directional waveguide coupler has been also described. Based on theoretical principles, the antenna array as well as the corresponding power splitter have been developed and fabricated while meeting mechanical and electrical system demands. The measurement results of the manufactured prototype have been presented and a good agreement with requirements has been achieved.

17:20 ***Radial Line Patch Array Antenna with Enhanced Circularly Polarized Beam-Steering Performance for K-Band Fixed Radio Links***

Alfonso-Tomás Muriel-Barrado and Óscar-Alberto Pla-Terrada (Universidad Politécnica de Madrid, Spain); Pablo Sanchez-Olivares (Universidad Politecnica de Madrid, Spain); José Manuel Fernández González and Manuel Sierra-Pérez (Universidad Politécnica de Madrid, Spain)

This paper presents a design procedure for circularly polarized radial line patch array antennas that allows the steering of the main beam whereas the axial ratio is not drastically affected. This method is an extension of a previous publication, in which the radiated phase of each element was adjusted by rotation depending on its position in the lattice. This way, a partial sequential rotation is included. The used radial line patch array antenna is composed by double stacked patches as radiating elements. The design procedure allows to radiate with both circular polarizations at K-Band (19.7 - 20.2 GHz) for SATCOM. An axial ratio below 2.2 dB for a ±30º steering angle in the azimuth and the elevation plane is achieved, with a gain decay of 2.5 dB with respect to broadside. All the configurations exhibit a good behaviour in terms of efficiency, with values near to 90%.

17:40 ***"Self-Adaptive" Antenna That Can Maintain Its Beam Direction Irrespective of Device Orientation***

Haoran Cao (University of Sheffield, United Kingdom (Great Britain)); James Kelly (Queen Mary University of London, United Kingdom (Great Britain))

This paper presents an updated version of a passively steer antenna. This kind of antenna uses liquid dielectric to provide a fixed main beam direction. This is achieved by utilizing the movement of a liquid dielectric, due to gravity. To improve the radiation efficiency and gain of the antenna, we had added a hemispherical container filled with the liquid metal below the antenna. The container acts as a reflector. An antenna prototype has been proposed with a fundamental resonant band of 1.45-1.55 GHz. Additionally, the realized gain, radiation efficiency and total efficiency of the antenna has been improved, in comparison with the previously reported design.

18:00 ***Low Cost Active Phased Array with Switchable Circular Polarization in Ka Band for SATCOM Application***

Xiaoliang Sun and José Manuel Fernández González (Universidad Politécnica de Madrid, Spain); Pablo Sanchez-Olivares and Jorge Calatayud-Maeso (Universidad Politecnica de Madrid, Spain); Alfonso-Tomás Muriel-Barrado (Universidad Politécnica de Madrid, Spain)

This article presents the design and development of a switchable circular phased array antenna in reception for SATCOM polarization in frequencies from 17.7 GHz to 20.2 GHz. The design of the radiating element consists of a double patch with a hybrid couple to generate polarization LHCP/RHCP. The Xphased RFIC chip provides the phases for the sequential rotation to improve the axial ratio and phases for beam steering, in addition to switching the two polarizations. This array is upgradable to larger arrays to provide higher gain for SATCOM applications. In this paper, we will present the design of the radiating element, the design of subarray 2x2 and the characterization of the MMIC chip separately for subsequent integration.

E03: Frequency/polarization selective surfaces for space applications

T08 Space (incl. cubesat)/ / Electromagnetics

Chairs: Carlos Molero (University of Granada, Spain), Miguel Salas-Natera (Universidad Politécnica de Madrid, Spain)

16:40 ***An Anisotropic 3D Printed Circular Polarization Converter for a Patch Antenna Array Operating in the Ka Band***

Max Rigby, Tom Whittaker and William Whittow (Loughborough University, United Kingdom (Great Britain))

This paper proposes and evaluates a method for creating circular polarization using a linearly polarized patch antenna array tuned for 30.5 GHz and an anisotropic polarization converting superstrate fabricated by means of additive manufacturing. The simulated efficiency and far field performance of this antenna is evaluated, as well as its ease of design and manufacture. This takes the form of an analysis of measured results using the design for a copper etched linearly polarized array and 3D printed polylactic acid (PLA) polarization converting superstrate. This resulted in a highly directive antenna array, expressing directivity of 23.4 dBi and gain of 19.9 dBi. Good circular polarization was observed.

17:00 ***Reconfigurable FSS with a Switchable Passband for Space Applications in X and Ka Bands***

Mousa Abdollahvand (University of Mohaghegh Ardabili, Iran); Eduardo Martinez-de-Rioja (Universidad Rey Juan Carlos, Spain); Jose A. Encinar (Universidad Politecnica de Madrid, Spain); Kanishka Katoch (Jaypee University of Information Technology, India); Amir Ebrahimi (RMIT University, Australia); Saptarshi Ghosh (Indian Institute of Technology Indore, India)

In this work, an active frequency selective surface (FSS) is proposed for space applications in X and Ka bands. The FSS offers three reflection bands at 20 and 30 GHz (uplink and downlink frequencies of Ka-band satellites) and presents a switchable passband at 10 GHz. The unit cell of the FSS is made up of three metallic layers, and four PIN diodes on the bottom layer are used to control the switching between transmission and reflection in X band. The FSS performance has been studied through an equivalent circuit model. The proposed FSS supports dual polarization and shows a robust spectral response for incidence angles of up to 30°.

17:20 ***Dispersion Control in Metallic 3D Cells to Synthesize Polarization Conversion***

Carlos Molero (University of Granada, Spain); Hervé Legay (Thalès Alenia Space, France); María García-Vigueras (IETR-INSA Rennes, France)

This paper presents original three-dimensional unit-cells allowing to synthesize polarization conversion when arranged in periodic arrays. The three-dimensional character of the structure allows to profit from enhanced flexibility in the design. The proposed topologies allow to control the dispersion of the cells in order to attain broadband operation. In addition, monolithic manufacturing employing only metal can be envisioned.

17:40 ***Improved Axial Ratio Bandwidth for Dual-Band Dual-Circular Polarization FSS in Transmission Mode for Satellite Communications by Stub Tuned Resonator***

Roberto Garrote, Miguel Salas-Natera and Ramón Martínez (Universidad Politécnica de Madrid, Spain)

A dual-band and dual-circular polarization Frequency Selective Surface (FSS) is presented. The unit cell proposed for the FSS have an improvement with respect to the state of art employing stub tuned resonators. This element provides a much more efficient decomposition of the incident vector tilted with respect to the symmetry axes of the cell and so best axial ratio performance lower than 1dB is obtained. The bandwidth for such axial ratio performance is 18% at K band with one circular polarization, and 13.6% at Ka band for the orthogonal circular polarization. This design provides a low-profile antenna implementation and low-cost solution with a total thickness of about 1.2mm

18:00 ***A Broadband Inhomogeneous Frequency Selective Surface on Quartz Glass Substrate***

Andreas Roehrner and Georg Strauss (University of Applied Sciences Munich, Germany); Thomas F. Eibert (Technical University of Munich (TUM) & Chair of High-Frequency Engineering (HFT), Germany)

Frequency selective surfaces are often manufactured as standard printed circuit boards. The advantages of sophisticated design processes can only be exploited if very fine structures can be realized. This poses enormous challenges for the technology used. In order to be able to realize the finest structures, the thickness of the metallization layer must not be too large in order to be able to maintain a technologically feasible aspect ratio between structure width and metallization thickness. Quartz glass as a substrate with a structured silver metallization allows such an aspect ratio. In addition, quartz glass offers the further advantage of having a very low loss factor. A frequency-selective surface with a quartz glass substrate and silver metallization was simulated, manufactured and measured. The fact that good reflectivity is achieved despite the low layer thickness of the metalization is also shown in calculations.

E10: Emerging applications of metasurfaces and metamaterials

T09 EM Modelling and Simulation tools/ / Electromagnetics

Chairs: David González-Ovejero (Centre National de la Recherche Scientifique - CNRS, France), Stefano Vellucci (Roma Tre University, Italy)

16:40 ***Highly Transparent Fully Metallic 1-Bit Coding Metasurfaces for Near-Field Applications***

Foez Ahmed and Muhammad Usman Afzal (University of Technology Sydney, Australia); Khushboo Singh (University of Technology Sydney, Australia & Macquarie University, Australia); Touseef Hayat (Macquarie University, Australia); Karu Esselle (University of Technology Sydney, Australia)

This paper presents a low-cost coded metallic metasurface (CMM) to manipulate electromagnetic waves with a 1-bit fully metallic meta-atoms. The proposed CMM provides polarization-independent transmission for any code sequence at a low cost with a lightweight structure. The concept is validated with four different CMMs, which were characterized through full-wave numerical analysis. Each CMM can split the boresight beam into symmetric multi-beams in directions predicted through analytical formulations. This investigation reveals the significant potentialities of CMM as a building block to design multi-beam antenna systems.

17:00 ***New Uniplanar and Broadside-Coupled CSRR Substrate Integrated Waveguides for mmWave Components***

Maria - Thaleia Passia and Traianos Yioultsis (Aristotle University of Thessaloniki, Greece)

We hereby propose two new metamaterial-inspired substrate integrated waveguide (SIW) designs, based on complementary split-ring resonators (CSRRs). The first variation of the CSRR SIW is uniplanar, synthesized by grounded single-CSRRs. This version is characterized by a considerable ease-of-fabrication, due to its uniplanar form and simple resonator pattern. A broadside-coupled CSRR SIW is also proposed, with both complementary gaps facing in the outward direction. The broadside-coupled design features lower losses than the rest CSRR SIWs, as it may be fabricated on much thicker substrates, resulting in components with lower conductor losses and, consequently, lower total losses. Both waveguides are appealing alternatives as platforms for designing low-loss, fully-planar, easy-to-fabricate mmWave components, with the uniplanar version aiming at easier fabrication, whereas the BC-CSRR SIW is preferred, when loss minimization is of greater importance.

17:20 ***A Miniaturized Wideband Circularly Polarized Antenna Using Metasurface***

N Nasimuddin and Xianming Qing (Institute for Infocomm Research, Singapore)

A single-feed miniaturized wideband circularly polarized (CP) antenna with metasurface is planned for L-band applications. The projected multilayered antenna comprises of a patch radiator with embedded ring-shaped slot and grounded-via, a stacked slit-slotted-circular patch, a metasurface with 5×5-unit cells, and a coaxial feeding probe. An antenna prototype at L-band exhibits -10-dB reflection coefficient(|S11|) bandwidth of 15.7% (1.488 GHz– 1.742 GHz), 3-dB axial ratio(AR) bandwidth of 11.0% (1.50 GHz– 1.675 GHz), and gain of 5.0dBic within the 3-dB AR-bandwidth with an overall size of 0.375λo×0.375λo×0.065λo at 1.5 GHz.

17:40 ***Exploiting Metasurfaces in Wire Antennas Beyond Cloaking Applications***

Stefano Vellucci (Roma Tre University, Italy); Alessio Monti and Mirko Barbuto (Niccolò Cusano University, Italy); Alessandro Toscano (University Roma Tre (IT), Italy); Filiberto Bilotti (University Roma Tre, Italy)

Many different applications of electromagnetic cloaking for wire antenna systems have been proposed in the literature in the last decades. The scattering engineering of the antenna has been made possible thanks to the use of thin and conformal metasurface wrapped around the radiating element. More recently, the cloaking functionality of the metasurface has been enriched by loading the conformal coat with electronic elements, allowing to conceive unprecedented configurations in antenna systems. Here, we aim at further expanding the degree of freedom in antenna design, by reporting new possibilities enabled by reconfigurable covering metasurface for tailoring not only the radiation and scattering characteristics of the antenna but also its electrical properties. These new potentialities introduced by metasurface coats may pave the way to a new class of wired antennas where the electrical and radiation characteristics are made reconfigurable by simply varying the covering metasurface properties.

18:00 ***Ultra-Small Bent Meta-Waveguide Filters***

Maliheh Khatibi Moghaddam (École Polytechnique Fédérale de Lausanne (EPFL), Switzerland); Romain Fleury (EPFL, Switzerland)

This paper demonstrates the capability of locally resonant metamaterials (LRMs) for creating compact metallic waveguide E- and H-bends, which are simultaneously working as bandpass filters. For creating these bent meta-filters, we use composite pin-pipe waveguides (CPPWs). Similar to linear-shaped CPPWs, the subwavelength spatial dispersion in E- and H-bent CPPWs can nucleate a hybridization bandgap and subwavelength modes with custom frequency and bandwidth. To guarantee compatibility with standard waveguides and to improve the matching, we design subwavelength metamaterial ports. Finally, we build and test narrow and wideband H-bent CPPW filters, compatible with WR75 (10-15GHz) interfaces. Our measurements demonstrate the good performance of the small bent meta-filters as well as the customizability of the bandwidth. Our findings enable us to merge assembly components, such as bends, and filters in an ultra-small volume. It may find applications for reducing the size of waveguide networks with complex geometries in telecommunication and radar applications.

IW04: Cutting-edge PWG and Applications from VHF to mmWaves Bands

Industrial Workshop

A11: Additive manufacturing

T10 Fundamental Research and Emerging Technologies/ / Antennas

Chairs: José Manuel Fernández González (Universidad Politécnica de Madrid, Spain), Philippe Ratajczak (Orange Innovation, France)

16:40 ***Analysis of Ka-Band Waveguides Manufactured by In-House 3D Printing and Electroplating Processes***

Alvaro Camacho-Hernández (Universidad Politécnica de Madrid, Spain); Adrián Tamayo-Domínguez and Pablo Sanchez-Olivares (Universidad Politecnica de Madrid, Spain); José Manuel Fernández González (Universidad Politécnica de Madrid, Spain)

This paper shows in detail the 3D printing and electroplating process for a WR-28 rectangular waveguide. The characteristics of the printing process that must be taken into account to obtain the best possible print and to avoid problems that may arise are analyzed. Several studies are also carried out on the copper plating process using the electroplating method, changing the current applied to the piece, the amount of plating time and adding a copper deposition retardant additive that helps to reduce the roughness of the surfaces. In addition, possible errors that can lead to faulty electroplating are discussed.

17:00 ***Millimeter-Wave Lightweight 3D-Printed 4x1 Aluminum Array Antenna***

Leticia Alonso-González (GMV Aerospace and Defense, Spain); José Rico-Fernández (Universidad de Oviedo, Spain); Álvaro F. Vaquero (Universidad Politécnica de Madrid & Information Processing and Telecommunications Center, Spain); Manuel Arrebola (Universidad de Oviedo, Spain)

In this work, the additive manufacturing technique of Laser Powder-Bed Fusion is evaluated to manufacture metallic-only antennas for single-piece and lightweight prototypes. The proposed technique enables the production of metallic antennas without the need to, first, manufacturing a dielectric structure, and then, the application of a coating procedure. To validate the technique, a horn array antenna operating at the mm-wave frequency range is designed. The prototype is produced in a single piece of aluminum, including the radiating elements and the feeding network. The prototype is matched at 34.5 GHz, showing a good agreement with simulations. The prototype is measured in an anechoic chamber, and measurements show a good agreement with simulations at the frequencies in which the antenna is matched. The results show that Laser Powder-Bed Fusion is a potential alternative to produce metallic-only solutions, reaching single-piece and lightweight prototypes

17:20 ***3D-Printed Dielectric Leaky-Wave Bull-Eye Antenna***

Tomas Lira (Pontificia Universidad Católica de Valparaíso, Chile); Francisco Pizarro (Pontificia Universidad Catolica de Valparaiso, Chile); Eva Rajo-Iglesias (University Carlos III of Madrid, Spain)

In this article, the design of a fully 3D-printed bull-eye dielectric leaky-wave antenna is presented. The antenna replaces the concentric metallic rings of a traditional bull-eye implementation with rings made with high-permittivity dielectric filaments. This introduces two extra degrees of freedom in the design, namely the permittivity of the rings and their height. The effect of these two new parameters in the antenna performance is studied. Simulation results show that the proposed antenna maintains the cylindrical leaky-wave mode behavior, generating a conical beam pattern depending on the operating frequency. Finally, the antenna was successfully 3D-printed using a low-cost 3D-printer and commercially available dielectric filaments with the required relative permittivity values.

17:40 ***Design of a 3D Printed Antenna for Grid of Beams Applications at mm-Wave Frequencies***

Philippe Ratajczak (Orange Innovation, France)

In this paper, an antenna system based on a Luneburg lens associated to a conformal array is proposed for multiple beams applications in which the angular coverage sector is ensured by a grid of beams. A preliminary design is presented to evaluate the performance of such system, then the final design considering the manufacturing process by 3D printing is presented. The antenna prototype will be manufactured and tested.

18:00 ***Coplanar Waveguide Fed U-Band Horn Antenna Manufactured Using 3D Printing and Electroplating***

Anne Lena Vaske, Altan Akar and Björn Neubauer (Technische Universität Braunschweig, Germany)

The following contribution presents the design and manufacturing of a coplanar waveguide (CPW) fed horn antenna operating in the frequency range from 33 - 67 GHz. The antenna is manufactured cost effective using stereolithography (sla) and selective laser melting (slm) and fed using a Coplanar Waveguide (CPW) on a low cost printed circuit board (PCB). This leads to a overall cost effective, low weight, flexible and scalable design, whose limitations concerning accuracy, repeatability and resolution of the 3D Print are shown and compared in detail.

CS11: Antennas and Propagation for Wireless Power Transfer & Harvesting in Space

T10 Fundamental Research and Emerging Technologies/ / Antennas and Propagation

Chairs: Qiang Chen (Tohoku University, Japan), Hubregt J. Visser (imec The Netherlands, The Netherlands)

16:40 ***The Caltech Space Solar Power Project: Design, Progress, and Future Direction***

Austin Fikes (California Institute of Technology, USA); Richard G Madonna (California Institute of Technology & System Engineering Consultants, USA); Eleftherios Gdoutos (California Institute of Technology, USA); Michael Kelzenberg (Caltech, USA)

We provide an update on the Caltech Space Solar Power Project with a focus on the wireless power transfer portion of the system and the antennas supporting that function. We use highly flexible photovoltaics (PV), substrates for printed circuit boards, and either patch or pop-up antennas supported by a foldable and rollable carbon fiber structure to package a large multilayered structure into a relatively small cylindrical volume. We employ radio frequency (RF) transparent PV over the antenna layer on one side of the sandwich and PV on the other to allow the antennas to point at the earth almost all the time while in orbit. We have explored using optically transparent antennas over the PV layer opening up more options for the types of antennas we can use. We summarize our progress to date, discuss our impending on-orbit demonstration payload, and the direction our research is taking us in.

17:00 ***Optimal Design Method of RF-DC Conversion Circuits for Various Input and Load Conditions Required for Rectenna Site Design***

Kensuke Kobayashi and Kazuhiro Fujimori (Okayama University, Japan)

The RF-DC conversion circuit measurement system that can determine the optimum microwave circuit with the input power and load resistance fixed was constructed. By measuring the diode operating impedance and microwave circuit impedance with the constructed system, it was found that both impedances are not complex conjugate. From the result and constructed measurement system, we showed the RF-DC conversion circuit design method for various input power and load resistance conditions.

17:20 ***Accurate Ranging Exploiting a 32-Patch Frequency Diverse Array with Circular Symmetry***

Enrico Fazzini (Università di Bologna, Italy); Alessandra Costanzo (DEI, University of Bologna, Italy); Diego Masotti and Ahmet Baris Gok (University of Bologna, Italy)

In this work an effective solution at millimeterwave for real-time focusing via Frequency Diverse Arrays (FDAs) is proposed, to be exploited for intentional far-field Wireless Power Transfer (WPT) applications. A confined and precise spot where concentrate the power is obtained by circular concentric frequency diverse array (CCFDA). The system is conceived as a multi-layer structure with the top layer hosting the patches, the microstrip feeding network, located in the bottom layer, directly connected with the radiating elements through metallized via holes. The main drawback offered by the FDAs' family, i.e. the displacement in time of the main beam, is solved with the exploitation of the time-controlled FDA (TCFDA) technique. The system is theoretically developed and numerically demonstrated by the full-wave analysis of the realistic layout of a multi-layer, 32-element, circularly arranged FDA with a center frequency of 24 GHz.

17:40 ***Preliminary Study of a Lens Antenna for a Solar Power Satellite***

Ricardo A. M. Pereira (University of Aveiro, Institute of Telecommunications, Portugal); Nuno Borges Carvalho (University of Aveiro/IT Aveiro, Portugal)

Aiming to develop a lunar solar power satellite system, this study deals with the power transfer subsystem, specifically the microwave radiation and focusing. In order to reduce the spillover losses the radiation will be analyzed through the quasioptics framework. For that purpose, a 27 GHz gaussian beam generated by a rectangular horn antenna was focused by a dielectric lens. The design procedure for the components is presented here as well as the simulation results of just the horn antenna and the horn with the lens. A comparison of both results will be provided, with a discussion

on the use of the dielectric lens for focusing the radiation.

18:00 ***Power Reception and Verification Procedure for Small-Scale SPS Satellite Demonstration***

Yoshiyuki Fujino (Toyo University, Japan)

In order to evaluate the transmitting antenna using the SPS demonstration test satellite, a phased array antenna mounted on a low earth orbit satellite is assumed as the demonstration satellite, and satellite signal is received by a terrestrial receiving station. In this paper, we examined the method of reproducing the antenna pattern on the ground. In addition to approximating the antenna pattern using the two-dimensional least squares method, we described the examination when there was a reception level deviation between each receiving station, and were able to obtain data useful for the evaluation.

Wednesday, March 30

Wednesday, March 30 9:00 - 10:40

A03: Wideband Antennas for 5G

T01 LTE and Sub 6GHz 5G/ / Antennas

Chairs: Miguel Ferrando-Bataller (Universitat Politècnica de València, Spain), Andrea Neto (Delft University of Technology, The Netherlands)

9:00 ***Mutual Decoupling for Wideband and Dual-Polarized Antenna Array by Using Compact Decoupling Walls***

Shengyuan Luo, Gert Pedersen and Shuai Zhang (Aalborg University, Denmark)

This paper proposes a decoupling technology of compact decoupling wall combining split resonant ring (SSR) and grid metal stubs for a two-element wideband and dual-polarized antenna array. By integrating the metal grid stubs and SSR on the same substrate to form a compact decoupling wall. The four identical compact decoupling walls are installed around the antenna array element to reduce the mutual coupling between the antenna array elements. The dimensions of the SRR and the grid metal stubs are optimized to achieve the best decoupling level for the array. The results demonstrate that the compact decoupling wall has the capacity to reduce the mutual coupling of the array from -13.8 dB to lower than -24 dB within 4.25 GHz - 4.98 GHz. In contrast, it almost does not affect the radiation characteristic of the array.

9:20 ***Application of Classical Filter Theory in the Design of Broadband Microstrip Antennas***

Nieves Garcia-Alcaide (University of Seville, Spain); Armando Fernández (Universidad de Sevilla, Spain); Rafael R. Boix (University of Seville, Spain); Vicente Losada and Francisco Medina (University of Sevilla, Spain); Jesus Martel (Universidad de Sevilla, Spain)

A systematic methodology is introduced for the design of broadband microstrip antennas (MAs) made of two stacked patches that are fed by an aperture coupled to an open-ended microstrip line. The MAs are modelled by an equivalent circuit (EC) consisting of two LC parallel resonators that are capacitively coupled, the EC being connected to the microstrip line by a LC series resonator that models the feeding. The circuit parameters are de-embedded from Momentum antenna simulations by using a novel technique based on the total least squares method. The EC of the MAs is adjusted as a second order filter with quasi-Chebyshev response, and the filter bandwidth is maximized so as to achieve broadband MAs. A MA has been designed with a center frequency of 5.57 GHz and a bandwidth larger than 30%. The MA has been fabricated and measured, and good agreement has been found between simulations and measurements.

9:40 ***2-8 GHz Connected Array for Wireless Base Stations***

Riccardo Ozzola (Delft University of Technology, The Netherlands); Zhuang Chen (Chen, The Netherlands); Ulrik Imberg (Huawei Technologies, Sweden AB, Sweden); Andrea Neto and Daniele Cavallo (Delft University of Technology, The Netherlands)

We present the design of a wideband wide-scanning phased array for mobile communications. The array elements are connected slots in a dual-polarization configuration, radiating in the presence of a superstrate made of artificial dielectric layers (ADLs). Two interchangeable ADL superstrates have been designed, the former one allowing narrowband operation from 6 to 8 GHz (NB), and the latter one operating over a wide band between 2.3 and 8 GHz (WB). The performance is analyzed in terms of unit cell simulations, including the feeding structure. The NB design achieves an active reflection coefficient lower than -10 dB for scanning up to 60 degrees in all azimuthal planes. The WB design exhibits an active reflection coefficient lower than -6 dB for the same scan range. The designed feeding networks, based on microstrips and striplines for the two polarizations, respectively, are also presented.

10:00 ***A Compact Size CPW-Fed an Ultra-Wideband (UWB) Antenna for Wireless Networks***

Sarosh Ahmad (Universidad Carlos III de Madrid (UC3M), Spain & Government College University Faisalabad (GCUF), Pakistan); Daniel Segovia-Vargas (Universidad Carlos III de Madrid, Spain); Adnan Ghaffar (Auckland University of Technology, New Zealand); Shakir Ullah (University of Engineering and Technology Peshawar, Pakistan)

This paper presents an ultra-wideband (UWB) compact size printed monopole antenna with improved gain and efficiency. This broadband printed monopole antenna contains a cup-shaped radiator fed by a coplanar waveguide (CPW) technique. The designed UWB antenna is fabricated on a less-priced FR-4 substrate with relative permittivity of 4.3, loss tangent of 0.025, and a standard height of 1.6 mm, sized at 31.68 mm × 23.76 mm × 1.6 mm suitable for wireless communication system. The designed UWB antenna works with maximum gain (peak gain of 5.5 dBi) across the whole UWB spectrum (3-11 GHz). The S11 results are simulated and measured and the results are debated in detail.

10:20 ***Design of a MIMO 5G Indoor Base Station Antenna Using Unit Cells***

Jaime Molins-Benlliure (Universitat Politècnica de València & ITEAM, Spain); Eva Antonino-Daviu (Universitat Politècnica de València, Spain); Marta Cabedo-Fabrés (Universidad Politécnica de Valencia, Spain); Miguel Ferrando-Bataller (Universitat Politècnica de València, Spain)

A methodology based on the design of antennas with the use of unit cells is presented in this paper. The methodology is applied to a previously presented 4-port cavity-backed MIMO antenna which is split in 4 identical unit cells due to its symmetric geometry. In the presented study, it is demonstrated that with the analysis of only the unit cell of the antenna the behaviour of the whole design can be predicted. Thanks to this methodology, the design of complex N-port antennas is simplified to the analysis of a unit cell and opens a new via for designing symmetric N-port antennas for massive MIMO applications.

CS02: Advancements and Challenges on Measurement Techniques for 5G and Beyond

T02 Millimetre Wave 5G and 6G/ / Measurements

Chairs: Michael D. Foegelle (ETS-Lindgren, USA), Tian Hong Loh (UK, National Physical Laboratory, United Kingdom (Great Britain))

9:00 ***Production Measurement of 5G Millimeter Wave Plane Wave Generators***

Francesco Scattone (Microwave Vision Group (MVG), Italy); Darko Sekuljica (MVG, Italy); Andrea Giacomini and Francesco Saccardi (Microwave Vision Italy, Italy); Ruben Tena Sanchez (Microwave Vision Group (MVG), Italy); Alessandro Scannavini (Microwave Vision Italy, Italy); Kim Rutkowski (Microwave Vision Group, Satimo Industries, France); Evgueni Kaverine (MVG Industries, France); Shoaib Anwar (Microwave Vision Group, Satimo Industries, France); Nicolas Gross (MVG Industries, France); Per Iversen (Orbit/FR, USA); Lars Foged (Microwave Vision Italy, Italy)

A Plane Wave Generator (PWG) is an array of elements with suitable complex excitation that approximates a plane wave condition at close distance within a Quite Zone (QZ). The StarWave system has been designed to enable transmit and receive testing of 5G devices in dual polarization, within a 380 mm diameter QZ. The testing is performed using up to seven individual PWG's generating plane wave conditions from different directions. Each PWG undergoes a production testing to verify the amplitude and phase dispersion of the array elements by the feeding network. As several individual PWG are required, each with many array elements, the production testing becomes time consuming and impractical. In this paper we report and experimentally validate a fast production testing procedure that allow to verify amplitude and phase conformance and to determine the QZ performance of a PWG from a quick Planar Near Field (PNF) scan of the aperture.

9:20 ***A Novel CATR Design with Diamond-Shape Reflector for 5G/6G OTA Measurement***

Rong-Chung Liu (Yuan Ze University & WavePro, Taiwan); Chung-Huan Li (WavePro Inc., Taiwan)

A novel compact antenna test range (CATR) design is presented in this study. Conventionally, the edges of the reflector are parallel to the chamber walls. Instead, a diamond-shape reflector (DSR) is proposed in this design. The reflector is rotated for 45 degrees, so the corners of DSR point to the walls (patent pending). This design suppresses the scattering from the absorbers on the walls, which improves quiet-zone (QZ) performance accordingly. This is important for some applications, such as angle-of-arrival (AoA), which are sensitive to clutters. In addition, the chamber size can be more compact as the new design allows shorter distance between the reflector and the walls. The design has been realized and validated with QZ measurement.

9:40 ***Potential of Edge-Soldering in Millimeter-Wave Antenna Design***

Katerina Galitskaya, Mikko K. Leino and Jari Van Wonterghem (Radientum Oy, Finland)

A dual-polarized, cavity-based antenna array with implemented edge-soldered transition technique is presented for 5G millimeter-wave applications. The working band of the proposed antenna is 26.5-29GHz. Full structure consists of two PCBs soldered together to achieve end-fire radiation pattern. A 4x1 array prototype supporting single polarization has been manufactured and measured.

The measured reflection coefficient over the band is -12 dB, and with uniform amplitude distribution, a maximum gain of nearly 10 dBi is measured. The measured array exhibits a scanning potential up to 30 deg. The measured results have good agreement with the simulations.

10:00 ***Measurements of IP3 and P1dB for Spectrum Monitoring with Software Defined Radios***

Mike McNulty (Colorado School of Mines, USA); Dazeh Gu and Daniel Kuester (NIST, USA); Payam Nayeri (Colorado School of Mines, USA)

This paper discusses methodology for characterizing basic power linearity parameters of software-defined radios. First, we introduce a highly automated testbed for 1-dB compression point (P1dB) and third-order input intercept point (IIP3). With this system, we have observed some surprising deviations from the expected slope of 3 dB/dB in the power response of the third order intermodulation distortion (IMD3). In response to this, we developed a measurement technique based on linear regression that accounts for the actual slope. A methodology study considers this technique in comparison with existing techniques for IIP3 measurements of spectrum monitoring receivers. In consideration for the increase in IM3 model complexity, we also propose an alternative parameter to simplify the quantitative evaluation of spectral regrowth near the receiver noise floor. We argue that this equivalence point provides a designer with more valuable information than an IIP3 point for spectrum monitoring applications.

10:20 ***An Investigation into the Effects of Spatial Correlation Error on 5G MIMO OTA Testing Using Single-Probe Anechoic Chamber Method***

Qiwei Zhang (University of Chinese Academy of Sciences, China); Tian Hong Loh (UK, National Physical Laboratory, United Kingdom (Great Britain)); Zhibei Huang (University of Chinese Academy of Sciences, China); Fei Qin (Chinese Academy of Sciences, China)

Multiple-input-multiple-output over-the-air testing evaluates the multi-antenna wireless systems' performance in a controlled laboratory environment by emulating realistic real-world fading channel conditions. Spatial correlation is the key metric to character the accuracy of MIMO OTA testing system. Along with the evolution into 5G era, the MIMO OTA measurement setup complexity increase as well, especially for accurate implementation of three-dimensional channel model. Furthermore, extension of the two-dimensional multi-probe anechoic chamber (MPAC) method into full spherical three-dimensional MPAC is impractical due to cost consideration and setup complexity. In this paper, we present the use of a cost-effective single-probe anechoic chamber (SPAC) method for MIMO OTA testing and demonstrate that better spatial correlation accuracy can be achieved over implementation of the 3D spatial channel model as compared with MPAC. The development of such method can significantly reduce implementation cost to support wireless device R\&D process. Both the theoretical derivation and simulation results are validated.

10:40 Coffee Break

11:00 ***Developing a MIMO Test Methodology Using Dynamic Channel Models and Link Adaptation***

Michael D. Foegelle (ETS-Lindgren, USA); Thorsten Hertel (Keysight Technologies, USA); Pekka Kyösti (Keysight Technologies & University of Oulu, Finland); Jukka Kyröläinen (Keysight Technologies Finland oy, Finland); Doug Reed (Spirent Communications, USA)

Industry standards for over-the-air testing of LTE MIMO devices have used multi-probe anechoic chamber based systems to evaluate device performance in a spatially static environment. The spatial distribution of clusters in the chosen channel models are fixed, and the only geometric variation relative to the device under test is accomplished by physically rotating the device in the generated test environment. For 5G FR1 testing, the CTIA MIMO OTA working group is developing a test plan based on the use of dynamic channel models that vary the spatial configuration as a function of time, and allowing the communication tester base station emulator to perform link adaptation, allowing the device to choose the best MIMO or SISO diversity mode and data rate for a given channel condition. This paper will discuss the design considerations associated with developing this new channel model and the related test system requirements.

11:20 ***All-Optical Fiber Link Antenna Measurement System Using an Industrial Robot System***

Satoru Kurokawa (National Institute of Advanced Industrial Science and Technology, Japan)

Our developed system consists of an optical fiber link microwave transmitting system, an antenna-coupled-electrode electric-field sensor system for 28 GHz-band as a microwave receiving system, and a 6-axis vertically articulated robot with an arm length of 1 m. Our developed optical fiber link microwave transmitting system can transmit the microwave from 23 GHz to 33 GHz with more than -20 dBm output level. Our developed electric-field sensor can receive the microwave from 27 GHz to 30 GHz. In this paper, we show a measured near field radiation pattern for the WR-28 standard gain horn antenna using the system.

11:40 ***Investigation on Simplified Test Environment of OTA In-Band Blocking for 5G Millimeter-Wave Radio Base Stations***

Hans Andersson, Stefan Nilsson, Jonas Fridén, Sam Agneessens, Joakim Lysell, Anders Fransson, Arya Khan-Amidy, Jacob Mannerstråle, Noor Choudhury, Bo Xu and Queenie Zhang (Ericsson AB, Sweden)

Over-the-air testing enables realistic verification of radio base stations with antenna panels. To conform with the requirements, most over-the-air measurements for uplink of 5G radio base stations are performed in fully anechoic chambers. In this work, the comparison between using the fully anechoic chamber and the reverberation chamber for in-band blocking testing is conducted on a 5G millimeter-wave radio unit. The use of the reverberation chamber can reduce the time and cost of the tests. Good agreement can be observed between the results obtained from the anechoic

chamber and the reverberation chamber for the in-band blocking testing.

12:00 ***MIMO mmWave Over-The-Air Testbed Calibration Using Symmetries and Experimental Verification***

Koen Buisman (University of Surrey, United Kingdom (Great Britain) & Chalmers University of Technology, Sweden); Thomas Eriksson (Chalmers University of Technology, Sweden)

Calibration and validation of mm-wave transceiver arrays with respect to phase and amplitude of all elements is an essential part of production testing. Also afterwards during operation it may be necessary to update calibration coefficients. Here we present an algorithm based on channel symmetries, derive mathematically its expression, experimentally verify its results with respect to amplitude in a mm-wave testbed and compare the results to an extract model.

12:20 ***Definition of Far Field Measurement Distance for 5G mmW Antenna Arrays: Application on N x M Patch Arrays***

Walid El Hajj and Tsitoha Andriamiharivolamena (Intel Corporation, France); Juan Antonio Del Real (Intel Corporation SAS & CCG WCS WTCC WRF Lab, France); Nawfal Asrih (Intel Corporation, France)

The purpose of this paper is to define a mathematical formulation for patch arrays Far Field (FF) distance allowing to calculate the FF distance from the array size (N x M), the operation frequency and substrate permittivity. It illustrates how the theoretical FF distance based on the antenna dimension and wavelength overestimate the practical FF distance by 5 times.

A12: Antennas for Wireless & IoT applications

T03 Wireless LANS, IoT and M2M/ / Antennas

9:00 ***Towards Improved IoT LoRa-WAN Connectivity Using Broadband Omnidirectional Antennas***

Mahmoud Wagih and Peter Birley (University of Southampton, United Kingdom (Great Britain))

Despite the growing volume of Long Range (LoRa) wide area networks (WAN) devices, there is limited research on the antenna's influence on a node's connectivity. In this paper, the channel gain of an 868~MHz LoRa-Wan node in an urban environment is used to evaluate the performance of different antennas, as well as evaluate motion, elevation, and shadowing effects on the nodes connectivity. A dual-transmitter node with two tightly-coupled antennas is utilized to characterize the channel gain between the antenna-under-test, and multiple indoor and outdoor gateways over 1~km away, through the relative signal strength (RSS). It is demonstrated that using a broadband UWB-inspired monopole implemented on an inexpensive cardboard substrate, the channel gain can be improved over commercially available whip antennas.

9:20 ***Dual RFID Tag System for AC Current Sensing***

Irfan Ullah (University of Southampton, United Kingdom (Great Britain)); Benito Sanz-Izquierdo and John Batchelor (University of Kent, United Kingdom (Great Britain))

We present a wireless and battery-free sensing system operating at the UHF band to measure domestic ac current ranging from 0 to 13 A in a power cable. The proposed sensing system uses two tag antennas operating at 868 MHz, each connected to a tuning circuit. The reactance of the tuning circuits varies as a function of the dc bias from a current transformer, causing a shift in the resonance frequency of the tag antennas. The Magnus S2 RFID transponder chip is used to compensate for differences in the applied reactance, and transmits the extent of the tuning capacitance parameter in the form of a 5-bit sensor code which can be correlated to the current drawn by an electrical load. Results indicate currents can be measured reliably over 0 to 12 A representing a significant improvement over a single diode version of the technology.

9:40 ***Backscattered Field of a Random Set of Dipoles as a Model for Highly Coupled RFID Tags***

Aiman Mughal, Jithin Mudakkarappilli Sudersanan, Shermila Mostarshedi, Benoit Poussot and Jean-Marc Laheurte (University Gustave Eiffel, France)

Mono-static radar cross-section (RCS) is estimated for a set of randomly distributed loaded thin dipoles. The RCS calculation is performed using two techniques based on the total backscattered field and the radar equation. Different dipole configurations and the effect of complex load impedances are studied in order to highlight the RCS distortion. Numerical Electromagnetics Code (NEC) simulator is used for the computations.

10:00 ***Evaluation of Chipless RFID Indoor Landmarks at 80 GHz and 240 GHz Using FMCW Radars***

Jesús Sánchez-Pastor (Technische Universität Darmstadt, Germany); Lukas Piotrowsky (Ruhr University Bochum, Germany); Alejandro Jiménez-Sáez (Technische Universität Darmstadt, Germany); Martin Schüßler (TU Darmstadt, Germany); Nils Pohl (Ruhr-University Bochum & Fraunhofer FHR, Germany); Rolf Jakoby

(Institute for Microwave Engineering and Photonics, Technische Universität Darmstadt, Germany)

This paper presents measurements of chipless RFID radar landmarks designed for indoor localization applications at 80 GHz and 240 GHz by means of frequency modulated continuous wave (FMCW) radars. Compared to a vector network analyzer, these radars have the advantage of achieving the readout of a complex signal at a significantly lower cost and footprint. Even without a full calibration, the radars are able to successfully measure the complex backscattered response of the landmarks. This enables the use of FMCW radars as monostatic readers for indoor self-localization applications in highly dynamic and densely cluttered environments.

10:20 ***Design of a UWB/Tri-Band Reconfigurable Flexible Antenna for IoT Applications***

Mohammad Alibakhshikenari (Universidad Carlos III de Madrid, Spain); Syed Muhammad Rizvi Jarchavi (Beijing Jiaotong University, Beijing, China); Muhammad Shabbir (Islamia University of Bahawalpur, Pakistan); Francisco Falcone (Universidad Publica de Navarra, Spain); Ernesto Limiti (University of Rome Tor Vergata, Italy)

In this paper, a compact, geometrically simple, ultra-wide band, flexible and tri band antenna is proposed for IoT applications. The proposed antenna is designed on commercially available flexible substrate material Roger RT5880, having relative permittivity, loss tangent and thickness of 2.2, 0.0009 and 0.79 mm, respectively. The circular patch is loaded with rectangular stub in order to enhance bandwidth and return loss, afterward, the circular patch is divided in two parts to place a diode in order to achieve frequency reconfigurability. The simulation and analysis of proposed reconfigurable antenna was done using Higher Frequency Structural Simulator (HFSS). Furthermore, to demonstrate the potential of the proposed work it is compared with state-of-the-art works for similar applications.

CS16: Biomedical Microwave Techniques and Devices: from Diagnosis to Treatment

T04 Biomedical and Health/ / Electromagnetics

Chairs: Raquel C. Conceição (Instituto de Biofísica e Engenharia Biomédica, Faculdade de Ciências, Universidade de Lisboa, Portugal), Jorge A. Tobon Vasquez (Politecnico di Torino, Italy)

9:00 ***Metasurface-Enhanced Antenna for Microwave Breast Imaging***

Eleonora Razzicchia (King's College London, United Kingdom (Great Britain)); Aleksandar Janjic (Istanbul Technical University, Turkey); Navid Ghavami (King's College London, United Kingdom (Great Britain)); Ibrahim Akduman and Mehmet Çayören (Istanbul Technical University, Turkey); Panagiotis Kosmas (King's College London, United Kingdom (Great Britain))

In this paper, a hardware advancement for a microwave multi-static system for breast cancer detection is presented. In particular, we propose a metasurface-enhanced antenna capable of enhancing relevant "weak" signals back-scattered by a tumour-mimicking target inserted in a breast phantom. Furthermore, we simulate a radar-based approach in CST Microwave Studio and use our previously developed Huygens principle-based algorithm to produce images of the target. Our results indicate that the proposed metasurface-enhanced antenna can significantly improve target localization and decrease image artefacts.

9:20 ***Initial Experimental Validation of a Microwave Imaging System to Monitor Liver Microwave Thermal Ablation***

Mengchu Wang (National Research Council-Institute for Electromagnetic Sensing of the Environment, Italy); Marta Cavagnaro (Sapienza University of Rome, Italy); Soroush Abedi (Group of Electrical Engineering - Paris, France); Nadine Joachimowicz (Group of Electrical Engineering - Paris / CentraleSupelec, France); Hélène Roussel (Sorbonne Université, France); Sandra Costanzo (University of Calabria, Italy); Lorenzo Crocco (CNR - National Research Council of Italy, Italy)

This study presents the initial experimental validation of a mono-static microwave imaging system to monitor liver microwave thermal ablation. The system consists of a tank filled with a coupling medium in which a 3D-printed phantom mimicking the ablation region is embedded. A slot-loaded Vivaldi antenna is moved in front of the phantom along a linear path, measuring the S-parameters on a finite number of positions. Both simulation and measurement results are found to agree with each other. The differential signal of the microwave imaging system with and without the presence of the phantom is over -90 dB, which is above the detection capacity of commercial VNA. The experimental validation of the system paves the way for the design of a multi-static microwave imaging system.

9:40 ***Effect of Varying Prior Information in Axillary 2D Microwave Tomography***

Matteo Savazzi (Universidade de Lisboa, Portugal); Olympia Karadima (King's College London, United Kingdom (Great Britain)); Joao M. Felicio (Instituto de Telecomunicações, Portugal); Carlos A. Fernandes (Instituto de Telecomunicacoes, Instituto Superior Tecnico, Portugal); Panagiotis Kosmas (King's College

London, United Kingdom (Great Britain)); Raquel C. Conceição (Instituto de Biofísica e Engenharia Biomédica, Faculdade de Ciências, Universidade de Lisboa, Portugal)

We numerically assess the potential of microwave tomography (MWT) for the detection and dielectric properties estimation of axillary lymph nodes (ALNs), and we study the robustness of our system using prior information with varying levels of accuracy. We adopt a 2-dimensional MWT system with 8 antennas (0.5-2.5 GHz) placed around the axillary region. The reconstruction algorithm implements the distorted Born iterative method. We show that: (i) when accurate prior knowledge of the axillary tissues (fat and muscle) is available, our system successfully detects an ALN; (ii) +/-30% error in the prior estimation of fat and muscle dielectric properties does not affect image quality; (iii) +/-7mm error in muscle position causes slight artifacts, while +/-14mm error in muscle position affects ALN detection. To the best of our knowledge, this is the first paper in the literature to study the impact of prior information accuracy on detecting an ALN using MWT.

10:00 ***Hardware Acceleration of Biomedical Microwave Techniques Using High Level Synthesis***

Mohammad Amir Mansoori and Mario Roberto Casu (Politecnico di Torino, Italy)

Microwave radiations have been proven to be effective in biomedical applications, including brain stroke monitoring. However, microwave algorithms in these applications are computationally expensive with compute-intensive parts that are termed "kernels". To speed up the medical diagnosis, it is crucial to adopt new methodologies to accelerate the execution of these kernels by using specific hardware solutions. A recent trend in designing hardware accelerators is High Level Synthesis (HLS), which creates an implementation starting from a high-level description (C or C++) of an algorithm. In this paper, we first categorize the recurrent medical microwave techniques and kernels. Then, we propose efficient hardware accelerators for these kernels in programmable devices by using HLS. Several hardware optimization strategies are introduced and their impact on the overall performance is explored. We believe that the analysis of these kernels and their corresponding hardware acceleration techniques can be greatly beneficial to the biomedical microwave research community.

10:20 ***New Method for Calculation of Average Electric Properties of Reference Head Phantom in Microwave Imaging***

Tushar Singh (University of Belgrade & WIPL-D, Serbia); Branislav Ninkovic (WIPL-D, Serbia); Miodrag S. Tasic (University of Belgrade, Serbia); Marija Nikolic Stevanovic (School of Eletrical Engineering, University of Belgrade, Serbia); Branko Kolundzija (University of Belgrade, Serbia)

Microwave imaging has many applications in the biomedical area, and one of the most promising application is brain stroke detection. The full-wave 3D modeling of medical imaging scenarios requires significant computational resources due to the complex anthropomorphic phantoms and antenna systems. Hence, it is of paramount interest to simplify unnecessary details in numerical models, without sacrificing accuracy. Algorithms for reconstruction are based on scattering parameters and electric field in the domain of interest. Hence, by comparing the S-parameters of the original model and the simplified one, we can assess the quality of the simplification. Here, we propose the algorithm for computing the equivalent homogeneous phantom from a realistic human head model. In the qualitative algorithms, the equivalent phantom can be used for the reference model as the patient's head before the stroke onset. In quantitative algorithms, such model can be employed as the intelligent solution for initializing the iterative process.

10:40 Coffee Break

11:00 ***Microwave Antenna Array Calibration via Simulated and Measured S-Parameters Matching***

Cristina Origlia, David O. Rodriguez-Duarte, Jorge A. Tobon Vasquez and Francesca Vipiana (Politecnico di Torino, Italy)

This paper extends the validation of an innovative calibration framework for microwave imaging systems combining measured scattering parameters with numerically simulated ones. The aim is to improve the imaging operator accuracy by overcoming possible variations between the measurement system and its numerical model. Here, we investigate the possibility of reconstructing the transmission coefficients, measured at the antenna ports, employing a custom set of simulations where manufacturing tolerances are introduced. The experimental validation considers a microwave antenna array designed for brain imaging; each antenna is immersed in a brick of custom coupling medium whose dielectric properties variability is mainly analyzed. Further, the simulated dataset is provided by a high-fidelity full-wave electromagnetic tool coupled with a 3-D CAD model. This work presents an essential step forward in the whole calibration scheme, to then be able to estimate the electric field within the domain of interest, thus improve the imaging operator.

11:20 ***An Integrated Microwave-Ultrasound Breast Imaging System: Initial Phantom Results***

Hannah C Fogel and Max Hughson (University of Manitoba, Canada); Mohammad Asefi (AGCO Corporation (Winnipeg), Canada); Ian Jeffrey and Joe LoVetri (University of Manitoba, Canada)

A novel, integrated microwave-ultrasound breast imaging system that requires minimal or no movement of the breast between scans has been developed. In this work, we present initial imaging results using a tissue-mimicking phantom, with experimental data obtained from the dual-mode system. The breast phantom is composed of four regions: skin, fat, fibroglandular and tumour, each with complex-valued permittivity and acoustic speed that approximate those of real breast tissue. Quantitative ultrasound imaging is performed using a ray-based sound-speed reconstruction algorithm. Prior information is extracted from the ultrasound image and incorporated into the microwave inversion algorithm. Although the resolution of the ultrasound imaging system itself is insufficient to detect the tumour, the low-resolution sound-speed reconstructions are used to improve tumour detection via microwave imaging. Resultant images with and without the ultrasound-derived prior are presented. Preliminary findings are indicative of the potential of ultrasound-derived prior information in enhancing microwave imaging of the breast.

11:40 ***The Effect of Contact Pressure on Ex-Vivo Measurements of the Conductivity of Liver***

Niko Ištuk (National University of Ireland, Galway & Translational Medical Device Lab, Ireland); Hamza Benchakroun (National University of Ireland Galway, Ireland); Muhammad Adnan Elahi and Martin O'Halloran (National University of Ireland, Galway, Ireland)

In this study we measured the electrical conductivity of bovine liver. The measurements were performed at frequencies from 10 Hz to 10 kHz (N=5 frequencies) using a custom four-electrode probe and a galvanostat. We examined how the pressure applied between the probe and the tissue influenced the conductivity of the tissue. We performed measurements at N=10 different pressure levels by both increasing (forward direction) and decreasing (reverse direction) the pressure. We found that the conductivity of the tissue drops with pressure, regardless of the direction. However, we found that the decrease of conductivity with respect to applied pressure was small compared to other soft tissues (e.g. muscle tissue). The results from this study suggest that the dependence of conductivity on applied pressure should not have a significant impact on the design of medical devices which depend on accurate knowledge of the impedance provided that their target is the liver.

12:00 ***A Portable Microwave Scanner for Brain Stroke Monitoring: Design, Implementation and Experimental Validation***

David O. Rodriguez-Duarte, Jorge A. Tobon Vasquez and Santiago de Luque Arias (Politecnico di Torino, Italy); Rosa Scapaticci (CNR-National Research Council of Italy, Italy); Lorenzo Crocco (CNR - National Research Council of Italy, Italy); Francesca Vipiana (Politecnico di Torino, Italy)

This paper presents the design, the realization, and the experimental assessment of a novel portable microwave scanner prototype for brain stroke monitoring. The device employs a 22-antenna-array, placed conformal to the upper head part, composed of compact, flexible, and custom-made antennas working at around 1GHz. The validation includes the monitoring of an experimentally emulated evolving hemorrhagic stroke. The progression of the medical condition is emulated via a non-static phantom (custom-shape balloon), derived from medical images, and a single-cavity 3-D anthropomorphic head phantom. The phantoms are filled with liquids mimicking the dielectric properties of the hemorrhage and the average brain tissues, respectively. The imaging-based follow-up is approached using a differential scheme that receives the scattering matrices, taken at two different instants, and exploits the distorted Born approximation to form the image in real-time. The results verify the capabilities of the system to assess the continuous evolution of the stroke.

12:20 ***APA Optimization on Realistic Phantoms for Cancer Hyperthermia Treatments***

Rossella Gaffoglio (Fondazione LINKS, Italy); Marco Righero (LINKS Foundation, Italy); Giorgio Giordanengo (LINKS Foundation & Politecnico di Torino, Italy); Giuseppe Vecchi (Politecnico di Torino, Italy)

The effectiveness of a hyperthermia treatment is strictly dependent on the ability to sharply control the administered heating in the region of interest. Different optimization routines have been implemented to focus the electromagnetic radiation of an array applicator on the tumor target, minimizing the risk of hotspots in the surrounding healthy tissues. This problem is usually tackled in the literature by means of global optimizations involving the specific absorption rate (SAR). In this paper, we analyze the possibility to use an alternating projections algorithm (APA) to optimize the power deposition on a tumor located near the larynx of a realistic numerical phantom. The comparison with a standard global optimization algorithm (particle swarm optimization) shows how the APA could provide a more pronounced hotspot suppression and faster computational times for a proper choice of the constraining power mask.

CS07: AMTA Convened Session: UAV-based Antenna and Field Measurements

T05 Aircraft (incl UAV, UAS, RPAS) and automotive/ /Measurements

Chairs: Hans-Juergen Steiner (Aeroxess UG, Germany), Giuseppe Virone (Consiglio Nazionale delle Ricerche, Italy)

9:00 ***Understanding Phase Pattern Discrepancies in UAV-Based Measurements of a SKA-Low Prototype***

Lorenzo Ciorba (Institute of Electronics, Computer and Telecommunication Engineering (IEIIT-CNR), Torino & Politecnico di Torino, Torino, Italy); Giuseppe Virone (Consiglio Nazionale delle Ricerche, Italy); Fabio Paonessa (National Research Council of Italy (CNR - IEIIT), Italy); Pietro Bolli (INAF - Osservatorio Astrofisico di Arcetri, Italy); Oscar Peverini (IEIIT-CNR, Italy); Giuseppe Addamo (Istituto di Elettr. e di Ingegneria dell'Inform. e delle Telecom. (IEIIT-CNR), Italy); Mauro Lumia (CNR, Italy)

In-situ far-field phase pattern measurements of a prototype of the Square Kilometre Array known as Aperture Array Verification System 1.5 (AAVS1.5) are reported and discussed. Such phase patterns have been measured using a UAV as flying test source. This paper presents a preliminary analysis of discrepancies between the expected and the reconstructed phase patterns. These discrepancies are attributed to a position offset (with respect to the nominal position) common to all elements belonging to the same subarray. A method that estimates this position shift exploiting a combination of measurements and simulations is presented and applied. The resulting position shift could be due to both non-regularity (non-flatness) of the ground and installation errors.

9:20 ***Environmental Reflections Diagnostics Through Radius Flights Using UASs***

Cosme Culotta-López, Snorre Skeidsvoll, Andrian Buchi and Joakim Espeland (QuadSAT, Denmark)

The increasing popularity of Unmanned Aerial Systems (UAS) as a novel solution for antenna testing is introducing new outdoor diagnostic techniques. Thanks to their flexibility, measurements that are only possible with restrictions even in indoor measurement ranges are becoming possible. However, outdoor ranges introduce error sources due to the presence of a reflective environment. In this work, the use of UASs for the characterization of outdoor operation sites through the Voltage Standing Wave Ratio (VSWR) method is proposed. The flexibility of UASs is used to perform flights along the radial component of a sphere centered at an illuminating antenna, characterizing the reflectivity level through ripple analysis. The system is introduced, as is the theory related to the VSWR method and its application to outdoor measurements and, using it, a reflectivity map of a test site is calculated, enabling the detection of sources of reflectivity and the possibility to prevent them.

9:40 ***Latency Validation Method for 3D 5G Networks' URLLC Applications***

Marjo Heikkilä, Virve Malkamo, Pentti Eteläaho, Tero Kippola and Marjut Koskela (Centria University of Applied Sciences, Finland)

This paper focuses on developing a measurement method for analysing the quality of service of a three dimensional (3D) beyond 5G network. The study's aim is efficient and reliable testing method development for the industrial communications network with the unmanned aerial vehicle (UAV). 5G and beyond 5G networks are seen as having potential in industrial environments that need cost-efficient connectivity services to Industry 4.0-the fourth industrial revolution that aims to integrate cyber-physical systems, artificial intelligence, and Internet of things in industrial processes. The industrial environment consists of various vertical sectors (i.e. manufacturing, logistics) with numerous communications use cases and peremptory requirements in terms of availability, reliability, latency and safety. Industrial use cases such as autonomous surveillance UAVs and automated cranes demand reliable 3D communication services for their operation.

10:00 ***OTHR Phase-Only Beamformer Drone-Based Measurements***

Simon Henault (Defence Research and Development Canada, Canada)

The Defence Research and Development Canada (DRDC) antenna measurement drone was used to evaluate the beamforming performance of the Ottawa experimental OTHR transmit antenna array. Optimal and phase-only beamformers were compared and various calibration approaches were used with the intent of maximizing power toward a target and minimizing power toward the auroral clutter. Phase-only beamforming gave 7.5 dB more power on target than optimal beamforming. Surprisingly, theoretical calibration appeared to give better results than experimental calibration, making the far-field calibration task significantly easier.

10:20 ***Measurement Path Optimization in Non-Structured Near-Field Acquisitions***

Marco Righero (LINKS Foundation, Italy); Martina Mammarella (Consiglio Nazionale delle Ricerche, Italy); Fabrizio Dabbene (Politecnico di Torino, Italy); Giorgio Giordanengo (LINKS Foundation & Politecnico di Torino, Italy); Chiara Ravazzi (CNR, Italy); Giuseppe Vecchi (Politecnico di Torino, Italy)

A numerical investigation about the optimal way to acquire Near Field (NF) samples to determine the Far Field (FF) pattern of an Antenna Under Test is performed, where the samples are supposed to be acquired with a robotic arm or an Unmanned Aerial Vehicle. The probe movement unit is modelled as a device that can move with constant velocity along paths bounded curvature. Within this framework, some numerical experiments are performed and the results compared in term of FF accuracy obtained with different paths of similar length.

10:40 Coffee Break

11:00 ***What Positioning Accuracy is Sufficient for Reliable mmWave A2G Channel Measurements?***

Vasilii Semkin (VTT Technical Research Centre of Finland, Finland); Aki Karttunen (Tampere University, Tampere, Finland); Seongjoon Kang (New York University Tandon School of Engineering, USA); Jukka Talvitie (Tampere University, Finland); Marco Mezzavilla (NYU Tandon School of Engineering, USA); Sundeep Rangan (New York University, USA); Mikko Valkama (Tampere University, Finland)

In this work, we investigate the significance of position accuracy for unmanned aerial vehicle (UAV) during millimeter-wave (mmWave) channel measurements. The studies are performed at 28 and 60 GHz frequencies. First, we study the effect of the error in the positioning on the 3GPP channel models. Second, we present ray tracing simulations performed in urban environment. We verify that the horizontal/vertical accuracy of ±0.5/0.8 meters may be enough to get reliable data. It should be noted that better accuracy can still improve the results but will require more effort to achieve. In addition, it is confirmed that more severe effect will be visible on the path loss values, while other parameters are not affected as strongly for the LOS case. Power angular delay profile might be severely affected for the NLOS if the positioning error is large, however, defined accuracy values are enough to get realistic channel estimation.

11:20 ***Fully Coherent UAV-Based Near-Field Measurement and Transformation of the S67-15m Ground Station Antenna at the German Space Operations Center in Weilheim***

Stefan Punzet (Technical University of Munich & Chair of High-Frequency Engineering (HFT), Germany); Fabian T. Faul and Thomas Mittereder (Technical University of Munich, Germany); Christian Oettl, Matthias Ganser and Martin Häusler (DLR Deutsches Zentrum für Luft- und Raumfahrt e. V., Germany); Thomas F.

Eibert (Technical University of Munich (TUM) & Chair of High-Frequency Engineering (HFT), Germany)

Fully coherent unmanned aerial vehicle (UAV)-based near-field measurements of the S67 parabolic ground station antenna in Weilheim, Germany at 2.063 92GHz are presented. The utilized measurement setup involves a vector network analyzer (VNA), radio frequency optical fiber connections, a laser tracking device (LT), and a specially designed light-weight dual-polarized Vivaldi antenna. The measurement data has been collected on a quasi-planar measurement surface in front of the reflector and the far-field patterns are obtained by field transformation from the irregular near-field data. Despite the complexity of this outdoor measurement setup with full exposure to varying weather conditions and the influence of the UAV on the near-field probe antenna, the far-field results show remarkable agreement with satellite based far-field measurement data.

11:40 ***Multi-Beam Tracking for Phased Array Antenna Measurement by Multiple UAVs***

Saki Omi (Cranfield University & QuadSAT, United Kingdom (Great Britain)); Hyo-Sang Shin (Cranfield University & KAIST, United Kingdom (Great Britain)); Antonios Tsourdos (Cranfield University, United Kingdom (Great Britain)); Joakim Espeland and Andrian Buchi (QuadSAT, Denmark)

Phased array antenna is increasingly applied for satellite communication on the move terminals. Phased array antenna radiation pattern has been evaluated in the conventional facilities by measuring the entire sphere or plane from different steering angles. As the demand of satellite communication is growing, it is required to make the terminal antenna evaluation process faster than ever before. In this paper, new framework to partially evaluate phased array antenna characteristics is proposed by introducing dynamical UAV system with RF payload. The process of the evaluation can be accelerated by focusing on a few key aspects such as transition of the multiple beam peaks gain and their directions as steering angle is changed. UAVs can track multiple beams autonomously thanks to the trained system by reinforcement learning algorithm.

12:00 ***Verification of RTK Positioning of UAVs with High-Precision Laser Tracker***

Patrick Henkel, Markus Lamm and Ulrich Mittmann (ANavS GmbH, Germany); Torsten Fritzel, Rüdiger Strauß and Hans-Juergen Steiner (Aeroxess UG, Germany); Matthias John (FARO Europe GmbH & Co. KG, Germany)

Near-field antenna measurements can be efficiently performed with Unmanned Aerial Vehicles (UAVs). An accurate knowledge of the position and timing is needed, and can be provided by Real-Time Kinematic (RTK) positioning systems using Global Navigation Satellite System (GNSS) signals. In this paper, we assess the accuracy of a GNSS RTK positioning system with a laser tracker that provides ranging measurements with a precision of up to 16µm. The measurement results show that the positioning solutions of the GNSS RTK system and of the Laser tracker agree within a few centimeters. This accuracy is also correctly indicated by the self-assessment of the RTK system.

12:20 ***5G Communication QoS Measurements for Smart City UAV Services***

Seppo Horsmanheimo and Lotta Tuomimäki (VTT Technical Research Centre of Finland Ltd, Finland); Vasilii Semkin and Stephan Mehnert (VTT Technical Research Centre of Finland, Finland); Tao Chen (VTT, Finland); Marko Ojennus and Lasse Nykänen (Indagon, Finland)

This paper concentrates on studying 4G/5G mobile network technologies applied to smart city Unmanned Aerial Vehicle (UAV) services. It reviews the state of the 5G technology and introduces proposed UAV services for smart cities. The paper describes our drone measurement platform and the results of the conducted communication QoS measurements in urban environment. The results indicated that 5G is more sensitive to altitude changes than 4G network and this should be considered in the future mobile network planning.

P04: Satellite propagation I

T08 Space (incl. cubesat)/ / Propagation

Chair: Marianna Biscarini (Sapienza University of Rome, Italy)

9:00 ***Long-Term Measurements of Tropospheric Scintillation at Very Low Elevation Angles - Initial Analysis***

Martin Rytir (Norwegian Defence Research Establishment (FFI), Norway)

Four years of scintillation measurements at very low elevation angles at Kjeller, Norway are analyzed and compared with the ITU-R model. One year is at Ka band with an elevation angle of 3°, and three years are of simultaneous measurements at Ka and X band with an elevation angle of 4.2°. The measured scintillation is highly asymmetrical with more than 40 dB fades recorded at Ka band. In agreement with previous results, the scintillation spectra for low elevation angles have a low corner frequency. Compared with the ITU-R model, the measurements highlight issues with uncertainty of input parameters, as well as accuracy of the deep-fading part of the model. The model predicts the measured scintillation well for high percentages of the time, but poorly for low percentages of the time. The deep-fading part of the model significantly overestimates fades at X band, highlighting a previously observed issue with frequency scaling.

9:20 ***Long Term Scintillation Measurements at Ka and Q-Bands***

Armando Rocha (University of Aveiro & Instituto de Telecomunicações, Portugal); Susana Mota (University of Aveiro & Institute of Telecommunications, Portugal); Ana Gomes (Universidade de Aveiro, Portugal)

Scintillation is a phenomenon that affects microwave links and is still poorly modeled. Results of long-term measurements -5 years with almost 100% data availability- performed simultaneously from the same location at two different frequencies (Ka and Q-bands) in a converging link are presented here. The similarity of the time series of scintillation intensity in the two bands is commented. The variability of the standard deviation of the scintillation with the time of day on an annual basis and also on a monthly basis is analyzed. Annual cumulative distributions are also presented and explored. The performance of some available models in the literature for scintillation amplitude is evaluated using locally measured meteorological data. The ITU model seems to slightly over predict the experimental results.

9:40 ***Tropospheric Scintillation Fading Analysis of Alphasat Satellite Measurements in Ka and Q Bands***

Arsim Kelmendi (Jozef Stefan Institute, Slovenia); Andrej Hrovat (Jožef Stefan Institute, Slovenia); Ales Svigelj (Jozef Stefan Institute, Slovenia); Mihael Mohorcic (Jozef Stefan Institute & Jozef Stefan International Postgraduate School, Slovenia)

Tropospheric scintillation of signal is caused by rapid fluctuation of refractive index due to random changes of humidity, pressure, and temperature in clear air, clouds and precipitation particles. The refractive index is continuously changing along the propagation path, causing random fades and enhancements in the signal level. In the system design phase, the prediction of long-term statistical distributions of signal fades and enhancements are needed. Long periods of measurement data are needed to characterize and model the scintillation statistics. In this paper, annual, seasonal and monthly statistical analyses of the scintillation fades based on the three-year beacon measurements of the Alphasat satellite at 19.7 GHz and 39.4 GHz in Ljubljana, Slovenia, are presented. The annual curves are also compared with the scintillation fades predicted by the ITU-R P.618-13 model.

10:00 ***BepiColombo Mission to Mercury: Designing RadioMetOP Weather-Forecast Based Operations to Improve Satellite Data Throughput at Ka-Band***

Marianna Biscarini and Frank S. Marzano (Sapienza University of Rome, Italy); Paolo Antonelli (HIMET, Italy); Saverio Di Fabio and Livio Bernardini (CETEMPS, Italy); Paolo Scaccia (HIMET, Italy); Maria Montagna (SciSys @ ESA, Germany)

The weather-forecast based Radio Meteorological Operation Planner (RadioMetOP) model for the dynamical satellite link-budget design and its operative application to the BepiColombo ESA deep-space mission to Mercury are described. BepiColombo is the first European deep-space mission adopting Ka-band for the downlink of telemetry data. At such high frequency, classical link budget techniques based on static climatological statistics for the characterization of the atmospheric channel are not suitable. RadioMetOP provides a dynamical model exploiting weather forecasts on the specific satellite transmission period coupled with a radiopropagation model for the prediction of atmospheric attenuation. This allows an improvement in the data throughput compared to classical link budget design techniques. For the first time, RadioMetOP model will be operationally adopted and tested thanks to the collaboration with ESA for the BepiColombo mission. RadioMetOP model can be extended to become multi-mission, multi-site, and multi-frequency in order to be adopted for future satellite missions.

10:20 ***Rainfall Measurements in Bolivia: Conversion of Statistics from 15-Min to 1-Min by EXCELL RSC Model and Accuracy Test of ITU-R P.837***

Gustavo Siles and Martin Alvarez (Universidad Privada Boliviana, Bolivia)

The comparison of 1-min rainfall rate measurements with predictions from ITU-R P.837-7, in different regions and climates is useful for testing and improves its accuracy. We report for the first time, results of a comparative study in Bolivia. The ITU-R P.837-7 method is tested against precipitation data gathered in 3 pluviometric stations, with 15-min time resolution. EXCELL RCS model is used for downconverting statistics to 1-min integration time. A slight correction on this model was needed for 2 stations located at high altitudes. Error analysis for each station shows that ITU-R P.837-7, using monthly mean total rainfall as input, has good performance. In absence of this information, predictions based on digital maps produce an increase of error metrics. EXCELL RCS model has demonstrated being a tool helping to overcome the lack of 1-min rainfall measurements. We believe our findings contributes to rainfall modelling for propagation purposes in South America.

A27: Computational EM for antenna analysis

T09 EM Modelling and Simulation tools/ / Antennas

Chairs: Jesús Rubio (University of Extremadura, Spain), Kurt Schab (Santa Clara University, USA)

9:00 ***Characteristic Modes Evaluated Using the Finite Element Method***

Mats Gustafsson (Lund University, Sweden); Lukas Jelinek (Czech Technical University in Prague, Czech Republic); Kurt Schab (Santa Clara University, USA); Miloslav Capek (Czech Technical University in Prague, Czech Republic)

The formulation of characteristic modes using a transition matrix is independent of the associated computational tools. This enables frequency-domain solvers such as the finite element method to complement classical method-of-moment-based formulations in characteristic mode analysis. Here, it is shown that standard finite element solvers can be used to determine characteristic modes

for heterogeneous objects, exemplified by a dielectric coated metallic cylinder.

9:20 ***Comparison of Coefficient Calculation Techniques for NLPLS PCE Models of Antennas***

Dieter Gert Klink, Petrie Meyer and Werner Steyn (Stellenbosch University, South Africa)

Non-linear Partial Least-Squares based Polynomial Chaos Expansions (NLPLS-based PCE) has recently been shown to allow yield analysis for high-dimensional problems. A comparison of coefficient calculation techniques in the PCE step of the algorithm is done to determine the appropriate technique for generalized antenna problems. An NLPLS-based PCE surrogate of an 8-variable dual-band patch antenna and a 37-variable diplexer is constructed using Ordinary Least-Squares (OLS), Least Angle Regression (LAR), and Orthogonal Matching Pursuit (OMP). LAR and OMP provided a more stable solution when compared to OLS for both the dual-band patch antenna and diplexer, with OMP outperforming LAR for the 8-variable dualband patch solution. The choice of an appropriate coefficient calculation method is thus determined to have a significant influence on the effectiveness of NLPLS-based PCE.

9:40 ***Analysis of Infinite Arrays of Antennas by Using FEM and Spherical Modes***

Jesús Rubio (University of Extremadura, Spain); Miguel A. González de Aza (Universidad Politecnica de Madrid, Spain); Juan Córcoles (Universidad Autónoma de Madrid, Spain); Rafael Gómez Alcalá (University of Extremadura, Spain)

This communication introduces a methodology to analyze infinite arrays of antennas by a fast post processing of the Generalized Scattering Matrix of a single, non-coupled, element, in terms of spherical modes. First, the Generalized Scattering Matrix is computed with the Finite Element Method only once whatever the array lattice or scan angle. Next, the active reflection coefficient and the embedded radiation pattern of the infinite array is quickly calculated for any lattice or scan angle thanks to an efficient computation of lattice sums of spherical harmonics.

10:00 ***Improved Iterative DGFM Convergence, Towards Large-Scale Antenna Array Analysis***

André S Conradie and Matthys M. Botha (Stellenbosch University, South Africa)

This paper presents an improvement to an iterative domain decomposition method for the analysis of large antenna arrays. The method considered, is the iterative domain Green's function method (DGFM), with extended local MoM domains. It yields an approximate solution to the global method of moments (MoM) problem via the solution of a succession of local sub-problems. The local sub-problems are obtained by rigorously formulating the MoM on local domains, with all array elements outside these local domains modelled using an improved far-current approximation which is a hybridisation of the DGFM and standard Jacobi approximations. Numerical results demonstrate that this new far-current approximation improves the convergence rate of the iterative DGFM-MoM. The improved formulation retains the main benefit of the DGFM, which is that it is well-suited to parallelisation.

10:20 ***Theory and Analysis on Omnidirectional Mode of Cylindrical Laminated Resonator Antenna***

Yaowei Hou, Yao-ping Zhang and Junfa Mao (Shanghai Jiao Tong University, China)

This paper studies the cylindrical Laminated Resonator Antenna (LRA) fed by the coaxial probe theoretically. A theoretical model is proposed to analyze the omnidirectional radiation characteristics of the cylindrical LRA. Based on the waveguide excitation theory, analytical expressions for inner fields, modal coefficients, radiation pattern, directivity, radiation efficiency and gain have been developed. For verification, a cylindrical LRA in the dominant TM011 mode operation is simulated. Acceptable agreements among the calculated and simulated results are achieved and omnidirectional radiation patterns are observed. The proposed theoretical model provides physical insight into the cylindrical LRA in omnidirectional mode operation, which can be applied to predict the performances of LRAs and to instruct the design of LRAs.

IW11: From antenna design and placement to RF propagation and Co-site interferences: meet the latest challenges with Altair

CS24: Future trends in reflectarray synthesis and analysis for communications and sensing

T10 Fundamental Research and Emerging Technologies/ / Antennas

Chairs: Jose A. Encinar (Universidad Politecnica de Madrid, Spain), Giacomo Oliveri (University of Trento & ELEDIA Research Center, Italy)

9:00 ***Dual Polarization Reflectarray Elements with Dynamic Reconfiguration Based on Liquid Crystal***

Sergio García-Ruano, Robert Guirado and Gerardo Perez-Palomino (Universidad Politécnica de Madrid, Spain); Jose A. Encinar and Eduardo Carrasco (Universidad Politecnica de Madrid, Spain)

The dynamic control of the phase in reflectarray antennas (RA) with dual-polarization using liquid crystal (LC) technology is a very challenging task. The selected reflecting elements must have an

almost independent response for each orthogonal polarization, with 360o of phase range, smooth linear variation of the phase, minimizing the losses and avoiding the coupling between polarizations. This contribution proposes a multi-resonant element made of two sets of dipoles, with orthogonal orientation to be used in W-band (100 GHz), using liquid crystal for reconfiguring the phase of the reflected, wave with an independent response for each polarization.

9:20 ***Single Layer Multimodal OAM Reflectarray***

Michele Beccaria and Paola Pirinoli (Politecnico di Torino, Italy)

In this work, the procedure for the design of innovative reflectarray (RA) antennas able to radiate multiple Orbital Angular Momentum (OAM) modes is introduced. Extending the concepts at the base of multifocal lenses, the RA is designed in such a way that, depending on the direction of arrival of the incident field, it radiates a broadside beam carrying an OAM with different index. As a proof of concept, a circular RA with diameter D = 20lambda at the the frequency f0 = 30 GHz, able to radiate OAMs with l = 2 and l = 4 has been designed. The results obtained through its full-wave simulation, confirm the effectiveness of the proposed solution.

9:40 ***Inverse Design of a Dual-Band Reflective Polarizing Surface Using Generative Machine Learning***

Parinaz Naseri (University of Toronto, Canada); George Goussetis (Heriot-Watt University, United Kingdom (Great Britain)); Nelson Fonseca (European Space Agency, The Netherlands); Sean V Hum (University of Toronto, Canada)

Reflective linear-to-circular polarization (LP-to-CP) converters are desired for satellite communication applications to reduce the complexity of the antenna system and the number of the required apertures in single-feed-per-beam configurations. Moreover, wideband operation and angular stability are important polarizer attributes in these applications. Here, for the first time, we use a machine-learning technique employing a generative adversarial network (GAN) to systematically and efficiently explore and exploit the solution space of single-layer structures for this problem. By using a GAN to optimize the shape of the polarizing element, superior performance in terms of overlapping axial ratio bandwidth for normal and oblique incidence of 30 degrees compared to the previously studied designs is achieved.

10:00 ***Recent Advances in Complex Reflectarray Synthesis Within the System-By-Design Framework***

Andrea Massa (University of Trento, Italy); Giacomo Oliveri (University of Trento & ELEDIA Research Center, Italy); Marco Salucci (ELEDIA Research Center, Italy)

System-by-Design (SbD) has recently emerged as a powerful and efficient approach in reflectarray antenna (RA) synthesis and optimization. The features/properties of SbD (e.g., its flexibility and natural capability to handle complex multi-scale task-oriented problems) and the intrinsic challenges associated to advanced RA synthesis have motivated a great interest in developing and applying SbD-based approaches in reflectarray engineering. Within this framework, the objective of this contribution is to present a review of the current and most recent advances of SbD formulations as applied to reflectarray design developed at the ELEDIA Research Center. Towards this end, the customization of the SbD loop to the RA synthesis problem is illustrated, and the integration of advanced micro-scale modeling techniques based on learning-by-example strategies with macro-scale task-oriented optimization strategies is discussed. Current challenges and trends in the application of SbD to the solution of advanced RA design problems are remarked, as well.

10:20 ***RF Modeling and Measurements of a Reflectarray for Synthetic Aperture Radar for Earth Observations***

Niels Vesterdal, Min Zhou, Michael F. Palvig, Stig Sørensen and Jakob Rosenkrantz de Lasson (TICRA, Denmark); David Marote Alvarez (Airbus/CASA, Spain); Giovanni Toso (European Space Agency, ESA ESTEC, The Netherlands)

Design and simulation results of a polarisation selective reflectarray in Ka band are presented. The reflectarray is part of a dual-offset antenna system for a high-resolution and wide-swath Synthetic Aperture Radar (SAR) instrument that operates in both a high-resolution mode with a directive beam in one polarisation, and a low-resolution mode with a broader beam in the orthogonal polarisation. Fed by orthogonal modes, a sectoral horn illuminates the reflectarray antenna with different beam widths for the two operational SAR modes. Radiation patterns of the feed and reflectarray antenna system are presented.

10:40 Coffee Break

11:00 ***Near-Field Synthesis of Spatially-Fed Arrays for Uniform Field Distribution in Complex Areas***

Álvaro F. Vaquero (Universidad Politécnica de Madrid & Information Processing and Telecommunications Center, Spain); Marcos R. Pino and Manuel Arrebola (Universidad de Oviedo, Spain)

In this work, a novel approach to define masks in near-field syntheses is presented. This technique improves the convergence of the algorithm when dealing with complex scenarios and uniform field requirement. First, the methodology of the synthesis process is fully described. Second, an example is presented to better understand the concept. The technique is combined with the generalized Intersection Approach for near-field, and a transmissive spatially-fed array is synthesized. The synthesis aims to reach uniform field distribution in a large and complex-shape area. A major challenge is to overcome the issues presented because of the electromagnetic propagation. The strategy followed in the synthesis reaches the desired uniform field distribution, reducing the starting ripple

from more than 30 dB to almost 5 dB in an area larger than 14 meters.

11:20 ***Design of an E-Band 1-Bit Reconfigurable Reflectarray Antenna Using PIN Diodes***

Changhao Liu, Yongli Ren, Fan Yang, Shenheng Xu and Maokun Li (Tsinghua University, China)

A 1-bit reconfigurable reflectarray antenna using PIN diodes is presented for 71-76GHz millimeter-wave communication applications. Based on the method of polarization conversion, the 0∘/180∘ element phase is accurately realized by loading 2 PINs on each element in order to overcome the unstable parameters of PIN in E-band. A square aperture reflectarray consisting of 16×16 elements is then designed and analyzed. Full wave simulation results demonstrate that the gain of the antenna is 17.1dBi, and the beam scanning angle can cover 45∘.

11:40 ***Enhancement of 5G Millimeter-Wave Coverage in Indoor Scenarios by Passive Shaped-Beam Reflectarray Panels***

Eduardo Martinez-de-Rioja (Universidad Rey Juan Carlos, Spain); Álvaro F. Vaquero (Universidad Politécnica de Madrid & Information Processing and Telecommunications Center, Spain); Manuel Arrebola (Universidad de Oviedo, Spain); Eduardo Carrasco and Jose A. Encinar (Universidad Politecnica de Madrid, Spain); Safa Salman (Metawave Inc, USA); Maha Achour (Meta Wave Corporation, USA)

This contribution proposes the use of passive reflectarray panels as an efficient and low-cost technology to enhance millimeter-wave coverage in 5G indoor scenarios. A dual-polarized shaped-beam reflectarray has been designed to produce a highly broadened beam in the azimuth plane (half-power beamwidth of 13°) with a deviation of 45° with respect to broadside. A single-layer reflectarray cell has been used to obtain an angularly-stable phase response at the 28 GHz band with independent phase control in each linear polarization. The phase shift distribution on the reflectarray panel has been computed by a phase-only pattern synthesis, considering the beam specifications of the indoor scenario. The reflectarray panel shows stable gain and side-lobe levels, and very low cross-polarization in a 1 GHz band (from 27.3 to 28.3 GHz).

12:00 ***Dual-Band Polarizer Reflectarray Operating in Dual-CP for High-Gain Antenna in CubeSats***

Eduardo Martinez-de-Rioja (Universidad Rey Juan Carlos, Spain); Ignacio Linares and Daniel Martinez-de-Rioja (Universidad Politécnica de Madrid, Spain)

This contribution describes the design process of a dual-band polarizer reflectarray antenna in K/Ka-bands for CubeSat applications. The reflectarray has been designed to focus a high-gain beam at 19.7 and 29.5 GHz while converting the incident polarization from dual-linear into dual-circular polarization. The independent operation at two separate frequency bands is accomplished by a dual-layer reflectarray cell. The flat surface of the reflectarray simplifies the mounting of the antenna on the small spacecraft and the linear-to-circular polarization conversion allows to reduce the number of components in the feed chain, also reducing the cost and complexity of the antenna subsystem.

12:20 ***Design of Circularly Polarized and Highly Depointing Reflectarrays with High Polarization Purity***

Andrea Guarriello (IETR & INSA Rennes, France & Heriot-Watt University, United Kingdom (Great Britain)); Daniele Bresciani (Thales Alenia Space, France); Hervé Legay (Thalès Alenia Space, France); George Goussetis (Heriot-Watt University, United Kingdom (Great Britain)); Renaud Loison (IETR & INSA, France)

This work aims to investigate the limitations and possible solutions in designing highly tilted radiation pattern reflectarrays working in double circular polarization and fed by an onset single primary source. To this extent, three single-layer monolithic reflectarrays, producing a pencil beam at increasing radiation angles with high X-polarization discrimination (XPD) have been designed and analyzed. A direct optimization technique shows that an XPD=20 dB can be attained for radiation patterns pointing at sixty degrees, at the cost of co-polarised directivity degradation. An analysis of the target aperture fields, obtained through backscattering techniques, shows that an amplitude modulation on the aperture field components is necessary to obtain highly tilted radiation patterns with high XPD. Since reflectarray cells are not able to produce such amplitude components unbalance, an elliptically polarized source is considered, producing an incident field components amplitude unbalance that results in a radical reduction of the X-polarization levels.

Special Session In Memoriam Prof. Jørgen Bach Andersen

Scientific Workshop

9.00-9.10: Introduction - "The Waves Find Their Path Anyway", Thomas Kürner, TU Braunschweig, Germany

9.10-9.40: "The Research-Life of Jørgen Bach Andersen" (Keynote), Gert F. Pedersen, Aalborg University, Denmark

9.40-10.00: "Wandering the Complex Plane with Jørgen Bach Andersen", Rodney Vaughan, Simon Fraser University, Canada

10.00-10.15: "Seawind collaboration: Using Jørgen Bach Andersen's Room Electromagnetic Theory and Method to Assess Absorption in Humans", Wout Joseph, Ghent University, Belgium

10.15-10.25: Closing - ""The Tale of Two Dipoles et al. Lives On", Buon Kiong Lau, Lund University, Sweden

Wednesday, March 30 10:40 - 11:00

Coffee Break / Exhibition

Wednesday, March 30 11:00 - 12:40

A02: Antenna design and technologies

T01 LTE and Sub 6GHz 5G/ / Antennas

Chairs: Antonio Clemente (CEA-LETI Minatec, France), Pablo Sanchez-Olivares (Universidad Politecnica de Madrid, Spain)

11:00 ***Amplifier-Antenna Array Optimization for EIRP by Phase Tuning***

Veli-Pekka Kutinlahti and Anu Lehtovuori (Aalto University, Finland); Ville Viikari (Aalto University & School of Electrical Engineering, Finland)

In this paper, we analyse an antenna array fed with element-specific phase shifters and amplifiers. The elements of the array are mutually coupled and the operation of the amplifiers depend on the load impedance presented by the array. We derive a method for maximizing EIRP in a given direction and demonstrate the concept by simulations with 2x2 array fed with element-specific phase shifters and amplifiers at 2.5 GHz. Compared to the reference case, the optimization provides up to 0.7 dB improvement in EIRP in the -3 dB beam steering range.

11:20 ***Experimental Demonstration of a Supergain Three-Dipole-End-Fire-Array***

Alexandre Debard (LEAT, France); Antonio Clemente (CEA-LETI Minatec, France); Lotfi Batel (CEA-Leti, France); Christophe Delaveaud (CEA-LETI, France)

This paper presents the experimental validation of a three-dipole array optimized for maximum gain. The complex excitation coefficients associated to the array are calculated using a synthesis procedure based on the array factor. A parasitic array architecture has been selected to implement the proposed antenna solution. The high gain reached (8.6 dBi for a ka of 1.4) shows the interest of the proposed optimization method. Furthermore, it was shown that this optimization method decreases the sensitivity to errors in the dipole excitation coefficients at the cost of a lower directivity compared to the superdirectivity.

11:40 ***A 5.5GHz-Band 2x2 Array Antennas Module Based on Compact 2-D Beamforming Network in Broadside Coupled Stripline***

Jean Temga (Tohoku University & RIEC, Japan); Mizuki Motoyoshi (Shizuoka Institute of Science and Technology, Japan); Takashi Shiba and Noriharu Suematsu (Tohoku University, Japan)

This paper proposes a 2x2 array fed by a compact 2-D beamforming network (BFN) in a 5 metals-layer Rogers substrate. The BFN is composed of four interconnected 3dB/90o stripline couplers designed in the broadside coupled stripline structure in the lower (1-4) layers allowing an easy and compact design. The 2x2 patch antenna array designed in the upper (5) layer is connected to the BFN by probes generating four beams with unique directions on azimuth and elevation planes. The array inter-element distance is 0.5λ0. To validate the performance of the proposed structure, a prototype of a 2x2 patch array has been fabricated and measured. Simulated and measured four beams have been realized. An 8.85dBi highest simulated gain and a 5.97dBi highest measured gain are realized respectively in (θ=26o, Φ=55o) and (θ=30o, Φ=55o) directions when port 1 is excited. The size of the 2x2 array without feeding TML is 0.76 λ0×0.81λ0×0.04 λ0.

12:00 ***Reduction of Radiation Pattern Distortion of Beam Scanning Antennas Inside Radome***

Juan Andrés Vásquez Peralvo (Universidad Politécnica de Madrid, Spain); Jose Iglesias-Gonzalo (Sistemas Radiantes F. Moyano S.A., Spain); Pablo Sanchez-Olivares (Universidad Politecnica de Madrid, Spain); Manuel Sierra-Castañer (Universidad Politécnica de Madrid, Spain)

This paper presents the design of a radome corner support that offers mechanical stability and low reflections for 2, 3, 4, 5G technologies. This corner frame, which has a winged platen shape, is based on the multiple-layer A-sandwich radome design model. This type of radome design is known for reducing the reflections of incident waves, reducing the E-Field perturbations inside the radome. A radome is simulated with the proposed frame to validate the design, enclosing a +/-45 degrees polarization crossed dipole array antenna. Radiation pattern simulations of the antenna array alone and inside the radome are obtained at different frequencies and incidence angles. The results show that using the proposed model considerably reduces the perturbations in of antennas radiation pattern inside the radome, obtaining, in the worst case, a mean square error between the antenna alone and with the radome of 22.64.

12:20 ***Advances on CS-Processing Applied to Phased Arrays Synthesis, Processing, and Characterization***

Lorenzo Poli (ELEDIA Research Center, University of Trento, Italy); Giacomo Oliveri (University of Trento & ELEDIA Research Center, Italy); Nicola Anselmi and Marco Salucci (ELEDIA Research Center, Italy); Mohammad Hannan (ELEDIA Research Center, University of Trento, Italy); Francesco Zardi (ELEDIA Research Center, Italy); Marco Donald Migliore (University of Cassino, Italy); Paolo Rocca (University of Trento & ELEDIA Research Center, Italy)

This paper presents an overview on the recent advances on Compressive Processing methods as applied to phased arrays synthesis and analysis with main focus on (i) synthesis of sub-arrayed antenna arrays, (ii) failure detection in planar phased arrays, and (iii) antenna characterization. The novelty as well as the main advantages of the proposed methods with respect to conventional state-of-the-art approaches are discussed in the paper.

CS10: Antenna Systems for Wireless Power Transmission and RF Energy Harvesting

T03 Wireless LANS, IoT and M2M/ / Antennas

Chairs: Sotirios Goudos (Aristotle University of Thessaloniki, Greece), Paolo Rocca (University of Trento & ELEDIA Research Center, Italy)

11:00 ***Dual Frequency MIMO Rectenna with Two-Branch Rectifier and Common Power Storage Unit***

David Chatzichristodoulou (RF AND MICROWAVE SOLUTIONS LTD & Frederick Research Center, Nicosia, Cyprus); Giacomo Paolini (University of Bologna, Italy); Abdul Quddious (KIOS Research and Innovation Center of Excellence, University of Cyprus, Cyprus); Diego Masotti (University of Bologna, Italy); Alessandra Costanzo (DEI, University of Bologna, Italy); Photos Vryonides (Frederick University Cyprus & Frederick Research Center, Cyprus); Symeon Nikolaou (Frederick Research Center & Frederick University, Cyprus)

A dual frequency (433 MHz and 2.45 GHz) circularly polarized MIMO rectenna with dual-branch rectifiers and a common power management unit is presented. For the lower frequency a dual-layer, four-element, monopole antenna array is implemented. The four monopoles are oriented along the perimeter of a square and are fed with 90° phase difference resulting in a circularly polarized antenna array. For the 2.45 GHz antenna, an elliptical patch is used implementing it in the middle of the square substrate that is used for the 433 MHz monopoles. The coaxial cables are connected on the dual-branch, dual-frequency rectifiers. The combined use of both frequencies results in RF-to-dc efficiency up to 70% for input power close to 0 dBm. The dual rectifiers have a common load since they are terminated with a common power management unit circuit.

11:20 ***Limits of WPT Through the Human Body Using Radio Frequency***

Rodrigo Duarte (Instituto Superior de Engenharia de Lisboa, Portugal); Carolina T. S. Gouveia (Instituto de Telecomunicações, Aveiro & University of Aveiro, Portugal); Pedro Pinho (IT - Instituto de Telecomunicações & ISEL - Instituto Superior de Engenharia de Lisboa, Portugal); Daniel Albuquerque (CISED - Polytechnic of Viseu, Portugal)

The goal of this work is to study the performance of the Wireless Power Transfer (WPT) to inside the human body, while respecting the Specific Absorption Rate (SAR) limits. Therefore, the levels of absorbed power in different body parts were verified by simulation, in order to reach conclusions about the user's safety. More specifically, two biological models that represent the thigh and the arm were considered. The simulation results led us to conclude that it is possible to transmit approximately 140 mW on the limbs location, while respecting the SAR limits. In turn, it is possible to receive a power superior to 93 µW inside the human body. Additionally, real tests were also carried out in three subjects to verify the power attenuation related to each body structure.

11:40 ***Extending the Range of 5G Energy Transfer: Towards the Wireless Power Grid***

Aline Eid, Jimmy Hester and Manos M. Tentzeris (Georgia Institute of Technology, USA)

In this work, the authors demonstrate the potential of 5G/mm-wave signals, coupled with wide-coverage Rotman-lens-based harvesters (a.k.a. tag) to achieve efficient and long-range powering. First, the rationale for the approach is described, before the elements of the harvester and their design specifications are presented and their performance is reported. Finally, the emitting system is detailed, followed by the presentation of its use with the tag to demonstrate long-range wireless power transfer (WPT) at mm-wave frequencies. For the first time, a relatively-compact rectenna system is shown to be able to collect 5G signals at ranges exceeding 16 m with a wide angular coverage, thereby extending the range relative to previous efforts by more than 5x and demonstrating a pathway towards the emergence of the Wireless Power Grid (WPG), a key to enabling the accelerated deployment of energy-autonomous wireless sensors ubiquitous constellations for digital twinning, smart cities, and intelligent infrastructure.

12:00 ***A Broadband CP Elliptical-Slot Antenna for Ambient RF Energy Harvesting***

Khatereh Nadali, Patrick McEvoy and Max James Ammann (Technological University Dublin, Ireland)

In this paper, a compact broadband CPW-fed circularly polarised elliptical-slot antenna with an inverted-L tuning stub is proposed. The antenna impedance is optimized for broadband operation from 1.62 GHz to 2.97 GHz. The measured CP bandwidth is 934 MHz (1.747-2.681 GHz), that covers common wireless communication bands GSM 1800, GSM 1900, 3G/LTE 2100, 3G/LTE 2300, 4G/LTE 2500, and 2.4G Wi-Fi bands. This makes the designed antenna an appropriate candidate for ambient RF energy harvesting purposes.

12:20 ***Radial Line Helical Phased Array with Antenna Elements Rotated by Motors for Microwave Power Transmissions***

Narihiro Nakamoto, Jun Goto, Yusuke Suzuki, Toru Fukasawa, Toru Takahashi, Yoshio Inasawa and Hiroaki Miyashita (Mitsubishi Electric Corporation, Japan)

In this paper, we propose a novel radial line planar phased array in which helical antenna elements are individually rotated by their respective connected micromotors to realize dynamic beam-scanning. We designed, fabricated, and evaluated a 7-circle array with 168 helical antennas fabricated using molded interconnect device technology. The prototype antenna exhibits dynamic and accurate beam-forming performance, and also exhibits a low reflection coefficient of less than –17 and high antenna efficiency of 77%.

P09: Satellite propagation II - modelling

T08 Space (incl. cubesat)/ / Propagation

11:00 ***Accuracy Assessment of Water Vapor and Cloud Attenuation Estimated from ERA5 Single Level Parameters at Two Sites with Large Difference of Altitude***

Gustavo Siles, Juan Pablo Arciénega and Yasmín Balderrama (Universidad Privada Boliviana, Bolivia)

ERA5 reanalysis provides meteorological parameters that can help to predict atmospheric propagation effects. We investigate the accuracy of using ERA5 single level parameters, TCWV and TCLW, to calculate water vapor and cloud attenuation, respectively, in El Alto (4065 m.a.s.l, Bolivia) and Madrid (633 m.a.s.l, Spain), locations having different climatological conditions. The assessment is performed using as reference the attenuation predicted by physical models combined with atmospheric vertical profiles from radiosondes: 4 years (El Alto) and 8 years (Madrid). The most recent global prediction models from ITU-R are also implemented to complete testing analysis: P.676-12 and P.804-8 global maps based methods. The results obtained show that water vapour attenuation from TCWV predict statistics than can be used with small errors. Cloud attenuation from TCLW show large discrepancies in El Alto. However, in Madrid, good agreement with RAOBS-based statistics is observed when using Salonen08 Tunned model as cloud detection model.

11:20 ***Short-Term Forecast of Radiocommunication Geostationary Satellite Links Coupling Weather Prediction and Radiopropagation Models***

Marianna Biscarini (Sapienza University of Rome, Italy); Lorenzo Luini and Carlo Riva (Politecnico di Milano, Italy); Paolo Antonelli (HIMET, Italy); Saverio Di Fabio and Livio Bernardini (CETEMPS, Italy); Paolo Scaccia (HIMET, Italy); Tiziana Cherubini (University of Hawaii, USA); Roberto Nebuloni (Ieiit - Cnr, Italy); Laura Dossi (CNR, Italy); Domenico Cimini (IMAA-CNR & CETEMPS University of L'Aquila, Italy); Tommaso Rossi (University of Rome "Tor Vergata", Italy); Mauro De Sanctis (University of Rome "Tor Vergata", Italy & Peoples' Friendship University of Russia (RUDN), Russia); Antonio Martellucci (European Space Agency, The Netherlands); Frank S. Marzano (Sapienza University of Rome, Italy)

The objectives and the preliminary results of the RadioSatMet numerical simulator are here described. The simulation chain is aimed at assessing the radio-propagation channel over the coverage region of a geostationary satellite communication (SatCom) system, featuring adaptive techniques as smart gateway diversity, through link quality estimates provided by its ground terminals as well as numerical weather prediction data. The RadioSatMet channel assessment system generates short-term statistical nowcasts and forecasts of the propagation conditions in each point of the coverage area. The RadioSatMet channel assessment output feeds an end-to-end system simulator, which evaluates the performances of the SatCom system with a particular focus on its gateway stations, in terms of data throughput, number of gateway switches and availability gains that can be achieved by using these methods.

11:40 ***Effects from Equatorial Plasma Bubbles on the Propagation of Transionospheric Wideband Signals***

Emanoel Costa (Pontifícia Universidade Católica do Rio de Janeiro (PUC-Rio), Brazil)

The power spectra associated with wideband transionospheric signals received at Ascension Island (7.93oS, 14.25oW) during an observational campaign in October 2016 displayed flat and selective fading. The present contribution will combine the Method of Moment with the thin amplitude and phase screen formulation, in an attempt to identify structures that could be responsible for the observed behavior.

12:00 ***Modelling 3D Dynamic Cloud Fields to Investigate the Performance of FSO SatCom Systems***

Alef Comisso and Lorenzo Luini (Politecnico di Milano, Italy)

With increasing data rate requirements on SatCom systems there is a push to use higher frequency carriers. Although free space optical communications would meet these demands, they are

severely limited by the weather conditions affecting the ground stations. Therefore, it is important to model these phenomena to predict the possibility of link outages so that an appropriate fade mitigation technique can be applied. This contribution aims to extend a model in the literature (Stochastic Model of Clouds) to include the time variability of the cloud field. The temporal evolution is studied using satellite observations and is introduced into the model by inputting ERA5 data chronologically, which has been linearly interpolated to a temporal resolution of 1 minute. The new model is then used to study the effect of site diversity for the mitigation of cloud attenuation on a GEO-Earth optical link operating at 1.55 µm.

12:20 ***Internal Probing of an Asteroid Analogue by Electromagnetic Method***

Astrid Dufaure (Institut Fresnel, Aix-Marseille Université, CNRS, Centrale Marseille, France); Yusuf Oluwatoki Yusuf (Tampere University, Finland); Jean-Michel Geffrin (Institut Fresnel & Aix Marseille Univ, CNRS, Centrale Marseille, France); Liisa-Ida Sorsa (Tampere University, Finland); Sampsa Pursiainen (Tampere University, France); Christelle Eyraud (Institut Fresnel, Aix Marseille Université, CNRS, Centrale Marseille, France)

The internal structure of small solar bodies are not well-known yet. The imaging of the interior of asteroids and comet will provide important information about their formation. In this paper, we aimed to provide a fast and efficient method to roughly image the shape and the interior of small bodies of the Solar system. We focused on monostatic measurements on two analogues of the 25143 Itokawa asteroid. The back-propagation technique was applied to promptly image the shape and internal structure of the analogues. The result shows the external shape of the analogue and that the inner void core can be reached and distinguished.

E07: Computational EM in frequency domain

T09 EM Modelling and Simulation tools/ / Electromagnetics

Chairs: Conor Brennan (Dublin City University, Ireland), Juan Córcoles (Universidad Autónoma de Madrid, Spain)

11:00 ***Shape Representation in a Fixed Discretization Grid for Accelerated Topology Optimization***

Vojtech Neuman, Miloslav Capek and Lukas Jelinek (Czech Technical University in Prague, Czech Republic)

The topology optimization based on iterative changes of discretization is introduced. The optimal solution on coarse discretization is translated and enhanced on dense discretization. The similarity matrix used for solution translation is defined. Two examples of Q-factor minimization are shown to depict improvements in evaluation speed.

11:20 ***Computation of Scattering from Rough Surfaces Using Successive Symmetric over Relaxation and Eigenvalue Deflation***

Conor Brennan and Imtiaz Islam (Dublin City University, Ireland); Jason Basquill (University of Dublin, Trinity College, Ireland); Kirk M Soodhalter (Trinity College Dublin, Ireland)

The problem of computing 2D EM wave scattering from rough surfaces is addressed using an integral equation formulation discretised using the method of moments. Successive Symmetric Over-Relaxation (SSOR) is applied to the governing matrix equations along with eigenvalue deflation which is designed to separately account for the effect of those eigenvectors of the iteration matrix that have eigenvalues greater than 1. Numerical results are presented applying the method to a variety of scattering profiles and examining the resultant convergence performance.

11:40 ***A Broadband Potential-Based Boundary Element Method for Modeling Electromagnetic Scattering from Dielectrics and Conductors***

Shashwat Sharma and Piero Triverio (University of Toronto, Canada)

We present a boundary element method for electromagnetic scattering analysis, formulated in terms of the magnetic vector and electric scalar potentials rather than electromagnetic fields. The proposed potential-based formulation does not rely on the mutual coupling between electric and magnetic fields, and is therefore able to simulate dielectric objects over a wider range of frequency than is possible with state-of-the-art field-based methods, as demonstrated via numerical examples.

12:00 ***Mode-Matching Procedure for Second Order Rotationally Symmetric Modes***

Gines Garcia-Contreras (Universidad Autonoma de Madrid, Spain); Juan Córcoles (Universidad Autónoma de Madrid, Spain); Jorge A Ruiz-Cruz (Universidad Autonoma de Madrid & Escuela Politecnica Superior, Spain)

For waveguide devices, Mode-Matching represents one of the most widely used tools to compute the electromagnetic behaviour of structures due to its ability for the accurate modelling of discrete discontinuities. As devices with higher-order symmetries appear in the literature, it becomes relevant to study how it would affect the technique to use sets of modes which also have higher-order symmetry properties, such as discrete rotational symmetry. In this paper we provide a tailored Mode-Matching formulation which is capable of handling rotationally symmetric modes, while also discussing its most important properties. It has been used to analyse a variety of devices appearing in existing literature, in all of them greatly reducing the computational time and amount of modes needed for their correct modelling with regards to general-purpose Mode-Matching.

12:20 ***Results on Shadowing Determination with Linear Cost Scaling for Physical Optics Analysis***

Dao P. Xiang (Hunan Institute of Engineering, China); Matthys M. Botha (Stellenbosch University, South Africa)

The physical optics (PO) approximation is widely used for scattering analysis involving electrically very large objects. A key step in its application is structural shadowing determination with respect to the source field. This requires determining which parts of the scatterer are visible (line-of-sight) to the source. The results presented in this paper are concerned with plane wave illumination shadowing determination for mesh-based PO. The authors have been developing a multi-level field-of-view buffer-based shadowing determination algorithm with the objective of yielding linear (optimal) runtime scaling even under very extreme circumstances. This paper reports the most recent results obtained with this algorithm, comparing it with a multi-level quadtree-based reference scheme, for a challenging example featuring both severe mesh inhomogeneity and grazing incidence. Linear runtime scaling is demonstrated. Further results will be presented at the symposium.

IW03: Advanced antenna simulation methods for new communication systems with Ansys

Industrial Workshop

SW01: First edition of EurAAP Journal: Reviews of EurAAP-RoE

Scientific Workshop

Wednesday, March 30 12:40 - 14:00

Lunch / Exhibition

Wednesday, March 30 13:30 - 15:00

Poster Session Wednesday

Compact Wideband Antenna-In-Package Based on PCB Technology for 39 GHz 5G mmWave Applications

Thi Huyen Le, Ivan Ndip and Oliver Schwanitz (Fraunhofer IZM, Germany); Stefan Kosmider (Fraunhofer Institute for Reliability and Microintegration, Germany); Kavin Senthil Murugesan (Technische Universität Berlin, Germany); Uwe Maaß (Fraunhofer IZM, Germany); Martin Schneider-Ramelow (Fraunhofer IZM & TU Berlin, Germany)

In this paper, a compact wideband antenna-inpackage (AiP) for 5G mmWave applications in the 39 GHz frequency band is presented. The proposed 1x2 antenna array consists of two identical patch antenna elements, which are designed, simulated and fabricated using a multilayer PCB substrate technology suitable for chip embedding. To improve the antenna bandwidth two U-shaped slots are etched in each patch element. The fabricated 1x2 U-slot patch antenna array exhibits a measured impedance bandwidth of 3 GHz at 39 GHz frequency band, and a measured peak gain of 8.8 dBi.

FPC-Based Integration of 5G Mm-Wave Antennas and 5G Non-Mm-Wave Antennas for Mobile Phones

Huan-Chu Huang (Etheta Communication Technology Co., Ltd., Taiwan); Zhixing Qi, Dasong Gao and Hong Lin (Etheta Communication Technologies Co., China)

An innovative and practical integration of 5G millimeter-Wave (mm-Wave) antennas and 5G non-mm-Wave antennas based on the flexible printed circuit (FPC) for mobile phones is proposed. Therefore, the integrated antennas are well conformal to the curved phones shapes due to the flexible substrate. The integrated 5G mm-Wave antennas are in a 1 × 4 array which covers the 3GPP band n261 (27.5-28.35 GHz) and the two 5G non-mm-Wave antennas are integrated in an equivalent form by reusing the ground of the mentioned 5G mm-Wave antenna array to achieve MIMO function in the 3GPP band n79 (4.4-5.0 GHz). The FPC-based integrated 5G antennas (with a total length of 26.07 mm) can be attached on the inside of the curved edges of back covers to attain the

elegant applications to mobile phones.

Miniaturized 5G Module of Wideband Dual-Polarized Mm-Wave Antennas-In-Package as Non-Mm-Wave Antennas (AiPaA) for Handsets

Huan-Chu Huang (Etheta Communication Technology Co., Ltd., Taiwan); Zhixing Qi, Dasong Gao, Yanchao Zhou and Hong Lin (Etheta Communication Technologies Co., China)

This paper presents an innovative and advanced miniaturized 5G module of wideband dual-polarized (pol.) millimeter-Wave (mm-Wave) antennas-in-package as non-mm-Wave antennas (AiPaA) for handsets. That is, the module of mm-Wave antennas-in-package (AiP) can also function as virtual equivalent non-mm-Wave antennas. This AiPaA module can cover 3GPP mm-Wave bands n257, n261, n260 and the mm-Wave band (24.75-27.50 GHz) in China. Moreover, without physical non-mm-Wave antennas, the module itself can operate in 3GPP non-mm-Wave bands n78 and n79. Thus, this AiPaA module can serve as a miniaturized compelling 5G antenna total solution to handsets without expanded volumes for physical non-mm-Wave antennas.

SICL Excited Dual Band Uniform Crossed Dipole Array for Endfire Applications at 5G Millimeter Wave Frequencies

Naman Baghel and Soumava Mukherjee (Indian Institute of Technology Jodhpur, India)

This paper presents a novel technique to implement crossed dipole antenna fed by Substrate Integrated Coaxial Line (SICL) technology. The inherent advantage of out of phase surface current of the SICL transmission line is utilized efficiently to excite the two dipole antennas. The crossed dipole is implemented to obtain dual band response at 26 GHz and 28 GHz. Two 45 inclined dipoles are printed on the top/bottom of the substrate and simultaneously fed by top/bottom plate of the SICL line. SICL 1:4 power divider is employed to feed four crossed dipole antenna to form an array. The array exhibits a gain of 9.7 dBi and 10 dBi at 26 GHz and 28 GHz respectively exhibiting wide 3.1 GHz bandwidth . The cross polarization better than 20 dB is obtained for the proposed design. The proposed antenna finds its suitability for the much focused 5G millimeter wave frequency bands.

Designing a Microwave Moisture Content Sensor for Carasau Bread: A Feasibility Study

Giacomo Muntoni (University of Cagliari, Italy); Alessandro Fedeli (University of Genoa, Italy); Matteo Lodi (University of Cagliari, Italy); Marco Simone (Univerity of Cagliari, Italy); Andrea Randazzo (University of Genoa, Italy); Giuseppe Mazzarella and Alessandro Fanti (University of Cagliari, Italy)

The design and numerical simulations of a microwave sensor for the moisture content of traditional Carasau bread is presented in this paper. The results highlight the ability of a simple patch antenna to discriminate small percentage variations in water content in the food product, avoiding misinterpretations due to other parameters modifications, such as distance of the sensor and thickness of the bread sample.

Preliminary Design of a Double Ridge Waveguide Device for Monitoring the Complex Permittivity of Carasau Bread Doughs

Claudia Macciò and Matteo Lodi (University of Cagliari, Italy); Nicola Curreli (Italian Institute of Technology, Italy); Lorena Mariani and Andrea Melis (University of Cagliari, Italy); Marco Simone (Univerity of Cagliari, Italy); Giacomo Muntoni (University of Cagliari, Italy); Tonino Pisanu (INAF - OAC, Italy); Maurizio Bozzi (University of Pavia, Italy); Giuseppe Mazzarella and Alessandro Fanti (University of Cagliari, Italy)

The Industry 4.0 paradigm calls for engineering solutions for monitoring the industrial production and quality of food products. Microwave devices can be powerful tools in this scenario. This work deals with the preliminary design of a double ridge waveguide to perform indirect measurements of the complex permittivity of a traditional food product from Sardinia (Italy), i.e. the Carasau bread, produced in a small bakery industry. To this aim, the complex dielectric permittivity of doughs was measured with open-ended coaxial probe in the range 0.5-8.5 GHz. The dielectric spectra were fitted to a third-order Cole-Cole model. Then the data were used to numerically study the microwave signal propagation in the double ridge waveguide investigating different sample configurations. With our full-wave simulations, the thickness of the sample holder, the occupation length of the sample in the waveguide, as well as the inclination angle were determined to achieve suitable transmission performance.

Microwave and Contactless Sensor for Millimeter Inclusions Detection in Biomedical Applications

Angelica Masi, Sabrina Rotundo and Eliana Canicattì (University of Pisa, Italy); Francesco Molesti (Free Space SRL, Italy); Danilo Brizi (University of Pisa, Italy); Agostino Monorchio (University of Pisa & CNIT, Italy)

In this paper, we present an innovative sensor for non-invasive detection of millimeter inclusions by using a microwave radiating system. The proposed device consists in a microstrip self-resonant spiral coil inductively coupled to an external concentric planar probe loop, working at a frequency of 570 MHz. The microwave sensor configuration is the result of an optimization process of the spiral coil Q-factor maximization, required to obtain a millimeter resolution for the inclusions detection. In particular, the detection is achieved by observing the amplitude and frequency shift variation of the external planar probe input impedance. We performed full-wave simulations to design and evaluate the radiating system performance. Numerical results validated the introduced theorical approach, encouraging further analysis for the potential use of such sensor in biomedical applications.

Sensorized Facemask with Temperature RFID Sensor for Cough Analysis

Nicoletta Panunzio, Francesca Ciafrei and Cristina Magnante (University of Rome Tor Vergata, Italy); Giulio M. Bianco (University of Roma Tor Vergata, Italy); Gaetano Marrocco (University of Rome Tor Vergata, Italy)

One of the most common symptoms of respiratory pandemics, like COVID-19, is cough. Its monitoring is useful to trace the progress of the disease and to evaluate its severity. Traditional measurement methods are bulky and wired. Instead, wearable and wireless technologies such as the Radio Frequency Identification (RFID) could allow the implementation of platforms able to monitor patients remotely. The monitoring of the respiratory function has already profited from the operation of temperature sensors put close to the airways as well as from the sensorization of facemasks, widely used in case of respiratory viruses. In this paper, a UHF RFID temperature sensor tag integrating auto-tuning capability is integrated inside a FFP2 facemask to retrieve temperature profiles used to count and detect three different types of coughing. All the cough shots are consistently detected by the system, and their periodicity and duration can be determined.

A Novel RCS Based CRFID Tag Design

Nadeem Rather (Tyndall National Institute, Ireland); John Laurence Buckley (Tyndall National Institute & University College Cork, Ireland); Brendan O'Flynn (Tyndall National Institude, Ireland); Mélusine Pigeon (Tyndall National Institute, Ireland)

In this paper, a Chipless RFID tag design based on Radar Cross Section (RCS) operating principle is proposed. The tag is implemented using a series of circular ring resonators to enable tag identification. The resonators are simulated and then fabricated on an FR4 substrate. A calibration technique using a ring resonator to improve the detection of 8-bit data is proposed and demonstrated. The fabricated tag is measured at a distance of 160 mm using the monostatic RCS method. The measurement results verify the simulation results and show accurate detection of the encoded information.

A Novel Polyimide Flexible Antenna Design for S-Band Applications

Alassane Sidibe (LAAS-CNRS, France); Alexandru Takacs (LAAS-CNRS Université de Toulouse, France); Daniela Dragomirescu (LAAS-CNRS, France); Samuel Charlot (LAAS, France); Jan Mannekens (Uwinloc, France)

The technological advances in electronic devices and the Internet of Things bring us to be surrounded by multiple sensors in the coming years. These devices should be conformable and adapted to small or irregular shapes and surfaces. This is why flexible materials are becoming important in this field thanks to their lightness, stretchability, and robustness especially in wearable electronics to get integrated on clothes for biomonitoring. Our proposal in this paper concerns the design, printing process, and performance of a novel antenna on a polyimide flexible substrate. It is based on a loop antenna and has dimensions of 40 mm × 35 mm × 0.127 mm. Its very wideband behavior from 2.4 GHz to 4 GHz allows targeting S-Band applications such as LTE and Wi-Fi. Interesting performances are also achieved in terms of radiation patterns. At 2.45 GHz, the maximum antenna gain is about +2.6 dBi with an omnidirectional pattern but at higher frequencies, the antenna is more directive with a higher gain.

Compact and Broadband CPW Fed Ring Pair Slot Antenna

Surbhi Arora and Girish Kumar (IIT Bombay, India)

A compact and broadband coplanar waveguide (CPW) fed ring pair slot antenna is presented in this paper. The designed antenna operates in the frequency range from 2.6 to 7.13 GHz (93%) for $|S11| \leq -10$ dB with a peak gain of 5.06 dBi at 5.6 GHz. The designed antenna is uniplanar having the size of $0.39\lambda_0 \times 0.3\ \lambda_0 \times 0.007\ \lambda_0$ (λ_0 is the wavelength at the lowest operating frequency in free space). The proposed configuration has a stable radiation pattern over the operating frequency band. The designed antenna is fabricated and simulated results are validated with measured results.

A Frequency Domain Approach for Estimating the Angular Dependent Delay of an UWB Antenna

Ali Rashidifar (Technische Universität Ilmenau, Germany); Sebastian Semper (Ilmenau University of Technology, Germany); Christoph Wagner (Technische Universität Ilmenau, Germany)

The procedure of estimating the angular dependent delay of an Ultra Wideband (UWB) antenna, directly in frequency domain, is presented. It is shown that in this approach any occurrences that can lead to inaccurate results, such as the windowing effect, can be entirely avoided. It alleviates the need to design a specific pulse, since the transfer function can be obtained by a frequency sweep. Moreover, polarization mismatch is accounted in the analysis. To this end, an UWB monopole antenna is designed and it is simulated with time and frequency domain solvers. The simulation results demonstrate that only frequency domain analysis is sufficient for the delay estimation. The outcome of this work provides a clear procedure for obtaining the angular dependent delay of an antenna in an accurate way.

Frequency Reconfigurable and Circularly Polarized Patch Antenna over Dual Ultra-Wideband Channels

Amina Benouakta (University Côte d'Azur & CNRS LEAT : Electronics, Antennas and Telecommunications Laboratory, France); Fabien Ferrero (Université Cote d'Azur, CNRS, LEAT & CREMANT, France); Leonardo Lizzi (University Côte d'Azur, CNRS, LEAT, France); Robert Staraj (University Cote d'Azur, CNRS, LEAT, France)

This paper presents an Ultra-Wideband (UWB) patch antenna which is aimed to be an Anchor-antenna in UWB localization systems. It can operate distinctively in two different UWB frequency channels. Both of these channels have 500 MHz bandwidth, the lowband channel is centered at 4 GHz and the highband channel at 6.49 GHz. Reconfigurability to switch from one channel to another

is achieved by changing the size of the radiating element. Additionally, this UWB antenna is aimed to be circularly polarized over both channels, which is realized through two branchline couplers placed on a bottom layer. Results of reconfigurability and circular polarization operation are verified by simulation and measurements.

Wideband Top-Loaded Monopole Antenna

Bingyue Qu (Faculty of Electronic and Information Engineering, Xi'an Jiaotong University, China); Yongqiang Pang, Luyi Wang and Anxue Zhang (Xi'an Jiaotong University, China); Zhuo Xu (Electronic Materials Research Laboratory, Xi'an Jiaotong University, China)

This paper proposes a low-profile and wideband monopole antenna. The low-profile property is achieved by capacitive and inductive loading to adjust the impedance of the antenna, and the wideband operation is achieved by designing the current paths on the top-loaded patch. The antenna has height of 0.07λL and stable omnidirectional radiation pattern in the operating band. The measured relative bandwidth is 69% and the gain in the operating band is higher than 2.2 dB.

An E-Band Reconfigurable Phase Shifter Based on Gap Waveguide

Enlin Wang, Jian Yang and Ashraf Uz Zaman (Chalmers University of Technology, Sweden)

A compact low-loss reconfigurable phase shifter based on gap waveguide (GW) is proposed. The phase shifter is realized by controlling the different lengths of the transmission line. A movable metal block is placed on the transmission line, and different phase shifts can be obtained through different moving distances to realize reconfiguration. In this paper, the possible errors in practical application are considered and the solutions are given. The use of GW technology enables the design to achieve low-cost manufacturing and simple implementation. The simulation S-parameters show that the impedance matching bandwidth with reflection coefficients below –15 dB is 19.1%, covering 71 – 86 GHz, and the maximum phase shift of 180° can be achieved.

Feasibility Study for the Design of a Simultaneous X/Ka/Ka-Radar Feed System

Christophe Granet (Lyrebird Antenna Research Pty Ltd, Australia); John Kot (Young & Kot Engineering Research, Australia)

A feasibility study to design a complex X/Ka-band feed system that also incorporates a Ka-band Radar function is undertaken. An unconventional wide-band Ka-band polarizer design was needed due to the high-power nature of the application.

Comparative Study of Struts' Geometry and Material in Reflector Antennas

Stefanos Lampiris (NCSR Demokritos, Greece); Vasileios Vlachodimitropoulos (NCSR Demokritos, Switzerland); Aris Tsolis and Antonis A Alexandridis (NCSR Demokritos, Greece)

Reflector antennas systems use struts in order to antenna structural parts such as feeders or sub-reflectors. Struts' presence generates scattered fields that affect the antenna performance. In this paper, a comparative study between different struts' materials and cross-sections is presented. For the analysis, a Cassegrain configuration was used, designed for X-band operation. Struts' analysis was conducted through simulations at 8.425 GHz. Two different struts' positions (setups) were also studied. Detailed discussion on performance results is presented.

Reduction of Sidelobe Level for Dual Frequency and Dual Polarization Reflectarray

Hiroshi Hashiguchi, Naobumi Michishita and Hisashi Morishita (National Defense Academy, Japan); Hiromi Matsuno and Takuya Ohto (KDDI Research, Inc., Japan); Masayuki Nakano (KDDI Research, Japan)

To reduce the coverage holes from the base station, reflectarray has gained attention for 5G mobile wireless communication. This paper proposes the design method for dual frequency and dual polarization reflectarray operating at 28 and 39 GHz. The proposed method combines the modified phase and pattern mask, which can reduce the sidelobe level of the dual frequency and dual polarization reflectarray. This paper demonstrates the reflectarray designed by the proposed method in simulation and measurement.

Design of Tunable Millimetre-Wave Pass-Band FSS Loaded with GaAs Air-Bridged Schottky Diodes

Ioannis Gerafentis and Alexandros Feresidis (University of Birmingham, United Kingdom (Great Britain))

In this paper, a tunable passband Frequency Selective Surface (FSS) loaded with GaAs air-bridged Schottky diode is presented, appropriate for beam-steering and beam-scanning applications. The proposed structure allows the simultaneous control of both phase and magnitude of the electromagnetic waves transmitted by each unit cell through the introduction of tuning, which is achieved by the Schottky diode technology. The single-layer obtained a tuning bandwidth lies within 7.04-9.42 GHz, with a central frequency of 40.5 GHz, the insertion loss has an average value around 1.47dB and the phase shift is equal to 101°. This FSS can be used as the building block for the development of higher-order tunable FSS filters or for transmitarrays find applications in future 5G/6G and satellite communication systems. In this work, a multilayer tunable unit cell is reported which achieves a phase shift higher than 360°, average insertion losses within 5-11dB, and a 3dB bandwidth of 3.5GHz.

Broadband Pancharatnam-Berry and Dynamic Phase Unit Cells for Dual Circularly Polarized Reflectarrays

Sheng Gao, Jinlin Yang, Yan Deng and Shun Li Li (Southeast University, China); Hongxin Zhao (State Key Laboratory of Millimeter Waves, Southeast University, China); Xiaoxing Yin (State Key Laboratory of Millimeter Waves, China)

Broadband Pancharatnam-Berry (P-B) phase and dynamic phase hybrid unit cells for realizing dual circularly polarized (DCP) independent beam control reflectarrays is proposed. The unit cells present independent reflection phase shift for left hand circularly polarized (LHCP) and right hand circularly polarized (RHCP) incident waves, which are achieved by simultaneously utilizing P-B phase and dimension vary dynamic phase. A broadband P-B phase unit cell with reflection coefficient greater than -0.5 dB in the range of of 6.9-15.7 GHz (bandwidth of 77%) is designed, and then independent dynamic phase achieved by adjusting the dimension of the unit cell. Simulation results reveal the P-B phase shift range and dynamic linear phase shift range of the single-layer unit cells are 360◦ in the range of 8-12 GHz (bandwidth of 40%).

Estimation of Characteristics for the Reflective Rectangular Slot Element Using MoM with One Basis Function

Svyatoslav Ballandovich, Liubov Liubina and Mikhail Sugak (Saint Petersburg Electrotechnical University LETI, Russia)

Estimation the reflected field phase, admittance and unknown basis functions coefficients are presented for the case of single-layer rectangular slot element in unit cell. The analysis is based on a solution of an integral-equation system with the Method of Moments in spectral domain. Only one basis function is used for the analysis. It is shown that this approach provides satisfactory accuracy for the development of the slot reflectarray antennas. Characteristics of the unit cell and reflectarray antennas obtained by proposed approach and full-wave simulations are presented.

Effect of Integrated Lens Antenna Diameter on Scan Loss

Sabin Kumar Karki and Juha Ala-Laurinaho (Aalto University, Finland); Ville Viikari (Aalto University & School of Electrical Engineering, Finland)

An integrated lens antenna (ILA) is desired to have high directivity and a wide steering range. The directivity of an ILA is proportional to its diameter. In this work, the relation between the diameter and the scan loss of the elliptical and hemispherical ILAs is studied using the ray-tracing simulation. The simulation study finds that the scan loss of an ILA, both elliptical and hemispherical, is proportional to the diameter. In addition, the optimum extension lengths of the extended hemispherical ILA are presented for various diameters and relative permittivities which serve as the design guideline for ILA designers.

Flat Luneburg Lens Antenna System in Gap Waveguide Technology at V-Band

Dayan Pérez (Public University of Navarra (UPNA) & Institute of Smart Cities (ISC), Spain); Christos Bilitos (University of Rennes 1, France); Jorge Ruiz-García (Université de Rennes, France); David González-Ovejero (Centre National de la Recherche Scientifique - CNRS, France); Miguel Beruete (Universidad Publica de Navarra, Spain)

In this paper, a flat lens antenna using Gap Waveguide (GW) technology is designed at V-band. A Groove Gap Waveguide (GGW) horn antenna is used to feed the metamaterial lens placed in a parallel plate waveguide (PPW), in order to achieve a plane wavefront in the direction of propagation. Both devices, the metalens and the GGW antenna, achieve excellent radiation results when combined together. Due to its fully metallic composition, the structure presents more robustness, lower loss, and adaptability to a flat surface. These features make it an apt solution for millimeter-wave applications.

Dual-Circularly Polarized 3D Printed Gradient Index Flat Lens Antenna at W-Band

Javier Melendro Jiménez (Universidad Politécnica de Madrid, Spain); Pablo Sanchez-Olivares (Universidad Politecnica de Madrid, Spain); José Manuel Fernández González (Universidad Politécnica de Madrid, Spain); Adrián Tamayo-Domínguez (Universidad Politecnica de Madrid, Spain)

A gradient index flat lens with a directive beam-steering radiation pattern and configurable dual circular polarization is discussed in this contribution. The dielectric lens, designed to operate at W band, is perforated to achieve a radial decreasing dielectric permittivity characteristic, so high-directivity beam with planar wave front can be obtained. A precisely designed stereolithography 3D structure is adhered to the surface of the lens to turn the vertical or horizontal electric field polarization into RHCP (Right-hand circular polarization) or LHCP (Left-hand circular polarization), respectively. An open-ended square waveguide is used as feeding structure to generate the vertical and horizontal polarization exciting the two degenerate modes TE10 and TE01. The system can achieve a wide beam-steering range of ±30° in both azimuth and elevation planes, attained by applying precise displacements to the feeding square waveguide position. In order to experimentally validate the antenna performance, the design is manufactured and measured

Decoupling Between Multiple Planar Inverted-F Antennas Without Adjusting Antenna Configuration

Phung Quang Quan (National Defense Academy of Japan, Japan); Naobumi Michishita (National Defense Academy, Japan); Hiroshi Sato (Panasonic Corporation, Japan); Yoshio Koyanagi (Panasonic, Japan); Hisashi Morishita (National Defense Academy, Japan)

In this study, a simple decoupling method using parasitic elements (PEs) connected by a bridge line (BL) for multiple planar inverted-F antennas (PIFAs) is proposed. The PEs and BL only need to be loaded in close proximity onto the PIFAs. Thus, redesigning the original antenna elements is not necessary. This feature is useful when design conditions make it difficult to redesign the original

antenna, for example, to redesign small modular antennas. For the case of two PIFAs, using PEs and BL reduces the mutual coupling from –6.6 to –16.7 dB, and simultaneously maintains the resonance at the desired frequency (2.0 GHz), resulting in an improved total antenna efficiency from 77.4% to 96.0%. In the case of four PIFAs, the proposed method still showed its efficiency in decoupling, but some deteriorated efficiencies are also observed compared with the case of two PIFAs. This deterioration will improve in the future.

Absorptivity Modulation with Salisbury-Inspired Structures for X-Band

Xhoandri Lleshi, Thi Quynh Van Hoang, Paolo Martins and Brigitte Loiseaux (Thales Research & Technology, France); Didier Lippens (Institut d'Electronique, de Microélectronique Et de Nanotechnologie, France)

Absorptivity control is a very desired feature in many RF applications as it allows enhancing EM properties such as antenna radiation patterns and reducing radar cross section. In this paper, two Salisbury-inspired structures with absorption level of 20% and 50% in X-band frequencies (8 - 12 GHz) are presented. Both structures are fabricated by electron beam evaporation technique with Nickel Chrome as material for the resistive coating on a PEKK dielectric substrate, which is manufactured by thermal compressing. The characterization in non-anechoic environment confirms the results obtained by numerical computations. For both vertical and horizontal polarizations, quasi-perfect agreement over the frequency band of interest is found with a maximal variation of the absorptivity less than 5% between the center frequency at 10 GHz and the edges frequencies at 8 GHz and 12 GHz. The absorption behavior of the two structures was also evaluated under oblique incidence.

Enhancing the Beamwidth of Low Profile Single-Fed Microstrip Antennas Using Parasitic Elements

Ismael Vico Trivino and Anja K. Skrivervik (EPFL, Switzerland)

In this paper we present a technique to broaden the beamwidth of conventional patch microstrip antennas by using parasitic elements. This technique allows to keep the main advantages of microstrip antennas while increasing their beamwidth. We provide guidelines on how to tune the shape of the pattern from directive patterns to broad beam by tuning a few key parameters. The antenna that we propose operates in the ISM band at 2.4GHz and is compatible with linear and circular polarization. Using this technique, the beamwidth of a regular patch antenna can be increased from the usual 70° up to 200°, and is compatible both with linear and circular polarization.

3-D Modeling of Human Hands for Characterizing Antenna Radiation from a 5G Mobile Phone

Lauri Vähä-Savo (Aalto-University, Finland); Pasi Koivumäki and Katsuyuki Haneda (Aalto University, Finland); Clemens Icheln (Aalto University & School of Electrical Engineering, Finland); Jingjing Chen (Huawei Technologies Sweden AB, Sweden)

A method to obtain the three-dimensional (3D) model of a hand for an antenna-hand interaction analysis of a mobile phone is presented. The radiation and reception performance of millimeter-wave signals is more susceptible to intervention by a user's hand than that of legacy below-6 GHz radios. Hand models representing a wide range of natural handgrips of mobile phone users are therefore essential. The 3D modeling is based on the photogrammetry using a video footage of a hand. Multiple 3D models of natural handgrips can be obtained with reasonable efforts. The radiation performance of a canonical antenna array implemented into a mobile phone sized chassis is evaluated using a developed series of 3D hand models, showing the uncertainty of repeatable antenna-hand interaction analyses.

Digital Switch Matrix: A New Approach and Realization for Switch Matrix Structure

Nuri Yaris and Serkan Yıldız (The Scientific and Technological Research Council of Turkey, Turkey); Huseyin Aniktar (Tubitak & Bilgem, Turkey); Muhammed Çalış and Dursun Baran (The Scientific and Technological Research Council of Turkey, Turkey); Enes Karav (TUBITAK, Turkey); Hakan Yaren (The Scientific and Technological Research Council of Turkey, Turkey)

In this letter a new switch matrix topology has been introduced for HF applications. A HF switch matrix is designed and realized by digitally on a Zynq Ultrascale FPGA core. This topology is named as Digital Switch Matrix (DSM). The DSM performs switching between 32 input ports to 32 output ports in full fan out configuration. This structure provides switching any output can be switched to any input without blocking any other output or input. Traditional switch matrixes so called analog switching matrix in this letter, consists of number of distinct RF boards for each input and output channels. These solutions are costly and have a big form factor. The proposed DSM does the same job on a single board. Therefore, it has superior advantages regarding both low cost and form factor. The measurement results of the proposed DSM are presented.

A 868 MHz Compact Antenna with No Impact of the Material Support

Shandipsing Robee (IMT ATlantique / Lab-STICC, France); Jean-Philippe Coupez (IMT ATlantique/ Lab-STICC, France); Francois Gallée (IMT Atlantique, France); Darius Jakonis (RISE Research Institutes of Sweden, Sweden); Valerio Beni (RISE Research Institutes of Sweden, France); Stephane Rioual (University of Brest, France)

An ISM band sectorial compact antenna working at 868 MHz is presented in this paper. The antenna is designed to have very low perturbations in terms of radiation pattern, bandwidth and input impedance when mounted on different environments at the rear (i.e. wood, plastic or metal support). Furthermore, the PIFA topology of the antenna allows an easy matching either to a 50 Ohm input

impedance for IoT/LoRA applications or to a complex impedance value for RFID applications with the help of a simple matching circuit.

Additively Manufactured Helix Antenna for X-Band Applications

David Panusch, Florian Hubert and Felix Bachbauer (Friedrich Alexander University Erlangen-Nuermberg, Germany); Konstantin Lomakin (Friedrich-Alexander University, Germany); Gerald Gold (FAU Erlangen-Nürnberg, Germany)

This work presents an additively manufactured helical antenna for X-Band. A comparison between stereolithography and selective laser sintering processes is made. The proposed antenna concept includes a transition from the helix coil to an X-band waveguide, which allows for matching of the antenna to the waveguide. In our measurements, the proposed antennae featured a -10dB-bandwidth of 2.8 GHz and a -20 dB-bandwidth of 0.28GHz respectively. The suggested manufacturing and de- sign process is, therefore, a major step towards enabling complex antenna geometries.

Design Optimization of Pyramidal Horn Antennas for 3D Printing in the mm-Wave Range

Konstantin Lomakin (Friedrich-Alexander University, Germany); Jan Schür (Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), Germany); Gerald Gold (FAU Erlangen-Nürnberg, Germany)

In this work, additively manufactured pyramidal horn antennas are presented which are fabricated from UV-curable polymer resin by a DLP 3D printing system and subsequently coated by copper electroplating. In order to improve printing and metal plating quality, the models are adapted following the slotted waveguide approach and build orientation is discussed to cope with support of overhanging structures. The manufactured specimens reveal almost identical performance compared to a commercially available equivalent. This way, successful application of the slotted waveguide approach is demonstrated with horn antennas for mm-Wave frequency range.

Effective Permittivity Measurement of 3D-Printed Dielectric Crystals

Simon P Hehenberger (DLR- German Aerospace Center, Germany); Aparna Adithyababu (Institute of Communication and Navigation, German Aerospace Center (DLR), Germany); Stefano Caizzone (German Aerospace Center (DLR), Germany)

Additive manufacturing offers new possibilities in the design of innovative antennas. In order to fully exploit its potential, it is necessary to fully use the capabilities offered by the 3D printing technology. 3D-printed structured dielectrics are currently receiving a lot of interest in this respect. However, the characterization of the dielectric properties of such crystal structures is not easy and often assumptions on such properties need to be done. This paper shows a characterization of additively manufactured structured dielectrics in terms of their permittivity and loss tangent in a simple cubic (SC) and face centered cubic (FCC) crystal geometry with different fill fractions. Measurement results are compared to values predicted by the Maxwell-Garnett effective media approximation or by the effective refractive index extracted from a three-dimensional plane wave expansion method (PWEM) in the long wavelength limit.

Dual Circularly-Polarized K-Band Horn Antennas with Bow-Tie Mode Converter

Eduardo Garcia-Marin (Universidad Autonoma de Madrid, Spain); Pablo Sanchez-Olivares (Universidad Politecnica de Madrid, Spain); Jose Luis Masa-Campos (Universidad Autonoma de Madrid, Spain); Jorge A Ruiz-Cruz (Universidad Autonoma de Madrid & Escuela Politecnica Superior, Spain)

In this article, three dual circularly-polarized K-band horn antennas are designed and experimentally validated. All designs are based on a common topology: a square waveguide input, a bowtie-shaped polarizer, and a flare section. Either left or right-handed radiation can be achieved by exciting either mode in the square waveguide. The bowtie polarizer outstands as a simple, easy-to-manufacture way of obtaining circular polarization. The three designs differ just in the flare section: a circular aperture, a square aperture and a bowtie-shaped aperture have been considered. The advantages of each aperture type will be discussed. The prototypes have been manufactured by Direct Metal Laser Sintering, allowing a single-block assembly. Over 20% bandwidth with axial ratio under 3 dB and gain around 19 dBi has been experimentally obtained.

Multi-Permittivity 3D-Printed Ceramic Dual-Band Circularly Polarized Dielectric Resonator Antenna for Space Applications - Measurement

Quentin Lamotte, Gautier Mazingue, Jacek Bhatker and Maxime Romier (Anywaves, France); Nicolas Capet (ANYWAVES FRANCE, France); Nicolas Delhote (XLIM - UMR CNRS, University of Limoges, France); Cyrille Menudier (XLIM UMR 7252, Université de Limoges/CNRS, France); Olivier Tantot (XLIM - University of Limoges, France); Marc Thevenot (XLIM-UMR CNRS 7252, University of Limoges, France); Kevin Elis (CNES, France)

This document follows a previous article \cite{eucap2021} which present the design of a Dielectric Resonator Antenna (DRA) developed by ANYWAVES with the support of the French Space Agency (CNES) and the help of an academic partner XLIM. This antenna is circularly-polarized, dual-band (Upper-L-Band (1.559 - 1.61 GHz) and TT\&C S-Band (2.025 - 2.29 GHz)) and designed to be integrated on a CubeSat or Nanosatellite. The particularity of this DRA is that the dielectric part is a structured 3D-printed block of Zirconia with two different permittivities. Two different feeding lines have been designed: with and without an integrated diplexer. Two breadboards of this antenna had been fabricated and measured in the premises of XLIM.

Microstrip-To-Waveguide Transition for 3D-Printed mm-Wave Sectoral Horn Array

James R Henderson and Marcus C Walden (Plextek, United Kingdom (Great Britain))

This paper discusses a novel PCB transition to feed an H-plane sectoral horn array intended for use with highly integrated mm-wave beamforming devices. To maintain the half-wavelength element spacing necessary for grating-lobe free operation, the signal launch into rectangular waveguide is oriented such that the waveguide 'b' dimension aligns with the PCB edge. The fabricated design achieves a good impedance match over a 14 GHz bandwidth centred at 64 GHz.

Linear-To-Circular Polarization Converter Based on Four-Arms Star FSS at 5.2 GHz for 5G Applications

Deisy Mamedes and Jens Bornemann (University of Victoria, Canada); Alfredo Gomes Neto (Federal Institute of Paraíba & Grupo de Telecomunicações e Eletromagnetismo Aplicado - GTEMA, Brazil)

A single-layer frequency selective surface (FSS) polarizer is proposed as a linear-to-circular polarization converter, operating at 5.2 GHz for 5G applications. The analyses are based on the magnitude and phase of the transmission coefficient of two orthogonal electric field components. The four-arms star geometry used in the FSS polarizer is simple to design, and equations are provided. The design approach is validated by a good agreement between numerical and measured results.

Performance of Doubly Periodic Absorpbing Structures Formed by Spherical Black Holes on a PEC Screen

Yana Chizhevskaya (Moscow Institute of Physics and Technology, Russia)

The problem of electromagnetic plane wave scattering by doubly periodic dielectric structures composed of spherical radially inhomogeneous absorbing elements of black hole type arranged on a perfectly conducting screen is considered. An algorithm accounting for the features of the black holes is developed on the basis of the hybrid projection method for solution of the problem. A number of numerical results characterizing both the effectiveness of the algorithms themselves and the properties of the black-hole-based absorbing structures are presented and discussed.

Low Radar Cross Section Dipole Antenna Integrated with Absorptive Frequency Selective Reflection Structure

Mehran Manzoor Zargar (Indian Institute of Technology Jammu, India); Archana Rajput (IIT JAMMU, India); Kushmanda Saurav (Indian Institute of Technology Jammu, India); Shiban K Koul (Indian Institute of Technology Delhi, India)

This paper presents the design of an AFSR backed low RCS dipole antenna. The polarization-insensitive AFSR structure consists of a reflection notch within the two broad absorption bands. A dipole antenna having operating frequency synchronized with the reflection notch of the AFSR structure is integrated with the 6 x 6 array of the AFSR unit cell. The AFSR backed dipole exhibits an RCS reduction of more than 20 dB at the side-bands of the operating frequency for TE and TM polarized incident waves without any significant degradation in the antenna performance. The AFSR integrated dipole shown an enhancement in the gain by 1.27 dB in the broadside direction. The proposed AFSR being polarization-insensitive, can suitably be employed for the RCS reduction of a dual-polarized/circularly polarized antenna in future works.

Microwave Absorber Made of Hanoi-Tower Shaped Dielectric Resonators and a Magnetic Support

Pablo Helio Zapata Cano, Erika Vandelle, Thi Quynh Van Hoang and Brigitte Loiseaux (Thales Research & Technology, France)

This paper presents a 3-D printing-compatible wideband absorber with high angular robustness. A periodic structure, composed of Hanoi-Tower shaped resonators, is fabricated with a lossy 3-D printable dielectric material using additive manufacturing, and glued on a magnetic elastomeric material. Exploiting the resonating modes in the periodic resonators, high absorption is achieved over a large bandwidth. The resonators' shape and dimensions are chosen accordingly to the material properties so that a high angular robustness is reached. Moreover, the presence of a magnetic support enhances the absorption capabilities of the structure, specially for the TM polarization, where a reflectivity below -10 dB for most incident angles over the 4-12 GHz band is reached. Finally, diffraction phenomena happening at high frequencies are studied, showcasing that high-order diffraction can be avoided by reducing the size of the structure and increasing the permittivity of the dielectric material.

Polarization Dependent Multi-Functional Engineered Surface

Fereshteh Samadi (École de technologie supérieure (ÉTS)); Ammar Kouki (Ecole de Technologie Supérieure, Canada)

In this study, we propose a multi-functional unit-cell that integrates reflectarray and linear polarizer functions together. The unit-cell is composed of a multi-layer structure and depending on the polarization, it can perform as a reflectarray or transmission type linear polarization converter. Our results demonstrate that in the reflection mode, the unit-cell shows high reflection magnitude around one and a nearly full phase coverage of 310° at 14GHZ. In the transmission mode, the unit-cell functions as a highly efficient linear polarization converter with PCR more than 95% in the broad frequency range of 3 GHz to 14 GHz. Our results reveal that the proposed unit-cell is suitable for multi-functional applications such as bidirectional wireless Communication.

Dual-Band and Dual Linear to Dual Circular Polarization Transformer FSS in Reflection for Satellite Communications

Miguel Salas-Natera, Roberto Garrote and Ramón Martínez (Universidad Politécnica de Madrid, Spain)

A Dual-band and dual linear to dual circular polarization single-layer transformer Frequency Selective Surface (FSS) in reflection mode for satellite communications is presented. The unit cell proposed provides a low-profile antenna implementation and low-cost solution, achieving an axial ratio below 1dB in a frequency range from 17.7-20.9GHz (16%) at K band and 28.6-30.1GHz (5%) at Ka band. The obtained bandwidth fulfils the ITU frequency band for most of the global region. Besides, the dual-circular polarization is obtained be using a two linear polarization feed with two ports. This reduces feed chain complexity, weight and cost.

Design of High-Frequency Selective Rasorber with Wide-Angle Broadband

Ying Sun and Shuai Zhang (Aalborg University, Denmark)

a novel wide-angle rasorber with a wide transmission window and two wide absorption bands at both sides of the transmission window based is presented in this article. The rasorber consists of a metallic absorption layer (loss layer) and a metallic FSS transmission layer (lossless layer). The transmission channel is achieved by a staggered grid slot. An equivalent circuit model is proposed to explain the fundamental operating principle of this model and how to achieve the characteristic of the transmission window within the absorption band. The simulated results show that a flat less than 1 dB transmission window can be obtained from 9.5-10.8 GHz, and the -10dB absorption bands are 6.2-8.9 GHz and 13.7-22 GHz under TE polarization. The transmission bandwidth and absorption bandwidth of FSR under TE and TM are almost the same. At the same time, oblique incidence can reach 50°, with good angular stability

Mosaic Frequency Selective Surface with Wideband Response for the Optically Transparent and Absorber Applications

Nur Biha Mohamed Nafis (Universiti Teknologi Malaysia, Malaysia); Mohamed Himdi (Université de Rennes 1, France); Mohamad Kamal A. Rahim (Universiti Teknologi Malaysia, Malaysia); Faissal Merzaki (Université de Rennes 1, France)

This study investigated the performance of a Mosaic Frequency Selective Surface (MFSS) for two different applications: optical transparency and absorber. The MFSSs comprising the transparent MFSS fabricated from the polycarbonate substrate (permittivity, εr of 2.9) and the absorber MFSS that utilized the Polyethylene Terephthalate (PET) substrate (εr of 2.7). For optical transparency application, the MFSS unit cell was composed of a conductive metallic element design that integrates the Koch fractal and the double hexagonal loop, while the resistive MFSS unit cell with sheet resistivity of 100 Ω/sq was utilized for the absorber application, were fabricated on the aforementioned substrates. Based on the results, it was concluded that the transparent MFSS yielded a wideband stopband and passband responses (fractional bandwidth (FBW) > 50%) with a low cross-polarization (-37 dB), and a wideband absorptivity response with FBW of 121 % was achieved with the thin MFSS absorber

Efficient Computation of Radomes and Lenses by MLFMM-FFT with NURBS

Alejandro Pons-Abenza (Universidad de Alcalá, Spain); Alvaro Somolinos (University of Alcala, Spain); Ivan Gonzalez (Universidad de Alcala, Spain); Felipe Cátedra (University of Alcala, Spain)

A MLFMM-FFT based strategy for the computation of electromagnetic (EM) radiation and scattering in dielectrics is presented. The objective is to reduce the computational resources required for the application of the method of moments (MoM) to problems with electrically large dielectric structures. For this purpose, the storage of the near-field couplings in the MLFMM algorithm is reduced taking advantage of the Toeplitz symmetries present in regular hexahedral meshes. Therefore, the rigorous MoM matrix becomes smaller, thus significantly reducing the amount of memory required for the computation in this kind of problems. The FFT is employed for a fast computation in the convolutions required in the near-field part of the algorithm. In addition, a new approach for the numerical treatment of the transitions between dielectrics and dielectric and the free space is introduced.

A Numerical Investigation of Ultrawideband Metamaterial Absorber for Infrared Wavelength Spectrum

Vishal Parsotambhai Sorathiya (Marwadi Education Foundation Groups of Institute, India); Sunil Lavadiya (Marwadi University, India)

We propose a numerical study of the three-layered Tungston-MgF2-Gold based ultrawideband metamaterial absorber for infrared wavelength spectrum. The behavior of the metamaterial absorber is investigated over the wavelength range of 0.25 µm to 3 µm. The absorber's behavior is examined under a variety of physical conditions to determine the best possible outcomes and structural dimensions. More than 98% of the near-infrared and visible light spectrums may be trapped by this structure. Far-infrared and THz spectral absorption are both well-served by the proposed structure. This proposed infrared absorber design can be used for designing a high-efficiency solar cell.

Non-Dense Thin Sheets Electromagnetic Analysis with a Second-Order Transition Condition

Agnese Mazzinghi (University of Florence, Italy); Alessandro Mori (Università di Firenze, Italy); Mirko Bercigli and Mauro Bandinelli (IDS Ingegneria Dei Sistemi S. p. A, Italy); Angelo Freni (University of Florence, Italy)

The paper reports a second-order approximation of the transition boundary condition for not very thin layers of non-dense materials. It allows reconstructing with an error of less than 1% the scattering from a dielectric slab characterized by a thickness of the order of a tenth of wavelength, even when the relative dielectric constant is 2. Furthermore, the independence of the formulation from the incidence angle of the impinging wave allows its implementation in a numerical method as the method of moments.

Computation of Fundamental Bounds for Antennas

Jakub Liška, Lukas Jelinek and Miloslav Capek (Czech Technical University in Prague, Czech Republic)

Fundamental bounds play an important role in antenna design. Using method of moments and electric field integral equation, this paper shows a formulation of fundamental bounds based on quadratically constrained quadratic programs. This methodology is applied to two representative and challenging examples. The first example examines Yagi-Uda antenna and compares it with performance limits on Q-factor, radiation efficiency, and directivity. The second example shows how to determine fundamental bounds when a designer has far-field constraints. In their entirety, the examples demonstrate variability and generality of this treatment and also recall the existence of an open-source computational package, which can be used for evaluation of fundamental bounds on various metrics including their mutual trade-offs.

Physics-Based Model Order Reduction for CAD: Shrinking Electromagnetics into a Simple Circuit

Valentin de la Rubia (Universidad Politecnica de Madrid, Spain)

Electromagnetics today underpins all modern information and communication technologies. Increasing deployment of telecommunication services is urging RF industry to carry out better and better electrical designs, where a single device is no longer conceived to perform a single functionality, but rather multiple tasks at the same time. Unfortunately, much electrical design activity is still based on brute-force computational simulations to predict the actual physical behavior of electromagnetic devices. In our work we use computational electromagnetics as an actual design tool, rather than just an analysis one. This can be achieved by shrinking computational electromagnetics into a simple parameterized equivalent circuit form, from which an electrical engineer can get actionable design insights. Our efforts stand upon model order reduction techniques, such as the reduced-basis method. However, a new physics-based strategy is carried out to provide further physical insight of the electromagnetic device under analysis and, ultimately, extremely valuable design information.

An Efficient Strategy for Distributing the Mesh of Parallel Electromagnetic Solvers Based on the AIM

Damian Marek, Shashwat Sharma and Piero Triverio (University of Toronto, Canada)

Parallel electromagnetic solvers require efficient strategies to distribute the mesh of large structures encountered in advanced antenna designs. In addition, parallel solvers based on the adaptive integral method (AIM) require processes to access additional mesh entities that lie within the near region of their mesh partition. In this paper, we propose a parallel solution for loading, processing, partitioning, and redistributing the mesh of AIM-based solvers. The proposed method is demonstrated on problems as large as 200 wavelengths, with up to 200 million unknowns, and up to 8000 cores involved.

Analysis of Microwave Absorber Scattering Using Ray-Tracing and Advanced Measurement Techniques

Willi Hofmann, Andreas Schwind, Christian Bornkessel and Matthias Hein (Technische Universität Ilmenau, Germany)

Ray-tracing methods can be applied to evaluate the wave propagation in anechoic electromagnetic environments, in order to improve measurement concepts. The accuracy of the data obtained from such a chamber model depends crucially on the modeling of the microwave absorbers. Often the scattering off the absorbers is simplified by specular reflections, ignoring the actual direction dependent scattering properties of the absorbers resulting from their geometry, arrangement, and material. In this paper, the scattering of 18" absorbers with pyramidal and wedge geometries is analyzed and expected scattering patterns are described. Based on an existing shooting-and-bouncing- rays software, a simulation approach is introduced and used to relate the analytical findings with results of measurements of the angle-dependent reflectivity. In addition to the primarily specular reflection for wedge absorbers and scattering in many directions off the pyramidal absorbers, the results show that nearfield effects influence this scattering pattern, as confirmed by the simulations.

Closed Metal Chamber Configuration for Estimating RF Attenuation in Vehicles with Advanced Thermal Properties Windows

Rocio Chueca, Raul Alcain, Carlos Heras and Iñigo Salinas (University of Zaragoza, Spain)

Windows with advanced thermal properties are commonly used in the railway industry. However, these glasses suppose a problem to the RF signal transmission and many solutions are studied to avoid the attenuation of the electromagnetic waves. To characterize the attenuation of the different windows different systems can be used. In this paper, a system with a closed metal chamber is studied as it is closer to the real situation due to its similarity to a wagon. Simulations and experimental measurements are carried out to compare this setup with the anechoic chamber one.

Fast Gain Switching on TwinRX USRPs

Maximilian Engelhardt and Julia Beuster (Fraunhofer Institute for Integrated Circuits IIS, Germany); Carsten Andrich (Technische Universität Ilmenau, Germany); Alexander Ihlow (Ilmenau University of Technology, Germany); Giovanni Del Galdo (Fraunhofer Institute for Integrated Circuits IIS & Technische Universität Ilmenau, Germany)

In this paper, we investigate the gain switching performance of the software-defined radio USRP X310 with the TwinRX daughterboard and propose a method to optimize it for fast transitions. This receiver uses a complex structure of two switchable amplifiers and two digital step attenuators to realize the wide gain setting range of up to 92 dB. Our measurements of the settling time show that the bulk of transitions between two gain settings take below 1.5 µs, but some require more than 50 µs, caused by the power-up of the switchable amplifiers. Based on this knowledge, we propose a

modified switching regime, in which the amplifiers are not toggled in time-critical phases, e.g., during a running measurement, so that a transition time of 1.5 µs can be reliably realized. Thus, a gain switching range of 62 dB is achieved, within which, for example, a fast automatic gain control can be realized.

Enhancement Indoor mmWave Coverage Using Passive Reflector for NLOS Scenario

Marwan El Hajj (IETR-INSA de Rennes, France); Mbissane Dieng (Rennes & INSA de Rennes, France); Gheorghe Zaharia and Ghais El Zein (IETR-INSA Rennes, France)

Millimeter wave (mmWave) coverage is relatively limited due to high path loss (PL), that makes radio frequency planning difficult especially for the non-line-of-sight (NLOS) scenarios. In this work, we are looking to improve mmWave signal coverage in NLOS indoor scenario using passive reflectors. Measurements have been performed in L-shaped hallway using a vector network analyzer (VNA) and the path loss is evaluated with and without reflector. Experimental results show that in the presence of the passive reflector, the path loss can be reduced up to 24 dB. This type of configuration could be an economical solution to expand the mmWave coverage area. Moreover, a study is provided to compare the path loss when the reflector is placed horizontally to the path loss obtained when the reflector was placed vertically.

Greedy Channel Allocation in Meshed Wideband HF Radio Networks with Channel Aggregation

Jens Zander (KTH Royal Institute of Technology, Sweden)

Current HF communication systems use sequential probing and scanning of narrowband (typical 3kHz) channels and transmissions in a single frequency band resulting in low efficiency.. In this paper we extrapolate the ideas in the HF-XL("Salamandre")-system and study a system where both the ALE and transmission procedures are fully parallel, i.e. channel probing and data data transmission can occur simultaneously in many channels on many available bands ("Channel aggregation"). An interesting problem is how distributed spectrum management for multiple links can be done in a meshed HF-network. We propose the simple "Constrained Greedy" channel allocation schemes and study the performance of a sample network in terms of throughput and message delay for various time-of-day and seasons. Result indicate that performance improvements up to an order of magnitude are possible compared to conventional systems. Finally, implementation aspects and constraints are discussed.

Angle of Arrival Retrieval from Power Angular Spectrum Using Antenna Pattern Deconvolution at K-Band

Glaucio L. Ramos (Federal University of São João Del-Rei, Brazil); Mario Vala (Instituto de Telecomunicações de Portugal, Portugal); Rafael F. S. Caldeirinha (Polytechnic Institute of Leiria & Instituto de Telecomunicações, Portugal); Nuno R. Leonor (Instituto de Telecomunicações, Portugal); Luiz da Silva Mello (CETUC-PUC-Rio & Inmetro, Brazil)

In this paper a simple deconvolution process for angle of arrival (AoA) retrieval is applied in a environment composed of up to five metallic poles to mimic a cluster of scatterers in the vicinity of the receiver. A measurement campaign was performed inside an anechoic chamber in two different configurations and a deconvolution process is applied to the measured signal. Preliminary results at K-band show that the proposed technique can be used to effectively retrieve the angle of arrival in a controlled environment as well as the relative power between the direct and the reflected components, that are of most importance for angular spread evaluation so that the refinement of existing and new propagation models can be achieved. In future works the algorithm will be tested within a polarimetric modelling of the propagation channel and will also be used to obtain the angular spread (AS).

Height of the 0ºC Isotherm and the Melting Layer in Madrid: Comparison of Estimations from Different Sensors

Ana Benarroch (Universidad Politécnica de Madrid, Spain); Gustavo Siles (Universidad Privada Boliviana, Bolivia); Jose M Riera (Universidad Politécnica de Madrid, Spain)

The 0ºC isotherm height is used in rain attenuation prediction models to calculate the rain height, as proposed in ITU-R Recommendations. In a previous study, statistical results on the variability of the 0ºC isotherm were obtained for Madrid from ten years of radiosonde measurements. Such results are compared in this paper with statistics calculated using the 0ºC isotherm height provided by ERA5. The height of the melting layer was investigated previously through the comparison of the 0ºC isotherm height, considered to be the top of the melting layer, with the height of the bottom of the melting layer derived from measurements performed with a vertical Doppler radar (MRR-2). The profiles of the velocity of falling particles provided by this radar have been used recently to calculate both the top and bottom of the melting layer. The first results are presented in this paper.

Measured Radiation Behaviour of a UAV-Attached LTE Antenna

Philipp Reingruber and Robert Langwieser (TU Wien, Austria); Taulant Berisha (Dimetor GmbH, Altenberg bei Linz, Austria); Christoph F Mecklenbräuker (TU Wien, Austria)

In wireless systems, the realised characteristics of antennas in their operational environment are of major interest. This is especially true for wireless remote-control systems in combination with unmanned aerial vehicles (UAVs). In this paper we discuss measurement-based evaluations of a commercially available multi-band long term evolution (LTE) antenna mounted to the fuselage of a UAV. In comparison to the same antenna operated without the UAV, we observe an impact on antenna impedance as well as shadowing effects caused by the geometry of the UAV. Both lead to a

reduced performance of the antenna and subsequently a reduction in communication reliability and range may be expected.

The Hybrid Chamber for OTA Measurements: Plane Wave Spectrum Quality vs. Dynamic Range Trade-Off

Oleg Iupikov and Pavlo Krasov (Chalmers University of Technology, Sweden); Rob Maaskant (CHALMERS, Sweden); Andrés Alayón Glazunov (University of Twente, The Netherlands & Chalmers University of Technology, Sweden); Jonas Fridén (Ericsson AB, Sweden); Marianna Ivashina (Chalmers University of Technology, Sweden)

In this paper, the trade-off between the quality of the plane wave spectrum synthesized in the test zone of the hybrid over-the-air (OTA) chamber and factors affecting the dynamic range of this measurement system is investigated. The hybrid chamber performance is compared to a plane wave generator (PWG) in free space. The performance evaluation is focused on the field radiated into the test zone (TZ) while maintaining its quality according to the 3GPP specification. It is demonstrated that good quality can be achieved for the synthesized plane wave spectrum.

Characterization and Calibration of the Hybrid OTA Chamber Using a Field Scanner

Pavlo Krasov and Oleg Iupikov (Chalmers University of Technology, Sweden); Jonas Fridén (Ericsson AB, Sweden); Rob Maaskant (CHALMERS, Sweden); Andrés Alayón Glazunov (University of Twente, The Netherlands & Chalmers University of Technology, Sweden); Marianna Ivashina (Chalmers University of Technology, Sweden)

This paper investigates the characterization and calibration procedure of the hybrid over-the-air (OTA) measurement chamber. We present a prototype of the hybrid chamber and analyze its capabilities to generate a plane wave spectrum in practice. A planar field scanner is used to acquire the embedded element fields of the chamber array for test zone (TZ) synthesis in post-processing. The repeatability of the field acquisition is evaluated. It is shown that the synthesized TZ meets the 3GPP specifications for TZ field variations for plane wave generators (PWG) in the presence of acquisition imperfections.

Cost-Effective 3D-Printed Antenna Measurement System for Educational Applications

Jesus Alamo-Albiol, Ana Arboleya and Eduardo Martinez-de-Rioja (Universidad Rey Juan Carlos, Spain)

In this contribution, a 3D-printed, cost-effective measurement system based on a roll-over-azimuth positioner is proposed. The antenna measurement system is designed for educational applications and quick prototype validations, and will help students become familiar with antenna measurement procedures and error characterization techniques. The presented measurement system has an open design, it is easy-to-deploy and its modular design allows to easily implement new functionalities. The system performs spherical acquisitions and can characterize medium and low directivity antennas at different distances. Measurements and error tests for the characterization of an X-band horn antenna are shown to validate the correct performance of the system.

A Synthesis Process for Microwave Absorber Design Based on Pyramidal Absorbers

Arya Fallahi (IT'IS Foundation, Switzerland); Amin Enayati (Emersun and Cumming Anechoic Chambers, Belgium)

Pyramidal absorbers used in anechoic chambers are one of the primary components in the measurement and performance assessment of antennas. To achieve absorbers with predefined specifications, optimum design and best material selection is an indispensable requirement. The proper material for fabricating an absorber has often been selected based on heuristic and intuitive approaches. Here, we introduce a process to find the most suitable electromagnetic material properties for achieving a target performance in an absorber with certain geometry. The method is based on using full-wave numerical simulations to obtain lines of equal absorption in the complex plane for material permittivity at certain frequency points. By locating the permittivity of available materials in the obtained plots, the best material to fabricate the absorber of interest is found. The example of 60-inch absorbers is taken into account, and the best carbon loading for fabricating such an absorber is gained through the developed process.

Measurements and Modeling of Radiohelmet-UAV LoRa Links in a Mountain Canyon

Giulio M. Bianco (University of Roma Tor Vergata, Italy); Abraham Mejia-Aguilar (EURAC Research, Italy); Gaetano Marrocco (University of Rome Tor Vergata, Italy)

The LoRa framework has been recently proposed to foster search and rescue (SaR) missions in mountain environments. The target to be rescued could wear a LoRa radio embedded in a safety helmet so that an unmanned aerial vehicle (UAV) can localize it based on the transmitted signal strength. However, radiohelmet-to-UAV links in a real mountain area have never been characterized. This paper reports measurements of the excessive aerial path loss (PL) seen by a UAV overflying a mountain canyon to derive an equivalent model with the final aim of applying signal-strength-based localization. The angle-dependent fitting well describes the excessive aerial PL, and, despite the iced canyon's walls, no significant seasonal difference in the PL is experienced.

Textile Star-Shaped Supershaped Patch Antenna for 5G Applications

Guilherme Martins (Instituto Superior de Engenharia de Lisboa, Portugal); Pedro Pinho (IT - Instituto de Telecomunicações & ISEL - Instituto Superior de Engenharia de Lisboa, Portugal); Caroline Loss (Universidade da Beira Interior, Portugal)

In this paper, a novel textile star-shaped supershaped patch antenna is proposed for 5G applications, operating at 3.5 GHz. The Gielis Formula, also called Superformula, was used to design the antenna and thus minimize its patch size. The characteristics of the antenna, such as return loss, realized gain and radiation pattern are simulated, and the return loss is compared with the measured results. The designed antenna attains a -45.48 dB return loss at 3.5 GHz, with operational bandwidth from 3.43 GHz to 3.56 GHz for -10 dB, with the peak gain around 8.5 dBi for 3.5 GHz.

Transparent Spherical Spiral Antenna for Capsule Endoscopy Systems

Amir Arayeshnia (Faculty of Technical and Engineering, Imam Khomeini International University (IKIU), Qazvin, Iran); Amirhossein Hajbagheri (University of Waterloo, Canada); Majid Rafiee (Ooj Institute of Higher Education, Iran & School of Electrical and Electronics Engineering, Universiti Sains Malaysia (USM), Malaysia); Roy B. V. B. Simorangkir (Tyndall National Institute, Ireland); Ali Lalbakhsh (Macquarie University, Australia)

A transparent spherical spiral antenna for endoscopy capsule systems for gastrointestinal monitoring is presented in this article. The capsule antenna is designed for operating in the Medical Implant Communication Systems frequency band (i.e., 401-406 MHz) and has an impedance bandwidth of 397-409 MHz. The transparency of the antenna allows it to be implemented in front of the camera. This leads to more available space inside the capsule for embedding more subsystems. The proposed antenna also has a circularly polarized omnidirectional radiation pattern. These characteristics allow a stable wireless communication link during the monitoring operation.

On the Maximum Power Density of Implanted Antennas Within Simplified Body Phantoms

Mingxiang Gao (EPFL, Switzerland); Zvonimir Sipus (University of Zagreb, Croatia); Anja K. Skrivervik (EPFL, Switzerland)

With the application requirements of wireless technology in implantable bioelectronics, knowledge of the fundamental limits for implanted antennas becomes critical. In this work, we investigated the variation of maximum power density within simplified body phantoms, caused by changes in the operating frequency, implantation depth, body phantom radius, and source size. Both spherical and planar body models are studied, and the corresponding results are compared to an efficient approximation method. The summarized results are used to derive design rules and can be used as benchmarks for the design of most implanted antennas, especially for shallow implants.

Examination of Impedance Response of Capsule-Integrated Antennas Through Gastrointestinal Tract

Erdem Cil (University of Rennes 1, France); Sema Dumanli (Bogazici University, Turkey); Denys Nikolayev (Institut d'Électronique et des Technologies du Numérique (IETR) - UMR CNRS 6164, France)

This work focuses on the investigation of the degree of possible detuning that may be observed in the impedance response of ingestible antennas during the transition through the gastrointestinal tract. For this investigation, two antennas are used: a meandered dipole and loop antenna. The antennas conform to the inner surface of the biocompatible capsule shell. They are optimized in spherical homogeneous time-averaged gastrointestinal phantoms at 3 frequencies of interest: 434 MHz, 1.4 GHz, and 2.4 GHz. Next, the optimized antennas are simulated in 3 different phantoms, each mimicking electromagnetic properties of one of the tissues in the gastrointestinal tract. The impedance response of each design in 4 different tissues is discussed. The results show that the maximum shift in the operating frequency is 7 MHz, indicating that the presence of the encapsulation layer makes the considered antennas robust against the changes in the electromagnetic properties encountered through the gastrointestinal tract.

A Practical Solution to Enhance Electromagnetic Transmission to an Implantable/Wearable Antenna

Ludovica Tognolatti, Cristina Ponti and Giuseppe Schettini (Roma Tre University, Italy)

This paper presents a possible solution to enhance electromagnetic transmission to an implantable/wearable device in wireless power transfer systems. Based on an analytical approach we have developed, we show how it is possible, using wearable dielectric cylindrical scatterers, to increase the intensity of the transmitted field to a possible receiver, which may be arranged in the textile fabric of a garment or implanted in the underlying biological tissue. In particular, we show some parametric studies on the dielectric constant of scatterers, which can be easily integrated into a fabric, showing which configuration achieves the greatest increase in electromagnetic transmission. The electrical parameters of the biological and textile tissues are considered in the millimeter frequency range (f = 24 GHz).

Miniaturized Circularly Polarized Implantable Antenna for Leadless Pacemaker Devices

Abdenasser Lamkaddem (Carlos III University of Madrid, Madrid, Spain); Ahmed El Yousfi (Universidad Carlos III De Madrid, Spain); Vicente González Posadas (Polytechnic University of Madrid, Spain); Daniel Segovia-Vargas (Universidad Carlos III de Madrid, Spain)

A circularly polarized implantable antenna working at 915 MHz industrial, scientific, and medical (ISM) band is presented. A meander line is used for miniaturization purposes, while a U-shaped structure is used not only to guarantee circular polarization performance but also to shift the band to lower frequencies. The designed antenna shows an impedance bandwidth of 20 % from 809.4 to 989.8 MHz and an axial ratio (AR) bandwidth of 27 % from 770 to 1010 MHz. The proposed antenna has a compact size of 5.2 mm × 5.6 mm. The proposed antenna achieves an acceptable gain value of -23 dBi. Furthermore, the geometry of the proposed antenna remains simple with a full ground plane and without using any via holes. Finally, the fabricated prototype has been experimentally tested inside minced pork, salmon fish, and beef meat, and the measured results show good agreement with the simulated one.

Pixel Optimization via Genetic Algorithm of a Flat Epidermal Antenna for Fat Channel Communication

Rossella Gaffoglio (Fondazione LINKS, Italy); Giorgio Giordanengo (LINKS Foundation & Politecnico di Torino, Italy); Marco Righero (LINKS Foundation, Italy); Giuseppe Musacchio Adorisio (Fondazione LINKS, Italy); Bappaditya Mandal (Uppsala University, Sweden); Mauricio D Perez (Uppsala University, Sweden & National Technological University, Argentina); Hansjörg Scherberger (German Primate Center, Germany); Robin Augustine (Uppsala University, Sweden); Giuseppe Vecchi (Politecnico di Torino, Italy)

Fat intra-body communication (Fat-IBC) is a novel concept of communication through the low-loss fat tissue layer of the body. This new data transmission approach is promising for the implementation of wireless, in-body, bidirectional Brain-Machine-Body connectivity, which will profoundly impact different fields, such as brain implants with read/write capability and human-like artificial sensors and limbs. In this paper, we apply an evolutionary algorithm combined with a full-wave electromagnetic solver to optimize a flat epidermal antenna, to improve the radiation coupling into the body and favor the signal transmission in the subcutaneous fat layer. The application of this method to a skin-fat communication channel shows satisfactory results when both the antennas of the link are considered and materials with high relative permittivity are used. A good radiation coupling into the body is observed, and transmission losses lower than 5 dB/cm are achieved.

Fine-Tuning Impedance Matching Circuit for a Triple-Band Meandered PIFA in Brain-Implantable Bio-Telemetric Systems

Nikta Pournoori and Lauri Sydänheimo (Tampere University, Finland); Leena Ukkonen (Tampere University); Yahya Rahmat-Samii (University of California Los Angeles (UCLA) & UCLA, USA); Toni Björninen (Tampere University, Finland)

This article presents a study of the tunable impedance matching to our recently reported compact self-matched triple-band brain-implantable planar-inverted-F antenna (PIFA). It operates at Medical Device Radiocommunication Service (MedRadio) band (401-406 MHz) and Industrial, Scientific, and Medical (ISM) bands (902-928 MHz and 2400-2483.5 MHz). To achieve this, we investigated the optimal reflection coefficient characteristics of PIFA at desired frequencies by employing four π- and T-type matching circuits. Our results show that a T-type circuit selected for further assessment provides suitable fine-tuning possibilities for all combinations of desired upwards and downwards frequency-tuning of the three operating frequencies to ensure reliable wireless implant communications.

Radiative Wireless Power Transfer System Using Circularly Polarised Transmitter-Receiver Antenna Module to Improve Power-Transfer-Efficiency

Alok Chandra Joshi (Indian Institute of Science, India); Jogesh Chandra Dash (Indian Institute of Science Bangalore, India); Debdeep Sarkar (Indian Institute of Science, India)

In this paper, a circular polarization based wireless power transfer system is proposed for implantable medical devices (IMDs). Initially, a sequentially rotated left-handed circular polarization (LHCP) array operating at 2:4 GHz is designed for transmitter. Similarly, for receiver a miniaturised LHCP implantable antenna is designed inside a skin box to develop the WPT link. To improve the power transfer efficiency (PTE) of the WPT link a parasitic patch is placed near the receiver antenna. Parasitic patch improves the transmission coefficient by 8 dB thereby increasing the PTE by 6:7% for separation distance of 100 mm between transmitter and receiver. It is also verified that the proposed WPT system is insensitive to the angular rotation and lateral shift of the transmitter while keeping the receiver stationary. Finally, the specific absorption rate (SAR) of the implanted device is evaluated to ensure the safety limits of the proposed system.

A Repeater Antenna System Utilizing Genetically Modified Bacteria for Multiscale Communications

Ozan Furkan Sezgen and Oguz Kaan Erden (Bogazici University, Turkey); Nedim Haciosmanoglu (Bilkent University, Turkey); Macit Lacin, Arda Deniz Yalcinkaya and Zeliha Canbek Özdil (Bogazici University, Turkey); Urartu Ozgur Seker (Bilkent University, Turkey); Sema Dumanli (Bogazici University, Turkey)

With the exponential advancements realized in communication technologies, synthetic biology, and nanotechnology, now it is time to aim high and design new generation implants. To achieve this vision, this paper presents a novel sensing platform based on genetically engineered bacteria and a repeater antenna system, including a biodegradable in-body reflector antenna and on-body reader antenna. The biodegradation process is controlled by the engineered bacteria which in the future will be utilized to sense a molecule of interest. The biodegradation, hence, the sensing can be wirelessly tracked. In this paper, we present the control of biodegradation experimentally by the engineered bacteria and show the wireless tracking numerically. The sensing at 1 cm implant depth in fat tissue in the 2.4 GHz ISM band is demonstrated.

Wednesday, March 30 14:00 - 15:00

Characteristic Modes Special Interest Group (CM-SIG)

Wednesday, March 30 15:00 - 16:20

Invited Speakers: Juan Mosig and Ke Guan

Chairs: Luis Jofre (Universitat Politecnica de Catalunya, Spain), Thomas Kuerner (Braunschweig Technical University, Germany)

15:00 ***Propagation and Channel Modelling for Smart Railways***

Ke Guan (Beijing Jiaotong University, China)

In the vision of smart railways, a seamless high-data-rate and dependable wireless connectivity both for communication and sensing will be required. It is of primary importance to generate realistic channel data in order to do properly all the application layer end-to-end tests for all the relevant use cases that will be enabled by these wireless systems in railways. In this talk, we identify the major challenges and present the state-of-the-art solutions towards realistic channels of smart railways, especially for high frequencies, such as the millimeter-wave and THz bands. Moreover, future research trends are pointed out towards a thorough understanding of the propagation and wireless channel characteristics to support the design and evaluation of future smart railway wireless sytems.

15:40 ***Stratified Media, Spectral Domain, Square Roots and Sommerfeld Integrals***

Juan R Mosig (Ecole Polytechnique Federale de Lausanne, Switzerland)

The study of stratified media, defined as layered configurations of material substrates, is of paramount relevance in many scientific and technological areas like Acoustics, Geophysics and Lightning. In Electromagnetics, the first treatment of these problems is due to Arnold Sommerfeld who, more than one century ago, solved the most basic of all stratified media geometries, i.e. the two semi-infinite media problem. In doing so, Sommerfeld developed the fundamentals of a mathematical method, which is now known as the spectral domain approach (SDA). After many decades of latency, the analysis of stratified media using SDA knew a strong regain of interest, due to the introduction of printed technologies (microstrip and striplines) and the development in the 70s of the first planar antennas. Nowadays, SDA is used in many other areas of Electromagnetics, like Ground Penetrating Radar, satellite-based Remote Sensing and Optics&Photonics. This tutorial will review the stratified media problem and its formulation through the so-called Sommerfeld Integrals. Some tricky points, like complex square roots definitions, the relevance of a ground plane at infinity and the existence of a Sommerfeld pole (and hence of a surface wave) will be discussed. Numerical techniques will be briefly discussed and used to illustrate some recent discussions in the literature about the behavior of electromagnetic fields as a function of radial distances and of elevation angles (radiation patterns).

Invited Speakers: Guy Vandenbosch & Sean Victor Hum

Chairs: Oscar Quevedo-Teruel (KTH Royal Institute of Technology, Sweden), Guido Valerio (Sorbonne Université, France)

15:00 ***A Holy Grail Quest: The Concept of Stored Electromagnetic Energy***

Guy Vandenbosch (Katholieke Universiteit Leuven (KU Leuven), Belgium)

In this talk the quest for the "final" expressions for the energy stored in a radiator is overviewed. First, the several forms of power and energy that have been defined and used in electromagnetics over the last 100 years are briefly summarized, and their most important characteristics are discussed. In a first step, frequency domain is considered. Starting from two power balance equations, a field based reactive energy is formally defined and compared to the numerous "definitions" already available in literature. Then the concept of recoverable energy is introduced. The differences with reactive energy are pointed out. Moving to time domain, it is possible to write unifying expressions generalizing the concept of reactive energy. It is shown that recoverable energy is just a special case for a specific current evolving in time. Illustrative examples are given where these energies can be used to solve practical problems. The paper clearly illustrates that the concept of stored electromagnetic energy is still not well-understood when a radiator is involved.

15:40 ***Recent Developments in the Design and Realization of Advanced Electromagnetic Surfaces***

Sean V Hum (University of Toronto, Canada)

Advanced electromagnetic surfaces (AESs) comprise a spectrum of artificially engineered surfaces for manipulating the temporal and/or spatial dispersion of electromagnetic waves, and include structures such as reflectarrays, transmitarrays, frequency selective surfaces, polarizers, and most recently, metasurfaces / metagratings. The design of such surfaces can be separated into two steps: a macroscopic step, where the surface parameters required to achieve particular manipulations of the incident field are determined; and a microscopic step, where the geometric structure of the underlying unit cells or meta-atoms is determined to realize those properties. This talk will review recent developments in systematic design techniques for both steps. In particular, synthesis methods will be described for carrying out the macroscopic step, particularly for spatially-dispersive AESs used to implement specific radiation patterns. Subsequently, a variety of techniques for solving the inverse design problem associated with the microscopic step will be presented, with emphasis on recently developed techniques based on machine learning. A selection of AES designs developed based on the proposed techniques will be presented, including experimental demonstrators of several metasurfaces.

Wednesday, March 30 16:20 - 16:40

Coffee Break / Exhibition

Wednesday, March 30 16:40 - 18:20

P08: Experimental methods and campaigns for mm-wave and above

T02 Millimetre Wave 5G and 6G/ /Propagation

Chairs: José I. Alonso (Universidad Politécnica de Madrid, Spain), Raffaele D'Errico (CEA, LETI & Université Grenoble-Alpes, France)

16:40 ***Propagation Experiment Using a G-Band Terrestrial Link: Design and Preliminary Results***

Lorenzo Luini and Carlo Riva (Politecnico di Milano, Italy); Claudio Franchini (Microvawe Engineering Consultant, Italy); Aurelio Colosimo (Independent Consultant, Italy); Augusto Marziani (Telespazio S.p.A. & Sapienza University of Rome, Italy); Laura Resteghini and Christian Mazzucco (Huawei Technologies, European Research Center, Italy); Angelo Milani (Huawei Technologies, Italy); Renato Lombardi (Milan Microwave Competence Center, Italy)

This contribution presents the design and preliminary results of an electromagnetic wave propagation experiment at G band. The research activity, resulting from the collaboration between Politecnico di Milano and the Huawei European Microwave Centre in Milan, focuses on the design, integration and installation of a custom G-band 325-m terrestrial link connecting two buildings in the university campus. The unidirectional link carries an unmodulated beacon signal at 261 GHz, which allows investigating with high accuracy the atmospheric impairments affecting the propagation of electromagnetic waves. To this aim, the signal attenuation, inferred from the received power, is correlated to the ancillary data measured by the collocated rainfall sensor. The preliminary results reported indicate quite a significant impact of precipitation, which needs to be further studied using the information on the microphysical properties of rainfall.

17:00 ***60 GHz Propagation Channel Measurements with a Real mmWave Communication Equipment in an Office Environment***

Randy Verdecia-Peña, María A. Serrano and Jorge Alvarez-Casado (Universidad Politécnica de Madrid, Spain); Adolfo Del-Solar (Keysight, Spain); José I. Alonso (Universidad Politécnica de Madrid, Spain)

In this paper, we compare measurements of the millimetre-band propagation channel at 60 GHz using Fujikura prototype communications equipment in an indoor office environment with those obtained using a Keysight N9042B Signal Analyser and simulations performed using Ray Tracing techniques. Based on the IEEE 802.11ad standard, the Fujikura equipment establishes a wireless network to measure the 60 GHz propagation channel. Wireless Insite software has been taken into account to emulate the scenario, where the simulation considers the three-dimensional environment model and proper material electromagnetic parameters. The experimental and simulation results include the Received Power, SNR, and Throughput. We show that there is a good agreement between experimental and simulation results. In addition, we have also verified that the measurements made with a horn antenna connected to the Signal Analyser, present a worse behaviour when there is Non Line of Sight with respect to the results obtained with Fujikura equipment.

17:20 ***Experimental Study of Loss and Variation of Human Blockage for Terahertz Wireless Communications***

Keiji Yoshikawa and Takahiro Hayashi (KDDI Research, Inc., Japan)

The 6th generation mobile communication system requires the realization of ultrahigh speed and high-capacity communication. To meet the diverse communication requirements of individual users, it is desirable to use the terahertz band for communication between user terminals and peripheral devices. For the design and evaluation of stable systems, it is necessary to clarify the propagation characteristics of the blockage loss. In this paper, we investigated the propagation characteristics of the blockage loss for the human body at frequencies up to 110 GHz. Based on the experimental results, we clarified that the characteristics of the blockage loss due to a part of the human body follow the existing model. In addition, the variation in the blockage loss for a stationary human body is attributed to differences in the propagation path length produced by slight movement of the human body, and an estimation method for such a range of variation is presented.

17:40 ***Impact of a Transmitting-RIS on the Geometrical Structure of Indoor mmWave Channels***

Alfred Mudonhi (CEA Leti and Universite Catholique de Louvain & Universite Grenoble-Alpes, France); Marina Lotti (University of Bologna, Italy & CEA Leti, France); Antonio Clemente (CEA-LETI Minatec, France); Raffaele D'Errico (CEA, LETI & Université Grenoble-Alpes, France); Claude Oestges (Université Catholique de Louvain, Belgium)

In this paper we investigate the impact of the use of Transmitting Reconfigurable Intelligent Surfaces (T-RISs) on the indoor millimeter wave (mmWave) radio channel characteristics. To this purpose,

two measurement campaigns were conducted by employing a T-RIS array and a virtual cubic array (VCA). The multipath component extraction was performed to embed the TRIS based antenna pattern and evaluate the effect on large-scale parameters such as the path loss, delay and angular spreads.

18:00 ***Characterisation of Frequency Selective Reflections off Indoor Surfaces for 92-110 GHz***

Demos Serghiou (University of Surrey, United Kingdom (Great Britain)); Mohsen Khalily (University of Surrey & 5G Innovation Centre, Institute for Communication Systems (ICS), United Kingdom (Great Britain)); Ali Jihad Ali (Institute for Communication Systems, United Kingdom (Great Britain) & University of Surrey, United Kingdom (Great Britain)); Tim Brown and Rahim Tafazolli (University of Surrey, United Kingdom (Great Britain))

In this paper, we investigate the reflection properties of different interior surfaces in the 92-110 sub-Terahertz (THz) band. The measurements are conducted in an indoor environment by placing the surface in a specular configuration between the Transmitter (Tx) and Receiver (Rx) and collecting a large set of data by offsetting the Tx and Rx in parallel to the surface. The measurements were performed using an Agilent N5230A Vector-Network-Analyzer (VNA). Particularly, we present a statistical analysis in the frequency domain to show how frequency selective each surface is and how constant this behaviour is across the whole data set. We introduce the Power-Delay-Profile (PDP) in the delay domain to characterize the multipath behaviour of the channel and calculate the RMS delay spread. The measurement results provide a good insight for future propagation work to be done for the development of future indoor communications systems at sub-THz frequencies.

A05: Arrays for Millimetre wave 5G

T02 Millimetre Wave 5G and 6G/ / Antennas

Chair: Sergio Matos (ISCTE-IUL / Instituto de Telecommunicações, Portugal)

16:40 ***Design of a Rotman Lens Operating in the Full K/KA Band Using Ridge Waveguide Technology***

Fábio Martinho Cardoso (Iscte - Instituto Universitário de Lisboa); Sergio Matos (ISCTE-IUL / Instituto de Telecommunicações, Portugal); Jorge R. Costa (Instituto de Telecomunicações / ISCTE-IUL, Portugal); Carlos A. Fernandes (Instituto de Telecomunicacoes, Instituto Superior Tecnico, Portugal); Joao M. Felicio (Instituto de Telecomunicações, Portugal); Nelson Fonseca (European Space Agency, The Netherlands)

Several services associated with Satellite on the move and 5G applications are populating the K and Ka frequency bands. Beam forming networks are crucial components for achieving the necessary beam flexibility and agility of these systems. Rotman lens is being widely investigate as cost-effective solution for overcoming the main limitations of other types of beam forming networks, namely bandwidth, losses, and size. One of the main design challenges is obtaining broadband transitions for the array and beam ports. In this work we used a standard K/KA double ridge (WRD180) for interfacing with the Rotman Lens. The main motivation for this choice is the wide bandwidth (K/KA band) and the avoidance of dielectric losses associated with microstrip implementations. We present a design capable of fully exploring the ridge waveguide bandwidth with wide beam scanning, outperforming previous works. The presented design consists of a 13x7 Rotman Lens with a scanning range of ±50 degrees operating between 17.3 and 40 GHz, validated through full-wave simulations.

17:00 ***Synthesis of Sparse Large Arrays via Sequential Convex Optimizations***

Christos Monochristou (University of Rennes 1, France); Shang Xiang (Lund University, Sweden); Mark Holm (Huawei Technologies (Sweden) AB, Sweden); Ronan Sauleau (University of Rennes 1, France); Mauro Ettorre (University of Rennes 1 & UMR CNRS 6164, France)

In this work a synthesis technique for designing sparse phased arrays of large size is presented. The procedure is based on an iterative convex optimization algorithm, also known as compressive sensing, which is straightforward to implement and efficient in terms of computational cost. It is capable of producing a layout with a significant reduction of active elements for predefined performance. Due to its effectiveness, it can also be employed for the optimization of large arrays. The capabilities and versatility of the algorithm are illustrated by different case studies. In particular, the possibility to reduce by 45% the number of elements in a large array is shown in details.

17:20 ***Efficient Design of H-Plane SIW Horn Antenna Array at mmWaves***

Cleofás Segura-Gómez (University of Granada, Spain); Angel Palomares-Caballero (Universidad de Granada, Spain); Pablo Padilla (University of Granada, Spain)

This paper presents an efficient design of an SIW horn antenna array for upper part of the Ka-band. The array is formed by a corporate network in substrate integrated waveguide (SIW) technology which feeds eight SIW horn. Impedance matching between each SIW horn and the free space is carried out by using a SIW-to-air transition that efficiently matches with the rest of the antenna elements. The array feed is based on an end launch connector over grounded coplanar-waveguide (GCPW) technology that makes an efficient transition to SIW. The corporate network has two-by-two electromagnetic (EM) field splitting levels through the use of H-plane T-splitters and waveguide bends. Thus, an in-phase and equal power symmetrical array structure is achieved from 34 GHz to 41 GHz (18.6% of bandwidth). The simulated results present a high stable gain of 14 dBi in the H-plane along the whole frequency range.

17:40 ***Penrose Tiling Subarrays for Large-Scanning and Energy-Saving Phased Array***

Francesco Dicandia (IDS - Ingegneria dei Sistemi SpA, Italy); Simone Genovesi (University of Pisa, Italy)

A novel partitioning scheme based on Penrose tessellation subarrays has been proposed for phased array design. More in detail, the radiating elements of a phased array arranged on a regular and periodic lattice are grouped into irregularly-shaped tiles by exploiting the features offered by the aperiodic Penrose tessellation. The preliminary results reveal that the novel array architecture ensures a remarkale reduction of the Transmit/Receive modules without compromising the performance in terms of scan angle and peak side lobe level.

18:00 ***Array Antenna Fault Diagnosis via near Field Amplitude-Only Data***

Roberta Palmeri (IREA-CNR, Napoli, Italy); Giada Maria Battaglia (Università Mediterranea di Reggio Calabria, Italy); Andrea Francesco Morabito (University Mediterranea of Reggio Calabria, Italy); Tommaso Isernia (University of Reggio Calabria, Italy)

The paper deals with the diagnostics of realistic array antennas by exploiting phaseless measurements. Provided the number of faults is not small with respect to the overall number of elements, the proposed approach allows performing the diagnostics whatever the kind of radiating elements even if the measurement surface is located in the near-field zone. Despite the high non-linearity induced by the adoption of phaseless measurements, the underlying optimization problem can be cast as a Convex Programming one taking decisive advantage of the Compressive Sensing theory. Examples concerning 1-D array diagnostics are given for both cases of ON-OFF and phase faults.

A14: Electrically small antennas

T03 Wireless LANS, IoT and M2M/ / Antennas

Chairs: Christophe Delaveaud (CEA-LETI, France), Lars Jonsson (KTH Royal Institute of Technology, Sweden)

16:40 ***Design and Optimization of a Compact Planar Radiator for UWB Applications and Beyond***

Michal Czyz, Jan Olencki and Adrian Bekasiewicz (Gdansk University of Technology, Poland)

A compact monopole antenna for ultra-wideband (UWB) and beyond applications has been proposed. The radiator is based on the monopole topology. The super-wideband behavior has been achieved using a combination of spline-based modifications applied to the driven element, as well as utilization of a tapered feed and a slot-modified ground plane. The electrical performance of the structure has been tuned using a numerical optimization algorithm. The proposed design features reflection below the level of -10 dB within 2.8 GHz to 30 GHz range, as well as a footprint of only 404 mm2. The proposed structure has been compared in terms of bandwidth and size with the state-of-the-art antennas from the literature. The numerical results are supported by measurements of the fabricated antenna prototype.

17:00 ***Study of MACKEY Type H Antenna Miniaturized Using Slits***

Kota Hakamata (7-1 Ogigaoka & Kanazawa Institute of Technology, Japan); Keisuke Miyashita (Kanazawa-institute-of-technology, Japan); Keito Yokoe, Shigeru Makino and Kenji Itoh (Kanazawa Institute of Technology, Japan)

The metasurface inspired antenna chip developed by the KIT EOE Laboratory (MACKEY, RFID 920 MHz) is an electrically small antenna that is sufficiently robust to metal objects. However, there have been demands for miniaturization of the available model, which has a length of 200 mm at 920 MHz. Therefore, a new model called the MACKEY type H (RFID 920 MHz band) is proposed herein and is miniaturized to the size of a card. The type H antenna can extend the current path in a meandered manner through slits cut along the long sides of the grid plate. This paper presents the characteristics of the MACKEY type H antenna and its measurement results.

17:20 ***Parasitic-Based Frequency-Agile Electrically Small Antenna Design***

Marwan Jadid (CEA & Grenoble Alpes University, France); Serge Bories (CEA, France); Christophe Delaveaud (CEA-LETI, France); Anthony Bellion (CNES, France)

In this paper, a miniature frequency-agile antenna is presented. The antenna is of balanced structure, composed of a driven element fed differentially, and a parasitic loop element loaded with a varactor. The antenna maximum dimension is 28.8 mm, electrical size ka=0.3, designed to operate near 1000 MHz. A prototype is fabricated and measured to validate the simulated performances. The measurement results show continuous eight states tunable bandwidth of 5.05% at the central frequency 1010.5 MHz corresponding to -10 dB |S11| maximum-acceptable input reflection coefficient, and a radiation efficiency of more than 34% over the tunable bandwidth.

17:40 ***A Study on Low Profile Orthogonal Polarization Antenna Using Halo Antenna***

Tomokazu Mizutani, Naobumi Michishita and Hisashi Morishita (National Defense Academy, Japan); Hiroshi Sato (Panasonic Corporation, Japan); Yoshio Koyanagi

(Panasonic, Japan)

In this paper, an orthogonally polarized antenna with a small diameter and low profile is proposed for mobile communication. The proposed antenna is composed of a Halo antenna loaded with two parasitic elements as the horizontal polarization element and dipole and sleeve antennas as the vertical polarization elements inside the Halo antenna. The simulation results show that the proposed antenna with the sleeve antenna has a relative bandwidth of 6.9 % (VSWR ≤ 2) and an isolation between polarizations of about 30 dB within the operating frequency. In addition, the antenna diameter and height of the proposed antenna are 0.14λ0 and 0.49λ0, respectively, and a low profile orthogonally polarized antenna is obtained.

18:00 ***Extremely Small Size Mechanical Antenna, Propagating Electromagnetic Waves***

Masoud Alipour Shirazi (Babol Noshirvani University of Technology, Iran); Bijan Zakeri (Babol Noshirvani University of Technology, Babol, Iran)

There are some challenges in effectively producing low frequency electromagnetic waves, such as the need of large scale antennas, particularly for submarine communications. Due to hardness and challenges of building low frequency antennas, some solutions are provided. Using acoustic wave is one of solution which is the most common alternative for low frequency electromagnetic waves. A new solution which is in the researching level, is known as Mechanical Antenna. This sort of antenna which enables us to propagate low frequency electromagnetic waves, has the advantage of being extremely small in comparison with common electrical antennas. Some efforts have been done on analyzing and testing this type of antenna in order to estimate the pattern and propagated power of mechanical antenna. In this paper, initially parameters affecting the power radiated in past researches has been investigated and a novel solution is provided in order to increase the propagated power.

A17: Implantable antennas

T04 Biomedical and Health/ / Antennas

Chairs: Sandra Costanzo (University of Calabria, Italy), Gaetano Marrocco (University of Rome Tor Vergata, Italy)

16:40 ***How to Transform an Aortic Valve Prostheses into an UHF Antenna for the RFID-Based Wireless Monitoring of the Cardiac Health***

Miriam Gagliardi, Cecilia Occhiuzzi and Roberto Verzicco (University of Roma Tor Vergata, Italy); Gaetano Marrocco (University of Rome Tor Vergata, Italy)

Heart valve replacement is one of the most common life-saving surgery procedures. Although valve prostheses can restore heart functionality and life expectations, they often suffer from to structural deterioration that can lead to the failure of the implant. Conventional diagnostic tools include minimally invasive and operator-dependent examinations. Alternative remote monitoring approaches would be extremely useful for evaluating the valve status from outside the body and for early detecting possible failure events. In the framework of Health 4.0 this paper proposes a method to extract an antenna mode out of an aortic valve so that it can be provided with communication capability without any need of battery. By minimal modifications of the mechanical layout, the valve integrates an RFID sensing IC capable to passively, sample the temperature in the surrounding tissues and communicate with an external reader. Numerical simulations and early experimental tests demonstrate the feasibility of the communication link.

17:00 ***Two-Channel Epidermal RFID Sensor for the Analysis of Nasal Respiratory Flow***

Elisa Fontana and Nicoletta Panunzio (University of Rome Tor Vergata, Italy); Francesco Montecchia (University of Rome "Tor Vergata", Italy); Gaetano Marrocco (University of Rome Tor Vergata, Italy)

Abnormal breathing can be a symptom of an unhealthy status. Conventional diagnostic exams involve cumbersome and intrusive instrumentation that are overall uncomfortable for the user. Ultra High Frequency (UHF) Radio Frequency IDentification (RFID) devices, instead, enable non-invasive wireless monitoring of respiration by means of epidermal antennas with embedded temperature sensors. Two sampling points in the same device could be useful to independently measure the respiratory flow of the two nostrils, which are known to work differently. At this purpose, this paper proposes a two-channel flexible epidermal sensor for the bilateral monitoring of nasal breathing based on temperature measurement. It compactly adheres on the prolabium, and comprises two coupled T-match asymmetric dipole antennas whose ICs are placed at the exit of the nostrils. The sensor can be read up to 60 cm. Experimental tests on some prototypes demonstrated that, thanks to negligible cross-sensitivity of the two ICs' temperature data, the breathing rate can be accurately estimated independently for the two nostrils.

17:20 ***Theoretical Efficiency and Dosimetry of Buffered On-Body Transmitter Antennas for Wireless Powering of In-Body Devices***

Icaro V Soares (Institut d'Électronique et des Technologies du Numérique & Université de Rennes 1, France); Anja K. Skrivervik (EPFL, Switzerland); Denys Nikolayev (Institut d'Électronique et des Technologies du Numérique (IETR) - UMR CNRS 6164, France)

The viable and safe application of wireless power transfer for powering bioelectronic implants requires understanding the wave propagation in heterogeneous and dispersive media, the electromagnetic exposure assessment, and the optimum design of the system parameters to achieve a trade-off between efficiency and specific absorption rate levels. Therefore, based on the case study of a wirelessly charged deep-implanted pacemaker, a parametric analysis on the transmitter dimensions and electromagnetic properties is carried out to achieve such a trade-off. The results show that the system reaches the maximum efficiency without increasing SAR levels when the transmitter is composed of an electric source, an air-like substrate, and a superstrate matched to the

wave impedance in the skin with a thickness of half the wavelength in this medium. Furthermore, this configuration is compared to a magnetic counterpart, and the reasons for its suboptimal performance are investigated in terms of near-field, reflection, and attenuation losses.

17:40 ***A Finger-Worn Epidermal Antenna for Pressure Sensing***

Martina Frattaioli (University of Rome Tor Vergata, Italy); Giulio M. Bianco (University of Roma Tor Vergata, Italy); Simone Nappi (University of Rome Tor Vergata & Radio6ense srl, Italy); Gaetano Marrocco (University of Rome Tor Vergata, Italy)

Radiofrequency finger augmentation devices (RFADs) are hand-worn systems based on the RFID (radiofrequency identification) that can sense the objects touched by the wearer while preserving the free-hand gestures. A pressure-sensing R-FAD could be useful for applications in physiotherapy, orthopedy, and even more with the upcoming Tactile Internet (TI) paradigm, which aims at extremely low-latency communications and the transmission of human senses through the internet. This paper proposes a pressure-sensing fingertip tag that is manufactured using a robust conducting thread. Following preliminary tests on a prototype, the tag was demonstrated sensible enough to swiftly detect small discontinuities of the human body, like the back-hand knuckles.

18:00 ***An Iterative Algorithm Enhancing the Resolution of Microwave Resonant Sensors for Biomedical Applications***

Giovanni Buonanno (University of Campania, Italy); Adriana Brancaccio (Seconda Università di Napoli, Italy); Sandra Costanzo (University of Calabria, Italy); Raffaele Solimene (Università degli studi della Campania Luigi Vanvitelli, Italy)

This paper discusses a method to improve the resolution of microwave biomedical sensors. Usually, the frequency response of these devices is relatively wide as compared to its ideal shape. Furthermore, only a finite number of its samples can be acquired in the measurement stage. Accordingly, to have an accurate estimate of the resonance frequency, high performance systems with high sensitivity are required. Thereafter, in order to overcome these drawbacks, an iterative algorithm is presented which aims at sharpening the microwave sensors response. The algorithm assessment is performed on measured data referred to a real scenario, which is inherent to return loss measurements of a microwave patch antenna submerged in a water-glucose solution with various glucose concentration levels.

P07: Aerial and vehicular propagation

T05 Aircraft (incl UAV, UAS, RPAS) and automotive/ / Propagation

Chair: Reiner S. Thomä (Ilmenau University of Technology, Germany)

16:40 ***Experimental 39-GHz Band Propagation Measurements for Coverage Extension from the Sky***

Yuki Hokazono and Yoshihisa Kishiyama (NTT DOCOMO, INC., Japan); Takahiro Asai (NTT DOCOMO, Inc., Japan); Tetsumi Takamori, Jun Suzuki and Hiromu Kitanozono (SKY Perfect JSAT Corporation, Japan)

A key issue facing the 5G Evolution and 6G eras is expected to be expanding the communications area to any place where its benefits can be enjoyed. To expand the communications area, we are focusing on implementing a communications area from the sky using satellites and a high-altitude platform station (HAPS). In particular for HAPSs, the use of broadband millimeter-waves is expected to enable the timely provisioning of the required high-speed high-capacity low-latency access in any location including at sea, in the air, or remote areas. Before using an actual HAPS system, we performed an initial experiment to measure the propagation characteristics in the 39-GHz band using a small aircraft. The experimental results assuming HAPSs in an urban area, a forest, and a remote island show propagation loss in the 39-GHz band in various environments under the influence of aircraft turning.

17:00 ***Reproducible Virtual Test Drive for C2C /C2X and Its Application on a New Parallel Sniffing Diversity Circuit***

Anton Dobler (Universität der Bundeswehr, Germany); Olha Voitsun (Universität der Bundeswehr München, Germany); Stefan Lindenmeier (Universität der Bundeswehr, Germany)

A reproducible semi-virtual test drive system for C2C/C2X-transmission is shown in its application on a new antenna diversity circuit at 5.9 GHz. The correct functionality of the system itself and the time-varying property of the output signal is verified. By help of this test drive system a new parallel sniffing diversity circuit is investigated. Due to the advanced circuit design, the diversity function is possible without the need of a cooperative receiver. Characteristic RF-functions of the RF-diversity circuit are explained and its performance in a typical driving scenario is shown. The antenna diversity shows a significant reduction in package error rate and moreover increases received signal strength.

17:20 ***Radio Transparency Control of Road Electromagnetic Barriers for C-V2X Communications***

Bruno Tribovane (Polytechnic of Leiria, Portugal); Rafael F. S. Caldeirinha (Polytechnic Institute of Leiria & Instituto de Telecomunicações, Portugal)

This paper presents the study of a multi-layered timber barrier of periodically arranged logs with the purpose of enhancing the electromagnetic (EM) shielding or transparency to radio propagation

through the fine-tuning of the barrier's parameters for applications in road electromagnetic barriers. Simulations were performed and analysed in 5.9 GHz band, where spacing between centre of wooden poles is parametrised in a EM simulation environment. Such tunable EM fence may find applications in roads where C-V2X communications are subject to high EM interference or low radio propagation exposures, which are intended to be controlled.

17:40 ***Micro Versus Macro Antenna Corridor for Trains Equipped with FSS Windowpanes***

Nima Jamaly, Adrian Schumacher and Daniel Wenger (Swisscom, Switzerland)

In this paper, the measured median pathloss between the ports of a pencil-beam antenna as a base station antenna near the railway track (i.e., antenna corridor), and a dipole antenna onboard a train wagon is presented. The selected wagon is an ordinary Swiss inter-city double-deck wagon recently equipped with RF-friendly windowpanes. Here our focus is the port-to-port median pathloss at around 3600 MHz band. The results highlight that the excess pathloss into the wagon compared to the line-of-sight free space pathloss with similar antennas is within the range 15-38 dB. We further address the polarisation pathloss imbalance present inside the wagon and quantify it. This imbalance is an outcome of the presence of non-rich multipath inside the wagons equipped with RF-friendly windowpanes. In the end, we show that the paths through the closest windowpane to the user equipment are likely the dominant ones and thus determining the pathloss.

18:00 ***Spatial-Temporal Correlations of U2V Channel Considering Fuselage Posture and Antenna Pattern***

Tongtong Zhou, Boyu Hua, Qiuming Zhu, Haoran Ni, Kai Mao and Xiao-min Chen (Nanjing University of Aeronautics and Astronautics, China)

Considering the fuselage posture and antenna pattern of unmanned aerial vehicle (UAV), a three-dimensional (3D) multiple-input multiple-output (MIMO) geometry-based stochastic model (GBSM) is proposed and the spatial-temporal correlations of UAV-to-vehicle (U2V) channel are studied. Based on the fuselage posture matrix and antenna pattern matrix, the temporal autocorrelation function (ACF) and spatial cross-correlation function (CCF) are deduced and investigated in detail. The simulation results show that variation of fuselage posture and antenna pattern has significant impacts on spatial-temporal correlations. In addition, the consistency of theoretical and simulation results verified the correctness of the proposed model and derivation.

A25: Antennas for small satellites

T08 Space (incl. cubesat)/ /Antennas

Chairs: Maria Alonso-delPino (Delft University of Technology, The Netherlands), Daniel Martinez-de-Rioja (Universidad Politécnica de Madrid, Spain)

16:40 ***X-Band Low-Profile Wideband Circular Polarized Microstrip Array for CubeSat Communications***

Gong Chen, Chaoran Hu, Mingchuan Wei and Jiyao Zhang (Harbin Institute of Technology, China); Fujiang Lin (USTC, China)

This paper proposes a novel circular polarized microstrip array with high gain for satellite communication in X-band. In order to extend the impedance bandwidth, the novel single-feed unit element is created without adding the profile. The proposed antenna employs the sequential rotation technique to improve the axial ratio bandwidth with high circular polarization purity. The final design, with an overall size of 91.6 mm×45.8 mm×1.7 mm is simulated. The proposed antenna can provide an impedance bandwidth of 62.1% from 8.83 GHz to 16.78 GHz, and 3 dB axial ratio bandwidth from 9.84 GHz to 11.52 GHz. The realized gain at the center frequency is 16.4 dBi (with 3-dB gain in band ranging from 9.70 GHz to 12.18 GHz, covering the whole axial ratio bandwidth). Thus, the proposed low-profile circular polarized antenna is suitable for X-band satellite applications.

17:00 ***Full-Metal X-Band Reflectarray for Small Satellite Constellations***

Gautier Mazingue (Anywaves, France); Louis Mangenot (ANYWAVES, France); Maxime Romier (Anywaves, France); Nicolas Capet (ANYWAVES FRANCE, France)

This paper presents a full-metal unit cell for reflectarray antenna. This unit cell has been designed to work in space environment and is versatile to a large range of frequencies from X-band to Ka-band. In this paper, An X-band 3-panel reflectarray for small satellite has been developed as an example of application. The size of each panel is 200x350 mm². The reflectarray has been designed for the [8-8.4] GHz band and shows a good stability on the band. The maximal gain is 28 dB and the half-power beamwidth is 8°.

17:20 ***Development of X-Band Antenna for CUBESAT Platform***

Dubravko Tomić, Ivan Kuljak, Josipa Vincetić, Petar Beršić, Josip Lončar, Juraj Bartolić and Zvonimir Sipus (University of Zagreb, Croatia)

Design, development, and measurements of X-band patch antennas for a CubeSat platform are presented in this paper. The challenge was in the design of circularly polarized patch antennas suitable for building an array since the goal is to achieve highest possible radiation efficiency. Therefore, six antenna designs were developed which can be differentiated by the number of PCB layers and by the method of excitation. Also, for achieving circular polarization two shapes were considered, a corner truncated square patch and a nearly square patch. The characteristics of the developed antennas were analyzed and measured showing the advantages and disadvantages of certain designs. Based on the analysis of measured results we reached guidelines that will be used further for designing the full X-band array.

17:40 ***Smart Apertures for In-Flight Electronically Steerable Antennas in LEO/MEO/GEO Satellite Constellations***

Manuel J Gonzalez (TTI, Spain); Alberto Pellón (Celestia Technology Group UK, United Kingdom (Great Britain)); Ana Rosa Ruiz (Celestia Technologies Group (UK) Ltd, United Kingdom (Great Britain))

In-Flight Connectivity services through satellite systems is expected to grow exponentially throughout the 2020 decade. The deployment of high throughput satellites and mega-constellations in low and medium earth orbits will result in higher demand and lower running costs. However, in addition to harsh environmental conditions, antenna systems must overcome important challenges derived from heterogenous scenarios and the associated regulations. This paper focuses on these aspects and proposes smart apertures based on electronically steerable antennas to enable multiple beam and fast steering capabilities and to mitigate the restrictions of emission in the geostationary arc.

18:00 ***Low-Profile and High-Gain Submm-Wave Lens Antenna for Compact Instruments***

Sven L van Berkel (NASA-JPL, Caltech, USA); Maria Alonso-delPino (Delft University of Technology, The Netherlands); Cecile Jung-Kubiak (NASA-JPL, Caltech, USA); Goutam Chattopadhyay (NASA-JPL/Caltech, USA)

In small volume instruments, such as CubeSat spacecraft, the realization of wideband THz spectroscopy instruments is challenging, since a practical antenna gain typically results in a large antenna form factor or small bandwidth. In this work, a low-profile submillimeter-wave lens antenna, operating over a broad, 20% fractional, bandwidth from 450 GHz to 550 GHz, is presented with a gain of 50 dB and aperture efficiency of 65%. A multi-layer leaky-wave stratification is synthesized to efficiently and uniformly illuminate a 7.4 cm diameter hyperbolic silicon lens over a wide angle, resulting in an overall antenna height of only 3 cm. The antenna is fabricated and currently in its measurement stage. Preliminary measurements in the WR2.2 frequency band are presented.

A26: EM modelling and simulation of antenna arrays

T09 EM Modelling and Simulation tools/ / Antennas

Chairs: Manuel Arrebola (Universidad de Oviedo, Spain), Shahab Oddin Dabironezare (Delft University of Technology, The Netherlands)

16:40 ***Antenna Design for Overlapped Array Fed Reflector OLAF SAR Instrument***

Tamara Coello (Airbus Defence and Space, Spain); Javier del Castillo Mena (Airbus, Spain); Quiterio García (Airbus Defence and Space, Spain); Giovanni Toso (European Space Agency, ESA ESTEC, The Netherlands); Ernesto Imbembo (Aurora Technology B. V. for ESA-ESTEC, Noordwijk, The Netherlands)

The results of the study of the large deployable reflector antenna for a SAR study project being conducted for the European Space Agency are presented. The antenna is fed by a large feedarray, and the effect on the antenna patterns of the different feeders are shown. Comparison between the ideal antenna surface and its deployable configuration are presented. An initial study of the rms errors of the deployable antenna configuration is presented.

17:00 ***On the Evaluation of Mutual Coupling in Integrated Lens Arrays***

Ashwita Nair, Shahab Oddin Dabironezare, Andrea Neto and Nuria LLombart (Delft University of Technology, The Netherlands)

Future applications in sensing and communications will benefit from having large integrated coherent arrays at THz frequencies. The use of lens arrays will enable the fabrication of integrated antenna front-ends with many potential independent beams as well as dynamic scanning capabilities. For certain types of applications such as MIMO communications, interferometric arrays and Tx/Rx duplexing capabilities, a key parameter is the mutual coupling between the integrated antenna front-ends. In this contribution we model such mutual coupling using PO techniques combined with a bi-directional forward ray-tracing, and compare its accuracy to full wave simulations. The proposed technique is then used to evaluate the mutual coupling for an example lens array architecture. A more complete study comparing several lens array architectures will be presented in the conference.

17:20 ***Linearly Polarized Transmit-Array Operating in mmWave Bands, Design, Optimization and Demonstration***

Alessandro H De Oliveira Cabral, Jr. and Jeanne Pages-Mounic (ONERA & Laplace Laboratory, France); André Barka (ONERA -The French Aerospace Lab, France); Hamza Kaouach (LAPLACE & Toulouse INP-ENSEEIHT & Université Férérale Toulouse Midi-Pyrénées, France)

This paper presents the design and optimization of a transmit-array (TA) operating at 10 GHz. This TA is based on a new Unit-Cell that allows to easily generate phase rotations required for TA design, while keeping insertion losses to a minimum (0.3 dB) and a relative working bandwidth of 9% at 10 GHz. The proposed unit-cell is a simple three metallic layer structure, in which two identical patches are interconnected through an inner via. The optimized structure has a low profile with a total thickness of 3.2 mm. To demonstrate its performance, a 1-bit transmit-array with 20x20 cells is simulated and manufactured showing a high gain of 21.01 dBi and low side lobe levels (-20.93 dB). Finally, to reduce its overall profile, a multiple feed TA is conceived using an particle swarm optimization algorithm to define the phase compensation distribution and allow a reduction of 50% of the focal length.

17:40 ***Fast and Accurate Database Using N-Linear Interpolation for Reflectarray Analysis, Layout Design and Crosspolar Optimization***

Daniel R. Prado (Universidad de Oviedo & Signal Theory and Communications, Spain); Jesús López-Fernández and Manuel Arrebola (Universidad de Oviedo, Spain)

This work provides an assessment in terms of computational speed and accuracy at the radiation pattern level of a database to characterize the reflectarray unit cell for use in analysis, layout design and crosspolar pattern optimization. Details of an efficient implementation of the database are provided, and its performance is compared to that provided by a machine learning technique based on support vector regression (SVR). A method of moments based on local periodicity serves as the baseline for the comparison, both in terms of accuracy and acceleration. The results show that, even when the database uses a simple N-linear interpolation, accuracy is similar to that provided by the SVR technique while accelerating the analysis and layout design of reflectarray antennas.

18:00 ***High-Gain Slotted Waveguide Array Fed by A Sectorial Horn***

Haim Matzner (HIT-Holon Institute of Technology, Israel)

A high gain slot array antenna with 5 waveguides and 60 elements is proposed. The antenna is balanced fed by a sectorial horn. The antenna is matched for VSWR = 1.8 between 9.7 to 10.7 GHz. The directivity of the antenna is between 22 to 24.5 dBi with low loss. The antenna can be easily optimized in the E-plane and in the H-plane beamwidths.

IW07: Outdoor antenna measurements using UASs

Beyond radiation pattern measurements

A09: Reflectarrays and transmitarrays

T10 Fundamental Research and Emerging Technologies/ / Antennas

Chairs: Raphael Gillard (IETR & INSA, France), Eduardo Martinez-de-Rioja (Universidad Rey Juan Carlos, Spain)

16:40 ***Circularly Polarized Shared Aperture Reflectarray and Patch Antenna Array for S- and Ka-Band***

Daniel E. Serup, Shuai Zhang and Gert Pedersen (Aalborg University, Denmark)

This paper presents a circularly polarized dual-band shared aperture antenna for satellite applications. The antenna achieves dual S- and Ka-band operation by housing both a circularly polarized high-frequency reflectarray and a circularly polarized low-frequency patch antenna array in the same aperture area. The high-frequency reflectarray part of the antenna has unit elements within the aperture area of the low-frequency patch antenna array which allows for a high realized high-frequency gain. The antenna has a layered structure with a middle layer of Polypropylene, this enables the low-frequency part of the antenna to achieve a wide impedance bandwidth and a high realized gain. The antenna has a total size of 136x136mm and the three layers of the reflective surface have a total height of 4.624mm. The antenna has an impedance bandwidth of more than 415MHz(12%) and 4.75GHz(19%) and a peak realized gain of 14.80dBi and 26.68dBi at 3.5GHz and 25.4 GHz, respectively.

17:00 ***Metal-Only Reflectarray Unit Cell for Dual-Polarization Control***

Angel Palomares-Caballero (Universidad de Granada, Spain); Carlos Molero and Pablo Padilla (University of Granada, Spain); María García-Vigueras (IETR-INSA Rennes, France); Raphael Gillard (IETR & INSA, France)

A metal-only reflectarray unit cell to independently control two polarizations is proposed in this paper. The unit cell is based on a nonresonant cross-shaped geometry backed by a metallic plate. Unlike previous metal-only nonresonant unit cell, the metallic arms of the proposed one are not connected to its neighboring unit cells. This fact enables the propagation of the incident wave along the longitudinal direction of the unit cell more specifically, along parallel-plate waveguides formed between unit cells. Depending on the polarization of the impinging wave, the propagation occurs in the waveguides located at vertical or horizontal directions. The simulated results for a designed unit cell at 60GHz show the independent modification of the phase response for one polarization being unaffected the phase response of orthogonal one. Moreover, phase linearity and a phase shift range over 360o are achieved along a operating frequency range with good phase stability under oblique incidence.

17:20 ***Phase Change Material Based Reconfigurable Transmitarray: A Feasibility Study***

Samara Gharbieh (CEA-Leti Minatec, Grenoble, France); Antonio Clemente (CEA-LETI Minatec, France); Jorick Milbrandt (CEA-Leti MIinatec, Grenoble, France); Bruno Reig (CEA-LETI, France)

In this paper, we present the design of a reconfigurable transmitarray operating in the D-band. The transmitarray unit cell has a relatively simple structure with three metal layers and two quartz

dielectric substrates. The active transmitting patch of the unit cell ensures a 1-bit phase shift resolution by alternating the states of two innovative switches. Here, we overcome the small dimensions challenge in the D-band by introducing compact switches that are compatible with the dimensions of the proposed unit cell. The switches are made of phase change materials that alternate between the amorphous and the crystalline states under the effect of heat. We present a full-wave simulation of the unit cell, which shows an insertion loss that is below 1.5 dB over a relative frequency band of 27%. Furthermore, we synthesize a 16×16 elements transmitarray using an in-house MATLAB tool and compare its theoretical results to a full-wave HFSS simulation.

17:40 ***Thermally Actuated Vanadium Dioxide Millimeter Wave Reflectarray***

Jordan A Ramsey (The Ohio State University, USA); Kendrick Q Henderson (Naval Surface Warfare Center - Crane, USA); Nima Ghalichechian (Georgia Institute of Technology, USA)

This paper presents the development of a reconfigurable vanadium dioxide (VO2) based reflectarray antenna using a novel 1-bit split patch element. The thermally actuated unit cell, composed of a quarter wavelength copper patch and a VO2 thin film switch is able to achieve 180° of phase at 35 GHz with a maximum loss of 0.35 dB. Such a design exploits the reversible metal to insulator transition properties of VO2 at 68 °C. The simplicity of such an element provides a low cost practical reconfiguration strategy that can be extended to large apertures. A full-wave 40 × 40 element simulation of the switchable device demonstrated a maximum gain of 21.1 dB at 0° and 1D beam scanning performance covering - 60° to +60° with a 4.5 dB reduction in peak gain over the full scanning range.

18:00 ***Design of FSS-Backed Reflectarray Cells for Coverage-Enhancing Panels with Suppressed Out-Of-Band Reflections in Millimeter-Wave 5G***

Roman Soroka, Eduardo Martinez-de-Rioja and Ana Arboleya (Universidad Rey Juan Carlos, Spain); Jose A. Encinar (Universidad Politecnica de Madrid, Spain)

A dual-polarization reflectarray cell backed by a frequency selective surface is proposed for the design of coverage-enhancing panels in 5G networks at the 28 GHz band. The FSS-backed reflectarray cell suppresses the undesired reflections of impinging signals which propagate at the frequencies of other mobile communications systems, such as the sub-6 and 39 GHz bands of 5G. Several FSS topologies have been evaluated for the design, seeking to get the structure to behave as a metallic ground plane at the 28 GHz band, while being transparent at the sub-6 and 39 GHz bands. The reflectarray elements have been placed on top of the FSS, and the performance of the FSS-backed reflectarray cell has been compared with that of a conventional reflectarray cell backed by a metallic plane. The simulations confirm the potential of the proposed structure to design reflectarray panels with suppressed out-of-band reflections to enhance coverage in 5G systems.

SW04: EurAAP Women in Antennas and Propagation

Scientific Workshop

Wednesday, March 30 17:30 - 18:30

Measurements WG meeting

Thursday, March 31

Thursday, March 31 9:00 - 10:40

A10: Adaptive and MIMO antennas

T02 Millimetre Wave 5G and 6G/ / Antennas

9:00 ***Comparative Study of MIMO Antennas for Radiative Near-Field Links at 300GHz***

Nina Beschoor Plug, Shahab Oddin Dabironezare and Nuria LLombart (Delft University of Technology, The Netherlands)

This paper presents a comparative study of different antenna array architectures for achieving ultra-fast Point to Point wireless links for potential use in future 6G backhauling applications. This study analyzes both focal plane and phased array architectures that can lead to higher throughput via Multiple Input Multiple Output architectures. It is found that to reach ultra-fast and radiated energy efficient Point to Point (PtP) wireless links, the antennas should exploit the multi-mode capacity of radiative near-field links. The study presents the theoretical achievable capacities based on the

channel matrix estimated in the radiated near-field and the application of the Shannon formula. The study focuses in the 220-320GHz spectral bandwidth defined by the new IEEE 802.15.3d standard and reports the curves versus the link distance. It is found that capacities well above Tbps can be theoretically achieved, even without the use of interference mitigation techniques.

9:20 ***A Novel Full-Wave Methodology for Channel Estimation in Digital mMIMO Applications***

Hugo R. D. Filgueiras and Marco Ferrero (Instituto Nacional de Telecomunicações - Inatel, Brazil); Igor da Costa and Joana Da Silva (ESSS, Brazil); Arismar Cerqueira S. Jr. (INATEL, Brazil)

This paper proposes a novel full-wave methodology for estimating the channel state information (CSI) in massive multiple-input multiple-output (mMIMO) applications. Our approach is based on a hybrid implementation of the shouting and bouncing rays (SBR) and finite-element (FEM) methods. Numerical simulations using FEM are carried out for designing a patch antenna, which provides 1.15 GHz bandwidth centered at 26 GHz and 7.5 dBi gain. The antenna is used to represent the user equipment (UE) and the antenna array element of a base station (BS). The antenna results are imported into the SBR solution region as linked sources. The chosen scenario is the Research Laboratory WOCA from Inatel (Brazil), with a 91-m² area, concrete walls and furniture made of wood and metal. Numerical SBR simulations are presented and a 16-order MIMO channel is successfully estimated in terms of magnitude and phase.

9:40 ***Maximization of Millimeter-Wave LoS OAM Link Using Beam Steering and Partial Receiving***

Yanlei Xiu (Chongqing University of Posts and Telecommunications, United Kingdom (Great Britain)); Yang Wang and Panpan Shi (Chongqing University of Posts and Telecommunications, China); Kuo Zhao and Tao Hu (Chongqing College of Electronic Engineering, China); Xi Liao (Chongqing University of Posts and Telecommunications, China)

Orbital angular momentum (OAM) can provide an additional multiplexing degree for millimeter wave multiple-input multiple-output (MIMO) communication. However, the performance of OAM link will suffer a great loss in non-ideal propagation scenarios, i.e. misalignment and incomplete receiving UCAs, since the divergence of OAM waves. In this paper, a partial receiving and beam steering scheme is proposed to improve the performance of millimeter OAM-MIMO link. While the beam steering scheme can direct the OAM beam to the receiver area, the partial receiving scheme can derive the complete receiving matrix by partial antenna array elements and demultiplex OAM signals. Numerical results show that the partial receiving scheme based on beam steering greatly improves OAM propagation and the system capacity.

10:00 ***UWB-MIMO Antenna for Wireless Communication Systems with Isolation Enhancement Using Metamaterial***

Omkar Ashish Shelar and Tanweer Ali (Manipal Institute of Technology, Manipal Academy of Higher Education, India); Praveen Kumar (Manipal Institute of Technology & Manipal Academy of Higher Education, Karnataka, India)

This paper proposes a 2x2 MIMO microstrip patch antenna for application in the ultrawideband frequency range. The design makes use of a metamaterial structure to enhance the isolation (S12/S21 parameter), keeping it well below -20dB. The impedance bandwidth of the proposed MIMO is from 2.06 GHz to 15.21 GHz, encompassing the entire UWB bandwidth. The proposed antenna's performance has been validated by measuring five MIMO diversity parameters throughout the impedance bandwidth. CCL is < 0.2 bps/Hz, DG is nearly 10, ECC is < 0.0014, TARC < -10 dB, and MEG stable around -6.25 dB. The overall dimensions of the proposed antenna are 89mm x 30mm x 1.6mm.

10:20 ***A Reconfigurable MuPAR Antenna System Employing a Hybrid Beam-Forming Technique***

Dimitrios K. Rongas, Leonidas Marantis and Athanasios G. Kanatas (University of Piraeus, Greece)

This research study proposes a 3.5 GHz array system that demonstrates a hybrid combination of beam-forming and beam-switching schemes. As basic antenna element, a printed ESPAR antenna is employed, with capability to direct its radiation pattern by means of PIN diodes switching. Furthermore, the antenna element impedance matching technique is investigated. Consequently, a four element ESPAR antenna array (MuPAR) is formed in order to exhibit the beam-switching operation of the elements, in combination to the beam-steering technique through a phase shift on the array elements. As a result, a novel hybrid beam-forming array system is implemented, demonstrating multiple scanning capabilities.

CS36: Progress in sub-THz and THz channel characterization

T02 Millimetre Wave 5G and 6G/ /Propagation

Chairs: Wei Fan (Aalborg University, Denmark), Pekka Kyösti (Keysight Technologies & University of Oulu, Finland)

9:00 ***Sub-Terahertz Path-Loss Characteristics in an Urban Microcell Environment for 6G***

Minoru Inomata, Wataru Yamada, Nobuaki Kuno and Motoharu Sasaki (NTT, Japan)

The establishment of 6G networks is being actively pursued worldwide. 6G will require extremely high-speed and high-capacity communications exceeding 100 Gbps, and one solution is to utilize

new frequency bands above 100 GHz. However, specific new radio- interface technologies and service frequency bands have not been determined yet, because propagation characteristics above 100 GHz in various environments have not been studied sufficiently. In consideration of exploiting new frequency bands for 6G, path-loss characteristics from the microwave to sub-terahertz bands in an urban microcell environment were investigated. Also, the dominant paths that affect the path-loss characteristics were clarified on the basis of the measured power angular profiles.

9:20 ***Simulating the Radar Cross Section of a Bare Tree: From Megahertz to Terahertz***

Oliver Csernyava and Katsuyuki Haneda (Aalto University, Finland)

An approach to estimate a radar cross-section (RCS) of a tree through numerical simulations is studied. This paper covers bare trees with a trunk and branches and without leaves. Recent advancements in three-dimensional (3D) modeling of trees and electromagnetic solvers allow simulation of field scattering from a whole tree. There are open issues in performing the simulations: 1) obtaining 3D models of tree trunks and branches, especially whether they have to be multi-layered or not; 2) knowing dielectric parameters of tree trunks and branches, especially for higher frequencies than 10 GHz; 3) using a right field solver depending on the electrical size of a tree. We propose suitable 3D models of tree trunks and branches, show our present knowledge of dielectric parameters of living trees, and finally demonstrate impacts of branches in addition to a trunk on the estimated RCS through numerical simulations at 1000 MHz to 0.1 THz.

9:40 ***Indoor Material Transmission Measurements Between 2 GHz and 170 GHz for 6G Wireless Communication Systems***

Mohamed Abdelbasset Aliouane (Telecom Paris, Ecole Polytechnique de Paris & Orange Labs, France); Jean-Marc Conrat (Orange Labs, France); Jean-Christophe Cousin (Telecom ParisTech, France); Xavier Begaud (LTCI, Télécom Paris, Institut Polytechnique de Paris, France)

The sixth-generation wireless communication research activities were launched worldwide. A tendency of some researchers to use the sub-terahertz frequency band for 6G is noticed. This frequency band is selected as a candidate for 6G due to its remarkable wide unused frequency bandwidth. In this paper, typical indoor environment material transmission measurements from 2 GHz to 170 GHz are presented. These measurements aim to further understand and compare wave-material interaction for above and below 100 GHz frequencies by providing a continuous measurement up to 170 GHz of 16 different materials e.g. glass, plasterboard, concrete, and wooden materials. The measurement system is based on a vector network analyzer, with frequency extension modules for frequencies above 50 GHz.

10:00 ***Analysis of Residential Sub-THz Deployments from Accurate Radio Simulations and Planning Techniques***

Laurent Maviel, Yoann Corre and Grégory Gougeon (SIRADEL, France); Djamel Amar (Siradel, France)

High-capacity bandwidth makes sub-THz spectrum a key element of beyond-5G or 6G networks. However wireless communications at frequencies such as in W-band, D-band or above do suffer from strong constraints at the physical layer, they may be greatly beneficial for adequately chosen ultra-broadband applications and network topologies. Multi-hop backhauling and Fixed Wireless Access (FWA) networks are both candidates that we decided to assess as a combination. The physical-layer performance is estimated from LiDAR-based ray-tracing predictions and by considering a sub-THz polar-QAM modulation. The site placement is optimized by an automated heuristic method. Finally, analysis of a case study in a North American residential area demonstrates that a FWA design at 150 GHz is challenging due to propagation, but feasible. The comparison between a coverage-constrained sub-THz design and a capacity-constrained 5G design shows interesting complementarity.

10:20 ***On the Phase-Compensated Long-Range VNA-Based Channel Sounder for Sub-6GHz, mmWave and Sub-THz Frequency Bands***

Yejian Lyu (Aalborg University, Denmark); Allan Mbugua (Huawei Technologies Duesseldorf GmbH, Munich Research Center, Germany); Kim Olesen (Aalborg University, Denmark); Pekka Kyösti (Keysight Technologies & University of Oulu, Finland); Wei Fan (Aalborg University, Denmark)

This paper presents an overview of the vector network analyzer (VNA)-based phase-compensated channel sounder at sub-6 GHz, mmWave and sub-Terahertz (sub-THz) bands. The optical cable solution can enable long-range channel measurements for all these three bands, since it can effectively minimize the cable loss. The phase compensation architecture and principle are also discussed in this paper. The phase compensation scheme could stabilize the phase change introduced by optical fiber of the channel sounder to enable accurate phase measurement, which is essential for application in multi-channel/antenna measurements. We summarized the performance of the designed channel sounder under two types of cable effect condition, namely thermal changes and mechanical stress. Under these two cable conditions, the phase compensated channel sounders are validated in back-to-back measurements. The compensated phases demonstrate the robustness and effectiveness of these channel sounder for the frequency bands of 1-30 GHz, and 220-330 GHz.

10:40 Coffee Break

11:00 ***Verification of THz Channel Sounder and Delay Estimation with Over-The-Air Multipath Artifact***

Diego Dupleich (Technische Universität Ilmenau, Germany); Sebastian Semper (Ilmenau University of Technology, Germany); Mohanad Dawood Al-Dabbagh (Physikalisch-Technische Bundesanstalt (PTB), Germany); Alexander Ebert (Technische Universität Ilmenau, Germany); Thomas Kleine-Ostmann (Physikalisch-Technische Bundesanstalt, Germany); Reiner S. Thomä (Ilmenau University of Technology, Germany)

In the present paper we introduce the empirical results of measurements with an over-the-air based propagation artifact for verification and validation of sub-THz and THz channel sounders and parameter estimation algorithms. This experiment produces a fixed number of multipath components with traceable propagation properties in the different domains that can be used to test resolution and performance. Because of the inherent characteristics of the measurement hardware, we have introduced an adaptation on a parametric high resolution estimation algorithm to account the imperfections of the channel sounder. The results have shown to account for a relative good performance of the sounder and the tested parametric and non-parametric estimation algorithms.

11:20 ***Initial Results on D Band Channel Measurements in LOS and NLOS Office Corridor Environment***

Joonas Kokkoniemi, Veikko Hovinen, Klaus Nevala and Markku Juntti (University of Oulu, Finland)

A need for measurement data for frequencies above 100 GHz has increased. In this paper, we present the measurement system for millimeter wave frequencies (30-300 GHz). It is based on Keysight PNA-X vector network analyser with frequency extenders mounted on custom built 3-axis rotation stages (both the transmitter and receiver sides). We present some initial results from measurements conducted in an office corridor. Both line-of-sight (LOS) and non-LOS (NLOS) cases are included in the measurement set-ups. The results show that in all cases the channels are sparse with clear clusters from large reflecting surfaces, such as walls and floors. The measured power levels are rather strong indicating relatively low reflection losses. While the channels were sparse, there were still typically relatively large numbers of distinguishable paths. The numbers of observable paths as well as the delay spread of the channel increase with increasing beamwidth.

11:40 ***Comparison of Indoor Channel Characteristics for Sub-THz Bands from 125 GHz to 300 GHz***

Marina Lotti (University of Bologna, Italy & CEA Leti, France); Mathieu Caillet (CEA-LETI, France); Raffaele D'Errico (CEA, LETI & Université Grenoble-Alpes, France)

This work presents an empirical indoor sub-THz channel characterization. The frequency aspect is studied through measurement campaigns conducted for different frequency ranges: 125-155 GHz, 235-265 GHz and 270-300 GHz, allowing to compare the channel of the D-band range with the channel above 200 GHz. Two different laboratory scenarios are taken into account. A double steering of the antennas at the transmitting and receiving side allows to perform a double angular characterization. The multipath components detection results are provided and path loss and delay spread models are reported. Finally, a clustering of the detected paths is also presented.

12:00 ***Propagation Measurements Comparing Indoor and Outdoor Hotspot Coverage at 28, 58, and 143 GHz***

Christina Larsson (Ericsson Research & Ericsson AB, Sweden); Bengt-Erik Olsson (Ericsson AB, Sweden); Sinh Nguyen and Martin Johansson (Ericsson Research, Sweden)

In this paper, we compare radio propagation channel characteristics of the 28, 60 and 140 GHz bands in one indoor and one outdoor hotspot scenario. The paper concludes that the excess loss, i.e., the loss in addition to the free-space path loss, is very similar for 28, 60 and 140 GHz as long as the measurements are conducted in open areas or where only one or two reflections are needed to get coverage. In areas requiring multiple reflections or wall penetration to achieve coverage, the excess loss increases for the higher frequencies.

12:20 ***Investigation of Eavesdropping Opportunities in a Meeting Room Scenario for THz Communications***

Christoph Herold, Tobias Doeker, Johannes M. Eckhardt and Thomas Kürner (Technische Universität Braunschweig, Germany)

Due to the large available bandwidth, wireless communications in the THz range are foreseen to provide high data-rate transmissions. Compared to transmissions at lower frequency ranges, wireless communications in the THz range are inherently more robust against eavesdropping attacks due to their propagation characteristics such as a high free space path loss. It does not connote, however, that eavesdropping is not possible. In this paper, ray-optical methods and confirming channel sounder measurements at 300 GHz are used to show that even common, ordinary features such as door frames or a TV screen in the selected meeting room scenario can have a significant influence on the wave propagation at 300 GHz. Thus, such objects can provide opportunities for eavesdropping signals even at unexpected locations outside of the main lope of the antenna diagram and behind the transmitter and cannot be neglected.

CS32: New trends in small antennas

T03 Wireless LANS, IoT and M2M/ / Antennas

Chair: Marta Cabedo-Fabrés (Universidad Politécnica de Valencia, Spain)

9:00 ***Electrically Small Antenna with Embedded Operational Amplifier Circuit Surpasses the Passive Upper Bound of the Gain-Bandwidth Product***

Yaqing Yu, Ming-Chun Tang, Da Yi, Dingmou Hong and Shi Ting (Chongqing University, China); Richard Ziolkowski (University of Technology Sydney, Australia & University of Arizona, USA)

A near-field resonant parasitic (NFRP) active electrically small transmitting antenna is reported in this paper. It consists of an electrically small NFRP antenna and an operational amplifier (OpAmp). In

the design, the NFRP element serves as the main radiator and the feedback pathway of the OpAmp simultaneously. This configuration significantly increases the effective gain of the electrically small antenna (ESA) without consuming any additional real estate. The overall electrical size is extremely small with ka = 0.15. The measured results of this active ESA, in good agreement with simulated values, demonstrate its effective gain can be dynamically tuned within a 6.01 dB range. Compared with its corresponding passive counterpart, the measured maximum effective gain and hence, the effective isotropic radiated power (EIRP) of developed active ESA witnesses 9.152 dB (8.23 times) improvement. Thus, the measured gain-bandwidth product (GBWP) surpasses the corresponding passive Bode-Fano upper bound by approximately 15.2 times.

9:20 ***A Dual-Polarized Wideband Planar Multiport Mobile Antenna***

Riku Kormilainen (Aalto University, Finland); Rasmus Luomaniemi (Huawei Technologies Finland, Finland); Anu Lehtovuori (Aalto University, Finland); Alexander Khripkov (Huawei Technologies LTD, Finland); Janne Ilvonen (Huawei Technologies Oy (Finland) Co. Ltd, Finland); Ville Viikari (Aalto University & School of Electrical Engineering, Finland)

Additional antennas are needed in smart phones to support 5G bands. The metal rim, which is the most attractive position for antennas, is already fully occupied by antennas supporting legacy bands. Therefore, there is a growing interest in new, more challenging antenna locations, such as the back cover of the phone. In this paper, we introduce a dual-polarized frequency reconfigurable wideband planar multiport antenna to the back cover of a mobile phone. The antenna has a height of only 0.5 mm. The simulations show that the introduced antenna achieves better than -5.8 dB efficiency from 3.3 GHz to 4.2 GHz.

9:40 ***A Conformal and Transparent Frequency Reconfigurable Water Antenna***

Abu Sadat Md. Sayem (University of Technology Sydney, Australia); Roy B. V. B. Simorangkir (Tyndall National Institute, Ireland); Karu Esselle (University of Technology Sydney, Australia); John Laurence Buckley (Tyndall National Institute & University College Cork, Ireland)

This paper presents a design of water-based flexible, optically transparent and frequency reconfigurable antenna having a unidirectional radiation pattern. The proposed antenna incorporates a dipole radiator on top of a reflector plane that makes the radiation unidirectional. The reflector is constructed from pure water enclosed inside a circular cavity made of polydimethylsiloxane (PDMS), which consists of several ring chambers arranged concentrically. Frequency tuning operation is achieved by an innovative mechanical tuning mechanism involving controlling the water configuration inside the circular cavity. Depending upon the presence or absence of the water in different chambers, the resonance frequency changes accordingly while maintaining the radiation pattern unidirectional. Detail simulation investigation of the proposed technique is presented in this paper.

10:00 ***Directional Modulation from a Wrist-Wearable Compact Antenna***

Abel Abdul Zandamela and Nicola Marchetti (Trinity College Dublin, Ireland); Adam Narbudowicz (Trinity College Dublin, Ireland & Wroclaw University of Science and Technology, Poland)

This work proposes compact multiport antennas for directional modulation (DM) on wrist-wearable devices to improve the secrecy and privacy of the transmitted data. The DM performance is investigated using the antenna in free-space and with a human forearm-phantom. The system achieves a low Bit Error Rate (BER) < 10^(−1) with 54° beamwidth, in a unique steerable secure direction over the entire azimuth plane. Full-wave simulations, including the phantom at 5 GHz, show realized gains of up to 4.26 dBi. The specific absorption rate is below the standard limits, with maximum values of 0.487W/kg and 1.42W/kg for the wrist-worn and next-to-mouth conditions, respectively.

10:20 ***On Spatial Visualization of Mutual Coupling with Applications to Small Embedded Antennas***

Lars Jonsson (KTH Royal Institute of Technology, Sweden); Johan Lundgren (CellMax Technologies, Kista, Sweden); Johan Malmström (Saab Surveillance, Sweden)

Mutual coupling between antennas is a key parameter in multi-antenna systems. The present paper describes a method to map contributions to the magnitude of the mutual coupling spatially on surfaces between the ports. The method utilizes the reaction theorem for electromagnetic fields to obtain the contribution of the coupling from different regions. The derived result is valid for and applied to the strong-coupling regime, where the mutual impedance is of the same order as the self-impedance.

10:40 Coffee Break

11:00 ***A Wideband and Miniaturized Metal Rim Antenna with A New Material for Smartphone Applications***

Xiantao Yang, Yi Huang and Lyuwei Chen (University of Liverpool, United Kingdom (Great Britain))

A new wideband and miniaturized metal rim antenna is developed based on a frequency-variant material for smartphone applications. The proposed antenna has a small clearance of 2 mm and uses a simple feeding method without impedance matching networks. This compact antenna, like a small module, can be designed at the top side of the substrate without extending to the long side which will reduce the user hand effect significantly. Three cases with/without new material are investigated and compared to demonstrate that the proposed antenna based on the new material is a good

candidate for modern smartphone antenna applications.

11:20 ***A New Approach for Matching Small Parasitic Superdirective Antennas Using Network Characteristic Modes***

Abdellah Touhami (University RENNNES1, France); Ala Sharaiha (Université de Rennes 1 & IETR, France); Sylvain Collardey (University of Rennes 1, France)

This paper presents a network characteristic modes based method for parasitic superdirective arrays matching. The proposed method is used for designing a two M-monopole array with a separation distance of d=0.1λ. that achieves a near 50 ohm input radiation resistance, resulting in a matched input impedance, and therefore, a substantial increase in realized gain or total efficiency. The designed array shows a maximal directivity of 7.37 dBi and an impedance bandwidth of 23 MHz. The array present a -1dB bandwidth of directivity, gain and realized gain respectively of 70 MHz, 70 MHz and 31 MHz.

11:40 ***Highly Miniaturized Folded-Slot Based MIMO Antenna Design for CubeSat Applications***

Rifaqat Hussain (KFUPM, Saudi Arabia); Abida Shaheen Rao (The Islamia University, Pakistan); Abdul Aziz (The Islamia University of Bahawalpur, Pakistan); Muhammad Umar Khan (National University of Sciences and Technology (NUST), Pakistan); Mohammad S. Sharawi (Polytechnique Montreal, Canada)

In this paper, a highly miniaturized folded slot-based multiple-input-multiple-output (MIMO) antenna design is presented for Cube Satellites (CubeSats) applications at UHF band. It consists of meandered slot structure folded on both sides of the substrate board. Miniaturization is achieved using a unique combination of meandered slot with folded structure along with reactively loading using a discrete capacitor. The antenna exhibits wide-band operation covering frequency bands from 430-510 MHZ. The proposed antenna is best suited for small satellite especially for CubeSat applications. The proposed antenna design has a total board dimensions of 100×100 mm2.

12:00 ***Beamforming for Antenna Array Using Modal Technique***

Jan Kracek and Pavel Hazdra (Czech Technical University in Prague, Czech Republic); Tomas Lonsky (RFspin, Czech Republic)

Beamforming for an antenna array using a modal technique is presented. The approach is suitable for the antenna array consisting of arbitrary elements in any mutual arrangement since its full-wave characterization is employed. The technique is demonstrated on an example of a planar antenna array with linear polarization.

12:20 ***Flexible and Adaptive Dipole-Based Triple-Fed Antenna for Single-Chip Transceiver***

Serafin Benedikt Fischer (University of Stuttgart, Germany); Shuo Wang (IMS CHIPS, Germany); Jan Hesselbarth (University of Stuttgart & IHF -- Institute of Radio Frequency Technology, Germany); Joachim Burghartz (Institut für Mikroelektronik Stuttgart, Germany)

Attaching a dipole antenna to dielectric material of largely different permittivity leads to strong variation of antenna feed impedance. The performance of a connected transceiver may deteriorate drastically. The proposed antenna provides three feed-points, which show respective feed-point match to 100 Ohm balanced feeds for three different dielectric environments (free-space and half-spaces of permittivity 4 and 42, respectively). The antenna is compact and implemented into a mechanically flexible foil. The three feed-points are very close to each other to accommodate a single RF chip. The antenna design for frequency of 5.5 GHz is supported by measurements, which agree well with simulations.

A16: Wearable antennas

T04 Biomedical and Health/ / Antennas

Chair: Zvonimir Sipus (University of Zagreb, Croatia)

9:00 ***A Bio-Degradable Textile-Based Graphene Antenna for the 5G Smart Wearables***

Owain O Thompson (Aberystwyth University, United Kingdom (Great Britain)); Shaker Alkaraki (Queen Mary University Of London, United Kingdom (Great Britain)); Qammer H Abbasi (University of Glasgow, United Kingdom (Great Britain)); Syeda Fizzah Jilani (Aberystwyth University & Queen Mary University of London, United Kingdom (Great Britain)); David Andrew Evans (Aberystwyth University, United Kingdom (Great Britain))

This paper proposes a bio-degradable antenna design well-suited for the 5th generation (5G) wearables. This antenna has a graphene patterning instead of conventional metallization on a textile substrate to make it eco-friendly as it avoids copper corrosion due to repeated washing of the wearable garments. The antenna design incorporates coplanar waveguide (CPW) feeding and directive stubs to converge the radiation pattern. The antenna patch footprint is reduced by fitting the radiating length into a small area by inserting the cut-outs through an iterative design process. The proposed antenna offers a bandwidth that covers the proposed newly launched 5G band (i.e., 3.4-3.8 GHz) with a resonant frequency at 3.55 GHz, realized gain of 4.11 dB, and an efficiency of 83%.

9:20 ***Wearable Sensor for Breath Rate Monitoring***

Mahmoud Elgeziry, Filippo Costa, Alessandro Tognetti and Simone Genovesi (University of Pisa, Italy)

Monitoring of the breath rate is important for assessment of patients' health condition, sleep quality, sports monitoring, operational health, safety and early detection of potential serious respiratory system infections. Despite the need for continuous respiratory rate (RR) monitoring, wearable RR sensors are highly demanded in the relevant application fields. In this article a wearable breath rate sensor based on a planar spiral resonator (SR) is presented. The SR is accommodated on a textile substrate allowing the sensor to conform to non-planar surfaces making it suitable for integration in garments. The respiration rate is retrieved by using the SR and a wireless reader probe placed close-by. The working principle is based on tracking the movement of the chest wall or abdomen during respiration. The proposed device is can measure the respiration frequency by analysing the modulated signal at the probe. The sensing concept was verified experimentally using a breath simulator.

9:40 ***Wearable Slotted Waveguide Textile Antenna***

Davorin Mikulic and Evita Sopp (University of Zagreb, Croatia); Davor Bonefačić (University of Zagreb, Faculty of Electrical Engineering and Computing, Croatia); Zvonimir Sipus (University of Zagreb, Croatia)

One of the challenges in development of body-centric communication and sensor systems is to design wearable antennas that are technically and aesthetically acceptable to be worn. This paper describes a novel wearable antenna design - textile realization of slotted waveguide antenna. In order to characterize the proposed antenna solution, the measured antenna parameters were compared with the parameters of the equivalent antenna made from aluminium. The realized antenna is suitable for realization of off-body communication mode and can be integrated into clothing, e.g. as a smart belt.

10:00 ***A Design Approach for In-Body Antennas for Animal Biotelemetry Applications***

Said Benaissa (Ghent University/imec, Belgium); Denys Nikolayev (Institut d'Électronique et des Technologies du Numérique (IETR) - UMR CNRS 6164, France); Gunter Vermeeren (Ghent University, Belgium); Frank Tuyttens and Bart Sonck (Institute for Agricultural and Fisheries Research (ILVO), Belgium); Luc Martens (Ghent University, Belgium); David Plets (Ghent University - imec, Belgium); Wout Joseph (Ghent University/IMEC, Belgium)

Boluses with biotelemetry capabilities enable wireless monitoring of animal physiological data (ruminal temperature, pH). These devices rely on antennas to interface with external receivers. Existing antennas typically provide a short-range (1-2 m) communication, which can be improved by addressing the radiation efficiency. In this paper, a novel design approach for in-body antennas for animal biotelemetry applications is presented. The optimal frequency band is studied prior to the design of the antenna based on the dielectric measurements of the antenna environment. A demonstrator conformal patch antenna is proposed for the 434 MHz ISM band. The performance of the antenna is simulated in phantoms with cow's rumen fluid electromagnetic properties. The antenna is integrated in a bolus with 13 cm length and 1.5 cm radius. The proposed antenna has a gain of -20.1 dBi and the radiation efficiency of 0.53% in a spherical phantom with a diameter of 200 mm.

10:20 ***Wideband Flexible Textile Antenna with Parasitic Shorted Strips for Body-Centric Communications***

Shengjian Jammy Chen (Flinders University, Australia & The University of Adelaide, Australia); Zhihan Xu (The University of Adelaide, Australia); Christophe Fumeaux (The University of Adelaide & School of Electrical and Electronic Engineering, Australia)

A wearable wideband textile patch antenna with two parasitic shorted strips for off-body communication is presented. The antenna exhibits excellent mechanical resilience thanks to the highly flexible polydimethylsiloxane (PDMS) substrate and textile conductor. The two parasitic shorted strips are introduced to create a new resonance which significantly widens the overall antenna bandwidth. A stabler broadside radiation is generated over the operation frequency from 5.4 to 6.0 GHz for off-body communications, covering some 5 GHz Wireless Local Area Network (WLAN) bands and the 5.8 GHz Industrial, Scientific, and Medical (ISM) bands. The antenna design is fabricated and experimentally validated, the good agreement between simulation and measurement suggests that the proposed antenna is promising for off-body communications.

CS37: Propagation of Smart Mobility empowered by 5G and Beyond

T05 Aircraft (incl UAV, UAS, RPAS) and automotive/ / Propagation

Chairs: Uwe-Carsten G. Fiebig (German Aerospace Center (DLR), Germany), Ke Guan (Beijing Jiaotong University, China)

9:00 ***Geometry-Based Stochastic Channel Model for Train-To-Train Communication in Open Field Environment***

Paul Unterhuber and Michael Walter (German Aerospace Center (DLR), Germany); Thomas Kürner (Technische Universität Braunschweig, Germany)

Future railway applications, e.g., wireless train bus or virtual coupled trains, will rely on train-to-train (T2T) communication. Those future applications require an exchange of safety critical data between trains within one train-set based on wireless communication. Hence, the investigation of the propagation effects and the influence on the wireless communication is tremendously important. Future developments of communication standards and systems demand a detailed characterization and modeling. We investigated the propagation mechanisms based on channel sounding

measurements and derived statistics for the propagation effects. Based on the environment, geometry and the propagation statistics we derive channel models for T2T communication. To cope with the movement of the trains, the changing environment and resulting temporal correlation effects we present a geometry-based stochastic channel model (GSCM) for T2T communication in open field environment.

9:20 ***Deep Learning-Based Joint Communication and Sensing for 6G Cellular-Connected UAVs***

José Rodríguez-Piñeiro, Wenjing Liu, Yu Wang and Xuefeng Yin (Tongji University, China); Juyul Lee and Myung-Don Kim (ETRI, Korea (South))

Unmanned Aerial Vehicles (UAVs) have been widely used in military and civilian fields in the recent years, being many of their applications dependent on some strategy for sensing the environment. With full Joint Communication And Sensing (JCAS) support, increased bandwidth and higher frequency bands expected for sixth generation (6G) communication systems, a new horizon on the usage of cellular radio frequency (RF) signals for joint air-to-ground (A2G) communications and precise environment sensing is open. In this short paper, the basics of a Deep Learning (DL)-based approach for environment sensing from an UAV by using RF signals from terrestrial cellular deployments is presented. Preliminary results prove that the achieved accuracy of the location of scatterers on the environment is currently around 1 m. The proposed approach constitutes a totally autonomous JCAS solution for environment sensing whose accuracy could be even further improved by learning from previously captured data.

9:40 ***Measurement-Based Propagation Channel Modeling for Communication Between a UAV and a USV***

Yuning Yu and José Rodríguez-Piñeiro (Tongji University, China); Xie Shunqin (Institute of Electronic Engeneering, China Academy of Engineering Physics, China); Yixiao Tong, Zhang Jing and Xuefeng Yin (Tongji University, China)

With the development of fifth generation (5G) mobile communication, unmanned vehicles have become more and more popular, with unmanned aerial vehicles (UAVs) and unmanned surface vehicles (USVs) being the most common ones. Collaborative operation between multiple kinds of unmanned vehicles is the trend for the future development and direct reliable communications between autonomous vehicles are mission-critical in some applications such as communication relaying and heterogeneous ad-hoc networks. This paper presents a measurement campaign for the channel between a UAV and a USV by the seaside. The UAV hovers at an altitude of 50 meters over the harbor, and the USV sails out from the breakwater with a total track length of around 3.1 km. Analyses are made on both large-scale and small-scale channel characteristics, including path loss, shadow fading, and multipath fading. The obtained results are of utmost relevance for the development of communication systems between UAVs and USVs.

10:00 ***Comparison of Sub 6 GHz and mmWave Wireless Channel Measurements at High Speeds***

Faruk Pasic, Daniel Schützenhöfer, Edgar Jirousek, Robert Langwieser, Herbert Groll and Stefan Pratschner (TU Wien, Austria); Sebastian Caban (Vienna University of Technology, Austria); Stefan Schwarz (TU Wien & CD-Lab Society in Motion, Austria); Markus Rupp (TU Wien, Austria)

Next-generation mobile communication systems employ mmWave frequency bands with high bandwidths to enable high data rate transmissions. Further, the importance of high mobility scenarios, such as vehicular communication or high-speed train scenarios, is steadily increasing. To learn how wave propagation and scattering effects change from classical sub 6 GHz to mmWave frequencies, measurements in both bands have to be conducted. We perform wireless channel measurements at 2.55 GHz and 25.5 GHz center frequency at high mobility. To ensure a fair comparison between these two frequency bands, we perform repeatable measurements in a controlled environment. Our measurement methodology enables measurements at the same transmitter and receiver positions and velocities, but at different center frequencies. We compare measured wireless channels at the two employed frequency bands in terms of the delay-Doppler function.

10:20 ***Measurement Based Identification of MPCs in an Urban Drone-To-Drone Propagation Scenario***

Dennis Becker and Uwe-Carsten G. Fiebig (German Aerospace Center (DLR), Germany)

The risk of mid-air collisions between flying drones has to be minimized to the greatest possible extent as it endangers people in the air and on the ground especially when being integrated into dense urban airspace. For a safe and efficient operation they will need to exchange information in a robust and reliable manner and one essential part will be direct D2D communications. Especially, for dense drone scenarios in urban environments a communication system must cope with the specific underlying channel propagation conditions. In order to characterize the propagation effects between two moving drones in urban environments, we performed a channel measurement campaign and presented an approach to localize the origin of the measured multipath components for a three-dimensional layout. In this work, we apply it on our measured scenarios in three different environments in order to identify the MPCs by assigning them to real-world objects and describe first characteristics.

10:40 Coffee Break

11:00 ***Terahertz Enabled Use Cases for Smart Mobility Towards B5G and 6G Communications***

Kun Yang (Guangdong Communications and Networks Institute, China); Haofan Yi and Ke Guan (Beijing Jiaotong University, China); Yang Shen (Guangdong Communications and Networks Institute, China); Danping He, Bo Ai and Zhangdui Zhong (Beijing Jiaotong University, China)

The emerging technology terahertz (THz) communication is envisioned to provide high-data-rate links. For the design of THz communication system, an accurate channel model is unavoidable. As a typical representative of deterministic models, ray-tracing (RT) method based on optical theory is relevant to the physical properties of THz waves. In this study, with the consideration of real-world use, two cases are made for vehicle-to-infrastructure (V2I) and drone communications. These two cases represent two ends of THz mobile communications from terrestrial to aerial one. The V2I channel is analyzed with the aid of RT. The Doppler effect caused by moving vehicles will be a great challenge for system design. As for the drone communications, the channel model should consider the three-dimensional characteristics, including scenario, velocity, trajectory, antenna pattern, etc. The provided brief survey on the two most relevant scenarios for smart mobility will be fundamental for the THz channel modeling.

11:20 ***A Study on Radio Propagation Channel Modelling for Tunnels***

Suying Jiang, Jiting Song and Wei Wang (Chang'an University, China); Ibrahim Rashdan (German Aerospace Center (DLR), Germany)

The tunnel environment is a semi-enclosed space, the electromagnetic wave propagation characteristics are very different from the typical outdoor and indoor environments. Propagation model of electromagnetic waves in tunnels plays an important role in designing advanced wireless communication systems. In this paper, we firstly establish narrowband channel model for the tunnel in Line-of-sight (LoS) and obstructed line-of-sight (OLoS) scenarios, such as the path loss model, small-scale fading model. Then, we analyze the power delay profile (PDP) and root-mean-square (RMS) delay spread in the tunnel. Results show that the PDP can be well modeled by a single exponential decay with a statistically distributed decay-time constant. In addition, it is shown that the generalized extreme value (GEV) distribution has better fit for the cumulative distribution function (CDF) of RMS delay spread than Lognormal distribution in LoS scenarios. In general, RMS delay spreads in LoS scenarios is smaller than OLoS scenarios.

11:40 ***Characterization of a 5G Wireless Train Backbone via Ray-Tracing***

Jorge Elizalde (Ikerlan & BRTA, Spain); Aitor Arriola (Ikerlan & BRTA, Spain); Manuel Alfageme Alonso (COMSA Corporation, Spain); Jérôme Härri (EURECOM, France); Igor Lopez (Construcciones y Auxiliar de Ferrocarriles (CAF), Spain)

In this work the antenna propagation has been characterized for a 5G Wireless Train Backbone (WLTB). For this purpose, a train model has been generated and ray tracing simulations have been performed with antennas installed on the roof of the train. In order to obtain the most optimal antenna locations, the position of the antennas has been modified in vertical and horizontal directions. Tunnels have also been simulated, changing their material properties to study their effect on the signal propagation. Obtained results have allowed to identify potential locations for the antennas of the WLTB

12:00 ***Measurement-Based Analysis of Atmospheric Attenuation by Considering Different Weather Types for Visible Light Communications***

Baobao Liu and Pan Tang (Beijing University of Posts and Telecommunications, China); Yin Yue (BUPT, China); Jianhua Zhang (Beijing University of Posts and Telecommunications, China); Liang Xia (China Mobile Research Institute, China)

Facing the current shortage of radio frequency spectrum resources, visible light communications (VLC) technology has been proposed to be a candidate technology in the sixth generation (6G), especially in the application of Intelligent Transportation Systems (ITS). And the propagation characteristics of VLC channel are critical for VLC system design and optimization. Furthermore, the impact of weather conditions on VLC channel cannot be ignored considering the vehicular VLC in ITS. In this paper, we experimentally investigate the impact of different weather types including fog and relative humidity (RH) on VLC in a laboratory atmospheric chamber. To simulate adverse weather conditions, we change the levels of fog density and water vapor introduced into the chamber, respectively. Then we measure the power attenuation and the bit error rate (BER) performance of VLC system under fog and RH conditions. We find that the VLC system will exhibit worse BER performance in the fog impaired channel than RH conditions. Besides, the results show that the bit errors will not happen until the attenuation reaches the threshold, i.e. attenuated by about 60% for both fog and RH conditions in our experiments. After that, the BER will deteriorate badly even up to 20%.

12:20 ***Connectivity Model for Mobile Ad-Hoc Networks***

Rasmus Liborius Bruun (Aalborg University, Denmark); Konstantinos Voulgaris (University of Edinburgh, United Kingdom (Great Britain)); Troels Pedersen (Aalborg University, Denmark)

We propose a probabilistic connectivity model suitable for imitating link connectivity in large mobile ad hoc networks. The model is based on a two state Markov chain and captures the vital aspects that successive connectivity states exhibits dependence, and that link connectivity is a function of distance between transmitter and receiver. The maximum likelihood estimator is used to estimate parameters from measurement data. The model is found to outperform the common fixed range connectivity model.

CS34: Passive beamforming networks for multi-beam antennas

T08 Space (incl. cubesat)/ /Antennas

Chairs: Mauro Ettorre (University of Rennes 1 & UMR CNRS 6164, France), Jiro Hirokawa (Tokyo Institute of Technology, Japan)

9:00 ***Numerical Design of Two-Dimensional Switching Matrices with a Triangular Lattice of Beams***

Jiro Hirokawa (Tokyo Institute of Technology, Japan); Nelson Fonseca (European Space Agency, The Netherlands)

This manuscript presents a numerical design of two-dimensional switching matrices with triangular lattice of an arbitrary number of beams, improving the overlap between beams in two-dimensional multiple beam coverage. The designs for 2x2-way and 3x3-way matrices are given as examples.

9:20 ***Developments of Fixed-Beam and Electronically Reconfigurable Circularly Polarized Reflect-Arrays at X-Band***

Fan Wu (Southeast University, China); Jingxue Wang (Hohai University, China); Zhi Hao Jiang (Southeast University, China)

Recent and ongoing researches regarding the developments of fixed beam and reconfigurable circularly polarized (CP) reflectarrays at the state key laboratory of millimeter waves of Southeast University are reported. The CP reflectarrays are designed based on the magneto-electric (ME) dipole or patch elements, realizing wide bandwidth, high efficiency and/or low cost. Three designs will be introduced and explained: a wideband design of CP reflectarray using asymmetric dual-polarized ME-dipole structure, a low-cost reconfigurable CP reflectarray based on pin-shorted patch elements and a wideband high-efficiency reconfigurable CP ME-dipole reflectarray. In particular, the design considerations and preliminary results of the reconfigurable ME-dipole CP reflectarray element will be revealed.

9:40 ***Crossover Level Improvement Between Beams in a Geodesic Lens Antenna Based on a Generalized Luneburg Lens***

Astrid Algaba-Brazález (Ericsson AB, Sweden); Philip Arnberg, Oskar Zetterstrom and Freysteinn Viðar Viðarsson (KTH Royal Institute of Technology, Sweden); Lars Manholm and Martin Johansson (Ericsson Research, Sweden); Oscar Quevedo-Teruel (KTH Royal Institute of Technology, Sweden)

In this paper, we propose a geodesic generalized Luneburg lens operating in the 60-GHz band (57-67 GHz), designed with the goal to improve the crossover level between beams with respect to previously reported fully metallic Luneburg lenses, while providing highly directive beams and wide scanning coverage. We have combined the use of a generalized Luneburg lens and the design of a compact feeding type based on ridge waveguide in order to achieve an optimum crossover level between beams keeping in mind manufacturing simplicity. The numerical evaluation of the final integrated lens design including 21 ridge waveguide feeding ports shows a S11 parameter below -13.6 dB over the frequency band of interest, a scanning range of +/-52°, a realized gain higher than 19 dBi over the whole operating bandwidth, and a crossover level value between -3.5 dB and -4.2 dB from the lowest to the highest frequency of operation.

10:00 ***Metal-Only Multi-Beam Fabry-Perot Antenna***

Jorge Ruiz-García (Université de Rennes, France); Christos Bilitos (University of Rennes 1, France); Enrica Martini (University of Siena, Italy); Giovanni Toso (European Space Agency, ESA ESTEC, The Netherlands); Stefano Maci (University of Siena, Italy); David González-Ovejero (Centre National de la Recherche Scientifique - CNRS, France)

In this paper, we present a Fabry-Perot (FP) antenna with full azimuthal beam-switching operating in the Ka-band. The system is composed of two stacked cylindrical layers. The bottom layer contains a Reflecting Luneburg Lens (RLL), which generates a plane wave and transmit it to the top part. Then, we place a Fabry-Perot cavity in the top layer that radiates the excited plane wave through a partially reflective surface (PRS) and produces a directive beam. Both the RLL and the FP cavity are azimuthally symmetric and allow one to generate identical pencil beams for any azimuthal direction. Moreover, it is possible to scan in elevation by varying the height of the FP cavity, which provides 2D beam-steering performance. The double-layer approach guarantees the compactness of the device, whereas the full-metal implementation minimizes the propagation losses. Our proposed antenna is well-suited for spatial applications, particularly for communication systems in SmallSats and CubeSats.

10:20 ***Parallel-Plate Lens Beamformer in Multilayer PCB Technology for Wide-Angle Scanning***

Thomas Ströber (University of Rennes 1, IETR, France); Ségolène Tubau (Thales Alenia Space, France); Hervé Legay (Thalès Alenia Space, France); Etienne Girard (Thales Alenia Space, France); George Goussetis (Heriot-Watt University, United Kingdom (Great Britain)); Mauro Ettorre (University of Rennes 1 & UMR CNRS 6164, France)

In this paper, the design of a continuous parallel-plate lens in multilayer PCB technology is presented. The beamformer consists of a continuously shaped lens doublet made from a stack of substrate layers and an integrated SIW feed system. Asymptotic techniques are used to optimize the lens and feed geometries. The proposed concept is validated by full-wave simulations of a lens design operating in the K-band (17.3-20.2 GHz). The final structure is matched to free-space using a linear flare and provides a total of nine beams over a +/-60° sector with low scan losses in the order of 2 dB.

CS08: AMTA Post Processing Techniques in Antenna Measurements

T09 EM Modelling and Simulation tools/ /Measurements

Chairs: Jeffrey Guerrieri (National Institute of Standards and Technology, USA), Francesco Saccardi (Microwave Vision Italy, Italy)

9:00 ***Single-Cut Phaseless Near-Field to Far-Field Transformation***

Fernando Rodríguez Varela (Universidad Politécnica de Madrid, Spain); Belen Galocha (Universidad Politecnica de Madrid, Spain); Manuel Sierra-Castañer (Universidad Politécnica de Madrid, Spain)

This paper introduces a fast single-cut near-field to far-field transformation method using amplitude-only data. By measuring the antenna near-field amplitude on two concentric rings, the complex far-field for the corresponding ring plane can be retrieved. This avoids the full spherical scanning of traditional near-field measurements if one is interested in only a few radiation pattern cuts. In addition, the phase retrieval algorithm benefits from the reduced dimensionality of the problem. Because the number of unknowns have been reduced to a single ring, the performance is improved with respect to standard full spherical phaseless approaches. The proposed single-cut phaseless technique is tested using simulated and measured data, showing its potential for fast and more reliable amplitude-only measurements.

9:20 ***Preconditioned Inverse Source Solutions***

Thomas F. Eibert (Technical University of Munich (TUM) & Chair of High-Frequency Engineering (HFT), Germany)

For large-scale inverse source problems with millions of unknowns after discretization, iterative linear systems of equations solvers are the method of choice for the solution of the resulting normal linear systems of equations. In order to reduce the related computational workload, a localized and a global preconditioning technique are presented, which speed up the iterative solution process especially for very large and complex inverse source problems. The performance of the preconditioning methods is demonstrated based on synthetic and realistic measurement data.

9:40 ***Phaseless Probe-Fed Antenna Measurement by Means of Flexible Freehand System***

Ana Arboleya (Universidad Rey Juan Carlos, Spain); Guillermo Alvarez Narciandi (University of Oviedo, Spain); Jaime Laviada (Universidad de Oviedo, Spain); Yuri Alvarez-Lopez (University of Oviedo, Spain); Cyril Luxey (University Nice Sophia-Antipolis, France); Frédéric Gianesello (STMicroelectronics, France); Fernando Las-Heras (University of Oviedo, Spain); Aimeric Bisognin (University Nice Sophia-Antipolis & STMicroelectronics, France); Diane Titz (University Nice Sophia Antipolis, France)

This work presents a Near-Field (NF) phaseless measurement system for probe-fed broadband antennas based on a flexible freehand acquisition system. The measurement probe is moved by hand in front of the Antenna Under Test (AUT), being its position provided by a sub-millimeter accuracy optical tracking system. Phase retrieval is done by means of an indirect holography technique capable of retrieving the phase of the field radiated by the AUT at each acquisition point coherently for all the frequency band. The Sources Reconstruction Method (SRM) is applied next in order to compute the aperture currents and radiated fields from the nonregular acquisition grid. Time-gating and spatial filtering techniques are employed to minimize the effect of the environment and feeding-probe, respectively, in the computed radiation pattern. The proposed system and techniques are validated by means of measurements of a broadband probe-fed antenna for WiGig applications working from 57 to 66 GHz.

10:00 ***Automotive Antenna Measurements in the Installed State Under Variable Boundary Conditions***

Muhammad Ehtisham Asghar, Christian Bornkessel and Ralf Stephan (Technische Universität Ilmenau, Germany); Matthias Hein (Ilmenau University of Technology, Germany)

The automotive industry often desires to evaluate installed automotive antennas under variable boundary conditions. This requires a combined approach to test and qualify vehicular antennas; however, facilities deploying variable boundary conditions for measurements are challenging to devise. Alternatively, numerical simulations can be used to perform such investigations; nevertheless, it is essential to verify such simulations through measurements. In the VISTA facility of Technische Universitaet Ilmenau, a new approach to providing variable boundary conditions for antenna measurements is realized to evaluate the impact of different boundary conditions and bridge the gap between numerical simulations and measurements. It consists of a modular and mechanically robust plastic frame carrying a customizable fabric substituting a ground plane. This paper presents and discusses the initial antenna measurement results performed over the conducting fabric. The convincingly good correlation of more than 74% between the measured data and numerical simulations shows the validity of the proposed method.

10:20 ***Experimental Testing of an Effective near to Far-Field Transformation for Flat Antennas Using Non-Redundant Spiral Data***

Francesco D'Agostino (University of Salerno, Italy); Florindo Bevilacqua (Università di Salerno, Italy); Flaminio Ferrara, Claudio Gennarelli, Rocco Guerriero, Massimo Migliozzi and Giovanni Riccio (University of Salerno, Italy)

The experimental validation of a near to far-field transformation (NTFFT) with planar spiral scan for flat antennas under test (AUTs) is provided in this work. Such a technique has been developed by properly exploiting the unified theory of spiral scans for non-volumetric antennas when these AUTs are assumed as enclosed in a disk with diameter equal to their maximum dimension. Moreover, it

uses an efficient two-dimensional optimal sampling interpolation algorithm to reconstruct the near-field data needed by the classical plane-rectangular NTFFT from those gathered along the spiral. Since the smaller the area of the modeling surface, the lower the number of near-field data and spiral turns, a further time saving is accomplished as compared to the non-redundant planar spiral NTFFTs using the modelings for quasi-planar AUTs, which instead involve a residual volumetric redundancy in such a case. The reported experimental results assess the practical feasibility of the developed technique.

10:40 Coffee Break

11:00 ***Investigation of Different Levels of Probe Compensation in Spherical near Field Measurements Performed with Wideband and Dual-Polarized Probes***

Francesco Saccardi and Andrea Giacomini (Microwave Vision Italy, Italy); Thierry Blin (MVG Industries, France); Lars Foged (Microwave Vision Italy, Italy)

Full probe compensation techniques for spherical near field antenna measurements have recently been proposed and validated with success. Such techniques allow the use of antennas with more than a decade of bandwidth as near field probes so that multi-service/frequency measurements can be performed dramatically reducing the number of probes and hence decreasing the downtime between measurements. By using dual-polarized probes the measurement efficiency can be further improved since two orthogonal field components are measured simultaneously. The possible differences between the pattern radiated by the two ports of the probe should sometimes be considered to maintain the overall measurement accuracy. A full PC technique accounting for generic dual-polarized probes was validated in a previous publication considering a wideband dual-polarized probe in the 0.4-6GHz frequency band. In this paper the validation is expanded to the 6-16GHz band considering as probe an antenna of the same family of the previous one.

11:20 ***Phaseless, Non-Redundant Planar Wide-Mesh Scanning for Antenna Characterization: Numerical Validation***

Florindo Bevilacqua (Università di Salerno, Italy); Amedeo Capozzoli and Claudio Curcio (Università di Napoli Federico II, Italy); Francesco D'Agostino, Flaminio Ferrara, Claudio Gennarelli and Rocco Guerriero (University of Salerno, Italy); Angelo Liseno (Università di Napoli Federico II, Italy); Massimo Migliozzi (University of Salerno, Italy); J (Yiannis) Vardaxoglou (Loughborough University, United Kingdom (Great Britain))

This paper aims to introduce a phaseless near-field- far-field (NF-FF) transformation with planar wide-mesh scanning (PWMS) and to give a numerical validation of the technique. The here considered NF-FF transformation, based on a non- redundant sampling representation of the electromagnetic field developed by modeling the antenna under test (AUT) with a double bowl, allows to achieve a remarkable reduction (about 90%) of needed NF samples, as compared to standard λ/4 sampling. The reliability and stability of the phase retrieval problem is improved exploiting a proper representation of the unknowns and the a priori information on the AUT. Numerical results, assessing the proposed characterization technique, are shown.

11:40 ***Fast Spline-Based Antenna Measurements for Robotic Test Ranges via Pointwise Probe Correction***

Roland Moch and Dirk Heberling (RWTH Aachen University, Germany)

Spline-based motion sequences, in contrast to canonical path definitions such as circular or linear paths, represent the optimal mode of operation for robot-based measurement setups. By specifying not a trajectory but a set of required sampling points, the robot controller is granted additional degrees of freedom to optimize the path speed or the smoothness of motion. A comparison of identical spherical near-field measurements based on canonically defined circular trajectories or based on splines yields that the latter enables to increase the average trajectory speed and, thus, to reduce the measurement time by up to 16%. Since one of the spline-based motion trajectories is derived from an irregular sampling grid, a higher-order pointwise probe correction (PPC) is used for all measurements to ensure comparability. It is demonstrated that the averaged equivalent error signal in the far-field radiation pattern is below -54 dB compared to the canonically defined reference.

12:00 ***Assessment of Automotive SAR from Direct Measurements and Post Processing***

Lucia Scialacqua (Microwave Vision Italy, Italy); Francesca Mioc (Consultant, Switzerland); Enrico Toniolo (Calearo Antenne S.p.A., Italy); Lars Foged (Microwave Vision Italy, Italy)

During the last few years more and more electrical devices are being integrated into automotive vehicles. For this reason, an assessment of the Specific Absorption Rate (SAR) for a person placed inside a vehicle is crucial to comply with human safety regulations. SAR values depend in general on the automotive environment specifically on vehicle models and device design. A method for the preliminary assessment of SAR, that could be used in the design phase of devices by resorting to the link between measurement and simulation, is presented. It allows to reduce design time and cost. The proposed technique consists of a single measurement of a prototype, then the measured device is modeled as a NF source that is imported in CEM tools for SAR calculation. In this paper the SAR assessment is demonstrated on a roof-mounted antenna system designed by Calearo and integrated in a portion of a car model.

12:20 ***Potentially Fast Spherical Near-Field Measurements for General Antennas Based on Signal Derivatives***

Kyriakos Kaslis (Technical University of Denmark, Denmark); Olav Breinbjerg (ElMaReCo, Denmark)

Increasing demand for antenna measurements has naturally increased the requirement for these measurements to be performed faster. The theory behind spherical near-field antenna measurements

places a certain boundary to the number of samples needed for a complete measurement which, subsequently, sets the minimum measurement time, given a specific mechanical scanner speed. Some papers have appeared in the literature addressing this problem, but most of them assume a priori information about the antenna, in addition to the radius of its minimum sphere. The new and unique method presented in this paper may facilitate an almost 50% reduction of the measurement time in spherical near- field antenna measurements by employing the derivative of the received signal with respect to the azimuthal angle. Since it does not assume anything beyond the minimum radius that encloses the antenna under test, it can be applied universally.

IW06: Modern Trends in RF Measurement Range Design

Industrial Workshop

E08: Fundamental research in EM theory

T10 Fundamental Research and Emerging Technologies/ / Electromagnetics

Chair: Guy Vandenbosch (Katholieke Universiteit Leuven (KU Leuven), Belgium)

9:00 ***Dispersion HIE-SF-FDTD Method for Simulating Graphene-Based Absorber***

Mohammad Moradi and Mohammad S. Sharawi (Polytechnique Montreal, Canada); Ke Wu (Polytechnique Montréal, Canada)

This paper presents a novel dispersion hybrid implicit explicit single-field finite-difference time-domain (HIE-SF-FDTD) method which can be effectively used to simulate the graphene-based absorber. The stability condition of the proposed method is relaxed from the spatial mesh sizes along one direction which makes it a robust tool to simulate structures having fine details in one Cartesian direction such as thin graphene sheet. By applying the Crank-Nicolson (CN) scheme only to the electric field and a new time-splitting scheme to the graphene current density, the proposed algorithm is developed. In this method, not alike most of the FDTD algorithms in which both electric and magnetic fields are updated, only the electric field needs to be solved in each iteration. Thanks to the few and simple updating equations of the proposed algorithm, higher computational efficiency in terms of runtime is achieved.

9:20 ***Waves in Linear Time-Varying Dielectric Media***

Amirhosein Sotoodehfar, Mohammad Sajjad Mirmoosa and Sergei Tretyakov (Aalto University, Finland)

In this paper, focusing on the frequency domain, we write the constitutive relation and the Helmholtz equation for linear, dispersive, and inhomogeneous time-varying media. Next, by assuming spatial homogeneity, we simplify the equations and explain how to calculate dispersion curves (the angular frequency with respect to the wave vector) for propagating waves. Furthermore, we show that under the simplifying assumption of instantaneous response, the developed general approach provides the same dispersion curves as reported earlier for the dispersionless model of time-varying dielectric media. We believe that this study is important for investigations of wave phenomena in time-varying media, properly taking into account inevitable frequency dispersion of materials.

9:40 ***Spatially Dispersive Electromagnetic Metasurfaces: Multipolar Modeling Vs Extended GSTCs***

Jordan R. Dugan, Joao Guilherme Nizer Rahmeier, Tom Smy and Shulabh Gupta (Carleton University, Canada)

This paper presents and compares two methods for modeling spatially dispersive metasurfaces as zero thickness sheets. In the first method, the standard Generalized Sheet Transition Conditions (GSTCs) are expanded to account for multipolar surface current densities. The extra terms in the current expansion allow for additional surface susceptibilities to be included which relate the multipolar components to the average fields and their spatial derivatives. The second method accounts for spatial dispersion by expressing the dipolar surface susceptibilities as complex rational polynomial functions of the transverse wave vector. This yields a set of differential equations relating the field differences across the surface to the average fields at the surface, leading to an extended form of the standard GSTCs. The two methods are then compared, and the multipolar modeling method is shown to be a subset of the extended GSTC method for the case of a uniform surface

10:00 ***Phase and Polarization Singularities in Circular Electric Dipole Array***

Jie Yang (KU Leuven, Belgium); Xuezhi Zheng (Katholieke Universiteit Leuven, Belgium); Zhensheng Chen (KU Leuven, Belgium); Guy Vandenbosch (Katholieke Universiteit Leuven (KU Leuven), Belgium)

We present an investigation into phase and polarization singularities of electric fields radiated by a circular electric dipole array with rotational and mirroring symmetries. By numerical evaluation, we demonstrate that the z, the right-circular and the left-circular components of the electric fields carry phase singularities with the orders of 0, 1 and -1, respectively. Furthermore, the interference of the right- and left-circular components gives rise to a V-type polarization singularity with the order of 1 in the in-plane components of the electric fields. Our work reveals the phase and polarization singularities in the circular dipole array, which could inspire further fundamental and applied explorations of electromagnetic singularities in other circular EM systems like circular antenna arrays.

10:20 ***Experimental Demonstration of Anomalous Refraction with a 3D-Printed Binary Grating***

Erika Vandelle (Thales Research & Technology, France); Matthieu Bertrand (Thales Research and Technology, France); Thi Quynh Van Hoang and Brigitte Loiseaux (Thales Research & Technology, France)

The anomalous refraction of an all-dielectric 3D-printed diffraction grating is experimentally demonstrated in the microwave domain. The dimensions of the binary grating are derived using the coupled wave theory and full wave simulations. A maximum diffraction efficiency of 89% is obtained for a TE polarized incident plane wave impinging the grating at 18 GHz with a 50° elevation angle. This efficiency remains above 50% over a 35° angular bandwidth around 50° in the frequency band 17-20 GHz. Outside this angular range, the device is electromagnetically transparent. A prototype is fabricated with ABS thermoplastic using a fused-deposition modelling manufacturing technique. The structure is experimentally characterized using a near-field bi-static test bench, and the refractive behaviour is demonstrated.

SW03: Active Array Antennas

Scientific Workshop

Thursday, March 31 10:40 - 11:00

Coffee Break / Exhibition

Thursday, March 31 11:00 - 12:40

Active array antennas WG meeting

E01: Metasurfaces for millimeter-wave 5G and 6G

T02 Millimetre Wave 5G and 6G/ /Electromagnetics

Chairs: James Churm (University of Birmingham, United Kingdom (Great Britain)), Santi Concetto Pavone (Università degli Studi di Catania, Italy)

11:00 ***Generation of Sum and Difference Radiation Beams with a 2-Bit Polarization-Dependent Metasurface***

Peng Mei, Shuai Zhang and Gert Pedersen (Aalborg University, Denmark)

This paper describes the generation of sum and difference radiation beams with a 2-bit polarization-dependent (PD) metasurface. A single-layer and cross-shaped dipole unit cell is proposed to implement the PD metasurface. By appropriately optimizing the dimensions of the unit cell, it can offer a 2-bit reflection phase for two orthogonal polarizations independently. A horn antenna is adopted as the feed source to illuminate the PD metasurface. Sum and difference radiation beams are achieved when the phase shifts of the PD metasurface are appropriately imposed in horizontal and vertical polarizations by mechanically rotating the PD metasurface 90 degrees. For demonstration, a circular PD metasurface is implemented at the millimeter-wave band. The simulations reveal that the PD metasurface-based scheme can offer stable sum and difference radiation beams from 24 to 28GHz, where the null depth levels at broadside direction are all below -20dB.

11:20 ***Comparisons of Scalar and Tensor Circularly-Polarized Holographic Artificial Impedance Surfaces***

Ming Yao, Peng Mei, Gert Pedersen and Shuai Zhang (Aalborg University, Denmark)

In principle, both scalar and tensor holographic artificial impedance surfaces (HAISs) can generate circularly-polarized waves. It is found, however, the previously-reported works on circularly-polarized holographic antennas are based on tensor impedance surfaces. This paper studies the generations of circularly-polarized waves by using scalar and tensor HAISs, and compare their performance in terms of design complexity, impedance bandwidth, 3dB axial ratio bandwidth, realized gains, etc. The mechanisms of producing circularly-polarized waves using scalar and tensor HAISs are first formulated and presented. Two right-hand circularly-polarized holographic antennas are then implemented with the scalar and tensor HAISs, respectively, and simulated. The simulations conclude that the tensor HAIS indeed outperforms the scalar HAIS in the generation of circularly-polarized waves. In particular, the peak gain of the tensor HAIS is much higher than that of the scalar HAIS. The conclusions obtained in this paper give a clear answer on designing circularly-polarized HAISs with good performance.

11:40 ***Piezoelectric Tuning for Ultra-Low-Loss Tuneable Mm-Wave and THz Components***

James Churm and Alexandros Feresidis (University of Birmingham, United Kingdom (Great Britain))

As the frequency of future communication and sensing devices increases, current proposed tuning technologies incorporate additional, and often prohibitive, losses when operating in the millimeter wave and terahertz bands. Piezoelectric tuning offers a promise of removing this inherit efficiency reduction with increased frequency, by removing the tuning element from the millimeter wave circuit and providing microsecond mechanical tuning of internal dimensions. A set of phase shifting surfaces on PDMS substrates have been simulated that operate between 20 GHz and 1 THz, that demonstrate how piezo-tuning maintains its low loss performance over this large range of frequencies. The constructs demonstrate >250° phase shift performance across all frequencies with average losses less than 1 dB. Simulations of devices using more standard substrates have been extracted from the proposed construct, which demonstrate the usefulness of piezoelectric tuning as the best-in-class method when considering loss performance.

12:00 ***Sustainable Multi-User Communication with Reconfigurable Intelligent Surfaces in 5G Wireless Networks and Beyond***

Hamidreza Taghvaee (University of Nottingham, United Kingdom (Great Britain)); Sergio Terranova (University of Pisa, Italy); Neekar Mohammed and Gabriele Gradoni (University of Nottingham, United Kingdom (Great Britain))

Reconfigurable intelligent surfaces show huge potential to provide significant performance improvement for wireless communications. Low cost and power consumption, lightweight, and flexible deployment make them perfect for integration within the 5G mobile network infrastructure. However, the problems of multipath fading interference and radiation losses are prominent at mmWave frequencies. To enable massive connectivity and low-latency communications, one should tackle and eventually exploit the randomness of the real-life wireless propagation channels. In order to enable multi-User Equipment communication broadcasting, achieving simultaneous beamforming on multiple beams is of paramount importance. This paper provides a strategy to control the propagation channel via reconfigurable intelligent surfaces and generate multiple pencil beams for concurrent user access at mmWave frequencies. Compared to simultaneous amplitude and phase surface reconfiguration, this technique requires only phase coding to engineer multi-beamforming dynamically. The proposed technique creates an arbitrary number of beams that are stable among a wide frequency band.

12:20 ***Meta-Surface Boosted Antenna to Achieve Higher than 50 dB TRX Isolation at 26 GHz for Joint Communication and Radar Sensing (JC&S)***

Mehrab Ramzan (Barkhausen Institut, Germany); Andre N Barreto (Barkhausen Institut gGmbH, Germany & Universidade de Brasilia, Brazil); Padmanava Sen (Research Group Leader, Barkhausen Institut gGmbH, Germany)

In this paper, sub-wavelength passive periodic structures are used to create high isolation between the transmitter (Tx) and receiver (Rx) antennas designed at 26 GHz. The periodic electromagnetic bandgap (EBG) structures composed of square mushroom shapes are used between Tx and Rx (TRX) antennas for increasing the isolation from 22 dB to 50 dB experimentally. The results are compared in terms of simulation and measurement and a close agreement is found between them. Moreover, the results are further used to extract system performance targeting joint communication and radar sensing (JC&S) applications.

SW05: General standardisation and the Antenna measurement standards (std1270)

Scientific Workshop

A23: Antenna feeds for space reflectors

T08 Space (incl. cubesat)/ /Antennas

Chairs: Carlos del-Río (Universidad Publica de Navarra & Institute of Smart Cities, Spain), George Goussetis (Heriot-Watt University, United Kingdom (Great Britain))

11:00 ***Circumplexer: A Novel Dual-Band Dual-Circular Polarization Antenna Feeding Network for Satellite Communications***

Fernando Teberio and Ibai Calero (Anteral, Spain); Jorge Teniente-Vallinas (Public University of Navarra & Institute of Smart Cities, Spain); Itziar Maestrojuán (Anteral, Spain)

In this paper, Anteral presents a novel dual-band dual-circular polarization antenna feeding network for satellite communications. Circumplexer is the idea of Anteral for compactness of an antenna feeding network by integrating a septum in the common port of a diplexer. Therefore, the new device provides dual circular polarization with excellent axial ratio levels and very high isolation between channels simultaneously. Two different waveguide filters are utilized to provide very high isolation between two different channels while a septum in the common port is used to provide with the dual circular polarization. This kind of components is presented for the first time in the literature. The proposed design example accomplishes measured results with more than 23 dB return loss, 70 dB isolation between channels with an axial ratio better than 0.45 dB. Due to its compact design, it is especially attractive for satellite communications where size and weight are key parameters.

11:20 ***Comparative Study of Beamforming Techniques for VHTS Array Fed Reflector Antennas***

Alejandro Baldominos and Andrea Segneri (Heriot-Watt University, United Kingdom (Great Britain)); Alberto Mengali and Nelson Fonseca (European Space Agency, The Netherlands); George Goussetis (Heriot-Watt University, United Kingdom (Great Britain))

This paper presents some techniques to estimate beamforming coefficients in multibeam array fed reflector antennas with an imaging geometry generating a large number of beams, of interest for very high throughput satellite (VHTS) systems. A comparative study of these techniques is proposed using an antenna configuration designed to meet VHTS system requirements with full earth coverage. The impact of removing the amplitude information from the elements excitations is also considered with different scenarios. Numerical results in terms of carrier-to-interference (C/I) are reported to compare the impact of the different scenarios and techniques on the performance of the satellite antenna system over the defined coverage.

11:40 ***A Doubly Curved Modulated Frequency Selective Surface Sub-Reflector in a Dual-Band (Tx/Rx) Multiple-Beam Reflector Antenna***

Andreas Ericsson, Min Zhou, Stig Sørensen and Tonny Rubæk (TICRA, Denmark); Mathieu Riel (MDA, Canada); Nelson Fonseca (European Space Agency, The Netherlands)

A dual-band (Tx/Rx) multiple spot beam reflector system for high throughput satellites in Ka-band is presented. The configuration is a multiple-feed-per-beam dual reflector Cassegrain antenna with a frequency selective surface (FSS) sub-reflector that separates the response between Tx and Rx frequency bands. Using this configuration, a full multiple-beam coverage employing the four-colour frequency/polarisation reuse scheme can be produced using only a single main reflector. By utilising a modulated FSS sub-reflector, the performance of the antenna system is significantly improved compared to using a periodic element distribution on the sub-reflector.

12:00 ***Feeder System Design for OLAF SAR Instrument***

Carlos Biurrun-Quel (Universidad Publica de Navarra & Institute of Smart Cities, Spain); Quiterio García (Airbus Defence and Space, Spain); Carlos del-Río (Universidad Publica de Navarra & Institute of Smart Cities, Spain)

The design of the feeding system for the focal array in OLAF (Over-Lapped Sub-Array Fed) antenna for SAR Instrument at L-Band is presented. The proposed design consists of a circular patch with a balanced excitation all of it embedded in a ground plane which is connected to the lower ground plane by some shorting pins, reducing the mutual coupling with the neighbour radiating elements of the focal array. The balanced excitation has been implemented with a 180° hybrid using the differential input port. Dual polarization is achieved by using two 180° hybrids within the same layer. The stringent requirements for the system, namely low in cross-polarization, high isolation between the two polarizations (both below the -25dB reference level) and azimuthal symmetry of the radiation pattern are fulfilled within all the working bandwidth.

12:20 ***Miniaturized CORPS-BFN to Feed OLAF SAR Instrument***

Carlos Biurrun-Quel (Universidad Publica de Navarra & Institute of Smart Cities, Spain); JuanCarlos Iriarte (Public University of Navarra & Antenna Group, Spain); Iñigo Ederra (Universidad Pública de Navarra & Institute of Smart Cities, Universidad Pública de Navarra, Spain); Carlos del-Río (Universidad Publica de Navarra & Institute of Smart Cities, Spain)

A miniaturization of a CORPS-BFN (Coherently Radiating Periodic Structures - Beam Forming Network) to properly feed OLAF (Over-Lapped sub-Array Fed) antenna for SAR Instrument at L-Band is presented. The original beam forming network was based on 4-ports Gysel power combiner/divider implemented in a suspended strip-line technology, and in this work a strong miniaturization technique has been applied to fit it in the desired lattice of 230 mm, which is slightly less than a wave-length of the higher frequency of the system (1.215-1.3 GHz). The minimized version still provides low insertion and return losses, high isolation between input/output ports and the required overlapping between the different equivalent beams.

IW08: Efficient EM design of phased array frontends at IMST

E09: Fundamental research in optimization and machine learning

T10 Fundamental Research and Emerging Technologies/ / Electromagnetics

Chairs: Slawomir Koziel (Gdansk University of Technology, Poland), Giacomo Oliveri (University of Trento & ELEDIA Research Center, Italy)

11:00 ***Low-Cost Feature-Based Tolerance Optimization of Multi-Band Antennas***

Anna Pietrenko-Dabrowska and Slawomir Koziel (Gdansk University of Technology, Poland)

Manufacturing inaccuracies are detrimental to performance of antennas. The effects of parameter deviations are particularly noticeable for narrow- and multi-band antennas and manifests themselves through relocations of the operating frequencies or bandwidth degradation. The ability to reduce the system sensitivity to tolerances is therefore an important design consideration. Unfortunately, robust design is a challenging task, primarily because it has to be carried out at the level of full-wave electromagnetic (EM) simulation models, which generates considerable

computational expenses. In this paper, we propose a novel approach to tolerance optimization of multi-band antennas. The objective is to enlarge the maximum levels of geometry parameter deviations that still ensure perfect (100-percent) fabrication yield. The presented approach involves feature-based regression surrogates as well as the trust-region framework to ensure low cost and convergence of the optimization process. Numerical validation of the method, conducted for a dual- and a triple-band microstrip antenna, corroborates its efficacy.

11:20 ***Efficient Microwave Wireless Power Transmission Using Optimization Algorithm***

Ho Yeol Kim and Sangwook Nam (Seoul National University, Korea (South))

In this study, we developed an efficient microwave wireless power transmission (MPT) system for multiple receivers using an optimization method. The optimization algorithm finds the optimal transmission signal for transferring the desired power to multiple receivers with maximum power transfer efficiency (PTE). We designed a 5 × 5 rectangular patch array antenna and patch element antenna operating at 10 GHz as the transmitter and receiver, respectively. The operating process of the MPT system using the optimization method is analyzed. Additionally, we compared the received power of each receiver and the PTE of the optimization (OPT) technique with that of the multi-receiver time-reversal (TR) technique considering various scenarios. The OPT algorithm generates a multibeam to charge multiple receivers simultaneously. We validated that the OPT technique can deliver power to receivers precisely at desired ratios with greater PTE than that of the TR technique in an MPT system.

11:40 ***Design of a Non-Periodic Mushroom Antenna Using Bayesian Optimization***

Yunjia Zeng, Xianming Qing, Michael Chia and Min Hlaing (Institute for Infocomm Research, Singapore)

A broadband non-periodic mushroom antenna is designed via Bayesian optimization. By tuning the length and width of the 16 patches of a 4 × 4 metamaterial mushroom structure, the non-periodic mushroom antenna achieves a 23.95% fractional bandwidth (|S11|<-10 dB), while keeping the gain variation small at boresight direction. Bayesian optimization is particularly suitable for design and optimization with a large number of design parameters, for example, 32 design parameters in this design, since the conventional exhaustive search becomes infeasible for such a large search space. The proposed antenna is prototyped and measured, with good agreement between the simulation and measurement achieved. The proposed antenna is able to operate in the widely deployed n78 band of 5G New Radio.

12:00 ***A Current-Based Algorithm for the Design of Metasurface Antennas***

Marcello Zucchi and Francesco Vernì (Politecnico di Torino, Italy); Marco Righero (LINKS Foundation, Italy); Giuseppe Vecchi (Politecnico di Torino, Italy)

This paper proposes an algorithm for the automated design of metasurface antennas. From the objective radiation field and the feeding structure, it allows to obtain a surface current distribution that leads to a passive and lossless impedance profile on the radiating aperture. The surface is modelled by a scalar impedance boundary condition and the electromagnetic problem is formulated as an electric field integral equation. The approach is entirely numerical, based on the gradient descent optimization of a scalar objective function that incorporates passivity and far field requirements. This procedure was applied to the design of an electrically large circular metasurface antenna at 32 GHz, obtaining a lossless impedance profile with satisfactory radiation properties.

12:20 ***Designing Disordered Metasurfaces to Engineer Antenna Radiation***

James Capers (University of Exeter, United Kingdom (Great Britain)); Stephen Boyes (DSTL, United Kingdom (Great Britain)); Alastair Hibbins and Simon Horsley (University of Exeter, United Kingdom (Great Britain))

We derive a simple and efficient method for designing wave--shaping materials composed of dipole scatterers. We apply our theory to design aperiodic metasurfaces that re-structure the radiation from a dipole emitter in many ways, including increasing the efficiency of a small emitter and re--shaping the far--field radiation pattern. Our proposed technique is relevant to designing metamaterials for a wide class of applications and has the key benefit of including all interactions within the system of scatterers.

Thursday, March 31 12:40 - 14:00

Lunch / Exhibition

Thursday, March 31 13:30 - 15:00

Best Paper Awards - Poster Session

Best Paper Awards - Poster Session

Best Electromagnetics Paper Award

Best Theory and Design Antenna Paper Award

Best Applied Technology Antenna Paper Award

Best Propagation Paper Award

Best Measurements Paper Award

Poster Session Thursday

Theoretical Calculation of the Phase Limit for Transmitarray Unit Cell

Zhishu Qu and James Kelly (Queen Mary University of London, United Kingdom (Great Britain))

This paper presents a theoretical study that establishes the performance limits for a multi-layer transmitarray unit cell. This is the first study to be applicable to unit cells in which the conducting resonators, on the different layers, are shaped differently. The study enables one to account for the effects of dynamically reconfiguring the resonators on certain layers (e.g. through shape change). Specifically, the paper quantifies the range of phase shift values, available from the unit cell, for a given amplitude of S21. The first step in the study was to derive theoretical calculations. The theoretical calculations predict that, for an S21 amplitude of -1 dB, unit cells having three conducting layers can provide a phase shifting range of 360°. It is achieved when the geometries of the resonators on the different layers are varied independently. Then the theoretical calculations have been validated through computer simulation

Analytical Form of the Scan Blindness Condition in an Infinite Phased Array of Printed Dipoles with a Superstrate

Andrey Kobyakov (Corning Incorporated, USA)

We use the exact form of the Green's function for a grounded dielectric slab with a superstrate to derive approximate analytical expressions for the propagation constant of the fundamental surface wave. The result is then used to obtain a closed-form expression for the scan blindness condition in an infinite phased array of printed dipoles with a superstrate. The analytical criterion of scan blindness is validated with a full-wave simulation of Maxwell's equations.

A 60 GHz-Band 4×4 Butler Matrix Based on Ridge Gap Waveguide

Davood Zarifi (University of Kashan, Iran); Ali Farahbakhsh (Graduate University of Advanced Technology, Iran); Ashraf Uz Zaman (Chalmers University of Technology, Sweden)

A 4×4 butler matrix based on ridge gap waveguide (RGW) is presented for 60 GHz applications. The proposed Butler matrix consists of four ridge gap waveguide-based couplers, a cross-over and four phase shifters .The simulation results show that return loss and isolation of the Butler matrix are better than 15 dB. Also, power-split imbalance of ±1 dB and phase error of ±7o is achieved over the bandwidth of 59-61 GHz. This wideband Butler matrix design can play a great role while designing wideband beam forming feed network, comparator network etc. for the antenna arrays at millimeter-wave frequencies.

Simple Geometrical Frequency Reconfigurable Antenna with Miniaturized Dimensions for 24.8/28GHz 5G Applications

Mohammad Alibakhshikenari (Universidad Carlos III de Madrid, Spain); Musa Hussain (Bahria University Islamabad Campus, Islamabad, Pakistan); Akash Hussain (University of Engineering and Technology, Pakistan); Francisco Falcone (Universidad Publica de Navarra, Spain); Ernesto Limiti (University of Rome Tor Vergata, Italy)

A compact frequency reconfigurable antenna is proposed in this paper for 5G applications. Conventional circular patch antenna was modified using two pairs of open ended horizontal and vertical stubs. Stubs cause the improvement in impedance matching along with increased effective area of the radiator. Afterwards, two PIN diodes were inserted in the vertical pair of stubs to achieve frequency reconfigurability between 24.8 GHz and 28 GHz band spectrum. The antenna was designed and simulated using Higher Frequency Structure Simulator (HFSS) using appropriate boundary conditions with RLC equivalent model of Pin diodes.

Low Cost Wideband Rectangular Patch Antenna Based on Complementary Structure in Transmission Configuration

Yordanis Alonso-Roque (School of Telecomms. Engin. and Institute of Oceanic Engineering Research, University of Málaga, Málaga, Spain); Francisco Marante-

Rizo (Telecomms. and Electronic Eng. Faculty, Technological University of Havana Jose Antonio Echeverria (CUJAE), Havana, Cuba); Manuel Arrebola (Department of Electrical Eng., Group of Signal Theory and Comms., University of Oviedo, Gijón, Spain); Pablo Otero (School of Telecomms. Engin. and Institute of Oceanic Engineering Research, University of Málaga, Málaga, Spain)

A wideband rectangular patch antenna based on complementary structure in two ports-configuration is presented. Electromagnetic analysis and a design of the mentioned structure in FR-4 substrate were performed. A very high matching bandwidth from 1 to 11 GHz (BW_RL≥10dB=10 GHz, 167%) was achieved. Two degrees of freedom were used to obtain this high matching behaviour (length and width of the slot). The analyzed two port-device has a bidirectional broadside radiation pattern. It shows good values of gain, radiation efficiency, and suitable radiation pattern from 4 to 7 GHz (BW_radiation=3 GHz), representing the 30% of the matching bandwidth and 54% of the radiation center frequency. A prototype was manufactured and measured. A very good agreement between the simulation and measurement results were achieved. The studied structure is simple, compact, of low cost, and easy and flexible to design. It can be used as a radiating element for broadband series fed arrays.

Equivalent Circuit Model of Unbalanced Fed Tightly Coupled Dipole Array for Analyzing Even and Odd Modes

Seongjung Kim and Sangwook Nam (Seoul National University, Korea (South))

In this paper, an equivalent circuit model of an unbalanced fed tightly coupled dipole array (TCDA) is proposed. Unbalanced excitation can be decomposed by even and odd modes excitation. Antenna input impedances of each mode are expressed and their relation to that of unbalanced mode is determined. Herein, determining an even mode circuit is focused on to construct an equivalent circuit of unbalanced mode. Additionally, the unbalanced fed TCDA with shorting vias is proposed, and its bandwidth is compared with that of the balanced fed TCDA.

Linear Polarization from Scalar Modulated Metasurfaces

Alex Arroyo (Sorbonne Université, France); Massimiliano Casaletti (Sorbonne Universités UPMC, France); Hélène Roussel (Sorbonne Université, France); Romain Contreres (CNES, France); Alexandre Piche (Airbus Defence and Space, France)

A new design approach for linear polarization scalar metasurface antennas is presented. The method consists in building up the required scalar surface impedance Zs using the already known phase-matching technique, whereas the novelty resides in achieving linear polarization as a sum of two reverse circular ones. The procedure leads to better antenna performances in terms of sidelobe levels and beams symmetry, using a smoother gradient metasurface comparing it to previous solutions. This approach is suitable for both broadside and tilted beams antennas.

Synthesis of a Metasurface-Based Bessel Beam Launcher at Microwaves and Millimeter Waves

Santi Concetto Pavone (Università degli Studi di Catania, Italy); Walter Fuscaldo (Consiglio Nazionale delle Ricerche (CNR), Italy)

We propose an alternative metasurface-based approach for the synthesis of Bessel beam launchers at microwaves/millimeter waves, based on an inward cylindrical traveling wave aperture distribution. Our approach simply allows the outward-to-inward cylindrical feeding wave conversion by metallic dihedrons. Although more involved from the manufacturing viewpoint with respect to single layer devices, it can in principle avoid the computationally-heavy design of holographybased Bessel beam launchers. The preliminary numerical results show the effectiveness of the proposed technique.

The Resonant Electrical Length of Helical Antennas Placed Between Metallic Parallel Plates

Mourad Ibrahim (Prince Sultan University & Modern Science and Arts University, Saudi Arabia); Walid Dyab (Prince Sultan University, Saudi Arabia); Ahmed Sakr (Polytechnique Montreal, Canada); Ke Wu (Polytechnique Montréal, Canada)

Helical antennas placed between two infinite metallic parallel plates are investigated. This study is concerned with the resonant electrical length of helical antennas. The first resonance appears as the helical antenna is transiting the frequency gap between its well-known normal and axial modes of operation. A parametric study is conducted to calculate the resonant electrical length as a function of the helical parameters, namely the radius and pitch of the helix. The results are validated by comparing the solutions of two independent problems, one is driven with a source and the other is an eigenvalue problem with periodic boundary conditions. The presented results are useful in the design of gap waveguides where the periodic media are made of helical wires.

Analysis of Antenna Radiation Patterns by Means of Spherical Wavelets

Alice Quennelle (University of Toulouse, France); Alexandre Chabory (ENAC, France); Pouliguen Philippe (DGA, France); Romain Contreres and Gwenn Le Fur (CNES, France)

A new tool for analysing antenna radiation patterns is proposed in this article. This tool consists in applying a spherical wavelet transform to the radiation which is assumed to be known on a regular spherical-coordinates grid. This is an alternative solution to usual plane-waves or spherical harmonics expansions. The interest of using wavelets is to obtain a better analysis in terms of localization in position and/or direction. The direct link between spherical wavelets and spherical harmonics is also highlighted. The properties of this tool are illustrated by means of numerical experiments performed on two typical antennas, a canonical aperture and a pyramidal horn.

A Compact Loaded DETSA Antenna with Enhanced Directivity Using Characteristic Modes Optimization

Hussein Jaafar (The French Alternative Energies and Atomic Energy Commission, France); Jean-François Pintos and Christophe Delaveaud (CEA-LETI, France)

This paper presents the design of an Ultra Wideband (UWB) antenna mainly dedicated for Ground Penetrating Radar (GPR) application in the frequency band between 150 MHz up to 550 MHz. With its compact electrical size in the low band, the initial double exponentially tapered slot antenna (DETSA) exhibits a low directivity and Front-to-Back ratio. With the guidance of the Characteristic Modes Analysis (CMA), it was possible to identify the best loading position as well as the optimized load values to enhance these antennas properties. The optimized loaded DETSA demonstrated a significant directivity enhancement and a Front-to-Back ratio that exceeds 4dB inside the band.

Investigation of a Flat High-Gain Omni-Directional Antenna

Haim Matzner (HIT-Holon Institute of Technology, Israel); Ely Levine (AFEKA, Academic College of Engineering, Israel)

A high-gain, Yagi-Uda like, omni-directional antenna is presented. The antenna is composed of a centered dipole, fed from downside and circular directors. No reflector is involved. The directivities of the antenna are 2.1, 2.6, 4.9, 5.5 and 6.0 dBi for the dipole alone and for the dipole with 1, 2, 3 and 4 directors respectively. The vertical height is less than half wavelength.

Characteristic Mode Analysis of SCMR and CSCMR Systems

Ferdaous Abderrazak (ITEAM-UPV, Spain); Eva Antonino-Daviu (Universitat Politècnica de València, Spain); Larbi Talbi (University of Quebec - Outaouais, Canada); Miguel Ferrando-Bataller (Universitat Politècnica de València, Spain)

A Conventional Strongly Coupled Magnetic Resonance (CSCMR) system provides higher Power transfer efficiency and less sensitivity to misalignment compared to a traditional Strongly Coupled Magnetic Resonance (SCMR) system.This paper proposes, for the first time, a physical investigation of the SCMR and CSCMR systems based on the Theory Characteristic Modes.

Bandwidth Improvement of Planar RFID Tag Antennas Using Characteristic Mode Theory

Pallavi Sharma (University of Illinois Urbana-Champaign & Applied Research Institute, USA); Jennifer T. Bernhard (University of Illinois at Urbana-Champaign & Electromagnetics Laboratory, USA)

Planar antennas have been widely used in UHF RFID systems. Placement insensitivity and thin form factor are essential qualities of planar RFID tag antennas. As the antennas become thinner, most of the energy is stored within the region between the antenna and the ground plane resulting in the degradation of bandwidth and radiation characteristics. Serrations can be used as edge treatment to improve the bandwidth of planar antennas. The analysis of edge-treated planar antennas using characteristic mode theory is presented in this article. The effect on serrations on the resonant frequencies and radiation characteristics of resonant characteristic modes of a rectangular plate is presented and guidelines are presented for improving the bandwidth of planar antennas.

Butler-Matrices-Based Omnidirectional Beamforming of Circular/Cylindrical Arrays

Rui Ma (Guilin University Of Electronic Technology, China); Wenning Gao (University of Electronic Science and Technology of China, China)

The tendency of customized communication has inspired the fifth-generation (5G) and above technologies, characterized by multi-node and localization. Therefore, high requirements are raised of the omni-directional beamforming of base stations. An omni-directional subarray beamforming scheme is proposed, based on Butler matrix fed array. For this purpose, two array configurations are provided, using circular and cylindrical structures, and fed by multiple Butler matrices, so as to flexibly select sub arrays as excitation. Combined with practical application, the general solution of the connection form of multiple overlapping Butler matrix is derived, based on the circular symmetry. The vertical and azimuth beamforming performance of the proposed array structure is numerically calculated, and the feasibility and superiority of the proposed scheme are verified.

UltraWideband Microstrip to Waveguide Transition for 5G MillimeterWave Applications

Ivan Zhou (UPC, Spain); Jordi Romeu (Universitat Politècnica de Catalunya, Spain)

In this paper, an ultrawideband microstrip to narrow wall waveguide transition operating at the E-Band is presented. The transition is based on exciting a microstrip folded dipole which radiates into the waveguide. The back-to-back transition provides a fractional bandwidth (FBW) of 20% and measured insertion losses (IL) ranging from 0.65dB to 1.35dB in the whole band of operation.

Integrated Wideband Dual-Polarized ME-Dipole Planar Antenna Array with Tight Coupled Elements

Bruno F Gomes (National Institute of Telecommunications (Inatel), Brazil); Jorge Ricardo Mejia Salazar (Instituto Nacional de Telecomunicações, Brazil)

We present a new integrated wideband dual-polarized magneto-electric dipole antenna array merging the concepts of tight coupled elements and gap-waveguide feeding technology. Our proposal consists of a 4x4 directly fed unit elements, with passive-behaving elements at the borders. The radiating element was chosen as a modified bowtie antenna, with slight transition for good impedance matching control. The antenna is fed by an air filled cavity backed layer, placed directly above two layers of a modified inverted microstrip gap waveguide. The complete device can be easily manufactured by low-cost printed circuit board (PCB) fabrication processes. Numerical results demonstrate an impedance bandwidth of 68.6%(16.1 GHz-32.9 GHz) for the vertical polarization and 73.3%(15.2 GHz-32.8 GHz) for horizontal polarization, considering a VSWR (voltage standing wave ratio)<2.

Miniature Super-Directive and Super-Gain Parasitic Antenna Array Based on Far-Field Pattern Synthesis

Marwan Jadid (CEA & Grenoble Alpes University, France); Serge Bories (CEA, France); Christophe Delaveaud (CEA-LETI, France); Anthony Bellion (CNES, France)

In this paper, a generalized far-field pattern synthesis technique is presented. This technique is used to design an electrically small directive parasitic antenna array with end-fire radiation characteristic, having an electrical size ka=0.9 and driven with a single feeding port. The CST-MWS simulated super-directivity condition shows 10.1 dBi directivity for a three-element parasitic array with a 28.6% radiation efficiency, resulting in a 4.7 dBi gain. For gain and radiation efficiency enhancement, the way to achieve a super-gain condition is demonstrated, with CST-MWS simulated gain showing 6.6 dBi and 99.7% radiation efficiency for a three element parasitic array.

Manufacturing and Testing of a 94GHz Linear Slot Array Designed by the MoM-FMP Technique

Ignacio Montesinos-Ortego and Mónica García-Peña (TTI, Spain); Belen Galocha (Universidad Politecnica de Madrid, Spain); Manuel Sierra-Castañer (Universidad Politécnica de Madrid, Spain)

This paper addresses the complete process of design, optimization, manufacturing and testing of a vector array of eight longitudinal slots, devised to work on the W band with a uniform amplitude taper distribution. Comparison between simulations and measurements are shown, revealing an almost perfect match in both radiation pattern and return losses.

Optimal MIMO Sparse Array Design Based on Simulated Annealing Particle Swarm Optimization

Xiaoyuan He (The University of Edinburgh, United Kingdom (Great Britain)); Cristian Alistarh (Heriot Watt University & University of Edinburgh, United Kingdom (Great Britain)); Symon K. Podilchak (University of Edinburgh, United Kingdom (Great Britain))

Compared to conventional uniformly spaced arrays, sparse arrays are effective and economical for many application scenarios. For example, sparse arrays can help to save on the number of antennas, and the supporting hardware costs, as well as improve the angular resolution which is useful for automotive radar systems and target identification applications. This paper will focus on implementing a hybrid approach to numerically determine an optimal 4x4 multiple-input multiple-output (MIMO) array considering simulated annealing and particle swarm optimization (SA-PSO). Results will show that the technique can achieve lower peak sidelobe level (PSLL) or narrower main lobe half-power 3dB beamwidth (3dB BW) with 8 fewer elements when compared to a corresponding 16 element uniform linear array (ULA). To the best knowledge of the authors, this is the first time that such a design technique has been applied to MIMO arrays whilst considering a hybrid SA-PSO synthesis algorithm.

A Novel Tightly Coupled Dipole Array Unit Cell

Kaan Arda (Middle East Technical University & ASELSAN, Turkey); Gulbin Dural (Middle East Technical University, Turkey)

A novel ultrawideband tightly coupled dipole array (TCDA) unit cell is presented. The proposed design uses spiral based coupling elements between the tips of the dipoles unlike capacitive coupling employed frequently in the design of TCDA's. The proposed unit cell delivers 1:4 bandwidth under -10 dB active S-parameter in the infinite array environment, similar to those with known design approaches. However, this proposed unit cell is capable of better control of resonance condition by employing inductive capacitive hybrid coupling between tips of the dipoles compared to the traditional approach of single discrete capacitive coupling. The proposed TCDA unit cell is optimized such that it provides -10 dB active S-parameter in the 0.5-2.0 GHz frequency band. Finite array characteristics and scanning abilities are investigated.

All-Metal Phased Array Antenna Element for High Power Applications

Piotr M. Kaminski, Alessandro Garufo and Erwin M. Suijker (TNO, The Netherlands); Raymond van Dijk and Stefania Monni (TNO Defence Security and Safety, The Netherlands)

In this paper, we present an all-metal antenna element with multiple feeding points for wide-scan angle arrays. The antenna element is composed of two slots feeding two stacked patches backed by integrated cavities. Dielectric material is used only in the feeding part of the antenna as a substrate supporting four asymmetric striplines feeding the slots. The radiating part of the antenna is built entirely from metal and air ensuring stable thermal behaviour of the antenna for high input power levels. The array supports wide-angle scanning up to a maximum of θ=60o for all ϕ-planes over almost ~16% bandwidth. The antenna element may find its application in the areas involving high radiated powers, e.g. communication systems, radar systems.

A Simple Antenna Element for Millimeter Wave Tightly Coupled Arrays

Gaeron Friedrichs (University of Colorado at Boulder); Mohamed Elmansouri and Dejan Filipovic (University of Colorado at Boulder, USA)

A novel application of the Planar Inverted-F Antenna (PIFA) is shown for operation as an element for a tightly coupled array. 3:1 impedance bandwidth is demonstrated at millimeter wave frequencies, with VSWR < 2.5 from 15-45 GHz. The proposed configuration has only a single substrate and superstrate matching layer. The array is designed for a 75-ohm feed through the ground plane. An additional matching section made through the bottom ground plane is utilized for matching to 50 ohms. Performance analysis is conducted on the unit cell using Ansys HFSS's frequency domain solver and CST Microwave Studio's time domain solver. Further demonstration is performed with a 4-by-4 finite array, where reasonable central-element match and realized gain is obtained.

Development of MMIC for the Three Dimensional Phased Array Antenna as Student Project

Takuya Nakata, Ryo Takamatsu and Keisuke Yoshimi (Kobe University, Japan); Nobuyuki Kaya (WaveArrays, inc., Japan)

Many companies are launching a lot of small satellites into the low Earth orbit in order to build the worldwide internet services. The ground stations are required to communicate simultaneously with several satellites. It is impossible for the parabolic antenna to track simultaneously several satellites. Therefore, we are newly developing a ground receiving station using the three dimensional Phased Array Antenna and the Digital Beam Forming technologies, which can simultaneously receive the signals from many satellites. We are developing the MMIC for the three dimensional phased array antenna as the student project. We will make a report on the designs of the MMIC and performances for the phased array antenna at my presentation.

Reconfigurable Wideband Linear-Polarized and Dual Left/Right-Hand Circularly-Polarized Waveguide Antennas for Beamforming Antenna Array

Yifang Wei (Heriot-Watt University, United Kingdom (Great Britain)); Christian Arnold (Tesat-Spacecom GmbH & Co. KG, Germany); Jia-Sheng Hong and Jiayu Rao (Heriot-Watt University, United Kingdom (Great Britain))

In this article, a reconfigurable waveguide antenna design with linear-polarized/Left-handed/right-hand circularly-polarized (LHCP/RHCP) modes in K/Ka-Band for a massive MIMO beamforming system based on active phased array is presented. Both the linear-polarized and dual LH/RH CP waveguide antennas provide wideband operation performance for K/Ka-Band, which are applicable for the antenna array in a beamforming system for different purposes and requirements in satellite communication applications. Both simulated results and some preliminary experimental results are presented for the demonstration.

Antenna Element Study for a Future SMOS Mission

Quiterio García, David Espinosa Adams and Alberto M Zurita (Airbus Defence and Space, Spain); Josep Closa Soteras (Airbus Defence & Space, Spain); Erio Gandini (ESA - European Space Agency, The Netherlands); Martin Suess (ESA/ESTEC, The Netherlands); Manuel Martin-Neira (ESA-ESTEC, The Netherlands)

This paper summarizes the initial phase of the study of the antenna element for a future SMOS radiometer mission. The paper shows the antenna main requirements, the potential antenna candidates and the main design constraints that drive the initial selection of the antenna candidate. A major difference with respect to the antenna element of the current SMOS mission is that the new element should respect the alias free spacing. An overview of the main preliminary antenna performances of the selected candidate is shown.

A Series-Fed Loop Array Antenna with Wideband Circular Polarization and Enhanced Gain

Kazuhide Hirose, Ryuga Matsumoto and Yusuke Kanda (Shibaura Institute of Technology, Japan); Hisamatsu Nakano (Hosei University, Japan)

We analyze a loop antenna array proximity coupled to a coplanar feed line using the method of moments. First, a novel-loop array at a uniform proximity distance (PD) from the feedline is investigated versus loop height above the ground plane. It is found that when the loop height is L0/5 (L0: wavelength), a 3 dB axial-ratio bandwidth reaches 11%, which is 3.5 times as wide as that of a conventional-loop array. Subsequently, we transform the uniform PD into multiform PD's to enhance the gain of the novel-loop array. It is revealed that the array has a gain enhancement of 1.8 dB compared with that at a uniform PD and still shows an axial ratio bandwidth of 7%.

A Compressive Sensing Approach for Directions-Of-Arrival Estimation in Planar Sub-Arrayed Arrays

Mohammad Hannan (ELEDIA Research Center, University of Trento, Italy); Paolo Rocca (University of Trento & ELEDIA Research Center, Italy)

The problem of the estimation of the directions-of-arrival (DoAs) in sub-arrayed planar arrays is addressed in this work by means of a strategy based on the Bayesian Compressive Sensing (BCS). The DoAs estimation performance for different sub-array configurations are discussed and compared, considering different noisy conditions. Preliminary numerical results are reported for single snapshot data to validate the proposed strategy.

A Novel Millimeter -Wave Series-Fed Microstrip Line Antenna Array

Sumin David Joseph (The University of Sheffield, United Kingdom (Great Britain)); Edward Ball (University of Sheffield, United Kingdom (Great Britain))

A novel millimeter wave series fed microstrip line antenna array is designed. The antenna array consists of stepped inverted-cone stub sections placed on both edges of the microstrip line at a guided wavelength spacing. The 5 strip stub sections can alter the surface current cancellation at each guided wavelength in an ideal microstrip line. By properly tuning the length and height difference of the strip stubs, the equivalent surface currents can be focused to the stubbed inverted-cone sections present on the microstrip line edges and results in an effective radiation. The

fabricated antenna array has return loss better than 10 dB around 27.3 GHz. Peak realized gain of 10.1 dBi is achieved and measured side lobe levels are better than -15 dB. The proposed antenna array has a very good radiation pattern and low side lobe levels which makes it a suitable direction for future integrated millimeter wave antenna arrays.

4x4 Butler-Matrix Based Beam Steering Antenna Systems Using Substrate Integrated Waveguide

N Nasimuddin (Institute for Infocomm Research, Singapore); Lu Chongqing and Arokiaswami Alphones (Nanyang Technological University, Singapore)

In this paper, two innovative 4x4 Butler matrix-based antenna system designs are proposed for mmWave/5G applications which are capable of beam scanning/steering at Ka-band. By utilizing the multilayered substrate integrated waveguide (SIW) structure, the size of antenna system design is miniaturized. Beam forming can be achieved due to the application of beam forming network (BFN) based on Butler matrix. Designed beam steering antenna systems with miniaturized 4x4 Butler matrix show frequency range from 26 GHz to 38 GHz. Overall design structure sizes of two designs are 114.3 mm x 23.8 mm x2.2 mm and 112.3 mm x 18.0 mm x 3.3 mm respectively.

Multibeam Leaky-Wave Antenna with Independent Beam Control at Millimeter Waves

Despoina Kampouridou and Alexandros Feresidis (University of Birmingham, United Kingdom (Great Britain))

A holographic-inspired one-dimensional leaky wave antenna is proposed, which is capable to control independently multiple radiated beams with a single feed. Contrary to previous implementations, where multiple feeds were used for the excitation of an equal number of beams, or where a metasurface was divided into sectors, each one controlling a different beam, here we offer a reconfigurable single-source metasurface antenna designed with superposition of each individual beam modulation. The unit cell of the proposed antenna is tuned with a low-loss Schottky diode for operation at millimeter-wave frequencies. Simulated results for the novel multiple beam antenna verify the theoretical analysis, and exhibit an independent beam steering at 85 GHz.

Array Antenna with HIS Metasurface for mmWave Imaging Applications

Alicia Flórez Berdasco (University of Oviedo, Spain); María Elena de Cos Gómez (Universidad de Oviedo, Spain); Humberto Fernandez Alvarez and Fernando Las-Heras (University of Oviedo, Spain)

An uniplanar compact array-HIS antenna suitable for imaging in the ISM mmWave frequency band (24.05 GHz - 24.25 GHz) is presented. Collision avoidance system to support blind people is the intended application. Different arrangements of the HIS unit cells are considered in the combination with the basic array, to improve the radiation parameters. Prototypes of both, the basic array and an optimized array-HIS are fabricated and measured in an anechoic chamber. Comparison between simulation and measurement is conducting in terms of impedance matching, bandwidth and gain. The achievements of the optimized array-HIS are compared with the state of the art antennas at 24 GHz

High-Gain Multi-Linear Polarization Reconfigurable Antenna in the Millimeter-Wave Band

Shu-Lin Chen (University of Technology, Sydney, Australia); Yanhui Liu (University of Electronic Science and Technology of China, China); Dingzhao Chen (Xiamen University, China); Y. Jay Guo (University of Technology Sydney, Australia)

High-gain polarization-reconfigurable antennas in the millimeter-wave (mm-wave) band are of high importance for 5G and future wireless platforms. This paper reports an innovative mm-wave antenna that accomplishes multi-linear polarizations (LPs) with high gains. It employs a TM510-mode cavity etched with a circular slot array on its top surface as the base excitation. A two-layer copper-cladded main substrate is introduced above the base cavity to produce a high gain beam with a low cross-polarization level. Moreover, five reconfigurable LPs can be attained by rotating the main substrate at a 36˚ interval. Simulated characteristics were validated by measuring the prototyping multi-LP cavity-backed antenna. The measured overlapped -10-dB impedance bandwidth ranges from 28.58 to 28.99 GHz for the five LPs. Within this bandwidth, measured realized gains vary between 15.5 and 16.8 dBi.

Millimeter Wave Antenna on Eco-Friendly Substrate for Radar Applications

María Elena de Cos Gómez (Universidad de Oviedo, Spain); Humberto Fernandez Alvarez and Fernando Las-Heras (University of Oviedo, Spain)

A compact low-cost series end-fed 1 x 10 array antenna on polypropylene (PP) for imaging applications in the 24.04 - 24.25GHz band is presented. The envisioned use is in a wearable radar system for collision avoidance to aid visually impaired people. The eco-friendly PP substrate is electromagnetically characterized at 24.15GHz for the first time. A modified Dolph-Chebyshev (DC) distribution is optimized in simulation to achieve an improved performance in terms of beam width, Side-lobe level (SLL) and Gain. A prototype of the PP based array antenna is fabricated and tested. The overall size of the antenna is 98.68 x 14.4 x 0.52 mm3. Consistent agreement is achieved between simulation and measurement results. Comparison with literature shows that the proposed array antenna overcomes the state of the art on 24GHz antennas for wearable radar applications.

Compact and Low-Loss Feeding System Design for Dual-Linear Polarized Holographic Antenna

Chan Yeong Park (Yonsei Universitiy, Korea (South)); Young Joong Yoon (Yonsei University, Korea (South)); Hyungrak Kim (Daelim University, Korea (South))

This paper proposes a dual-linear polarized compact feeding system that generates surface waves with low transmission loss. The proposed feeding system is designed for compact size and dual-linear polarized characteristics by using pillbox structure, and the hologram pattern for generating surface waves. The feeding system obtained the transmission loss of -0.74 dB(lossless material),

-3.41 dB(lossy material), and reflection loss below -10 dB from 21 to 27 GHz.

A 4x4 Double Slot Antenna Array Unit Based on Gap Waveguide Technology for mm-Wave Frequencies

Panagiotis Petroutsos and Stavros Koulouridis (University of Patras, Greece)

This work proposes a 4x4 double slot antenna array based on ridged gap waveguide feeding network for 39GHz. The antenna system is comprised of three independent layers. The top layer is the radiating layer with a 4x4 pair of slots configuration, the middle one is the resonant cavity, and the bottom layer involves the ridge gap waveguide. The use of pair of slots on the radiating layer achieves an alternative solution to radiating energy, as compared to previously published work, reducing the return losses and mutual coupling between the resonant elements, in the desired frequency operation. The presented design provides high gain and directivity over 18dB, due to the planar and multilayer structure, while the reflection coefficient is below -10dB over the operating frequency range 37.4GHz-40.2 GHz, covering a 7.2% bandwidth.

Circularly Polarized Wideband Planar Antenna Array Using Any-Layer PCB Technology for mm-Wave Applications

Masoud Roodaki-Lavasani-Fard (University of Tehran & KU Leuven, Iran); Guy Vandenbosch (Katholieke Universiteit Leuven (KU Leuven), Belgium); Karim Mohammadpour-Aghdam (University of Tehran, Iran & KUL, Belgium); Reza Faraji-Dana (Center of Excellence on Applied Electromagnetic Systems, Iran)

This article uses a new multi-layer PCB technology to design a low-cost mm-wave circularly polarized broadband antenna array for 5G handsets that operates from 57 to 64 GHz. This band covers many 5G bands. The design strategy is explained to allow the reader to easily design a similar antenna. The antenna is fabricated and measured. Measurement results show matching better than 17 dB across the band, gain greater than 10 dBi, and axial ratio less than 3 dB. Also, the measured radiation patterns for the array show good agreement with simulations.

Design of Dual Circularly Polarized Inclined Slot Pair Based on Stepped-Height Ridge Gap Waveguide with Series Excitation

Zhaorui Zang, Ashraf Uz Zaman and Jian Yang (Chalmers University of Technology, Sweden)

This paper presents a new stepped-height ridge structure to reduce the guided wavelength of a conventional ridge gap waveguide. Compared to other technology, the stepped-height ridge gap waveguide avoids dielectric loss and reduces the cost of manufacture. The simulation results prove that the guided wavelength could be decreased significantly by adjusting the step numbers and step depth. Based on this structure, a dual circularly polarized inclined slot pair is investigated and simulated. The slot pair is located on the top plate of the ridge gap waveguide and is fed by a traveling wave. The simulation results show that the inclined slot pair could generate a good dual circular polarization with the axial ratio below 3 dB over 76-81 GHz. The discrete models of the inclined slot pair are also shown in this paper.

A Fabry-Pérot Multilayer High Gain Frequency Scanning Antenna at 60GHz

Solomon Mingle, Muhammad S Rabbani and Alexandros Feresidis (University of Birmingham, United Kingdom (Great Britain))

A Fabry-Perot leaky-wave antenna with beam steering capabilities is presented.This design utilises a high impedance surface (HIS) as the first layer, a partially reflective surface (PRS) as the second layer and a plain dielectric slab as the third layer. The scanning of the antenna beam is accomplished by adjusting the operating frequencies within the 60 GHz range (58-67 GHz). This simple configuration generates a pencil beam with an S11 bandwidth (BW) of 9GHz, a scan range of 30° in the H-plane and a maximum gain of 24 dBi at 62.5 GHz.

A Single Layer Dual-Polarization Array Antenna Based on Parallel Plate Gap Waveguide

Ali Farahbakhsh (Graduate University of Advanced Technology, Iran); Davood Zarifi (University of Kashan, Iran); Ashraf Uz Zaman (Chalmers University of Technology, Sweden)

A dual-polarization array antenna based on over-moded parallel plate gap waveguide is presented in this paper. The antenna has only one metal waveguide layer that leads to simplification of manufacturing process. The antenna sub-array has four patches that are excited by a parallel plate gap waveguide through a cross slot. Two reflectors are utilized to feed the parallel plate gap waveguides in two directions. The simulated results show that the antenna bandwidth is 8.8% while its maximum gain is 25.5 dBi and its efficiency is about 85%.

Substrate Integrated Waveguide Cavity Backed Slot Antennas for Millimeter-Wave Applications

Sanaâ Finich (University of Porto, Portugal); Henrique M Salgado (University of Porto & INESC Porto, Portugal); Pedro Pinho (IT - Instituto de Telecomunicações & ISEL - Instituto Superior de Engenharia de Lisboa, Portugal)

A low-cost single-layer substrate-integrated waveguide (SIW) cavity-backed slot antenna is proposed for millimeter-wave applications. The structure is designed to operate at the W-band. The T-shaped slot antenna is placed on the back-side of the SIW and fed by a grounded coplanar waveguide (GCPW) transmission line. A transition between the (GCPW) and the SIW is also designed. The simulated results provide that the antenna has a stable gain over the frequency range (98.79-100.56) GHz with a maximum value of around 6 dBi also high radiation efficiency.

Ka-Band Mechanically Steered Phase Shifter for Satellite User Terminals

Cilei Zhang (Peng Cheng Laboratory, China)

In this paper, a mechanically steered phase shifter with planar structure is presented for Ka-band satellite user terminals. The proposed phase shifter is composed of a power divider based on ridge gap-waveguide (RGW) and a phase-shifting section based on double-layer groove gap-waveguide (GGW) with a shared rotatable plate. The simulated results show that the phase shifter could achieve 13.6% impedance bandwidth with the reflection coefficient below -15dB. Meanwhile, the insertion losses of all output ports fluctuate around 6 ± 0.5dB and the phase differences remain stably linear over the whole operational bandwidth.

A Dual-Circularly Polarized Antenna Using Gap Waveguide Based on Contactless Sliding Mechanism

Abdullah Alazemi (Kuwait University & University of California, Kuwait); Ali Farahbakhsh (Graduate University of Advanced Technology, Iran); Davood Zarifi (University of Kashan, Iran)

A dual circularly polarized (CP) slot array antenna is proposed for V-band applications. A sliding mechanism based on the groove gap waveguide is employed to achieve the left-hand circular polarization (LHCP) and the right hand circular polarization (RHCP). Due to the use of gap waveguide technology, there is no electrical contact between the different parts of the switch and the leakage of the electromagnetic wave is suppressed. The simulation results show that the proposed antenna has axial ratio (AR) below 3 dB, and pick gain of 14 dB in the desired impedance matching bandwidth from 58-62 GHz.

A Gap Waveguide-Based 2x2 Circularly-Polarized Monopulse Antenna Array

Carlos Vazquez-Sogorb (Universidad de Alicante, Spain); Miguel Ferrando-Rocher (Universidad de Alicante & Universitat Politècnica de València, Spain); Stephan Marini (Universidad de Alicante, Spain); Jose I Herranz-Herruzo (Universitat Politècnica de València & APL - iTEAM, Spain)

This paper presents a circular-polarized gap-waveguide-based compact monopulse array antenna for millimeter-wave tracking applications at Ka-band (29 to 31 GHz). The gap waveguide planar monopulse comparator network is integrated in a single layer with a 2 x 2 corporate-fed network combining ridge gap and groove gap waveguides. Radiating cavities consist of cubes with chamfered corners. Preliminary results show a bandwidth of 2 GHz with input reflection coefficients better than -20 dB for both ports of the antenna. In addition, the isolation between ports is greater than 50 dB. The design allows for scalability to build higher gain arrays as from the antenna presented in this communication.

Efficient Surface-Wave Excitation by Parallel-Plate Waveguide for Substrate Integrated Image Guides

Victoria Gómez-Guillamón Buendía (TNO, The Netherlands); Adrian Ayastuy Rodriguez (Moixa Technology, The Netherlands); Khalid M Alrushud (The University of Edinburgh & King Abdulaziz City for Science and Technology (KACST), United Kingdom (Great Britain)); Symon K. Podilchak (University of Edinburgh, United Kingdom (Great Britain))

Simple surface-wave (SW) excitation by means of a simple parallel-plate waveguide (PPW) for substrate integrated image guides (SIIGs) is proposed. As a proof of concept, a wideband, low profile and fully planar feeding network is designed. It consists of a surface-wave launcher (SWL) based on a truncated PPW with the addition of a sub-wavelength matching section. This method for SW excitation is intended to overcome the feeding limitations encountered when using SIIG based antennas or other non-radiating structures at microwave frequencies. A comparison between the performance of the proposed excitation method and structures that can be found in the literature are reported showing an improved bandwidth of more than 50% with respect to previous studies. In addition, this simple feed system has a reduced volume of more than 95% when compared with other alternatives, demonstrating its compactness. Applications include new SW driven feeds, leaky-wave antennas, sensors, or novel passive structures.

On the Use of the Volumetric Method of Moments for the Analysis and Design of Integrated Feeds

Riccardo Ozzola (Delft University of Technology, The Netherlands); Jinglin Geng (Tu Delft, The Netherlands); Nuria LLombart (Delft University of Technology, The Netherlands); Angelo Freni (Università degli studi Firenze, Italy); Daniele Cavallo and Andrea Neto (Delft University of Technology, The Netherlands)

A volumetric method of moments (V-MoM) for the analysis of integrated antennas is presented here. The developed numerical procedure discretizes the domain with a uniform and hexahedral mesh. For antennas radiating in the presence of dielectric slabs or lenses, the discretization required for the dielectric materials is typically coarser than the one required for the antenna. To enable a uniform mesh, a technique is proposed that allows efficient simulations of the dielectric together with the antenna feed. The antenna is first analyzed in a homogenous infinite medium. Subsequently, an auxiliary antenna is defined that is equivalent in terms of impedance, but characterized by much coarser details. The auxiliary antenna is then analyzed together with the finite size dielectrics, with a computationally efficient simulation.

Dual Linear Polarization Waveguide Feed Alternatives for Fabry-Perot Cavity Antennas

Iñigo Ederra (Universidad Pública de Navarra & Institute of Smart Cities, Universidad Pública de Navarra, Spain); JuanCarlos Iriarte (Public University of Navarra &

Antenna Group, Spain)

Two different alternatives of a dual polarization feeder for Fabry-Perot cavity antennas are discussed. They are based on a cavity baked double slot antenna fed by waveguides running in different directions, so that the double polarization is obtained. Their performance has been found to be similar in terms of return loss and radiation performance.

Sub-Millimeter-Wave Validation Standard Antenna Requirements and Design

Daniel Valcazar and Aitor Martinez (EOSOL, Spain); Bertrand Thomas, Kevin Lichius and Hugh Gibson (Radiometer Physics GmbH, Germany); Benjamin Braun (Space Structures GmbH, Germany); Fernando Rodríguez Varela and Xiaoliang Sun (Universidad Politécnica de Madrid, Spain)

A new sub-millimeter-wave Validation Standard ((sub)mm-VAST) antenna for use covering frequencies from 89 to 1200 GHz is being developed as a collaborative effort between EOSOL, Radiometer Physics GmbH (RPG), Space Structures GmbH (SPS) and Universidad Politecnica de Madrid (UPM) under contract from the European Space Agency. The electrical and mechanical requirements are discussed, with special attention given to the crucial measurement stability requirements. The antenna must be stable in typical measurement setups both thermally and mechanically due to gravity loads dependent on position and rotation. As well as this, it must present high gain and challenging features, such as asymmetric sidelobes, differing beamwidths and other electrical radiation qualities usually present in satellite antennas. Several antenna types are studied, after which a baseline electrical model is described and its results presented.

Leaky-Wave Lens Focal Plane Array for an Integral Field Unit at 7.8 THz

Alejandro Pascual Laguna (Delft University of Technology & SRON, The Netherlands); Juan Bueno (Delft University of Technology, The Netherlands); Jochem Baselmans (SRON, The Netherlands)

A focal plane array of extended-hemispherical silicon lenses coupled to aluminum coplanar-waveguide (CPW) Kinetic Inductance Detectors (KIDs) has been designed to operate at 7.8 THz. Low-dispersive leaky-wave radiation has been used to efficiently illuminate the antireflection-coated lenses. To minimize the radiation loss from the antenna feeding lines at these high frequencies, the CPWs have been miniaturized down to the microfabrication limits and placed on a dielectric membrane. The device is currently being fabricated and its experimental characterization in terms of optical coupling and beam patterns will follow.

Synthesis of Dual-Band Leaky-Wave Antenna Feeds for Submillimeter-Wave Imaging

Sjoerd Bosma and Maria Alonso-delPino (Delft University of Technology, The Netherlands); Darwin Blanco (Ericsson, Sweden); Sven L van Berkel and Cecile Jung-Kubiak (NASA-JPL, Caltech, USA); Goutam Chattopadhyay (NASA-JPL/Caltech, USA); Jose V Siles (NASA Jet Propulsion Laboratory, USA); Nuria LLombart (Delft University of Technology, The Netherlands)

We report on the progress towards a dual-band leaky-wave lens antennas operating at 210-240 GHz and 500-580 GHz simultaneously. The antenna can be used in a focal-plane array to be placed in the focus of a parabolic reflector, achieving overlapping beams and constant gain on-sky in both frequency bands. Such capability is essential for the COMETS spectrometer and radiometer that is currently under development at NASA/JPL. In this contribution, we emphasize the analysis and synthesis of the leaky-wave stratification for this antenna, which is then validated using full-wave simulations. The performance of the lens antenna in the quasi-optical system is presented. We report on the progress towards a submillimeter-wave dual-band lens antenna prototype.

V-Band Vivaldi Antenna for Beyond-5G Integrated Photonic-Wireless Millimetre Wave Transmitter

Dimitrios Konstantinou, Jasper de Graaf, Simon Rommel, Ulf Johannsen, Yuqing Jiao and Idelfonso Tafur Monroy (Eindhoven University of Technology, The Netherlands)

A V-band Vivaldi antenna design for beyond-5G base station applications operating within V-band is demonstrated. The device can be used for interfacing with radio-over-fibre links and optoelectronic components through a coplanar waveguide to slotline transition. Simulations show an end-fire radiation with a 3dB gain bandwidth ranging between 46.9-77.4 GHz combined with the reflection coefficients remaining below -10 dB for the same frequency range. A comb structure inspired by optical grating couplers is added providing an increased maximum gain of 12.6 dBi at 68.5 GHz. Measurement results validate the promising characteristics of the planar antenna.

Design of a D-Band Tilted Beam Antenna

Chao Gu and Vincent Fusco (Queen's University Belfast, United Kingdom (Great Britain))

This paper presents a tilted beam antenna design working at 155 GHz. The proposed antenna is based on a Fabry Perot resonant cavity antenna concept. Using a metallic partially reflective surface the reported antenna is fed by a rectangular waveguide, and as such is designed to be compatible with the available 3D metal printing techniques. The beam tilting is achieved by grading the size of the perforations in the unit cells of the PRS. A beam tilt of 15° is shown with a gain of 18 dBi at the operating frequency. Moreover, a feed offset approach is proposed to further improve the beam tilt angle.

Leaky Enhanced Photo-Conductive Connected Array for Efficient Generation of THz Power

Juan Bueno (Delft University of Technology, The Netherlands); Martijn Huiskes (TU Delft, The Netherlands); Huasheng Zhang, Paolo Sberna, Nuria LLombart and Andrea Neto (Delft University of Technology, The Netherlands)

Photoconductive antennas are devices that provide power up to THz frequencies at a relatively low cost. However, the power radiated by each antenna is typically quite low and arrays have been proposed to increase it. In this paper we present the design of an array architecture that surpasses the state of the art as it operates efficiently for frequencies up to 1THz, without excessive complications in the manufacturing. This architecture demonstrates clean radiation patterns and high bias efficiency.

A Phase-Gradient Metasurface Reflector for Millimeter Wave and 5G Applications

Sarawuth Chaimool (Khon Kaen University, Thailand); Chawalit Rakluea (Rajamangala University of Technology Thanyaburi & King Mongkut's University of Technology North Bangkok, Thailand); Pubet Sangmahamad and Yan Zhao (Chulalongkorn University, Thailand); Apisak Worapishet (Mahanakorn University of Technology, Thailand); Prayoot Akkaraekthalin (King Mongkut's University of Technology North Bangkok, Thailand)

In this work, we propose a phase-gradient metasurface reflector for millimeter wave (mmWave) and the fifth generation (5G) mobile network applications. The proposed metasurface is composed of periodically arranged metallic patches loaded with square rings, backed by a ground plane. Numerical simulations and experiments are conducted to validate the designed metasurface reflector, and results show that the RCS and beamwidth are considerably affected by the overall size of the reflector, and in situations when the receiver is in non-line-of-sight (NLOS) with the transmitter, the metasurface reflector can improve the received signal strength by more than 10 dB.

Dual-Band Millimetre-Wave Phase Shifting Metasurface Element Enabled by Air-Bridged Schottky Diodes

Evangelos Vassos and Alexandros Feresidis (University of Birmingham, United Kingdom (Great Britain))

A novel design of a dual band metasurface unit element using two diodes for independent phase shifting in two frequency bands with low reflection losses is presented. Control of the capacitance and thus of the reflected phase can be achieved by independently applying a reverse bias to the two air-bridged Schottky diodes that are embedded on the phase-shifting element. Simulations of the proposed design are presented and the currents and losses are studied. CST Microwave Studio was used to evaluate the tuning range and reflection characteristics of the proposed design.

A 2-Bit Tunable Unit Cell for 6G Reconfigurable Intelligent Surface Application

Luis Da silva (INATEL, Brazil); Pei Xiao (University of Surrey, United Kingdom (Great Britain)); Arismar Cerqueira S. Jr. (INATEL, Brazil)

This paper presents a 2-bit unit cell for reconfigurable intelligent surface (RIS) applications of beamforming and beam-steering in the frequency range 2 (FR2) from the fifth generation of mobile communications (5G). The proposed unit cell is based on a printed split-ring resonator (SRR) loaded with a varactor diode. The SRR-based structure comprises two circular loops connected by a varactor diode at the top and a ground plane at the bottom, resulting in a 0.245x0.245λ0 total area. The complete unit cell element encompasses four conducting layers, in which the first two ones form the SRR. RF chokes are printed at the middle layer to isolate the DC circuit, and the bias lines are routed at the fourth layer. The unit cell has been conceived using the full-wave electromagnetic solver ANSYS HFSS. Its numerical results demonstrate a reflection phase shift up to 270° and reflection magnitude higher than 0.5 at 24.5 GHz.

Simple Matching Technique Using Finite Metasurface to Control Surface Waves

Maksim Kuznetcov (Heriot Watt University, United Kingdom (Great Britain)); Victoria Gómez-Guillamón Buendía (TNO, The Netherlands); Khalid M Alrushud (The University of Edinburgh & King Abdulaziz City for Science and Technology (KACST), United Kingdom (Great Britain)); Symon K. Podilchak (University of Edinburgh, United Kingdom (Great Britain))

This article presents a simple matching technique to control surface-waves (SWs) by using a finite metasurface matching section. The approach is based on a sub-wavelength array of patches which are employed as a simple and effective approach to control and guide SWs on a grounded dielectric slab (GDS). In order to excite the fundamental TM0 SW mode, a horn-shape surface-wave launcher (SWL) in substrate integrated waveguide (SIW) technology is employed. The structure and the matching metasurface are modeled with an equivalent circuit.

2-Bit Digital Anisotropic Low-RCS Metasurfaces with Puzzles'-Type Modules with Improved Diffusion Scattering

Andrey Semenikhin and Diana Semenikhina (Southern Federal University, Russia)

A block of digital anisotropic low-visible puzzle-type coating, which also consists of puzzle-type antiphase modules, are offered to improve the diffusion of scattering. The scattering characteristics of this block are compared with the characteristics of a block with square-shaped modules. Both 2-bit meta-coatings (MCs) are made from meta-particles of a dumbbell-shaped form and constructed on the base of block matrices of coding. Simulation shows that the diffraction lobes of the bistatic RCS diagrams of the puzzle-like MC fill the front half-space more uniformly in the sector of meridianal scattering angle of 30°...70°, compared to MC made of square modules. Monostatic RCSs for co-polarizations under normal irradiation are reduced by no less than 10 dB in X-, Ku-bands.

Analysis of Normally Incident EM Waves Reflected from a Conformal Meta-Surface

Dinesh Rano (Moscow Institute of Electronics and Mathematics, NRU, Higher School of Economics, Moscow, Russia); Mohammad Hashmi (Nazarbayev University, Kazakhstan); Andrey Albertovich Yelizarov (Moscow Institute of Electronics and Mathematics, NRU Higher School of Economics, Russia); Muhammad Akmal Chaudhary (Ajman University, Ajman, United Arab Emirates)

This paper reports the conceptualization, and analysis of a geometrical approach to determine the shift in the in-phase reflection of three conformal meta-surfaces (MS). For the proposed approach, a planar array consisting of MS unit cells (MS-UCs) of a given dimension is drawn on a circle of desired radius (r). The path traveled by the reflected and incident EM wave in terms of an electrical length results in the shift of reflection angle. For the validation purpose, the conformed arrays are simulated under x- and y-polarized EM waves. The sum of the incident and reflected phases resulting in total shift is determined theoretically and compared with the simulated shifts of the three arrays. Furthermore, one of the conformed arrays is experimentally evaluated under the TEM incidence and compared with the theoretical and simulated result. The excellent agreement between the theoretical and measured results demonstrates the effectiveness of the proposed work.

Development of Ultra-Wideband Textile-Based Metamaterial Absorber for mm-Wave Band Applications

Gökberk Akarsu (Izmir University of Economics, Turkey); Hany Taher (Walton Institute, Ireland); E. Buse Zengin (Izmir University of Economics, Turkey); Nakmouche Mohammed Farouk (İzmir University of Economics, Turkey); Abdelmegid Allam (German University in Cairo, Egypt); Diaa Fawzy (Izmir University of Economics, Turkey); Frances Cleary (Walton Institute, Ireland)

This work presents a state-of-the-art development of an ultrawide absorber for wearable smart electronic textile applications. The design is based on a novel cell geometry that is previously developed and applied for RF energy harvesting applications. Different textile types were considered in this study, namely, Felt, Denim and Polyester and the achieved -10 dB reflective fractional bandwidths are about 42.828%, 43.65%, and 42.834% respectively. A comparison with traditional counterparts (FR-4 and Rogers dielectrics) shows that the bandwidth exhibited by textile materials is greatly wider. The bending effect of the textile materials is considered in this study and found that the -10 dB bandwidth is inversely proportional with the decrease in the surface curvature of the material. Compared to the currently developed absorbers and similar structures reported in the literature show that the current design is more compact, lighter, and more efficient in terms of the absorptivity.

Modified CSRRs in SIW Technology for Passband Improvement

Javier Martínez and Angela Coves (Universidad Miguel Hernández de Elche, Spain); Angel-Antonio San-Blas (Miguel Hernandez University of Elche, Spain); Enrique Bronchalo (Universidad Miguel Hernandez de Elche (UMH), Spain); Maurizio Bozzi (University of Pavia, Italy)

In this paper, a substrate integrated waveguide (SIW) loaded with three pairs of modified complementary split-ring resonators (CSRRs) is presented, in which the subwavelength waveguide passband can be significantly increased due to the appearance of new electromagnetic couplings between the different resonators. The obtained results are compared to those provided by a more classical topology based on CSRRs periodically etched along the waveguide wall, showing a significant bandwidth improvement, while maintaining a good matching level.

Dynamic Metasurface Antenna for Computational Polarimetric Imaging

The Viet Hoang (Queen's University of Belfast, United Kingdom (Great Britain)); Vincent Fusco (Queen's University Belfast, United Kingdom (Great Britain)); Thomas Fromenteze (University of Limoges, France); Okan Yurduseven (Queen's University Belfast & Duke University, United Kingdom (Great Britain))

A dynamically reconfigurable wave-chaotic metasurface antenna is presented to perform computational polarimetric microwave imaging. The metasurface is synthesized using sparsely distributed sub-wavelength super-cells, each consisting of two orthogonally separated complementary electric inductive-capacitive (cELC) unit-cells. These super-cells radiate selectively (under PIN diode control) in both vertical and horizontal polarizations, ensuring that the synthesized wave-chaotic modes are polarimetric in nature. Leveraging the dynamically modulated waveform diversity of the incoherent wave-chaotic radiations from the metasurface antenna, polarimetric imaging is computed in the near-field region at K-band frequencies and the polarimetric responses of specific targets are retrieved.

H-Polarized Plane Wave Scattering by Graphene Strip Grating on Top of a Dielectric Substrate

Mstyslav Kaliberda (Karazin National University of Kharkiv, Ukraine); Leonid Lytvynenko (Institute of Radio Astronomy of the National Academy of Sciences of Ukraine, Ukraine); Sergey Pogarsky (Karazin National University of Kharkiv, Ukraine)

The scattering of the H-polarized plane wave by the finite number of graphene strips with dielectric substrate is considered. We use accurate and mathematically grounded method of singular integral equations. The frequency dependences are presented. The excitation of plasmon resonances, the position of which can be controlled dynamically, as well as excitation of the grating-mode resonances and resonances near the Rayleigh anomaly are studied.

On the Scattering of Nondiffractive Beams by PEC and Dielectric Cylindrical Objects

Santi Concetto Pavone (Università degli Studi di Catania, Italy); Loreto Di Donato and Gino Sorbello (University of Catania, Italy)

In this paper, the scattering of a Bessel beam by PEC and dielectric circular cylindrical scatterers is analyzed and discussed. In particular, it is shown that the scattering by nondiffractive beams is in general spatially localized in both cases, due to the remarkable focused beam features: the wavefront inside the main beam is locally planar, and the sidelobes are not so high, due to the abrupt amplitude shaping of the zeroth order Bessel distribution. The inherent localized scattering process paves the way to novel applications in microwave imaging and ground penetrating radar design.

Numerical Analysis of the Azimuthally Magnetized Ferrite-Dielectric Circular Waveguide

Mariana Nikolova Georgieva-Grosse (Consulting and Researcher in Physics and Computer Sciences, Germany); Georgi Nikolov Georgiev (University of Veliko Tirnovo "St. St. Cyril and Methodius", Bulgaria)

An original numerical approach for investigation of a circular waveguide, containing a co-axially positioned ferrite cylinder of azimuthal magnetization and a dielectric toroid and that propagates normal-TE01mode, is developed. It utilizes certain positive purely imaginary roots in the independent variable of the characteristic equation of the structure, derived in terms of the-complex Kummer confluent hypergeometric and real zeroth and first order Bessel and Neumann functions and specific real numbers (L3_numbers). The latter are connected with other roots of the equation mentioned and have been defined and discussed by the authors in earlier studies. Tables of the roots in question and of the L3_numbers for selected values of parameters of the-configuration are given. Using them the lower and upper cut-off frequencies which specify the boundaries of the area of phase shifter operation of the transmission line are determined. The-discussion is confined to the case of a-thick ferrite and a-thin dielectric layers.

Electromagnetic Analysis of Lasing Eigenmodes of Twin Semiconductor Nanorods with Graphene Covers

Dariia O. Herasymova (Institute of Radio-Physics and Electronics NASU, Ukraine)

This work is dedicated to the electromagnetic eigenvalue problem for twin dielectric nanorods made of the gain material and coated with graphene monolayer covers. This problem is adapted to the modeling of the optical modes at the threshold of lasing, where they have real-valued frequencies. Each eigenvalue is a pair of numbers: frequency and threshold gain index. Due to two-fold symmetry, twin-rod open cavity possesses modes of four different symmetry classes. We derive separate determinantal equations for each class, using the separation of variables in the local coordinates, the addition theorems for the cylindrical functions, the Kubo formalism for the graphene conductivity, and the resistive boundary conditions on the rod contours. Sample numerical results demonstrate how the plasmon supermodes of graphene-covered twin rods form the quartets made of two doublets with close frequencies. Our analysis will be useful in the design of novel plasmonic nanolasers with graphene resonance elements.

Electromagnetic Triggering for Microfluidic Mixing

Mohammed Saad Shaikh (Queen Mary University of London, United Kingdom (Great Britain)); Robert Donnan and Rostyslav Dubrovka (Queen Mary, University of London, United Kingdom (Great Britain))

Microfluidic technology has been improving continuously in recent years due to constant research and development in the area motivated by the high efficiency and low cost features. Most of these devices are controlled or triggered using on board power supply, wired connections or specific chemical reactions. In this paper, we propose the wireless electromagnetic triggering for mixing in microfluidic chips. The preliminary results obtained from simulations in COMSOL Multiphysics show that interaction of microwaves with metallic microparticles can generate enough heat to switch thermosensitive valves in a microfluidic chip for enabling microfluidic mixing.

Reducing the Propagation of Switching Noise by Optimization of Vias Location Using CST Studio Suite

Ondrej Stejskal and Libor Janda (Valeo Autoklimatizace k s, Czech Republic); Ludek Subrt (Czech Technical University in Prague, Czech Republic); Miroslav Purnoch (Valeo Autoklimatizace k. s., Czech Republic)

This paper presents a detailed investigation of the propagation of noise generated by a switch mode power supply (SMPS) across an automotive sensor Printed Circuit Board (PCB). The noise propagation is simulated using a full 3D model of the board. CST Studio Suite was used to import the PCB and component models, perform the simulations and visualize the surface current distribution and the corresponding noise distribution. The paper demonstrates how the ground vias arrangement is critical for full understanding of propagation of the noise and its mitigation.

A Design Methodology for Response-Controlled Passive Magnetic Metasurfaces

Martina Falchi, Sabrina Rotundo and Danilo Brizi (University of Pisa, Italy); Agostino Monorchio (University of Pisa & CNIT, Italy)

In this paper, we introduce a design methodology for passive magnetic metasurfaces with controlled response excited by an active RF coil placed in its near-field region. Starting from conceiving the geometrical parameters of the radiating system, we first create the mask reporting the desired magnetic field distribution to be achieved at a certain plane. After that, the currents, in amplitude and phase, producing the desired field distribution, are evaluated. This step is carried out through an optimization algorithm, based on a magneto-static hypothesis. Then, we determine the capacitive loads required to achieve such behavior, exploiting a single full-wave simulation. Finally, numerical simulations of the overall designed radiating system are performed to validate the obtained results. The possibility to rapidly design and configure a passive metasurface, able to show the desired magnetic field distribution, can be a valuable tool in different applications, like magnetic resonance

imaging and wireless power transfer.

3D Microwave Breast Imaging Using Double Stage Delay Multiply and Sum Beamforming

Michelangelo Maria Malatesta (University of Bologna-ARCES, Italy); Luca De Marchi (University of Bologna, Italy); Jochen Moll (Goethe University Frankfurt am Main, Germany)

This paper introduces the DS-DMAS (double-stage delay multiply and sum) algorithm for 3-dimensional microwave breast cancer detection. In contrast to conventional confocal microwave imaging approaches, the DS-DMAS method performs the focusing twice which overcomes the limitations of conventional digital beamformers in terms of low image resolution and low contrast. This work presents image reconstruction examples based on numerical simulations with a comparison to DAS (delay and sum) and DMAS (delay multiply and sum) beamformers. Image analysis metrics have been implemented and discussed to quantitatively analyze the image quality. A significant improvement of DS-DMAS compared to both other techniques can be found.

Calibration of a 94-GHz Monopulse Feed Based on Hybrid Comparison of Its Experimental Patterns

Marta Ferreras, Mariano Barba and Jesús Grajal (Information Processing and Telecommunications Center, Universidad Politécnica de Madrid, Madrid, Spain)

This paper analyzes the tracking performance of a 94-GHz monopulse feed receiving two simultaneous beams: a circularly-polarized sum beam, and a difference beam generated from the first higher-order mode of circular waveguide. The experimental radiation diagrams of the prototype are processed in amplitude and phase to calibrate suitable polynomial estimators for both angles of arrival. It is shown that very simple linear estimators can be used for accurate tracking of both angular coordinates inside the 3-dB beamwidth of the sum beam. Moreover, the tracking model has been extended to cover the 10-dB beamwidth, and used to illustrate the monopulse processor outputs for several target trajectories.

Influence of Wave Diffraction on the Coastal Airfield Surface on the Glide Path Behavior

Ekaterina Iungaitis, Nikolay Voytovich and Aleksey V. Ershov (South Ural State University, Russia)

The influence of the diffraction of electromagnetic waves at a limited area in front of the glide path beacon on the behavior of the aircraft approach trajectory for landing is considered. The underlying surface at the coastal airfield is represented by a perfectly conducting half-plane. An asymptotic expansion of a rigorous solution to the problem of diffraction of a spherical wave by an ideally conducting half-plane is used. The calculated results are compared with the experimental results obtained in flight.

On the Sampling Effects of Disdrometer-Derived Data Measured by the 1D-Video-Disdrometer

Joel Flávio (JOANNEUM RESEARCH, Austria); Michael Schönhuber and Guenter Lammer (Joanneum Research, Austria)

Measurements performed by disdrometers are often used in order to study and characterize the impact that precipitation induces into electromagnetic waves. This paper presents the 1D-Video-Disdrometer (1DVD). Thanks to the generous measuring area offered by this device, the sampling effect often associated with the disdrometers available on the market can be attenuated. It was found that the rain amount measured by the 1DVD is affected by an error smaller than 0.6% and the specific attenuation can be derived with an error not larger than 3.5%.

Radar Cross Section Enhancement Using Metasurfaces for Road Safety Applications

Mohammed Kalaagi III (Universite Lille 1 & The French Institute of Science and Technology for Transport, Spatial Planning, Development and Networks, France); Divitha Seetharamdoo (IFSTTAR, LEOST & Univ Lille Nord de France, France)

The protection and safety of vulnerable road users such as pedestrians and cyclists is essential specially in urban areas. Project CYCLOPE aims to provide technical solutions to integrate cyclists and ensure safety for pedestrians in urban areas. Automobile radar technologies are integrated in automobiles for detection of vulnerable road users to decrease accidents. However, targets such as pedestrians and cyclists can have a low radar cross section and hard to detect. Retrodirective metasurfaces can be a key solution when integrated along side targets to enhance their RCS detection. In this paper, we design a dual polarized retrodirective metasurface at a given angle of incidence. Furthermore, we demonstrate a human model and measure its RCS at 24 GHz using an automobile radar system with and without the retrodirective metasurface. The results show a gain of 15 dBm in terms of RCS detection when implementing the metasurface design.

Preliminary Study of Bone Tumors Hyperthermia at Microwaves Using Magnetic Implants

Matteo Lodi (University of Cagliari, Italy); Nicola Curreli (Italian Institute of Technology, Italy); Giacomo Muntoni (University of Cagliari, Italy); Marco Simone (Univerity of Cagliari, Italy); Alessandro Fanti (University of Cagliari, Italy); Maurizio Bozzi (University of Pavia, Italy); Giuseppe Mazzarella (University of Cagliari, Italy)

Microwave hyperthermia as therapeutic modality in oncology can be the next breakthrough technology if translated properly to the clinical practice. For deep-seated tumors such as bone cancers, antennas and radiating sources fails in achieving therapeutic temperatures without overheating healthy tissues. In this framework, magnetic implant to be used as thermoseeds exposed to a several kHz magnetic field were studied. So far, the possibility of using magneto-dielectric biocompatible implant for performing microwave hyperthermia was not studied. In this work, we propose a simplified monodimensional electromagnetic model to study the propagation in a multilayer structure by means of the wave-amplitude transmission method. The model is aimed at finding suitable

properties of the bolus, to be used as matching medium, while determining a set of working frequency. Then, we investigate the temperature evolution to determine, preliminarily, the feasibility of this innovative treatment modality.

Multidisciplinary Data Fusion for THz Ray-Tracing

Andreas Prokscha (University of Duisburg-Essen, Germany); Fawad Sheikh (Universität Duisburg-Essen & The Mobile Terahertz Company UG, ID4US GmbH, Germany); Dien Lessy (University of Duisburg-Essen, Germany); Najah A. Abu Ali (UAEU, United Arab Emirates); Thomas Kaiser (Institute of Digital Signal Processing, Germany)

The human appearance can be interpreted as a disturbance, convenience or even necessity, for example, in technical applications with human-robot interaction and humangesture detection. This implies the need for implementing a realistic human digital twin with its positions, gestures and individual movements in ray-tracing simulations. Thus, bringing harmony between simulation and measurement owing to the more realistic assumptions within the simulation environment. In this paper, the human-digital twin combo is primarily realized based on two rationales: Firstly, a 3D human model is generated whose individual segment movement is represented by individual trajectories. Secondly, the inertial measurement units (IMUs) are placed on the human body for capturing the human motion estimation. The data fusion between different human postures and ray-tracing is achieved using a self-written script applying the translation and rotation of joint movements to the corresponding segments of its digital twin. Investigations using terahertz (THz) ray-tracing simulations for in-room environment scenario are carried out for different human gaits and velocities at 300 GHz center frequency. Moreover, upon comparing animated postures of this human model with its digital twin which executes the movements according to the measured data from the inertia sensors, the need to record human individual postures is stressed in order to simulate the interaction between humans and technical equipment whereby small changes in human movement might trigger a major impact.

Feasibility Study of Plaque Detection Using Electrical Impedance Techniques

Shauna Burke (Smart Sensors Lab, Lambe Institute for Translational Research, NUIG, Ireland); Katarzyna Polak-Kraśna (Biomedical Engineering, School of Engineering, NUIG, Ireland); Hamza Benchakroun (National University of Ireland Galway, Ireland); Patricia Vazquez (Smart Sensors Lab, Lambe Institute for Translational Research, NUIG, Ireland); Martin O'Halloran and Atif Shahzad (National University of Ireland, Galway, Ireland); William Wijns (Smart Sensors Lab, Lambe Institute for Translational Research, NUIG, Ireland); Marcin J. Kraśny (Smart Sensors Lab, Lambe Institute for Translational Research, NUIG, Galway, Ireland)

Cardiovascular disease is the leading cause of premature death globally. There is emerging evidence that the morphology and composition of atherosclerotic plaques is a more reliable predictor of acute plaque events than the degree of coronary stenosis. The currently used plaque diagnostic methods - x-ray angiography, computed coronary tomography angiography, optical coherence tomography (OCT) or intravascular ultrasound (IVUS) - are not capable of delivering accurate risk prediction. Thus the development of a novel and minimally invasive method of assessing plaques and their risk of causing acute events remains critical. One promising alternative is electrical impedance spectroscopy (EIS). Previous studies focused on contact measurement of plaque structures. Herein we investigate plaque detection and non-contact sensing ability with the plaque, aorta and blood phantom models. The results show the feasibility of using this modality as a plaque detection method in non-contact intravascular sensing and imaging.

A New Approach for the Evaluation of Time Averaged SAR of Multiple Emitting Antennas

Mounir Teniou (ART-Fi, France); Mathieu Chamaillard and Thomas Julien (ART-FI, France); Stephane Pannetrat (ART-Fi, France); Lyazid Aberbour (Art-Fi, France)

This paper introduces a novel approach for the measurement of time averaged Specific Absorption Rate (SAR) for multiple emitting antennas. The proposed approach is based on the use of the phase information of the E-field phasor given by radiofrequency vector SAR measurement system, for the retrieval of the instantaneous input RMS power injected in the emitting antennas from a small number of SAR measurement points. The approach is presented for the case of two emitting antennas. Numerical validation was performed in the case of two dipole antennas radiating coherently at a single frequency.

Low-Cost Setup for Electromagnetic SAR Evaluation in a Human Phantom

Santiago Isaac Rodriguez and Andres Gallego (Universidad Nacional de Colombia, Colombia); E. F. Pineda (National University of Colombia, Colombia); Juan Vargas González (Universidad Nacional de Colombia, Colombia); Manuel Pérez (Pontificia Universidad Javeriana, Colombia); Francisco Roman (National University of Colombia, Colombia); Javier Leonardo Araque Quijano (Universidad Nacional de Colombia, Colombia)

We describe a low-cost setup developed to carry out SAR measurements on a human phantom. The development comprises: a human phantom manufactured using a modified workflow from the mannequin industry, liquid preparations using recipes found in the literature, a system for the transmission and reception of RF signals, a system for tracking the position of a field probe during the scanning, which is carried out manually, and a system for the integration and post-processing of the measured data. Preliminary validation results demonstrate good performance for all the blocks described. Detailed results from an underway measurement campaign with these blocks will be presented during the conference.

EME-Net: A U-Net-Based Indoor EMF Exposure Map Reconstruction Method

Mohammed T.H. Mallik (University de Lille & IRCICA, IEMN, France); Sofiane Kharbech (University of Lille, France); Shanshan Wang (Chaire C2M, LTCI, Tel´ ecom Paris, Institut Polytechnique de Paris, France); Taghrid Mazloum and Joe Wiart (Telecom ParisTech, France); Davy P Gaillot (University of Lille, France); Laurent Clavier (Institut Mines-Telecom, Telecom Lille & IEMN / IRCICA, France)

In wireless communication systems, in order to respond to the perception of risks related to electromagnetic field exposure and allocate radio resources, the estimation of the received power and exposure map is an essential task and a challenge. This paper proposes an algorithm for estimating electromagnetic field exposure maps using U-net architecture based on convolutional neural networks. The power map estimation is transformed into an image reconstruction task by image color mapping, where every pixel value of the image represents received power intensity. The designed model learns wireless signal propagation characteristics in a realistic indoor environment while considering various positions of the Wi-Fi access points. Results show that indoor propagation phenomena and environment models can be learned from data producing an accurate power map to measure the electromagnetic field.

Numerical Dosimetry at 5G-Bands Using Time-Domain Methods and the Impact of Discretization and Uncertainty in Tissues Constitutive Parameters

Abdelrahman Abdallah Ijjeh and Soukaina Mifdal (Université Cote d'Azur, France); Marylène Cueille (University of Nice Sophia Antipolis CNRS, France); Jean-Lou Dubard (Université de Nice - Sophia Antipolis, CNRS, France); Michel Ney (IMT Atlantique, France)

Numerical dosimetry is an essential procedure in designing and optimizing propagating EM-devices that confirm to the recommended limits of Specific Absorption Rate (SAR). However, as frequencies go higher, the complexity of the computational problem increases substantially. Moreover, the high heterogeneity of the human body and the uncertainty in its tissues properties add to that complexity. Furthermore, as the numerical domain becomes very large, the impact of numerical dispersion becomes more visible leading to decrease the mesh-size even more. This article sheds some light on the 3D-simulation of such computational problems, and revisits the necessary mesh-size condition that ensures convergences and accuracy of results. Comparisons between FIT and TLM methods are presented to show the speed of convergence for both methods.

Investigation on User Shadow Suppression for Mobile Handset Antenna at 28GHz

Peiye Liu, Igor Syrytsin and Shuai Zhang (Aalborg University, Denmark)

In fifth-generation millimeter-wave mobile terminal communications, the user body blockage will significantly shadow the radiation pattern and severely affect communication performance. In this work, the antenna is moved on the mobile handset to find a suitable position to suppress the user shadow. The investigation is conducted with the user in data mode. The shadowed antenna power ratio (SAPR) and shadowed cumulative distribution function (SCDF) are used to characterize the user blockage. Both simulations with whole-body phantom and measurements with the actual user were conducted to validate the results to provide a large degree of repeatability. A significant improvement can be confirmed when moving the antenna to the top of the handset plane than the bottom. An average of 7dB in simulation and 5dB in measurement in SAPR can be improved. The proposed method can be applied in the 5G handset antenna construction to reduce the deterioration caused by the human blockage.

Thursday, March 31 14:00 - 16:00

Propagation WG meeting

Thursday, March 31 15:00 - 16:20

Invited Speakers: Wonbin Hong & Matthias Geissler

15:00 ***Antenna-On-Display for Near, Mid-And Long-Range Wireless Applications***

Wonbin Hong (Pohang University of Science and Technology (POSTECH), Korea (South))

Electronic devices equipped with high-resolutions display panels with the capability of high-speed, low-latency wireless communication are becoming increasingly popular. State-of-the-art wireless generations such as 5G, ultra-wideband (UWB), Wi-Fi 6 will rely on the implementation of efficient and intelligent radio antennas. However, the evolution of display panels such as foldable, stretchable, breezeless and large-screen displays have triggered the need to reevaluate antenna design strategies and methodologies. Classical antenna theory professes the radiation efficiency of an antenna to be proportional to the effective antenna volume. Given the fact that conventional antennas have been designed and implemented as independent components, antenna radiation and performance suffers as the antenna real estate is further decreased amid the increased portion of display panels within a device. This eventually leads to performance degradation of wireless devices which use the latest display panel technologies. This talk introduces the original concept of incorporating a transparent, optically invisible antenna circuitry within the display panel. Denoted

as an Antenna-on-Display (AoD), this approach demonstrates that electromagnetic fields can be generated and controlled within the view area of the display. This concept is applied and demonstrated across a variety of different wireless standards such as GPS, Wi-Fi and millimeter-wave 5G and 6G.

15:40 ***Industrial Design of Active Antenna Arrays***

Matthias Geissler (IMST, Germany)

From a theoretical and conceptional point of view, active array technology can be the basis for powerful and flexible antenna solutions for many applications. However, when it comes to the industrial realization, there is always a danger of ending up with a very complex system, suffering from e.g. high material costs, a complex assembly process and/or a heavy weight. Therefore, the industrial design process of active arrays starts with a careful selection of the material baseline in combination with an application specific tailoring of the antenna to the functionality needed. The design process applied is very much based on efficient 3D EM modelling of the whole system including all details of the antenna and the integration scenario. By using a modular approach, one can combine high design and tailoring flexibility with affordable production costs. The presentation gives insight into today's industrial design process and shows several examples of active array antennas realized e.g. in aluminum, plastic molding, organic substrate and LTCC. Based on latter systematic design process, the active array technology can provide very powerful industrial solutions at medium complexity and acceptable costs.

Invited Speakers: Alenka Zajic & Danielle Vanhoenacker-Janvier

Chairs: Nuria LLombart (Delft University of Technology, The Netherlands), Jose M Riera (Universidad Politécnica de Madrid, Spain)

15:00 ***Chip-To-Chip THz Communications - in Pursuit of Ultra High Throughput, Super Low Latency, High Reliability, and Minimal Energy Consumption***

Alenka Zajic (Georgia Institute of Technology, USA)

Reliable, high-speed connectivity with low energy consumption and latency is a fundamental need in data centers. The use of wires and optical links in current data centers precludes adaptive scalability and suffers drawbacks in terms of assembly cost, airflow blockage, maintenance, and lengthy service time. It has been envisioned that future data center interconnects would alleviate the aforestated problems and introduce a higher data rate and low-latency communication. In this talk, we will discuss various opportunities, challenges, and current experimental trials in an effort to accomplish this in future data centers with the use of wireless Terahertz (THz) technology. We will show how these performance objectives can be achieved by affording data rates of up to 1.5 Tera-bits-per-second (Tbps) at a low power consumption of about 2.75 pJ/b (Energy-per-bit value), latency of 4.78 ns and good signal fidelity that ensures a Bit-Error-Rate (BER) of 10−12.

15:40 ***Numerical Weather Prediction Models for the Simulation of Propagation Impairments on Earth-Satellite Communications.***

Danielle Vanhoenacker-Janvier (Université catholique de Louvain, Belgium)

The C to Ku frequency bands currently in use are becoming more and more crowded, whereas there is still a need for new services. Increasing the frequency to Q/V band increases the degradation due to the troposphere: not only rain, but also clouds, gases and turbulence are affecting the propagation. Radiowave propagation models for geostationary satellites links are available worldwide in ITU-R Recommendations. In the absence of Earth-LEO propagation measurements, however, only statistical models are available for non-GEO links and they were not validated against measurements. Numerical Weather Prediction models produce meteorological parameters that can be used to simulate the degradation of the GEO and non-GEO earth-space links. The talk will illustrate the results already obtained, their validation with existing GEO measurements and finally underline the potential of this method but also its limitations.

Thursday, March 31 16:20 - 16:40

Coffee Break / Exhibition

Thursday, March 31 16:40 - 18:40

ESoA meeting

Thursday, March 31 16:40 - 18:20

P06: Mm-wave and UWB propagation

T02 Millimetre Wave 5G and 6G/ /Propagation

Chair: Diego Dupleich (Technische Universität Ilmenau, Germany)

16:40 ***From Sub-6 GHz to mm-Wave: Simultaneous Multi-Band Characterization of Propagation from Measurements in Industry Scenarios***

Diego Dupleich, Han Niu and Alexander Ebert (Technische Universität Ilmenau, Germany); Robert Müller (TU Ilmenau, Germany); Stephan Ludwig (Aalen University & Robert Bosch GmbH, Germany); Alexander Artemenko (Robert Bosch GmbH, Germany); Joseph Eichinger (Huawei Technologies Duesseldorf GmbH, European Research Center (ERC), Germany); Tobias Geiss (Robert Bosch GmbH, Germany); Giovanni Del Galdo (Fraunhofer Institute for Integrated Circuits IIS & Technische Universität Ilmenau, Germany); Reiner S. Thomä (Ilmenau University of Technology, Germany)

In the present paper we introduce simultaneous multi-band measurements at sub-6 GHz and two mm-wave bands with the objective of characterizing propagation for multi-band channel modelling purposes in industry scenarios. The marginal power profiles show that the dominant scatterers are common in the different frequencies. In addition, a relation of decreasing average delay and angular spreads with increasing frequency is observed. The different measured parameters are contrasted with the 3GPP model for indoor factories.

17:00 ***Effect of Space Diversity for Fading Mitigation at 40 and 60 GHz Indoor Channels***

Miguel Riobó Prieto (AtlanTTic Research Center, Universidade de Vigo, Vigo, Spain); Rob Hofman (Ghent University, Belgium); Manuel García Sánchez, Iñigo Cuiñas and Isabel Expósito (AtlanTTic Research Center, Universidade de Vigo, Vigo, Spain); Jo Verhaevert (Ghent University - imec, Belgium)

Measurements at 5G Frequency Range 2 (FR2) and beyond (41.5 GHz and 60.5 GHz) were carried out in order to study how space diversity can be applied to compensate for the challenging conditions at those frequencies. Several indoor scenarios were analyzed, including Line-Of-Sight (LOS) and Non-Line-Of-Sight (NLOS). When considering an outage of 1%, space diversity was found to be a suitable impairment mitigation technique. Improvements in signal signal levels with increments from 7.53 dB up to 14.37 dB, depending on the case study in question were observed.

17:20 ***Sub-THz Time-Reversal***

Ali Mokh (ESPCI Paris, PSL Research University, CNRS, Institut Langevin, France); Ramin Khayatzadeh (Huawei, France); Abdelwaheb Ourir (Institut Langevin ESPCI Paris CNRS, France); Mohamed Kamoun (Huawei France, France); Mathias Fink (Institut Langevin, ESPCI Paris, France); Arnaud Tourin (Laboratoire Ondes et Acoustique (LOA), France); Julien de Rosny (CNRS, ESPCI Paris, PSL Research University, France)

For the first time, TR experiments are conducted at 273 GHz with a bandwidth that can be as large as 2GHz. Spatio-temporal focusing of pulses are observed through different complex media. The first medium is a 1 m long and 10 mm diameter straight hollow cylinder. The second one, is a 5 m long and 12 mm diameter curved waveguide. Finally, we present results obtained in a cavity of 72cm3 that leaks through a copper grid. The best focusing is observed with the longer waveguide. These results may open the path for electronic beam steering of EM pulses.

17:40 ***Propagation Graphs for UWB MIMO Channels: Modeling and Experimental Validation***

Richard Prüller, Stefan Pratschner, Robert Langwieser and Markus Rupp (TU Wien, Austria)

Propagation graphs (PGs) are a spatially consistent model for multiple-input multiple-output (MIMO) and potentially ultra-wideband (UWB) wireless channels. In this work, we extend the PG model with an existing theory for UWB channels to incorporate the frequency dependency of the involved antennas. The resulting model has very few parameters and allows fast channel simulations in a scattering environment. Static in-door UWB measurements were conducted using a vector network analyzer and virtual antenna arrays to confirm the validity of the presented model. A qualitative comparison between the simulation results and the measurements shows that the presented model fits the considered propagation environment very well.

18:00 ***Characterization of Rain Attenuation in 80-200 GHz Radio Links Considering Non-Spherical Raindrops***

Domingo Pimienta-del-Valle, Jose M Riera and Santiago Pérez-Peña (Universidad Politécnica de Madrid, Spain); Pedro Garcia-del-Pino (Universidad Politecnica de Madrid, Spain); Ana Benarroch (Universidad Politécnica de Madrid, Spain)

The use of EHF (30-300 GHz) in terrestrial radio links is one key element in future 5G and beyond 5G technologies. Rain attenuation is the major impairment affecting radio links operating at this band. Due to the lack of experimental measurements for the EHF band, one approach is to estimate rain attenuation by using information about the rain DSD. In previous works, rain attenuation and its variability have been estimated up to 200 GHz by applying the Mie Theory to experimental DSD, considering spherical raindrops. This work goes a step further and provides the derivation of rain attenuation using a non-spherical drop model. To that aim, full-wave electromagnetic software is used to derive the extinction cross section of non-spherical drops excited with horizontal and vertical polarizations. The results show that at such high frequencies the differences between polarizations are not large but the variability of rain attenuation is not negligible.

A06: mm-Wave antennas

T02 Millimetre Wave 5G and 6G/ / Antennas

Chairs: Artem Vilenskiy (Chalmers University of Technology, Sweden), Kun Zhao (Aalborg University, Denmark)

16:40 ***Dual-Band Metal Frame Blockage Reduction for 5G Mm-Wave Arrays in Mobile Phones***

Rocio Rodriguez-Cano, Kun Zhao, Shuai Zhang and Gert Pedersen (Aalborg University, Denmark)

This paper proposes a solution that allows reducing the obstruction from the mobile phone frame to electromagnetic waves in two bands of the mm-wave spectrum. This response is obtained by etching longitudinal corrugations of two different lengths in the metal frame. The corrugations are inspired on the hard surfaces principle, which supports the propagation of electromagnetic waves on metal. The proposed structure is matched to a 50-Ohm source in the following bands: 25.4-27.7 GHz, 28.7-29.9 GHz, and 36.4-40.3 GHz. The realized gain of the mm-wave array with the corrugated frame is higher than the one of the array in free space in the majority of the operating bandwidth. The proposed solution can increase the gain of the array with a normal frame up to 10 dB.

17:00 ***A 28 GHz Beam Steerable Elliptic Microstrip Array Antenna for 5G Applications***

Amir Mohsen Ahmadi Najafabadi, Firas Abdul Ghani and Ibrahim Tekin (Sabanci University, Turkey)

This paper discusses the design, fabrication, and measurement of a two layer, 2X10 elliptic, microstrip series fed antenna array operating at 28 GHz 5G and mm-wave user equipment. A branch line coupler (BLC) was used as a feeding network which generates three beams. The peak gain value of each beam was 13 dBi at 28 GHz. The gain value was above 10 dBi within a beam coverage of -45 to 45 degrees, and the peak gain value for the 26.5 GHz to 29.5 GHz band was above 10 dBi. The impedance bandwidth of the proposed design was below -10 dB in the 26.5 GHz to 29.5 GHz band. The dimensions of the 2 X 10 antenna array with coupler were 80 x 40 x 0.203 mm3 on Rogers RO4003 substrate. This design is suitable for 5G mobile user applications due to low cost and compactness.

17:20 ***A Dual-Polarized Dual-Band Flat-Top Pattern 5G mm-Wave Array Antenna***

Johan Wettergren and Xinxin Yang (Qamcom Research and Technology, Sweden); Per N Landin (Ericsson AB, Sweden)

A nine-element antenna array is presented. It has a flat-top radiation pattern and is matched for use in both the 24.25-29.5 GHz and the 37-40 GHz frequency bands for 5G mm-wave systems. The application of this antenna is for use in over-the-air test systems for mm-wave base stations.

17:40 ***Surface Current Optimization of Dipole Antenna Close to Ground Plane for 5G Mobile Applications***

Jin Zhang (Aalborg University, Denmark); Resti Montoya Moreno (Huawei Technologies Finland, Finland); Ville Viikari (Aalto University & School of Electrical Engineering, Finland)

When a dipole is placed close to a ground plane, the induced currents on the ground plane are opposite to dipole currents making the entity a poor radiator. This paper presents a dipole antenna design at the ground distance of only 0.5 mm (0.04\(math\lambda_0) at 25 GHz). The dipole-ground interaction is tuned with reactive loading so that induced currents on the ground and those on the dipole arms contribute additively in the far field. Thus, the radiation efficiency is significantly improved when the total current reaches the peak. The value of the components are obtained through a quick circuit optimization and can be easily converted to a discrete form. This method is verified in the simulations with both the lumped and discrete elements. The results show that the proposed antenna has reached a good radiation efficiency, realized gain, and impedance matching at 25 GHz.

18:00 ***Millimeter-Wave Quasi-Optical Feeds for Linear Array Antennas in Gap Waveguide Technology***

Artem Vilenskiy and Yingqi Zhang (Chalmers University of Technology, Sweden); Esmé Galesloot and A. B. (Bart) Smolders (Eindhoven University of Technology, The Netherlands); Marianna Ivashina (Chalmers University of Technology, Sweden)

A realization of the quasi-optical (QO) feed concept for linear millimeter-wave (sub-)array antennas is demonstrated in gap waveguide technology. The proposed feed architecture employs an input transition from a ridge gap waveguide (RGW) to a groove gap waveguide (GGW), a radial (H-plane sectoral) GGW section, and a transition to an output RGW array. A design decomposition approach is presented to reduce simulation complexity. Several 20-element QO feed implementations are investigated at W-band demonstrating a 20% relative bandwidth (85-105 GHz), 0.5 dB insertion loss, and a capability of an amplitude taper control within the 10-20 dB range.

M04: Material characterization

T09 EM Modelling and Simulation tools/ /Measurements

Chairs: Arya Fallahi (IT'IS Foundation, Switzerland), Abhijeet Kanitkar (Fraunhofer IZM, Germany)

16:40 ***A Sensor Using a Matryoshka Geometry Defected Ground Structure***

Deisy Mamedes (University of Victoria, Canada); Alfredo Gomes Neto (Federal Institute of Paraíba & Grupo de Telecomunicações e Eletromagnetismo Aplicado - GTEMA, Brazil); Jens Bornemann (University of Victoria, Canada); Jefferson Costa Silva (Federal Institute of Paraiba - IFPB, Brazil); Francisco Aldir Abreu (Federal Institute of Paraiba, Brazil)

A sensor using a Defected Ground Structure (DGS) based on the matryoshka geometry is described. The main idea is to take advantage of the miniaturization and selectivity characteristics of the matryoshka geometry. The proposed DGS sensor geometry is outlined, and initial design equations are presented. A prototype was fabricated and characterized. For the empty sensor, when comparing numerical and measured results, a very good agreement is achieved. Moreover, the resonant frequency determined using the proposed design equations represents a good agreement too. In order to verify the matryoshka DGS sensor sensibility, a mixture of distilled water and isopropyl alcohol was characterized and a calibration curve achieved. Finally, the matryoshka DGS sensor is compared with a dumbbell DGS sensor occupying the same area, confirming the miniaturization and selectivity characteristics of the matryoshka geometry. The achieved results and characteristics instigate the matryoshka DGS sensor research.

17:00 ***Level Measurement of Low-Permittivity Material Using an M-Sequence UWB Radar***

Tim Erich Wegner (Technische Universität Ilmenau, Germany); Giovanni Del Galdo (Fraunhofer Institute for Integrated Circuits IIS & Technische Universität Ilmenau, Germany); Stefan Gebhardt (RECHNER Industrie-Elektronik GmbH, Germany)

Due to increasingly complex and automated manufacturing processes, the demands on the control parameters of these processes are also increasing. One parameter is the fill quantity of e.g. liquids in production plants, whose precise determination is ever of growing importance. Up to now, the exact level determination under difficult conditions, such as high ambient temperatures, has been a particular challenge. This paper demonstrates a novel method by which an M-sequence UWB radar can determine levels of low-permittivity materials in small metal containers. For this purpose, hot melt is used as an example. Thus, the influence of large temperature differences on the long-term stability of level measurement can also be investigated.

17:20 ***Detection of Water Through Steel-Lined Grout Using a Stepped-Frequency Continuous Wave Radar***

Thomas Maetz (Goethe University Frankfurt, Germany); Manfred Hägelen and Rainer Jetten (IMST GmbH, Germany); Jochen Moll (Goethe University Frankfurt am Main, Germany)

Monopiles are one of the most common foundation types for offshore wind turbines (OWT). They are subject to large bending moments which can lead to crack formation and ingress of water in the grout that connects the monopile foundation to the rest of the OWT via a transition piece. It is therefore of great interest to be able to continuously inspect the grout. To characterize the grout material used in this paper in terms of its dielectric properties an open-ended coaxial probe is utilized. In addition, a simplified laboratory demonstrator is designed and manufactured to enable first radar measurements. Grout-filled TEM horn antennas and a stepped-frequency continuous wave (SFCW) radar are purpose-built to enable measurements from 100 MHz to 2 GHz. The antennas are characterized and compared to the simulation. Finally it is shown that water can be detected through one meter of steel-lined grout by analyzing differential signals.

17:40 ***Dielectric Spectroscopy of High Permittivity Thin Solids Using Open-Ended Coaxial Probes***

Arya Fallahi, Niels Kuster and Sina Hashemizadeh (IT'IS Foundation, Switzerland)

Open-ended coaxial probe (OCP), as a widely used conventional technique for dielectric spectroscopy in the microwave and millimeter-wave regime, suffers from two difficulties when applied to high-permittivity solids. They include high sensitivity to minute gaps between the probe and sample, and reflections from probe boundary when layered samples are measured. In this contribution, we present first a calibration algorithm that aims at measuring the effective air-gap between the probe and sample. The result of this algorithm is later used in the OCP measurement process to cover the effect of this air-gap. Second, we introduce using a lossy platform below the thin sample to mitigate the inaccuracies caused by probe truncation. An exemplary high-permittivity thin sample is outlined and measured using both conventional and new algorithm, which demonstrates a considerable reduction in measurement error when the proposed procedure is followed.

18:00 ***Temperature Dependent RF Characterization of Thin-Film Polyimid for 5G mmWave Antenna-In-Package Modules***

Abhijeet Kanitkar (Fraunhofer IZM, Germany)

In this paper, dielectric properties of thin-film materials in Fan-out Wafer Level Packages (FoWLP) used for the development of 5G mmWave Antenna-in-Package (AiP) modules are measured in the 5G New radio (NR) frequency bands (26.5-29.5 GHz and 37-40 GHz) in dependency on temperature (0°-150°C).

A21: Antennas for localization and tracking

T07 Positioning, Localisation and tracking/ / Antennas

16:40 ***Localizing Targets via Properly-Synthesized Orbital Angular Momentum Vortices***

Giada Maria Battaglia (Università Mediterranea di Reggio Calabria, Italy); Andrea Francesco Morabito (University Mediterranea of Reggio Calabria, Italy); Roberta Palmeri (IREA-CNR, Napoli, Italy); Tommaso Isernia (University of Reggio Calabria, Italy)

As an alternative to delta and delta-square patterns usually exploited in the receive mode for the localization of targets, we propose herein to use 'orbital angular momentum' (OAM) antennas. By so doing, it is possible to effectively generate a single isolated null of the pattern rather than a whole row (and/or column) of zeroes in the spectral plane, so that a better localization can be achieved. General considerations are first given showing that the 1 (or -1) OAM vortex order is the best-suited one for such a goal. Then, a Convex Programming synthesis procedure maximizing the localization performance by relying on OAM vortices is given and tested.

17:00 ***Angular Localization of Wideband Sources Using a Single Port Metamaterial Receive Antenna***

Abdelwaheb Ourir (Institut Langevin ESPCI Paris CNRS, France); Ali Mokh (ESPCI Paris, PSL Research University, CNRS, Institut Langevin, France); Ramin Khayatzadeh (Huawei, France); Mohamed Kamoun (Huawei France, France); Arnaud Tourin (Laboratoire Ondes et Acoustique (LOA), France); Mathias Fink (Institut Langevin, ESPCI Paris, France); Julien de Rosny (CNRS, ESPCI Paris, PSL Research University, France)

Indoor source localization becomes a major challenge for many applications such as beam-steering or MIMO communication. We propose to design a single port Rx antenna based on metamaterial dedicated to angular localization of a wideband source. We take benefit of the strong frequency dependence of the radiation pattern of an open balanced Composite- Right-Left-Hand structure to design the proposed antenna. We experimentally demonstrate with a microwave prototype that an efficient angular localization can be achieved with this approach.

17:20 ***3:1 Bandwidth Sinuous Antenna for Direction Finding Applications***

Mohamed Elmansouri (University of Colorado at Boulder, USA); Ljubodrag Boskovic (University of Colorado Boulder, USA); Dejan Filipovic (University of Colorado at Boulder, USA)

This paper discusses the design and performance of an eight-arm sinuous antenna for analog and digital direction finding (DF) systems. The multimode and dual-polarized capabilities of the eight-arm sinuous are utilized to achieve wideband angle of arrival estimation independent of the incoming signal polarization. The performance is evaluated for the classical analog amplitude/phase comparison and the importance of mode 3 to achieve more accurate estimation is highlighted. Also, the Cramér-Rao lower bound (CRLB) is used to evaluate the performance of the proposed design in the context of a digital receiver backend. The performance of the antenna is experimentally verified over the 1.5-4.5GHz frequency band and low estimation errors are demonstrated over wide field of view

17:40 ***One-Way Doppler and Interferometry: Space Domain Awareness***

Jean francois Guimond, Simon Henault and Kathia Levis (Defence Research and Development Canada, Canada)

An existing 4.6 meter Cassegrain antenna at the Ottawa Research Lab was modified to augment a passive RF observation space domain awareness capability currently under development. A commercial-off-the-shelf S-band flat panel antenna is now used as a feed to provide joint passive oneway Doppler and interferometry measurements of satellites in Earth orbit. These measurements can be used to improve orbit determination accuracy and contribute to space domain awareness in a very economical fashion. Near-field measurements of the feed, numerical simulations of the feed in the presence of the main and sub- reflectors, details on the RF front-end, and experimental Doppler and interferometry results are presented.

18:00 ***Selecting Characteristic Modes in Multi-Mode Direction Finding Antenna Design by Using Reconstructed Incident Fields***

Lukas Grundmann (Leibniz University Hannover, Germany); Dirk Manteuffel (University of Hannover, Germany)

The performance of a multi-mode direction finding antenna depends on the selection of the utilized characteristic modes. A numerically efficient way to determine the correlation of the incident fields reconstructed from these characteristic modes is introduced. These correlations are evaluated for several directions of arrival (DoAs) and assembled in a correlation matrix. This procedure is repeated for different combinations of characteristic modes and the Frobenius norm of the correlation matrices is used to determine the combination of modes best suited for a defined direction finding application. An example setup as well as computational results are provided and it is shown that the proposed method provides insight into the physical behavior of the direction finding setup.

A24: Earth observation antennas

T08 Space (incl. cubesat)/ /Antennas

Chairs: Leri Datashvili (Large Space Structures (LSS) GmbH, Germany), Daniel Segovia-Vargas (Universidad Carlos III de Madrid, Spain)

16:40 ***Overlapped Subarrays of Leaky-Wave Antennas for a Reflector-Based SAR Instrument***

Nafsika Memeletzoglou, Eva Rajo-Iglesias and Jose-Luis Vazquez-Roy (University Carlos III of Madrid, Spain); Quiterio García (Airbus Defence and Space, Spain); Javier del Castillo Mena and Lara Orgaz Blanco (Airbus, Spain); Giovanni Toso (European Space Agency, ESA ESTEC, The Netherlands); Ernesto Imbembo (Aurora Technology B. V. for ESA-ESTEC, Noordwijk, The Netherlands)

The design of a leaky-wave antenna array in the L-band is presented. The array has been developed to feed a large reflector that is part of a SAR system for Earth observation. The basic element of the array is a differentially fed patch antenna that excites the leaky modes in a resonant cavity that is defined by a metasurface. The performance of a 3x3 sub-array has been studied and is presented in this paper, as well as the individual element. Important aspects of the design that affect the overall performance of the array are discussed together with the measured results of the fabricated prototype.

17:00 ***Predicted and Measured Antenna Patterns of the European Large Deployable Reflector***

Cecilia Cappellin (TICRA, Denmark); Maurizio Lori (HPS GmbH, Germany); Alexander Geise and Christian Hunscher (Airbus DS GmbH, Germany); Leri Datashvili (Large Space Structures (LSS) GmbH, Germany)

The European Large Deployable Reflector (LDR) antenna underwent RF test in November 2020, becoming the first 5.1 m antenna in light mesh technology developed and measured in Europe. In this paper we present the correlation between the measured and predicted antenna patterns at 10.65 GHz.

17:20 ***183GHz Cavity-Backed Spiral Radiometer Antenna with Dual Circular Polarization for Earth Observation Applications***

Juan María Herrera-Martín (Universidad Carlos III de Madrid, Spain); Vicente González Posadas (Polytechnic University of Madrid, Spain); Daniel Segovia-Vargas (Universidad Carlos III de Madrid, Spain)

New radiometer technology is a key enabling factor for the upcoming new generation of space missions; earth observation applications, with the use of cubesats and nanosatellites, will benefit greatly from the insight into our own planet these sensors can offer. In this paper, a four-armed cavity-backed radiometer spiral antenna is designed and simulated to capture the 183GHz ±5GHz water absorption line, fundamental for measuring moisture levels in the atmosphere and evaluating the effects of climate change in our planet. Due to the manufacturing difficulties involved, a scaled design centered in 7GHz is also provided. This scaled design is manufactured and measured as a way to validate the EHF design.

17:40 ***Design and Test of a Circularly Polarized Microstrip Antenna Array for a Sentinel-1 SAR Active Reflector with Co- and Cross- Polarization Capability***

Fermin Mira Perez (Centre Tecnologic de Telecomunicacions de Catalunya, Spain); Guido Luzi (Centre Tecnològic de Telecomunicacions de Catalunya (CTTC/CERCA), Spain); Pedro Espín-López (CTTC, Spain)

This paper reports the design and implementation of a circularly polarized microstrip array antenna operating in C-band. The antenna was designed to upgrade a C-band active reflector to be used with the ESA Sentinel-1 satellite SAR. The use of circular polarization improves the exploitation of the single polarization active reflectors allowing their use for the complete set of linearly polarized radar images available from the SAR acquisitions. This improvement can be done simply by replacing one of its two antennas. High gain, low cost, and a fine axial ratio are the main requirements of this prototype. Results show a good agreement between simulations and measurements, moreover, the close-range operational test done with the active reflector using the proposed antenna demonstrates the feasibility of the idea described in this work.

18:00 ***Architecture of the Overlapped Subarray Fed Reflector Antenna OLAF SAR System***

Javier del Castillo Mena (Airbus, Spain); Tamara Coello and Quiterio García (Airbus Defence and Space, Spain); Giovanni Toso (European Space Agency, ESA ESTEC, The Netherlands); Ernesto Imbembo (Aurora Technology B. V. for ESA-ESTEC, Noordwijk, The Netherlands)

The electrical architecture of a multibeam hybrid Synthetic Aperture Radar system is presented. The SAR Instrument is a hybrid analogue-digital multichannel radar system intended to provide high resolution and wide swath coverage. To achieve that the system is composed of a large oversize reflector fed by a multibeam CORPS (Coherently Radiating Periodic Structure) feedarray. The architecture of the system corresponds to a distributed semiactive digital configuration that extends along the feedarray length. The paper presents the main characteristics of the electrical architecture of the OLAF SAR.

M03: Data acquisition, imaging algorithms and measurement post-processing

T09 EM Modelling and Simulation tools/ /Measurements

Chairs: Sergiy Pivnenko (Antenna Systems Solutions, Denmark), Lucia Scialacqua (Microwave Vision Italy, Italy)

16:40 ***Performance Analysis of Classification Algorithms for Millimeter-Wave Imaging***

Rahul Sharma (Queen's University Belfast, United Kingdom (Great Britain)); Raphael Hussung and Andreas Keil (Fraunhofer Institute for Industrial Mathematics, Germany); Fabian Friederich (Fraunhofer ITWM, Germany); Thomas Fromenteze (University of Limoges, France); Mohsen Khalily (University of Surrey & 5G Innovation Centre, Institute for Communication Systems (ICS), United Kingdom (Great Britain)); Bhabesh Deka (Tezpur University, India); Vincent Fusco (Queen's University Belfast, United Kingdom (Great Britain)); Okan Yurduseven (Queen's University Belfast & Duke University, United Kingdom (Great Britain))

A detailed analysis of the performance of traditional machine learning and deep learning techniques applied on a representative classification problem of millimeter-wave (mmW) images is presented in this paper. The dataset for training and testing are generated via a developed coded aperture computational imaging physical model. The models are tested with both synthesized as well as experimental data, generated from the physical model and a mmW handheld imager, respectively. Upon testing, accuracy of 90% is observed in the case of CNN classifier. Also, an inference speed test is conducted on all three algorithms. It was observed that CNN is the fastest to predict classes for all of the test samples. These findings establish the fact that when it comes to image classification, CNN-based classifiers perform better than any traditional machine learning algorithms with more accurate and faster predictions, paving the way for various real-time applications such as automatic threat detection.

17:00 ***A Fast Pattern Synthesis Method for Arbitrary Planar Arrays***

Rui Ma (Guilin University Of Electronic Technology, China); Wenning Gao (University of Electronic Science and Technology of China, China)

With the development of irregular antenna array, some fast methods are no longer applicable, and a lot of computation is required for calculation and optimization. This paper proposes a two-dimensional nonuniform fast Fourier transform (2D-NUFFT) method to calculate the nonuniform array pattern, as well as for nonuniform field points, achieved by two steps. First step is a rearrangement of the nonuniform array into uniform oversampled grids. Second step contains the general uniform FFT, as well as an approximation for computing the values at the nonuniform field points. The calculation amount of the proposed method is analyzed which shows superior effectiveness especially for large-scale arrays. The pattern of the nonuniform array example is calculated using the proposed method, with numerical results showing the effectiveness of the applied algorithm.

17:20 ***An Accelerated Source Reconstruction Method for Antenna Diagnostics Applications***

Oscar Borries, Andreas Ericsson, Martin Haulund Gæde, Peter Meincke and Erik Jørgensen (TICRA, Denmark); Erio Gandini (ESA - European Space Agency, The Netherlands); Dennis T. Schobert (European Space Agency, The Netherlands)

We present an accelerated source reconstruction method well suited for use in antenna diagnostics applications. A reformulation of the inverse electromagnetic scattering problem has been implemented numerically and is solved using a higher-order method of moments (MoM) discretization. The novel implementation achieves asymptotically better scaling in terms of computational time and memory requirements in comparison to commercially available source reconstruction solvers. A test case of a reflector antenna on a satellite platform was used to evaluate the new method, and significant improvements are observed in comparison to a commercial state-of-the-art solver in DIATOOL 1.1.

17:40 ***Influence of Stirrer Vibration During Stepwise Operation of a Reverberation Chamber***

Christoph Cammin, Thomas Doebbert and Gerd J. Scholl (Helmut-Schmidt-University, Germany)

Reverberation chambers (RCs) are proposed as repeatable test environments. Often, the mode stirrers inside a RC are operated stepwise, whereby the essential measurements are performed under quasi-static conditions. However, mechanical mode stirrers usually vibrate when arriving on a new position. The influence of this mechanical vibration on the repeatability is analyzed in this paper and the results open up opportunities for future enhancement of mode stirrers movement.

18:00 ***Accuracy of De-Embedding Models for the Open-Ended Coaxial Probe Considering Different Calibration Standards***

Klementina Vidjak (Sapienza, University of Rome, Italy); Laura Farina (Endowave Ltd, Ireland); Martin O'Halloran (National University of Ireland, Galway, Ireland); Marta Cavagnaro (Sapienza University of Rome, Italy)

This work investigates the accuracy of the open-ended coaxial probe technique for measuring the dielectric properties of well-characterized liquids. Two different de-embedding models are used for retrieving the properties of materials under test considering different calibration standards. Liquids of interest were both simulated and measured. Optimal calibration setups for achieving good level of accuracy are proposed.

CS22: EuMA-EurAAP joint session: Towards a Smart EM Environment - Network and Hardware perspectives

T10 Fundamental Research and Emerging Technologies/ / Electromagnetics

Chairs: Roberto Flamini (Huawei Technologies, Italy), Renato Lombardi (Milan Microwave Competence Center, Italy)

16:40 ***Information Processing at the Deep Physical Layer Level***

Marco Donald Migliore (University of Cassino, Italy)

Recently it has been proposed the introduction of an additional layer placed below the Physical Layer of the OSI model, called the "Deep Physical Layer" (DPL), to analyze the communication process at the electromagnetic field level. While the transmission process at the Physical Layer level is focused on bits, information at the DPL level is modeled in terms of distinguishable configurations of the electromagnetic field. In this approach, the numerous solutions proposed for 6G, which include intelligent modifications of the propagation environment, can be seen as "data processing" at the DPL level able to preserve information lost in previous generations of cellular systems.

17:00 ***Smart EM Environments: Current Trends and Future Perspectives***

Arianna Benoni (ELEDIA Research Center, Italy); Giacomo Oliveri and Paolo Rocca (University of Trento & ELEDIA Research Center, Italy); Marco Salucci and Francesco Zardi (ELEDIA Research Center, Italy); Andrea Massa (University of Trento, Italy)

The smart electromagnetic environment (SEE) is a rapidly evolving paradigm aiming at revolutionizing the design of next-generation mobile communication systems. It is founded on the main idea that the propagation scenario should be no more regarded as an impairment to the overall system performance, but rather as a powerful additional degree-of-freedom (DoF) for tailoring the complex EM propagation phenomena towards an enhanced quality-of-service (QoS). Current trends and future perspectives of such an emerging framework are discussed to provide an overview of the most recent advancements in this field as well as to identify open challenges and promising future tracks of research.

17:20 ***Smart Electromagnetic Environments Enabled by Metasurfaces 3.0***

Mirko Barbuto (Niccolò Cusano University, Italy); Zahra Hamzavi-Zarghani (RomaTre University, Italy); Michela Longhi (University of Rome "Tor Vergata", Italy); Alessio Monti (Niccolò Cusano University, Italy); Davide Ramaccia (RomaTre University, Italy); Stefano Vellucci (Roma Tre University, Italy); Alessandro Toscano (University Roma Tre (IT), Italy); Filiberto Bilotti (University Roma Tre, Italy)

The concept of smart electromagnetic environments has been proposed in the last years as an effective strategy to overcome the detrimental effects of the propagation scenario on the efficiency and robustness of communication systems. Specifically, a smart electromagnetic environment is a complex and properly designed environment able to maximize the efficiency and capacity of one or more communication channels. The environmental engineering has been made possible thanks to the new degrees of freedom introduced by metasurfaces, which allow generalized field transformations and play an active role in achieving unprecedented system performances. In this contribution, we present and discuss some recent applications of metasurfaces in the antenna frame and contextualize them in the scenario of next-generation wireless systems. We show their potentialities in overcoming some undesired effects introduced by conventional environments in wireless communications and discuss their crucial role towards the practical implementation of a smart electromagnetic environment.

17:40 ***A Summary of Actual Maximum Approach Studies on EMF Compliance of 5G Radio Base Stations***

Bo Xu, Davide Colombi, Paramananda Joshi, Fatemeh Ghasemifard, David Anguiano Sanjurjo, Carla Di Paola and Christer Törnevik (Ericsson AB, Sweden)

For radio base stations enabling massive multiple-input multiple-output (MIMO) and beamforming technologies, using the highest possible power and gain values for all beams result in a very unrealistic assessment of radio frequency (RF) electromagnetic field (EMF) exposure. A more accurate approach, namely the actual maximum approach, has been developed in the past few years and recommended by international RF EMF exposure assessment standards and regulatory bodies. In this paper, we summarize the recent EMF research studies on this approach, including statistical modeling studies, measurement campaigns, and related applications, such as the usage of time-averaged power monitoring and control features.

18:00 ***The Measurement-Based Intelligent Reflecting Surfaces Path Loss Model***

Qibo Qin (China); Zhimeng Zhong (Huawei Technologies Co., Ltd., China); Xinyu Gao (Huawei Technologies Co. Ltd., China); Jianyao Zhao and Chao Li (Huawei Technologies Co., Ltd., China); LI Fan (Shanghai Huawei Technologies CO., Ltd, China); Zhiyuan Jiang (Shanghai University, China)

IRS can control the reflection of electromagnetic wave, so the deployment of IRS can adjust the channel conditions to enhance the coverage and throughput in the 5G evolution networks. Since the IRS is only capable of passively reflecting the received signals, its path-loss modelling method is different from existing two-hop communication networks, such as repeater, or relay. In this paper, the path-loss model for IRS in real urban scenario is proposed. Based on the theoretical analysis, the novel measurement methodology is proposed that the path-loss channel measurement campaign can be divided into separate measurement and cascade measurement, so that the measurement efficiency is dramatically improved under the constraint of modelling accuracy. The measurement data at 3.7GHz verifies the accuracy of the proposed IRS path-loss model with the RMSE as 2.33dB. The work investigated in this paper could be the foundation for IRS-based network link budge

calculation and system level evaluation.

A28: Fundamental research on antennas

T10 Fundamental Research and Emerging Technologies/ / Antennas

16:40 ***Flat-Top Gaussian Arrays with Dynamic Range Ratio Control***

Goran Molnar (Ericsson Nikola Tesla d. d. & Research and Development Centre, Croatia); Dorian Ljubenko (Ericsson Nikola Tesla d. d., Croatia); Mile Šakić (Ericsson Nikola Tesla, Inc., Croatia)

The design of antenna arrays forming flat-top beampatterns prefers robust and computationally efficient methods. These features are usually met by analytical techniques or simple optimization procedures. On the other hand, in the flat-top array design, a common requirement is the ability to control the beampattern width and sidelobe level. However, it usually brings the excitation coefficients with high or unpredictable dynamic range ratio. In this paper, the authors propose a straightforward method for the design of symmetrical flat-top arrays with controllable dynamic range ratio. The method is based on the quadratic transform of a Gaussian excitation to the array having maximally flat main beam. In addition, the method deals with zero coefficients, whose positions are used to control the dynamic range ratio. As a special case, flat-top Gaussian arrays with minimum dynamic range ratio can be obtained.

17:00 ***Synthesis of L1 Pencil Beams with Constrained Sidelobe Level and Dynamic Range Ratio***

Katarina Vodvarka (University of Zagreb, Croatia); Maja Jurisic Bellotti and Mladen Vucic (University of Zagreb, Faculty of Electrical Engineering and Computing, Croatia)

Optimization-based methods for pencil-beam design often incorporate controlling the dynamic range ratio (DRR) of excitation coefficients. However, constraining the DRR causes the deterioration of sidelobe region, in which some lobes may rise and even exceed design specifications. To prevent such behavior, additional requirement can be specified to constrain maximum sidelobe level (SLL). This paper presents a global design of pencil beams with specified DRR and SLL. The design is based on branch and bound method that utilizes convex optimization and feasibility analysis for tree pruning. As a case study, the paper considers design of pencil beams optimum in L1-sense to which DRR and SLL constraints are added. The resulting beam patterns exhibit low DRRs and decreasing side lobes.

17:20 ***Studying the Noise Performance of CORPS Beam Forming Networks***

Carlos Biurrun-Quel and Carlos del-Río (Universidad Publica de Navarra & Institute of Smart Cities, Spain)

The classical noise wave theory is employed in the field of Coherently Radiating Periodic Structures (CORPS). The coherent properties of these type of networks allow the distribution of a signal across the network and the in-phase recombination of each distributed component at an output port. Whereas these distribution and recombination processes are coherent for the signal and hence do not incur in power loss, the intrinsically incoherent noise contributions incident at the port terminations are not sum coherently. This is especially significant in presence of incident noise powers much larger than the intrinsically generated thermal noise. As a result, an enhancement in terms of Signal-to-Noise Ratio (SNR) is demonstrated analytically by means of noise wave theory. The maximum achievable SNR enhancement depends on the internal structure of the CORPS network. Validation of the proposed theory is provided by means of a commercial circuital software.

17:40 ***Antennas and the Greatest Unsolved Maths Problem***

Brian Scannell (Leornardo, United Kingdom (Great Britain))

The nulls in antenna radiation patterns can show the non-trivial Riemann zeta zeros. Here is an attempt at simulating an antenna design that visualise these zeros

18:00 ***W-Band Waveguide Slotted Array Antenna Based on Stacked Glide-Symmetric Metal Sheets Fed by a Groove Gap Waveguide***

Hosnia Azkiou (Universidad Politécnica de Madrid, Spain); Adrián Tamayo-Domínguez (Universidad Politecnica de Madrid, Spain); José Manuel Fernández González (Universidad Politécnica de Madrid, Spain)

This paper presents the design, optimization and simulation of a novel 12x12 W-Band waveguide slotted array antenna. This antenna is based on stacked glide-symmetric metal sheets fed by a groove gap waveguide (GGW). This paper also proposes a new unit cell. The suggested unit cell has serpentine-shaped holes in a glide-symmetric configuration with the goal of minimizing the separation between parallel waveguides. To demonstrate the viability of the proposed unit cell, a 12x12 W-Band waveguide slotted array antenna at 92 GHz was designed and simulated. The results show that the proposed slot array antenna has a reflection coefficient below –10 dB within 91.3 GHz to 93 GHz, and the peak directivity and gain are about 29.7 dBi and 28.8 dB, respectively, at 92 GHz.

A29: Emerging Antenna techonologies

T10 Fundamental Research and Emerging Technologies/ / Antennas

Chairs: Eduardo Carrasco (Universidad Politecnica de Madrid, Spain), Jose Luis Masa-Campos (Universidad Autonoma de Madrid, Spain)

16:40 ***Analysis of Resonant Bessel-Beam Launchers Based on Isotropic Metasurfaces***

Edoardo Negri (Sapienza - Università di Roma, Italy); Walter Fuscaldo (Consiglio Nazionale delle Ricerche (CNR), Italy); Mauro Ettorre (University of Rennes 1 & UMR CNRS 6164, France); Paolo Burghignoli and Alessandro Galli (Sapienza University of Rome, Italy)

Resonant Bessel-beam launchers are azimuthally invariant structures characterized by a circular grounded dielectric slab with an isotropic metasurface on top. Previous works analyzed the launchers performance for some specific cases, assuming TE or TM polarizations, inductive or capacitive metasurfaces, cavities with sub-wavelength or half-wavelength height. We show here with both theoretical and full-wave results that the inductive or capacitive nature of the metasurface has a fundamental role in the radiating behavior of these devices. Results are reported for the relevant TM-polarized case, considering air-filled, half-wavelength thick cavities. The extension of this analysis to the TE-polarized and dielectric-filled case will be discussed at the conference.

17:00 ***Exploring Half-Mode Groove Gap Waveguide Performance and Advantages***

Miguel Ferrando-Rocher (Universidad de Alicante & Universitat Politècnica de València, Spain); Alejandro Valero-Nogueira (Universidad Politécnica de Valencia, Spain); Jose I Herranz-Herruzo (Universitat Politècnica de València & APL - iTEAM, Spain)

In this communication, a half-mode waveguide based on Gap Waveguide technology for rapid prototyping is presented. A power divider is designed for demonstration purposes. The power divider is constructed from two non-contacting metal pieces. The horizontally-polarized power divider is housed in the bottom piece. The height of the groove is about half that which would be required to propagate the fundamental mode. The top cover is a uniform pinned surface that acts as a High Impedance Surface (HIS) over the groove of the bottom plate. The simulated reflection coefficient shows values of less than -15 dB in the bandwidth of interest (28 to 31 GHz). This design stands out for its ease of fabrication and opens a horizon for cheaper and more robust GW designs for mass production.

17:20 ***A Microfluidic Approach for Implementing Liquid Metal Based Reconfigurable Reflectarray Antennas***

Eduardo Carrasco (Universidad Politecnica de Madrid, Spain); Juan Gómez-Cruz (Queen's University, Canada); Carlos Saavedra (Queen's University, Spain); Carlos Escobedo (Queen's University, Canada)

The use of an eutectic alloy composed of gallium, indium and tin (known as Galinstan) is proposed to implement electronic reconfiguration at different levels in reflectarray elements. This material allows to change the shape of the elements of the array, with direct impact on the reflected phase, frequency of operation or polarization. These properties can be independently or simultaneously optimized though the reshaping of the conductive part of the element. This contribution is focused in demonstrating the viability of Galinstan as a reconfiguration element. The microfluidics-based technology is presented as a key actor in the implementation of these kind of antennas, offering a wide range of micro-devices as valves, mixers, pumps or lab-on-a-chip systems, inherited from years of study in other fields, such as chemistry, biology and medicine. The proposed method opens a promising avenue to reconfigurable reflectarray elements.

17:40 ***Printed Non-Metallic Textile-Based Carbon Antenna for Low-Cost Green Wearable Applications***

Mahmoud Wagih, Sheng Yong, Kai Yang, Alex S Weddell and Stephen Beeby (University of Southampton, United Kingdom (Great Britain))

Anticipated by 2035, a trillion wirelessly connected Internet of Everything (IoE) devices will be deployed. Therefore, sustainable and low-cost antennas are crucial for enabling an environmentally-friendly IoE. We present the first non-metallic carbon-based microstrip patch antenna implemented on textiles for wearable applications. The antenna is fabricated on a standard felt/woven-polyester fabric substrate using stencil casting and demonstrated for S-band applications. The antenna maintains a wide 10% fractional bandwidth from 3.16 to 3.49 GHz and achieves at least 30\% radiation efficiency, 10.4~dBi measured directivity, and 6.1 dBi measured gain. It is demonstrated that non-metallic carbon-based antennas are suitable for future wearable IoE applications.

18:00 ***Horn Filtering Antenna with Internal Full Metal 3-D Frequency Selective Surface for X-Band Space Applications***

Asrin Piroutiniya and Mohamad Hosein Rasekhmanesh (Universidad Autónoma de Madrid, Spain); Jose Luis Masa-Campos (Universidad Autonoma de Madrid, Spain); Juan Córcoles (Universidad Autónoma de Madrid, Spain); Jorge A Ruiz-Cruz (Universidad Autonoma de Madrid & Escuela Politecnica Superior, Spain); Pablo Sanchez-Olivares (Universidad Politecnica de Madrid, Spain); Carlos A. Leal-Sevillano (SENER Aeroespacial, Spain); Esteban Celemin (SENER Aerospace, Spain)

This work presents a novel concept of three-dimensional (3-D) full metal Frequency Selective Surfaces (FSS) that is located inside of a circularly polarized conical horn antenna to add frequency filtering properties without an external structure for X-band space applications. Two parallel thicken sheet patches are connected by a self-supported mesh at their centers. In the final step, the

designed 3-D FSS is located inside a conical horn antenna to analyze its filtering response, as well as the possible interference of the designed isolated FSS structure when it is located inside the internal profile. The simulated results of this idea prove its appropriated performance for X-band applications, with a 10% fractional bandwidth for a 20 dB minimum return loss value. The antenna directivity is higher than 15 dBi in a field view of ±8°, with axial ratio below 1.5 dB from 7 to 8 GHz.

Friday, April 1

Friday, April 1 9:00 - 10:40

P01: Propagation Modelling

T09 EM Modelling and Simulation tools/ / Propagation

9:00 ***A Huygens' Principle Based Ray Tracing Method for Diffraction Calculation***

Han Na (Technical University of Munich, Germany); Thomas F. Eibert (Technical University of Munich (TUM) & Chair of High-Frequency Engineering (HFT), Germany)

In conventional ray tracing methods, diffraction calculations for wedges are typically based on the uniform theory of diffraction (UTD). However, UTD is both inaccurate and computationally expensive in the calculation of multiple diffractions. In order to mitigate these shortcomings, a Huygens' principle based method is proposed as an alternative or extension to the conventional UTD. This method captures rays on properly chosen Huygens' surfaces and creates equivalent emitters for subsequent secondary ray launches based on the captured rays. Despite the extra effort of creating a Huygens' surface, compared with UTD, this method has considerably improved flexibility in handling complex geometrical shapes and it preserves the accuracy over multiple diffractions. Furthermore, by properly choosing the Huygens' surface and equivalent emitters, both computational complexity and accuracy can be controlled.

9:20 ***Site-Level Deterministic Channel Emulator: Grid-Based Architecture and Continuous Channel Emulation Technique***

Nopphon Keerativoranan and Jun-ichi Takada (Tokyo Institute of Technology, Japan)

Deterministic channel emulator applicable in both static and dynamic scenarios are essential for testing a performance of a large-scale wireless communication system, such as cyber-physical system, with high accuracy. Despite providing a better accuracy than a stochastic approach, deterministic channel simulation such as ray tracing (RT) is time-consuming especially in the dynamic scenario. Therefore, implementing such deterministic approach in the channel emulator is challenging due to hardware constraint and real-time computation requirement. In this paper, a grid-based architecture is proposed to realize the deterministic channel emulator. Here, RT is utilizing to only generate spatial channel parameters at specific grid nodes and stores in the emulator database. Time-variant channel of a moving mobile station is synthesized by interpolating parameters of the tapped delay line channel at neighbor grid nodes, which has been converted from the spatial ones. Basic building-block of the proposed architecture and challenges will be addressed in the paper.

9:40 ***A Statistical Assessment of Anthropomorphic Characteristics Impacts on WBAN Communications***

Badre Youssef (Télécom ParisTech-Institut Mines-Télécom & LTCI, France); Christophe Roblin (Telecom ParisTech & LTCI - Institut Mines-Télécom, France)

In Wireless Body Area Networks, the subject characteristics are among the main sources of the channel variability. The objective is to highlight statistically the influence of the anthropomorphic characteristics on the on-body channel. We have simulated five radio links on five homogeneous men subjects with different morphological characteristics. Experimental results obtained for some radio links have been used to support the relevance of the simulations. Within the framework of this first semi-quantitative approach, this communication is limited to the modeling of the Path Loss as a function of two quantitative morphological parameters that are the BMI and the Waist Circumference. The objective is to identify the main trends and to extract "semi-quantitative" models giving the orders of magnitude of the variability for each radio link. The latter typically ranges from 4 to 10.5 dB for the phantoms considered. The importance of the variability obtained justifies the interest of this analysis.

10:00 ***A Study on Physical Layer Security Through Ray Tracing Simulations***

Simone Del Prete, Franco Fuschini and Marina Barbiroli (University of Bologna, Italy); Marco Zoli (Barkhausen Institut gGmbH, Germany); Andre N Barreto (Barkhausen Institut gGmbH, Germany & Universidade de Brasilia, Brazil)

Due to its broadcast nature, the wireless channel cannot be really private, i.e. restricted to the intended users only. Rather, it can always be available also to some unauthorized outsider, and, thus, security in wireless communications is crucial. Protection of communications from possible eavesdroppers is usually achieved through standard cryptography schemes, which nonetheless may not

always represent the best solution due to their complexity and power consumption. Physical Layer Security, in particular Secret Key Generation, leverages the fading/dispersive properties of the wireless channel to distill encryption keys with limited computational effort. In this study, ray tracing propagation modeling is proposed as a tool to investigate the performance of the physical layer approach to communications security, thanks to its capabilities to model the channel statistics and the more flexibility compared to a measurement campaign.

10:20 ***Estimation of FSO Path Length at Mid-IR Wavelength***

Elizabeth Verdugo (PUC RIO, Brazil & Politecnico di Milano, Italy); Luiz da Silva Mello (CETUC-PUC-Rio & Inmetro, Brazil); Carlo Riva and Lorenzo Luini (Politecnico di Milano, Italy); Roberto Nebuloni (Ieiit - Cnr, Italy)

With the unprecedented data rates targeted by 5G+, the attention on Free-Space Optics (FSO) is reviving. FSO provides point-to-point wireless connectivity over large and unlicensed bandwidths. However, the severe channel attenuation due to fog limits the maximum path length of optical links when high-availability targets are required. Here, we quantify the effect of radiation fog on the optical channel at two wavelengths, namely 1.550 \(\mu\)m (near-IR), where most of commercial FSO system operate and 10.6 \(\mu\)m (mid-IR). The approach adopted here is based on the particle size distribution of fog, which is modelled by both mono-modal and multi-modal functions. if radiation fogs, typical of mid-latitude continental regions are considered, the ratio between the achievable path length at mid-IR and at near-IR ranges from 2 to 3, but it can be much higher due to the sensitivity of mid-IR radiation to the microphysics of fog.

A07: Sub-mmWave antennas for B5G & 6G

T02 Millimetre Wave 5G and 6G/ / Antennas

Chair: Francesco Foglia Manzillo (CEA-LETI, France)

9:00 ***High Gain and Fixed Broadside Radiation at 140GHz Band by a Leaky Wave Slotted Waveguide***

Seyed Ali Razavi (Graduate University of Advanced Technology, Kerman, Iran); Ashraf Uz Zaman (Chalmers University of Technology, Sweden)

In this paper a new topology for high gain antenna aperture with fixed broadside radiation is presented for 140GHz band. In the proposed structure, two symmetrical sets of leaky wave radiating slots are placed back to back on the broad wall of a metal parallel plate waveguide. A Corrugated surface is also applied in the feeding waveguide in order to deal with the grating lobe problem. The designed aperture provides proper fixed broadside radiation with 27.8-30.2dBi directivity over 142-148GHz frequency band. The aperture efficiency of more than 60% up to about 80% is also obtained over the most of desired band.

9:20 ***Dielectric Image Line Rod Antenna Array with Integrated Power Divider at W-Band***

Henning Tesmer (TU Darmstadt, Germany); Daniel Stumpf (Technical University of Darmstadt, Germany); Ersin Polat (Technische Universität Darmstadt, Germany); Dongwei Wang (Technical University of Darmstadt, Germany); Rolf Jakoby (Institute for Microwave Engineering and Photonics, Technische Universität Darmstadt, Germany)

This paper presents a dielectric image line antenna array at W-band. The array consists of four dielectric image line rod antennas, fed by an image line multimode-interference power divider, which divides power without the use of y-branches. The whole array, including the power divider, is machined from one piece of low permittivity Rexolite, which is mounted on a ground plane. Gain is up to 21 dBi and the bandwidth is 15 GHz, from 93 GHz to 108 GHz with a nearly frequency-independent pattern. The image line topology proves to be an attractive alternative to fully dielectric arrays, since integration with conventional circuitry and increased gain is possible.

9:40 ***Stub-Loaded Sub-Terahertz Wideband Antenna Design and Measurement***

Dongjin Jung (Samsung Electronics, Seoul, Korea (South)); Chan Ju Park, Jung Woo Seo, Taek Sun Kwon and Jun Gi Jung (Samsung Electronics, 34 Seongchon-gil, Seoul Korea, Korea (South)); Sang Hyuk Wi (Samsung Research, Samsung Electronics, Korea (South)); Ilju Na and Sunghyun Choi (Samsung Electronics, Korea (South))

This paper presents a wideband dual-fed/dual-polarized sub-terahertz (THz) array antenna design and D-band measurement system setup. The designed array is 4x1 linear array operating from 136 to 148 GHz. The array is fed by vertically constructed corporate feeding network, and it is fabricated through printed circuit board (PCB) using modified semi-additive process (mSAP). For wideband impedance matching of the antenna element, stub-loaded proximity coupled stacked patch antenna is introduced. By employing two or more open/short stubs on vertical via transition of the proximity coupled line, wideband input impedance matching is achieved, and these stubs can be easily integrated into the antenna element without increasing the element size. A customized probe station is also built to enable probing from the bottom side of the probe station. The maximum gain is measured as 9.1 dBi in the proposed D-band measurement system.

10:00 ***Synthesis and Characterization of a Focused-Beam Transmitarray Antenna at 300 GHz***

Francesco Foglia Manzillo (CEA-LETI, France); Orestis Koutsos (IETR & CEA Leti, France); Benjamin Fuchs (University of Rennes 1 - IETR, France); Ronan Sauleau (University of Rennes 1, France); Antonio Clemente (CEA-LETI Minatec, France)

This paper presents the synthesis, design and characterization of a centrosymmetric transmitarray antenna operating at 300 GHz. A broadside pencil beam with reduced sidelobe levels is obtained by fixing the illumination (i.e. feed and focal distance) and using a phase-only array synthesis procedure. The optimal aperture phase distribution is determined by means of an iterative convex optimization algorithm using semidefinite relaxation. Based on this distribution, a 400-element transmitarray comprising eight different unit cells is designed at 300 GHz, fabricated using low-cost printed circuit board technology and characterized. The measured results provide a first experimental validation of the synthesis approach.

10:20 ***Cavity-Backed Broadband Microstrip Antenna Array for Photonic Beam Steering at W Band***

Jérôme Taillieu (Université de Rennes 1, France); Ronan Sauleau (University of Rennes 1, France); Mehdi Alouini (Institut de Physique de Rennes - Université Rennes 1 - CNRS, France); David González-Ovejero (Centre National de la Recherche Scientifique - CNRS, France)

We present here the design of a broadband antenna array for photonic beam-steering at W-band. The array unit-cell consists of two stacked microstrip patches that are cavity backed, and fed by aperture-coupling using an hourglass slot. The unit-cell shows a simulated impedance bandwidth of 37% for SWR<2 from 77 GHz to 112 GHz, thus covering most of the W band. The feeding network is designed using a low-loss Substrate Integrated Waveguide (SIW) and respects nearly the same bandwidth as the unit cell for a total SWR<2. Therefore, the structure is well-suited for fabrication by PCB technology. The final array is composed of 4 sub-arrays of 2×8 unit cells and exhibits a broadside directivity of 26 dBi. Each sub-array is expected to be fed by a Uni-Traveling-Carrier (UTC) photodiode, which enables power combining to overcome the low emitted power at mm-waves and also the use of optical phase shifters in the antenna architecture to achieve a +/-5° beam steering with reasonable grating lobes.

CS43: Unconventional techniques and applications for Inverse scattering problems

T10 Fundamental Research and Emerging Technologies/ / Electromagnetics

Chair: Rosa Scapaticci (CNR-National Research Council of Italy, Italy)

9:00 ***On Breast Imaging from Joint Microwave and Acoustic Data Within a Bayesian Framework***

Yingying Qin and Thomas Rodet (Ecole Normale Supérieure Paris-Saclay, France); Dominique Lesselier (Laboratoire des Signaux et Systèmes CNRS-CentraleSupélec-Université Paris-Sud, France)

Breast cancer is most common, so early diagnosis of tumors is wished for. Microwave (MW) and ultrasound (US) are non-invasive, non-ionizing, low-cost, and can be run without registration for free pending breasts. MW is to yield high-contrast images of low resolution, the converse with US, with the benefit of the common breast structure. That is, fusion of MW and US data should produce images with both high contrast and high resolution. Here a Bayesian formalism is chosen to that effect (Variational Bayesian Approximation or VBA), edges as hidden variables, a number of hyperparameters involved as expected. Once the mathematics sketched, one insists on imaging of a MRI- derived breast model, a tumor added into it. Comparison with a joint edge-preserving contrast source inversion (JCSI-EP) in a deterministic framework will illustrate pros and cons of VBA.

9:20 ***Multistatic Electromagnetic Imaging of Dielectric Targets with LSTM Cells***

Alessandro Fedeli, Valentina Schenone, Matteo Pastorino and Andrea Randazzo (University of Genoa, Italy)

Electromagnetic imaging of dielectric targets at microwave frequencies needs dealing with an inverse problem, whose solution process is further complicated by the unavoidable presence of model error. In this work, the adoption of a neural network based on long short-term memory cells is introduced for the compensation of such an issue. In particular, multistatic measurement settings are considered here for the first time. The proposed network performs a preliminary processing of the scattered field, which is then passed to a multifrequency nonlinear inverse-scattering algorithm formulated in non-Hilbertian Lebesgue spaces with non-constant exponents. The approach is initially validated in a simulated environment.

9:40 ***A Simple Imaging Strategy for In-Line Food Inspection via Microwave Imaging***

Gennaro Bellizzi (University of Naples Federico II, Italy); Lorenzo Crocco (CNR - National Research Council of Italy, Italy); Marta Cavagnaro (Sapienza University of Rome, Italy); Marco Ricci, Jorge A. Tobon Vasquez and Francesca Vipiana (Politecnico di Torino, Italy)

Microwave imaging can represent an alternative for in-line inspection of food products, to reveal the presence of possible foreign bodies that may have contaminated the product during the transformation and/or packaging stages. To this end, a microwave system specifically meant for such purpose has been recently proposed. With respect to this device, a novel imaging strategy is presented, which allows one to build the image of the target without the need of a contaminant-free item used as reference sample. The idea is still to perform a differential imaging taking advantage of possible symmetries of the object under test with respect to the imaging system. These symmetries only occurred in a contaminant-free item, while are broken by the presence of an inclusion,

thus revealing their presence. A quite common case is that of food packaged in circular plastic/glass jars. A simple numerical example is provided showing the capabilities of the approach.

10:00 ***Learning-Assisted Electromagnetic Inversion for Imaging High Contrast Target***

Qian Zeming and Kuiwen Xu (Hangzhou Dianzi University, China); Yu Zhong (A*STAR IHPC, Singapore)

When dealing with high nonlinear ISPs those the scatterers with high contrast and/or electrically large size, the nonlinearity would be increased significantly. The traditional iterative nonlinear inversion modeled by the Lippmann-Schwinger integral equation maybe trapped into local wrong solution or converge slowly and take lots of computation time. To circumstance above the challenges, a learning-assisted inversion approach in virtue of a new recently established contraction integral equation for inversion (CIE-I) is proposed with low computational cost. The preliminary profiles with low-frequency components can be got efficiently by the Fourier bases expansion with CIE-I (FBE-CIE-I) inversion method with only a few low-frequency components. In addition, in order to further speed up the inversion process and realize real-time imaging, FBE-CIE-I is accordingly replaced by a neural network to get the preliminary profile. Numerical examples are used to validate the effectiveness of the proposed method.

10:20 ***Deep Learning Strategies for Quantitative Biomedical Microwave Imaging***

Maria Maddalena Autorino (Università di Napoli Parthenope, Italy); Stefano Franceschini and Michele Ambrosanio (University of Naples Parthenope, Italy); Fabio Baselice (Università degi Studi di Napoli Parthenope, Italy); Vito Pascazio (Università di Napoli Parthenope, Italy)

This paper proposes a numerical performance assessment of the recovery capabilities in the framework of microwave imaging via deep learning approaches. More in detail, aim of the analysis is the comparison among different convolutional neural network architectures in order to understand the impact of each parameter on the recovery performance for quantitative imaging. To support the analysis, some quality metrics were evaluated and a comparison with a conventional nonlinear approach is considered. The results seem promising, both in terms of computational time and recovery accuracy, especially in very noisy scenarios with a limited amount of data.

10:40 Coffee Break

11:10 ***A Simple Approach to Modifying the Contrast Basis in Contrast Source Inversion***

Lucas Banting (University of Manitoba, Canada); Kevin Brown and Mohammad Asefi (AGCO Corporation (Winnipeg), Canada); Ian Jeffrey (University of Manitoba, Canada); Colin Gilmore (University of Manitoba & 151 Research Inc, Canada); Joe LoVetri (University of Manitoba, Canada)

A per-iteration processing technique is applied to the Contrast Source Inversion algorithm to project a standard element-based contrast recovery step onto an alternative set of basis functions. For the grain storage monitoring application the alternative basis is advantageously chosen based on problem geometry to improve algorithm performance in resonant enclosures. Results for both synthetic and experimental grain storage problems demonstrate that the proposed basis projections significantly improve imaging results without requiring any major changes to the CSI gradient calculations.

11:30 ***Low-Frequency Data Learning for Solving Highly Nonlinear Inverse Scattering Problems***

Zhichao Lin, Rui Guo and Maokun Li (Tsinghua University, China); Aria Abubakar (Schlumberger-Doll Research, USA); Tao Zhao (Schlumberger, USA); Fan Yang and Shenheng Xu (Tsinghua University, China)

In this paper, we apply the low-frequency data learning scheme to solve highly nonlinear inverse scattering problems (ISPs). High nonlinearity of ISP will cause the optimization process to fall into false solutions. To alleviate the nonlinearity, we can lower the operating frequency to reduce the electric size of the targets. However, low-frequency data are usually unavailable. Therefore, we apply a neural network named U-net to learn the low-frequency (LF) data from measured high-frequency (HF) data. The learned LF data is then inverted as an initial model for HF data inversion, which provides a reliable estimate for the targets and thus helps HF data inversion find the right solution. Furthermore, the U-net is fine-tuned by the inverted model to learn a more precise mapping from HF data to LF data. The effectiveness of this scheme is verified by both synthetic and experimental data inversions.

11:50 ***A Microwave Imaging Device for Detecting Contaminants in Water-Based Food Products***

Marco Ricci (Politecnico di Torino, Italy); Lorenzo Crocco (CNR - National Research Council of Italy, Italy); Francesca Vipiana (Politecnico di Torino, Italy)

Food industries are paying increasing attention to new technologies for non-invasive assessment of products, in particular to detect low-density plastic, rubber, wood and glass, unlikely to be located by X-Rays. To this end, we propose a microwave-based device, exploiting the dielectric contrast between potential intrusions and the surrounding medium. This work aims to numerically assess this detection principle to water-based products that are, due to the medium losses, a challenging category at microwaves. An antennas array surrounds the object moving along the line, to monitor signal variations with respect to a reference. The working frequency is chosen by selecting a proper trade-off between penetration depth and image resolution. Then, a procedure, based on the application of the distorted-Born approximation is applied to reconstruct a 3-D image of the contaminant. Finally, the successful detection of a millimetric-sized plastic sphere is presented in the case of a commercial bottle filled with water.

12:10 ***A New Approach for Solving Inverse Scattering Problems Based on Physics-Informed Supervised Residual Learning***

Tao Shan and Zhichao Lin (Tsinghua University, China); Xiaoqian Song (National Institute of Metrology, China); Maokun Li, Fan Yang and Shenheng Xu (Tsinghua University, China)

In this paper, we propose a new approach for solving inverse scattering problems (ISPs) by applying the physics-informed supervised residual learning (PhiSRL) to embody the Born iterative method (BIM). Stemming from the mathematical link between the fixed point method and residual neural network (ResNet), PhiSRL fulfills the alternate iteration process of BIM by predicting the modifications of the candidate solutions regarding the calculated residuals. Thus, the proposed approach can perform the inversions of both data and models at the same time.The effectiveness of the proposed approach is further validated by the representative synthetic data.This paper provides new insights for designing the deep learning (DL) based methods with the knowledge of traditional computational electromagnetic (EM) algorithms.

CS15: Assessment and modeling of antennas and radio channels jointly with increasing complexity/variability

T10 Fundamental Research and Emerging Technologies/ / Antennas and Propagation

Chairs: Ke Guan (Beijing Jiaotong University, China), Alain Sibille (Telecom Paris, France)

9:00 ***Indoor Radio Channel Modeling at D-Band Frequencies***

Brecht De Beelde (Ghent University & IMEC, Belgium); Emmeric Tanghe, David Plets and Wout Joseph (Ghent University & IMEC, Ghent, Belgium)

This paper presents indoor radio channel measurements and models at D-band frequencies. A Line-of-Sight (LOS) alpha-beta-gamma path loss model is created based on indoor measurements up to 8.5 m in a laboratory and office room, resulting in a floating intercept α of 34.2 dB, PL exponent β 1.9 and frequency dependency γ 1.9. The penetration losses for wood, acrylic, polyvinyl chloride (PVC) and glass are measured, resulting in a respective loss of 8, 3.5, 3 and 12 dB/cm. Furthermore, attenuation due to desk objects obstructing the LOS path is found to range from 3 to 10 dB for one or more universal serial bus (USB) cables, and 8 to 13 dB for a computer keyboard and mouse. A laptop screen completely blocks the LOS path. Therefore, we measured the attenuation of the reflected path when the LOS path is blocked, and conclude that desk objects provide valid fallback paths.

9:20 ***Characterization of EMF Exposure in Massive MIMO Antenna Networks with Max-Min Fairness Power Control***

Maarouf Al Hajj (Orange Labs, France); Shanshan Wang (Chaire C2M, LTCI, Tel´ ecom Paris, Institut Polytechnique de Paris, France); Joe Wiart (Telecom ParisTech, France)

In this paper, we analyze the EMF exposure, in terms of total received power, in the massive multiple-input multiple-output (MIMO) networks. With the recent deployment of 5G networks, the potential risks of electromagnetic field (EMF) exposure are gaining increasing attention. However, most of the current research that focus on the mathematical modeling of 5G networks ignore downlink power control. Therefore, we derive the framework of the average power received at nearest mobile terminal MT\(_0\) under max-min fairness power control using stochastic geometry. The total received power consists of three parts, useful signal, multi-user interference and inter-cell interference. We propose a tight approximation on the power control coefficient. Based on the proposed approximation, the framework on total received power is then validated by Monte-Carlo simulations. The results show that the average received power monotonically increases as the density of the base station increases and the number of users increases.

9:40 ***Channel Characterization for 5G-R Indoor Communication at 2.1 GHz***

Ting Liu, Danping He and Ke Guan (Beijing Jiaotong University, China); Dongliang Liu (State Key Laboratory of Mobile Network and Mobile Multimedia Technology, China); Fusheng Zhu (GuangDong Communications & Networks Institute, China)

With the development of the smart railway, new services need to be supported by fifth-generation (5G) technology. Comparing to 5G technology, 5G-railway (5G-R) is more suitable for complex scenarios and strict requirements of rail transit, with the potential frequency band of 2.1 GHz. An indoor server room containing servers and train control systems is a common scenario in the railway system, and its channel characteristics are still to be studied. In this paper, radio wave propagation in a server room at 2.1 GHz is predicted using the ray-tracing method, and channel characteristics analysis is conducted through the information acquired from the channel model and rays. Electromagnetic parameters of material are calibrated based on the limited measurement to ensure the validity of the model. Different configurations of the 5G-R indoor scenario simulation can refer to this method, which greatly reduces the equipment, time, and human effort required for measurement.

10:00 ***Channel Characteristics Analysis of Ultra-High Mobility MIMO Wireless System in Tunnel Scenario***

Sirou Wang, Guoxin Zheng and Heng-Kai Zhao (Shanghai University, China)

The speed of train in a tunnel is closely related to tunnel size, and the size of tunnel has a great influence on the channel characteristics of wireless communication. Facing the demand of increasing

train speed, it is important to choose a reasonable tunnel radius. This paper studies the effect of arch tunnel radius on the performance of MIMO wireless system in 3.5GHz and 28GHz tunnel scenarios. The channel of train communication under ultra-high speed is simulated based on ray-tracing approach. By analyzing the Root Mean Square delay spread and Doppler spread of signals under different arch tunnel, it is found that the delay spread and Doppler spread increase with the tunnel radius increment. Besides, the larger the tunnel radius, the greater the difference of the Delay spread between different frequency bands. These findings will have prolific values for the applications of MIMO channel based mobile communications in underground tunnels.

A22: GNSS Antennas

T07 Positioning, Localisation and tracking/ / Antennas

Chair: Miguel Salas-Natera (Universidad Politécnica de Madrid, Spain)

9:00 ***Circularly-Polarized GNSS Metasurface Antenna with Two Feed Points in a Sub-Wavelength Metallic Cavity***

Laura García-Gámez and Loic Bernard (ISL & IETR, France); Ronan Sauleau and Sylvain Collardey (University of Rennes 1, France); Kouroch Mahdjoubi (Université de Rennes, France); Pouliguen Philippe (DGA, France); Patrick Potier ((DGA), France)

A metasurface-inspired antenna embedded in a metallic cavity is introduced here. It is expected to be integrated on fast moving platforms enduring harsh accelerations and shocks. The metasurface allows enlarging the antenna bandwidth that is intrinsically reduced for small antennas embedded in sub-wavelength metallic cavities. Circular polarization is achieved using two feed points connected the radiating aperture. The proposed antenna covers the E1, L1, B1 and G1 GNSS bands and exhibits a realized gain larger than 4.4 dBic, a half-power beamwidth of 112° and a cross-polarization level better than -20dB over almost the entire upper hemisphere. The numerical results are successfully validated by measurements.

9:20 ***Small Conformal Cavity-Backed Magnetoelectric Antenna for GNSS Bands***

Alexandre Causse (Université de Rennes 1, France); Loic Bernard (ISL & IETR, France); Sylvain Collardey (University of Rennes 1, France); Ala Sharaiha (Université de Rennes 1 & IETR, France)

In this paper a linearly polarized cylindrically conformal cavity-backed magnetoelectric (ME) antenna is presented. This antenna has a wideband behavior (S11 < -10 dB from 1.15 to 1.68 GHz) which covers all the GNSS bands and a small size of 75x75x40 mm3 (0.285x0.285x0.15 λ3 at lowest frequency). It also provides very steady radiation properties with gain of approximately 5 dBi and 3dB Beamwidth over 100° for all GNSS band and for both E and H planes of the antenna. A prototype was fabricated and a good agreement is found between measure and simulation.

9:40 ***A GNSS Conformal Antenna Achieving Hemispherical Coverage in L1/L5 Band***

Federico Boulos, Wahid Elmarissi and Stefano Caizzone (German Aerospace Center (DLR), Germany)

Global navigation satellite systems (GNSS) positioning accuracy is nowadays important in many applications. The GNSS ideal antenna should exhibit an hemispheric coverage, in order to be able to receive signals at similar power levels for all positive elevations: this is not really the case with single antennas, exhibiting good coverage of near-zenith directions and then worse performance close to horizon. A conformal antenna for L1/L5 GNSS band is here presented. The antenna is a combination of multiple radiating elements, positioned on a conformal surface, such as to improve the coverage at low elevation angles, i.e. close to horizon. Simulations, manufacturing and measurements are shown in the paper.

10:00 ***Dual-Polarized/Dual-Band Antenna with Compact Size for GNSS and 5G NR Applications***

N Nasimuddin and Michael Chia (Institute for Infocomm Research, Singapore)

A compact dual-band ring-slots with grounded-via integrated square-patch antenna is planned for circular/linear waves radiations. Four small unequal circular-ring-slots with grounded-via are integrated at the square patch corners for CP waves to reduce size of the antenna. These ring-slots with grounded-via offer compact antenna with CP radiation at the L-band. The antenna operates at the GNSS L1-band of 1.6 GHz with CP and 2.07 GHz with a LP for 5G New Radio applications. An integrated ring-slot with via acts as a CRLH structure, so that the four-ring-slots with via can miniaturize the antenna structure at 1.6 GHz. The confirmed outcomes of a prototype antenna with size of 0.32λo×0.32λo×0.0264λo are: the bandwidth of 5.6% (1.585GHz - 1.675GHz) at the L-band and 0.75% (2.04GHz-2.07GHz) at the S-band for 10dB return loss; 2.5% (1.59GHz-1.63GHz) at the L-band for 3dB axial ratio; peak gain of 4.9dBic at 1.62 GHz and 4.0dBi at 2.07 GHz.

10:20 ***Robustness Testing of a Compact Distributed Automotive GNSS Array in Virtual Environment***

Syed Naser Hasnain, Uwe Stehr and Ralf Stephan (Technische Universität Ilmenau, Germany); Marius Brachvogel (RWTH Aachen University, Germany); Michael Meurer (German Aerospace Center (DLR) & RWTH Aachen University, Germany); Matthias Hein (Ilmenau University of Technology, Germany)

To develop a compact distributed array for safe and robust automotive satellite navigation, considerable work on testing prototypes is in progress. Before scheduling resource-hungry outdoor tests, functionality and robustness of a Galileo-compatible compact distributed 4-element L-shaped array receiver has been tested against interference in a virtual environment at E5a frequency band.

Such an array consisting of compact quarter wavelength sub-arrays distributed over many wavelengths, fed with a decoupling network, mounted in side mirrors of a mock-up car was measured and evaluated with and without a jammer. The effects of automotive mounting location and robustness of the receiver against the jammer have been analyzed in terms of measured radiation patterns and achieved carrier-to-noise-density ratio of the received satellite signals.

M02: Satellite and aerospace antenna characterisation

T08 Space (incl. cubesat)/ / Measurements

Chair: Olav Breinbjerg (ElMaReCo, Denmark)

9:00 ***A Deep Space Ka-Band Antenna for CubeSat: Design and Multiphysics Analysis***

Marco Simone (Univerity of Cagliari, Italy); Matteo Lodi (University of Cagliari, Italy); Nicola Curreli (Italian Institute of Technology, Italy); Santi Concetto Pavone (Università degli Studi di Catania, Italy); Claudia Macciò, Elena Marongiu, Lorena Mariani, Giacomo Muntoni, Giuseppe Mazzarella and Alessandro Fanti (University of Cagliari, Italy)

This paper presents a stacked patch antenna optimized to operate over the down- and uplink Ka-band for Deep Space applications. The design of the antenna is performed with a numerical optimization, to control the bandwidth and the impedance matching. A bandwidth of 5.53@33.185 GHz has been obtained, with a gain around 8 dB. On this design, a multiphysics thermal and mechanical analysis is performed to verify the operational stability of the optimized antenna, mounted on a 1U CubeSat satellite. The analysis verified that the antenna temperature patterns can affect the antenna matching, but it still allows correct operation in the [-100•C,100•C] temperature range. Moreover, the stress analysis reports a level of mechanical deformation which does not compromise the use and functioning of the proposed stacked geometry in a Low Earth Orbit space mission.

9:20 ***Electromagnetic Characterization of Lunar Dust Simulants***

Jose Cidrás Estévez, David Ramos Somolinos, David Poyatos Martínez, Borja Plaza Gallardo and Narek Stepanyan Stepanyan (INTA, Spain); Aidan Cowley (ESA, European Union)

The development of devices for In-Situ Resource Utilization (ISRU) of the lunar surface powder (regolith) by means of microwaves needs regolith simulants with electromagnetic properties similar to the lunar regolith. Electromagnetic properties of EAC-1A and JSC-2A simulants had never been measured before. This document deals with the measurement of complex permittivity, complex permeability, and tangent loss of the aforementioned regolith simulants at ambient temperature from 400 MHz to 20 GHz. The obtained results will be applicable for comparing the measured values of EAC-1A and JSC-2A among them and with other previously measured simulants and real samples. The measurements were carried out applying two different non-resonant techniques. The DAK and EpsiMu kits were used to carry out the measurements according to the Open-Ended Coaxial Probe (OECP) and Transmission Line Methods.

9:40 ***An SU-8/Glass Meshed Patch Antenna for Integration with Solar Cells***

Shirin Ramezanzadehyazdi, Cyrus Shafai and Dustin Isleifson (University of Manitoba, Canada); Philip A Ferguson (University of Manitoba & NSERC / CSA / Magellan Aerospace Industrial Research Chair in Satellite Engineering, Canada); Lotfollah Shafai (University of Manitoba, Canada)

In this paper, a wideband SU-8-based stacked meshed patch antenna is designed for integration with solar cells in CubeSats. The bottom meshed patch antenna is placed on glass substrate Corning 7070, and a thick layer of SU-8 negative photoresist serves as the upper patch substrate. The proposed antenna achieves a balanced compromise between the weight, robustness, transparency, and performance. The antenna bandwidth is 4.3%, from 2.376 GHz to 2.483 GHz, and the maximum gain in the entire frequency range is 5.3 dBi.

10:00 ***Measurement of Low Frequency Antennas in Indoor Reflective Environments with the Synthetic Probe Array Technique***

Ruben Tena Sanchez (Microwave Vision Group (MVG), Italy); Francesco Saccardi and Andrea Giacomini (Microwave Vision Italy, Italy); Maria Alberica Saporetti (Italian Space Agency, Italy); Paul Moseley (European Space Agency, Switzerland); Lars Foged (Microwave Vision Italy, Italy)

Performance verification of low gain antennas on small space platforms are challenging at frequencies below 400MHz, also owing to limitations in the anechoic environment. Spherical near-field measurement techniques are often applied in such cases, enabling different echo-reduction schemes to compensate for the non-ideal test environment. Uncertainties due to chamber reflections are also reduced with a directive probe but electrically larger probes are impractical at very low frequencies because of the resulting physical dimensions. A virtual probe, synthesized from an array of smaller probes, with limited wall illumination has been developed to reduce this error. The concept has been developed for measurements in the ESA/ESTEC HERTZ testing facility of the HERA-JUVENTAS mission with a 50-70 MHz dipole antenna mounted on a CubeSat. In this paper, we present the concept, feasibility and verification by measurements on a 10:1 scaled representation of the CubeSat scenario and the HERTZ facility.

10:20 ***The 2019-2022 ESA-EurAAP Facility Comparison Campaign with the DTU-ESA mm-VAST Antenna - Mid-Term Status***

Olav Breinbjerg (ElMaReCo, Denmark); Jeppe Nielsen (Technical University of Denmark, Denmark); Thomas M Gemmer (RWTH Aachen University, Germany); Anna Granich (RWTH - Aachen University, Germany); Fernando Las-Heras (University of Oviedo, Spain); Marcos R. Pino (Universidad de Oviedo, Spain); Manuel Sierra-Castañer (Universidad Politécnica de Madrid, Spain); Xiaoliang Sun (Universidad Politécnica de Madrid, Spain & Universidad Politecnica de Madrid, Spain); Philippe Ratajczak (Orange Innovation, France); Laurent Le Coq (University of Rennes 1 & IETR, France); Roberto Vallauri and Andrea Vicentini (Telecom Italia, Italy); Herald Garcia (THALES ALENIA SPACE, France); Denys Allenic (Thales Alenia Space, France); Luis Rolo (European Space Agency, The Netherlands); Ines Barbary (ESA-ESTEC, The Netherlands); Maria Alberica Saporetti (Italian Space Agency, Italy); Ruben Tena Sanchez (Microwave Vision Group (MVG), Italy); Christian Hunscher (Airbus DS GmbH, Germany); Javier Herreros (EADS-CASA Espacio, Spain)

During 2019-2022, ESA and EurAAP are conducting an antenna measurement facility comparison campaign involving 12 European institutions with a total of 13 spherical near-field and compact range measurement facilities. The employed reference antenna is the DTU-ESA mm-VAST antenna in three operational configurations at 19.76 GHz, 37.80 GHz, and 48.16 GHz, respectively. This paper documents the campaign background and organization as well as the first part of its execution. The comparison results will be published separately; this paper includes measurement results from DTU.

E04: Optimization and machine learning in EM and antenna design

T09 EM Modelling and Simulation tools/ / Electromagnetics

Chairs: Manuel Arrebola (Universidad de Oviedo, Spain), Miloslav Capek (Czech Technical University in Prague, Czech Republic)

9:00 ***Bayesian Optimisation of a Frequency Selective Surface Using a Regularised Objective Function***

Kilian Bihannic (University of Rennes 1, INSA Rennes, CNRS, IRMAR & Thales DMS France, France); Jeremy Omer (University of Rennes 1, France); Renaud Loison (IETR & INSA, France); Guillaume Reille (Thales DMS France, France)

This work introduces a penalty-based regularisation to optimise the geometric parameters of a periodic frequency selective surface. A multi-layer bandpass filter with an equivalent circuit is used to illustrate the benefits of the approach for wide band applications. The proposed regularisation is obtained by convolving the frequency response and the desired thresholds before measuring the infraction. We apply bayesian optimisation on the unconstrained optimisation problem and assess the performance of the strategy by the number of objective function evaluations. A faster convergence and better robustness in the initial design of experiment is observed with the regularisation.

9:20 ***Convex Optimization of Reactively Loaded Antenna Arrays with Backlobe and Sidelobe Constraints***

Michel A Nyffenegger (OST Eastern Switzerland University of Applied Sciences Rapperswil, Switzerland); Costas D Sarris (University of Toronto, Canada); Hans-Dieter Lang (OST Eastern Switzerland University of Applied Sciences Rapperswil & ICOM Institute for Communication Systems, Switzerland)

A semidefinite relaxation-based optimization framework originally developed for wireless power transfer systems in the near-field is adapted to maximize the antenna gain of reactively loaded antenna arrays in the far-field while simultaneously limiting the backlobe and sidelobe levels. The method is applied to a five-element linear dipole array and is successfully verified by simulation and measurements. The presented framework can be used for other types of loaded antennas as well as for geometrical optimization of dipole arrays.

9:40 ***The Application of Machine Learning for Computational Electromagnetic Solver Selection***

Willem Frederik de la Bat, Danie Ludick and Trienko Grobler (Stellenbosch University, South Africa)

The field of Computational Electromagnetics (CEM) consists of several techniques used to solve the electromagnetic (EM) response of arbitrarily shaped conducting objects. Selecting the most efficient and accurate solver usually requires extensive user experience and depends on the geometry and setup of the problem. This work aims to simplify this process by using machine learning models to predict whether a given solver would be sufficiently accurate before simulation. The hybrid Method of Moments and Physical Optics technique (MoM-PO) is considered in this investigation. It is found that predicting the accuracy of the MoM-PO when calculating the far field, near field and surface currents is in fact possible with F1-scores of 98.23, 97.61 and 92.26, respectively. Classification models such as Logistic Regression, Decision Trees and Artificial Neural Networks are considered.

10:00 ***Shape Regularization and Acceleration of Topology Optimization via Point Group Symmetries***

Miloslav Capek, Vojtech Neuman, Jonas Tucek and Lukas Jelinek (Czech Technical University in Prague, Czech Republic)

The existent technique for shape optimization based on exact reanalysis of method-of-moments models is extended by symmetry operators. Their application is twofold: to prescribe a given

symmetry and accelerate the optimization by reducing the number of unknowns, or to penalize unsymmetrical shapes, constraining thus the regularity and simplifying potential manufacturing.

10:20 ***An Encoder-Only Transformer to Generate Power Patterns from Far-Field Performance Criteria***

Chen Niu, Max Kelly and Puyan Mojabi (University of Manitoba, Canada)

This paper proposes a method for generation of Maxwellian far-field power patterns, to be used as input for a variety of electromagnetic inversion algorithms. Typically inversion source and scattering algorithms require a desired power pattern to reconstruct equivalent currents and/or material properties, but it is more common for the designer to provide only far-field pattern specifications such as beam directions, null directions, or half-power beamwidth. By using a method that represents an aperture antenna with a grid of infinitesimal dipoles, a set of training data is created consisting of current distributions (with varying phase and amplitude) and their corresponding power patterns as well as power pattern specifications. An encoder-only transformer neural-network model is then trained to recreate the full power pattern given only the specifications.

CS14: Artificial Intelligence for Antennas and Propagation: Current Trends and Emerging Applications

T10 Fundamental Research and Emerging Technologies/ / Antennas and Propagation

Chairs: Sotirios Goudos (Aristotle University of Thessaloniki, Greece), Maokun Li (Tsinghua University, China), Marco Salucci (ELEDIA Research Center, Italy)

9:00 ***Intelligent Design of Metamaterials via Machine Learning Techniques***

Che Liu and Tie Jun Cui (Southeast University, China)

Digital coding representation of metamaterials makes it possible to realize intelligent designs of metamaterials using machine learning algorithms. Recently, there have been some works that have successfully designed the S-parameters of coding metamaterials with the machine learning techniques. However, wide-band reflection phases are much more difficult to design because of the periodicity of phase representation. Here, a machine learning method is proposed to automatically design anisotropic digital coding metamaterials with desired wide-band reflection phase responses (8-12GHz) under both TE and TM polarizations. Meanwhile, a deep learning method is presented to predict the phase curves in real time, in which the phase curves are creatively represented by their sine and cosine curves. A binary-particle-swarm optimization method is then introduced, cooperating with the deep learning prediction module to design the coding metamaterials in seconds, and the testing results show a state-of-art fitness of anisotropic wide-band phase responses.

9:20 ***Recent Advances in Artificial Neural Networks for EM Parameterized Modeling and Optimization***

Li Ma (Tianjin University, China); Jianan Zhang (Southeast University, China); Shuxia Yan (Tianjin Polytechnic University, China); Qijun Zhang (Carleton University, Canada)

This paper reviews the recent advances in artificial neural networks (ANN) for electromagnetic (EM) parameterized modeling and optimization. As an advanced ANN-based EM parameterized modeling and optimization technique, the neuro-transfer function (neuro-TF) is discussed further in this paper. The trained neuro-TF parameterized models can be further used for EM design optimization with repetitive geometrical variations.

9:40 ***Simulation-Based Machine Learning Training for Brain Anomalies Localization at Microwaves***

Valeria Mariano, Mario Roberto Casu and Francesca Vipiana (Politecnico di Torino, Italy)

Machine learning enters the world of medical application and, in this paper, it joins microwave imaging technique for brain stroke classification. One of the main challenges in this application is the need of a large amount of data for the machine learning algorithm training that can be performed via measurements or simulations. In this work, we propose to make the algorithm training via simulations based on a linear integral operator that reduces by three orders of magnitude the data generation time with respect to standard full-wave simulations. This method is used here to train the multilayer perceptron algorithm. The data-set is organized in nine classes, related to the presence, the type and the position of the stroke within the brain. We verified that the algorithm metrics (accuracy, recall and precision) reach values close to 1 for each class.

10:00 ***Accelerating Electromagnetic Inverse-Design Using Deep Learning***

Ronald P Jenkins and Sawyer D Campbell (The Pennsylvania State University, USA); Pingjuan Werner and Douglas H Werner (Pennsylvania State University, USA)

One of the primary ways that deep learning has been applied to electromagnetics in recent years is for accelerating inverse design. We present one such method for designing metasurface supercells which are robust to structural erosion and dilation, a typical variety of nanofabrication error. A pair of deep neural networks are trained to high accuracy to predict diffraction efficiencies from a supercell mask, and then evaluated exhaustively to find tolerance bounds for freeform supercell designs.

10:20 ***Programmable Metasurface Intelligent Beamforming***

Shangyang Li, Zhuoyang Liu, Yan Wang and Feng Xu (Fudan University, China)

This paper proposes an intelligent beamforming architecture to predict the mapping relationship between codes and three-dimensional patterns. First, the two-dimensional intelligent beamforming (IB) framework is proposed. Then, the one-dimensional intelligent beamforming to realize the fast calculation of P-C and C-P is presented. The IB includes: 1) Substrate integrate waveguide programmable metasurface and automatic measuring systems design, 2) fast prediction from codes to patterns, 3) real-time prediction from patterns to codes, and intelligent beamforming architecture. Finally, the proposed IB is validated by the measured results.

10:40 Coffee Break

11:10 ***A Deep Learning Architecture for Augmented Shape Reconstruction via Microwave Imaging***

Álvaro Yago Ruiz (CNR, National Research Council, Italy); Marija Nikolic Stevanovic (School of Eletrical Engineering, University of Belgrade, Serbia); Marta Cavagnaro (Sapienza University of Rome, Italy); Lorenzo Crocco (CNR - National Research Council of Italy, Italy)

In this paper, an innovative microwave imaging approach that combines deep learning techniques and qualitative inversion methods is presented. In particular, the proposed approach is meant for imaging piece-wise homogeneous targets and aims at providing an augmented morphological reconstruction, which not only retrieves the shape of the targets, but also the spatial variations of the permittivity values. Such an information is not displayed by qualitative inversion methods; however it is efficiently encoded in the gradient of the unknown contrast. In particular in this paper, a physics-assisted deep learning technique, where domain knowledge is given in the inputs of a U-Net architecture, is developed. The domain knowledge is provided by the qualitative image of the unknown targets obtained using the orthogonality sampling method, thus allowing the architecture to provide, once trained, a fully automated and real-time prediction. An initial assessment for the approach with synthetic data is provided.

11:30 ***AI-Assisted Global Optimization for Solving Inverse Scattering Problems***

Marco Salucci (ELEDIA Research Center, Italy); Lorenzo Poli (ELEDIA Research Center, University of Trento, Italy); Paolo Rocca (University of Trento & ELEDIA Research Center, Italy)

The solution of inverse scattering (IS) problems supported by artificial intelligence (AI) is addressed. An innovative solution strategy based on the System-by-Design (SbD) paradigm is proposed for the computationally-efficient exploitation of a global optimization strategy for minimizing the data mismatch cost function. Towards this end, a suitable selection, customization, and interconnection of SbD functional blocks is adopted. Moreover, the computationally-unaffordable repeated evaluation of each trial solution during the optimization is bypassed thanks to the exploitation of a digital twin (DT) based on the learning-by-examples (LBE) paradigm. An illustrative numerical example is shown to prove the effectiveness and computational efficiency of the proposed solution strategy when dealing with 2D free-space microwave imaging (MI) scenarios.

11:50 ***Ensemble Learning for 5G Flying Base Station Path Loss Modelling***

Sotirios Sotiroudis (Aristotle University of Thessaloniki, Greece); Georgia E. Athanasiadou and George Tsoulos (University of Peloponnese, Greece); Sotirios Goudos (Aristotle University of Thessaloniki, Greece); Christos Christodoulou (The University of New Mexico, USA)

The usage of unmanned aerial vehicles (UAVs) as flying base stations (FBSs) for expanding coverage and assisting the terrestrial cellular networks constitutes a promising technology for 5G and beyond. The wide range of a flying base station's movement may stretch the boundaries of path loss at the receiver's site and induce the occurrence of extreme values. Thus, using machine learning techniques may help in accurate path loss modeling for this case. In this paper, we use a combination of the techniques of ensemble learning and oversampling to provide a satisfactory path loss model for FBSs.

12:10 ***Evolved Multiobjective Low Side-Lobe Taper for Beam Steerable Arrays***

Sudipta Das (National Institute of Technology Sikkim); Ritu Rimjhim (National Institute of Technology Sikkim, India); Durbadal Mandal and Rajib Kar (National Institute of Technology, Durgapur, India)

Antennas and arrays are indispensable elements of wireless communication systems. The directional characteristics is one of the most attractive features of antenna arrays. This article takes up a case of array pattern synthesis, and adopts two contemporary and highly competitive Evolutionary Algorithms, named Nondominated Sorting Genetic Algorithm III (NSGA III), and Double Niched Evolution Strategy for solving Multimodal Multiobjective Problems (DN-MMOES). The results show the effectiveness of Evolutionary Algorithms for such problems.

12:30 ***A Hybrid Machine Learning-Based Model for Indoor Propagation***

Aristeidis Seretis and Costas D Sarris (University of Toronto, Canada)

A common limitation among many applications involving machine learning techniques is the availability of training data. In propagation modeling scenarios, measurement campaigns are usually

undertaken for network planning decisions. However, this can be a challenging task, especially in electrically large environments. In these cases, simulation data generated by physics-based methods, such as ray tracing, can replace or augment the measured data. This paper provides a case study in a typical office environment, where both measured and simulated data are used to separately train two machine learning models. A hybrid model combines the predictions of these two models, to predict the signal levels at any location in the environment. In cases where the volume of measured data is insufficient, the hybrid model is shown to improve the accuracy of the overall predictions. It is also shown that a small number of measurements can improve the accuracy of a solver-trained model.

CS18: COST CA18223 (SyMat): Applications of artificial materials with higher symmetries

T10 Fundamental Research and Emerging Technologies/ / Electromagnetics

Chairs: Marko Bosiljevac (University of Zagreb, Croatia), Enrica Martini (University of Siena, Italy)

9:00 ***Wideband Flat Lenses Based on Artificial Dielectric Layers***

Caspar M Coco Martin and Daniele Cavallo (Delft University of Technology, The Netherlands)

The aim of this work is to provide guidelines on the design of wideband flat lenses composed of artificial dielectric layers (ADLs). Planar lenses based on metasurfaces or resonant elements are typically narrowband, due to the phase wrapping over the period of 360 degrees that is strongly frequency dependent. On the contrary, true-time-delay (TTD) planar lenses can achieve large bandwidths. One convenient way to design wideband TTD lenses is by means of ADLs, which are periodic arrangements of sub-wavelength patches embedded in a host medium to increase its effective permittivity. Tradeoffs including bandwidth, focal ratio, lens diameter and thickness are discussed and related to the manufacturing constraints of artificial dielectrics, such as number of metal layers and smallest features realizable in printed circuit board technology. An example of design is also presented, for 70-140 GHz operation, with a lens diameter of 11 wavelengths at the highest frequency.

9:20 ***Application of Glide Symmetry to Ridged Waveguides***

Angel Palomares-Caballero (Universidad de Granada, Spain); Carlos Megías and Carlos Molero (University of Granada, Spain); Antonio Alex-Amor (Universidad CEU San Pablo, Spain); Pablo Padilla (University of Granada, Spain)

In this paper, single and double ridged waveguides with glide symmetry are analyzed. By the inclusion of holes with semi-circle base in the ridge of the waveguides, the phase constant of the ridged waveguide can be effectively tuned. The value of the holes radii provides a fine modification of the slope allowing to set the desired phase difference in ridged waveguides. In addition, the separation between consecutive holes has been studied showing that when the glide symmetry is not preserved in the unit cell, a stopband appears in the dispersion diagram. The mirror-symmetric configuration of the holes provides the stopband with the largest bandwidth for both single and double ridged waveguides.

9:40 ***Reconfigurable Phase-Shifter Based on Glide-Symmetric Substrate-Integrated Holes and High-Impedance Metasurfaces***

Boris Fischer, Julien Sarrazin and Guido Valerio (Sorbonne Université, France)

To fulfill the need for low-loss, low-cost devices with continuously reconfigurable phase at millimeter-waves, a glide-symmetric substrate-integrated phase-shifter design is presented. It exploits both the contactless guiding properties of high-impedance metasurfaces, and the high refractive index variation of glide-symmetric waveguides. Mechanically moving the substrate-integrated layers yields a continuous phase change due to the effective refractive index variation. Glide symmetry reaches a larger index variation, reducing the length of the phase-shifter.

10:00 ***Parity-Time Glide-Symmetry and Third Order Exceptional Degeneracy in a Three-Way Microstrip Waveguide***

Alireza Nikzamir and Robert Marosi (University of California Irvine, USA); Tarek Mealy, Farshad Yazdi and Filippo Capolino (University of California, Irvine, USA)

A microstrip-technology three-way waveguide has been conceived to exhibit exceptional modal degeneracy in the presence of periodic gain and radiation losses. A third order exceptional point of degeneracy (EPD) is obtained in the dispersion relation of a periodic structure consisting of three coupled microstrip waveguides satisfying parity-time (PT) glide-symmetry. A third order EPD exists when three Floquet-Bloch eigenmodes of a periodic structure coalesce at a single frequency, in eigenvalue and polarization state. PT-glide-symmetry is achieved in the proposed structure using periodically spaced lumped (radiation) loss and gain elements. Such a degeneracy can be utilized in the design of devices such as radiating arrays with distributed amplifiers, arrays of oscillators, and sensors.

10:20 ***Planar Glide-Symmetric Dielectric Half-Luneburg Lens at K/Ka-Band***

Oskar Zetterstrom and Pilar Castillo-Tapia (KTH Royal Institute of Technology, Sweden); Jose-Manuel Poyanco (University Carlos III of Madrid, Spain); Nelson Fonseca (European Space Agency, The Netherlands); Francisco Pizarro (Pontificia Universidad Catolica de Valparaiso, Chile); Oscar Quevedo-Teruel (KTH Royal

Institute of Technology, Sweden)

In this work, we design a planar half-Luneburg lens antenna. The gradient of refractive index is realized using a dielectric slab periodically loaded with air-cavities of varying size. The cavities are glide-symmetrically arranged. It is demonstrated that by introducing glide symmetry, the bandwidth and range of realizable refractive indices are increased compared to a non-glide-symmetric structure. The lens antenna operates from 22 to 32 GHz and can scan its directive beam over a 50 degree range in the H-plane. The side lobe level in this scan range is lower than -10 dB throughout the band. The lens can be produced using additive manufacturing.

10:40 Coffee Break

11:10 ***Higher-Symmetries for Broadband Reflecting Luneburg Lenses at Ka-Band***

Christos Bilitos (University of Rennes 1, France); Jorge Ruiz-García (Université de Rennes, France); Ronan Sauleau (University of Rennes 1, France); Enrica Martini and Stefano Maci (University of Siena, Italy); David González-Ovejero (Centre National de la Recherche Scientifique - CNRS, France)

This paper reports the application of higher symmetries to the design of a Reflecting Luneburg Lens (RLL) with broadband response. RLLs consist of two circular parallel plate waveguides (PPWs) vertically stacked. The bottom PPW is filled with an azimuthally symmetric graded index (GRIN) medium. Owing to this GRIN medium, the wave launched by a primary feed in the bottom PPW is collimated in the top one, so that a plane wave with a different propagation direction is generated for any azimuthal position of the source. In this work, the GRIN medium in the bottom PPW is implemented by higher symmetry unit-cells consisting of metallic inclusions. This type of unit-cell achieves the required equivalent refractive index profile with reduced frequency dispersion, thus increasing the operational bandwidth of the lens. The proposed architecture constitutes a low-profile beam-forming solution that also provides complete azimuthal scanning in a wide frequency range.

11:30 ***Active Topological Metamaterials with Robust Oscillation Modes***

Dimitrios Sounas (Wayne State University, USA)

A new type of microwave oscillator arrays based on topological metamaterials is presented. The arrays are built upon a new form of microwave topological insulators consisting of a dual lattice of transmission lines. The proposed structures support extended oscillation modes with remarkable stability against discontinuities and disorder, and arbitrary phase profiles. A comparison with oscillator arrays based on conventional transmission lines is presented, demonstrating a clear superiority for the topological ones. The presented structures create a new direction in the design of microwave oscillator arrays over large areas for applications in phased antenna arrays and time-modulated nonreciprocal devices.

11:50 ***Spatially-Discrete Traveling-Wave Modulation: A Higher-Order Space-Time Symmetry***

Cody Scarborough (University of Michigan, USA); Anthony Grbic (University of Michigan, Ann Arbor, USA)

Spatially-discrete traveling-wave modulation (SDTWM) is a form of space-time modulation, in which staggered time-modulated signals are applied to a discrete array of unit cells, referred to as stixels: space-time pixels. SDTWM has been shown to support electromagnetic functionalities like amplification, frequency conversion, beam steering and nonreciprocity. Modeling SDTWM using standard techniques and commercial solvers is complicated by the fact that a single spatial period may include a large number of time-varying stixels. In this paper, a boundary condition, known as the interpath relation is shown to dramatically simplify the analysis of SDTWM structures. The interpath relation arises from the higher-order space-time symmetry inherent to SDTWM. By invoking this symmetry, the field solution throughout space can be determined from the field solution in a single stixel. The application of the interpath relation for computing the dispersion and scattering response of two representative SDTWM structures is reported.

12:10 ***PTD Symmetric Wideband Absorbers***

Kristy Hecht and Mario Junior Mencagli (University of North Carolina at Charlotte, USA)

Absorbers play a pivotal role in protecting sensitive electronic devices from unwanted signals. In this work, we present new types of absorbers based on structures that are invariant under the Parity Time-reversal Duality (PTD) transformation. Such structures produce zero backscattering under the illumination of a plane wave at normal incidence. This reflectionless feature is exploited to design wideband absorbers. Numerical results of the proposed absorbers are also discussed.

SW02: AMTA Scientific Workshop: Expanding the Limits - Antenna Metrology Using UAVs

Scientific Workshop

Friday, April 1 10:40 - 11:00

Coffee Break / Exhibition

Friday, April 1 11:00 - 12:40

P02: Machine learning for propagation

T09 EM Modelling and Simulation tools/ / Propagation

Chairs: Alejandro Ramírez-Arroyo (University of Granada, Spain), Alain Sibille (Telecom Paris, France)

11:00 ***DeepRay: Deep Learning Meets Ray-Tracing***

Stefanos Sotirios Bakirtzis and Kehai Qiu (University of Cambridge, United Kingdom (Great Britain)); Jie Zhang (University of Sheffield, Dept. of Electronic and Electrical Engineering, United Kingdom (Great Britain)); Ian James Wassell (University of Cambridge, United Kingdom (Great Britain))

Efficient and accurate indoor radio propagation modeling tools are essential for the design and operation of wireless communication systems. Lately, several attempts to combine radio propagation solvers with machine learning (ML) have been made. In this paper, motivated by the recent advances in the area of computer vision, we present a new ML propagation model using convolutional encoder-decoders. Specifically, we couple a ray-tracing simulator with either a U-Net or an SDU-Net, showing that the use of atrous convolutions utilized in SDU-Net can enhance significantly the performance of an ML propagation model. The proposed data-driven framework, called DeepRay, can be trained to predict the received signal strength in a given indoor environment. More importantly, once trained over multiple input geometries, DeepRay can be employed to directly predict the signal level for unknown indoor environments. We demonstrate this approach in various indoor environments using long range (LoRa) devices operating at 868 MHz.

11:20 ***RNN Based Prediction of Path Loss Fading Distribution by Interval Estimation***

Motoharu Sasaki and Nobuaki Kuno (NTT, Japan); Toshiro Nakahira (NTT Access Network Service Systems Laboratories, Japan); Minoru Inomata, Wataru Yamada and Takatsune Moriyama (NTT, Japan)

We report a method for predicting fading distribution of path loss using GRU, which is a RNN as deep learning. The training data and validation data use path loss measured in Yokosuka City, Kanagawa Prefecture, Japan, and the measurement frequency is 4.7 GHz. By using 100 points of fast fading data about every 0.1 seconds, the median data of path loss and the K factor of Nakagami-Rice distribution after 1 second were predicted. The median data and the K factor are derived using the fast fading data of 100 points (about 10 seconds). According to the prediction method using GRU, the RMSE for the validation data is about 1.7 dB for the median path loss and about 0.5 dB for the K factor. The prediction accuracy was improved by 0.9 and 0.1 dB compared with the case of using latest observed values.

11:40 ***Geographical Clustering of Path Loss Modeling for Wireless Emulation in Various Environments***

Tatsuya Nagao and Takahiro Hayashi (KDDI Research, Inc., Japan)

A testbed that emulates wireless communication in a virtual space is needed to efficiently validate a new wireless communication system in large-scale and various environments. For realistic wireless emulation, it is necessary to simulate the radio propagation characteristics site-specifically and accurately. Some modeling methods based on machine learning using map data have been proposed. However, using a single modeling approach in various propagation environments may result in lower accuracy. Also, single modeling in the extensive area has issues of computational cost and model-tuning efficiency. This paper proposes a method for clustering map data and modeling for each cluster using machine learning. This method optimizes the modeling area corresponding to the geographical features and improves accuracy and computational efficiency. The evaluation results using measurement data showed that the proposed method improved the accuracy and increased the speed by approximately 30%.

12:00 ***Applying Machine Learning Techniques to Compute Vertical Refractivity Profiles in Maritime Environments***

Jacques Claverie (CREC St-Cyr & IETR, France); Jean Motsch (IETR / Saint-Cyr, France)

Within the Marine Surface Boundary Layer, evaporation ducting greatly affects the radar performances. The vertical refractivity profiles are classically computed by bulk models and these profiles can be fitted, with a very good accuracy, by analytical expressions involving four parameters to be determined. With machine learning techniques and particularly a decision tree regressor, we directly obtained these parameters from the physical bulk inputs. The resulting refractivity profiles are generally very closed to the original ones and in terms of propagation results we obtained mean errors around 1 dB by computing the propagation factor for classical radar scenarios.

12:20 ***A NLOS Detection Method Based on Kernel Principal Component Analysis***

Tiantian Chang and Wei Wang (Chang'an University, China)

Radio signals propagating indoors will produce positive bias due to non-line-of-sight (NLOS) conditions, which seriously affects the accuracy of positioning. In order to distinguish between line-of-sight (LOS) and NLOS conditions, we combined the kernel principal component analysis method (KPCA), genetic algorithm (GA) and support vector machine (SVM) classification algorithm to propose a NLOS detection method based on KPCA-GA-SVM. A channel measurement campaign at frequency band from 2.4 GHz to 5.4 GHz was carried out in an indoor environment, and the proposed algorithm was evaluated through the measurement data. The results show that the KPCA-GA-SVM algorithm has a high accuracy for LOS and NLOS detection, and eliminates the correlation between different features, thus shortening the running speed of the algorithm.

A08: Lenses above 100 GHz

T02 Millimetre Wave 5G and 6G/ / Antennas

Chairs: Nelson Fonseca (European Space Agency, The Netherlands), Nuria LLombart (Delft University of Technology, The Netherlands)

11:00 ***On the Demonstration of Dynamic Beam-Steering with a Scanning Lens Phased Array at W-Band***

Sjoerd Bosma, Nick van Rooijen, Maria Alonso-delPino, Marco Spirito and Nuria LLombart (Delft University of Technology, The Netherlands)

We report on progress towards a sparse 4x1 scanning lens phased array at W-band (75-110 GHz) capable of beam steering a directive (>30 dBi) beam towards 15deg with sidelobe levels below -10dB. The lens array relies on a combination of mechanical and electrical phase-shifting to steer the beams. These concepts have been demonstrated separately, but we are working towards the first demonstration of the concept with mechanical and electrical phase shifting. The lens feed achieves high aperture efficiency illumination of the lenses by suppressing the spurious TM0-mode over a wide bandwidth with annular corrugations in a groundplane. We have fabricated a 4x1 W-band array prototype. Preliminary measurements of a single lens are in good agreement with simulations. We present preliminary measurements from a W-band electrical phase-shifting setup using low-frequency IQ-mixers that will allow 20deg scanning of the array. More measurement results from the array will be presented at the conference.

11:20 ***Core-Shell Leaky-Wave Lens Antenna for 150GHz Fly's Eye Communication Systems***

Nick van Rooijen, Maria Alonso-delPino, Marco Spirito and Nuria LLombart (Delft University of Technology, The Netherlands)

This work introduces a new core-shell lens antenna based on low-cost plastic materials and a leaky-wave in-packaged antenna at 150GHz. The lens antenna is made of an electrically small core lens made of a dense material to enhance the radiation from the in-packaged antenna, plus an electrically large shell lens made of a low loss dielectric material. The proposed lens antenna presents good quality patterns with aperture efficiencies above 80% over a bandwidth of 20%. A single layer feeding network using a coplanar waveguide line for connection to a 150GHz chipset is also discussed. Good impedance matching is achieved over a bandwidth of 25%.

11:40 ***Design Aspects of 3D Printing for Gradient Index Lenses***

Dmitry E Zelenchuk (Queen's University of Belfast, United Kingdom (Great Britain)); Irina Munina (St. Petesburg Electrotechnical University LETI, Russia); Igor Grigoriev (St. Petersburg Electrotechnical University LETI, Russia)

Various aspects of implementing a gradient refractive index distribution using 3D printing are considered. These approaches are applied to two types of lens design: cylindrical Luneburg lens and thick flat lens. Based on simulated and measured results the main constraints for the lens design using additive manufacturing are defined.

12:00 ***Stacked Geodesic Lenses for Radar Applications in the W-Band***

Germán León (Universidad de Oviedo, Spain); Omar Orgeira (KTH Royal Institute of Technology, Spain); Nelson Fonseca (European Space Agency, The Netherlands); Oscar Quevedo-Teruel (KTH Royal Institute of Technology, Sweden)

New radar architectures employ multiple transmitters and receivers to enhance their performance, combining wide and narrow beams to improve the spatial resolution. In this contribution, two antenna system configurations based on stacked geodesic lenses are compared. These lenses are fully-metallic parallel plate waveguides that present very low transmission losses in the millimetre-wave band. Narrow beams are generated by a 15-port Luneburg-Rinehart lens with a scanning span of 100º and 23.4 dB gain at 77 GHz. For wide beams, two alternatives are proposed. One alternative is a 3-port defocused lens antenna with a scanning angle of 100º and 14.5 dBi gain. The second proposal is a 12-port Luneburg-Rinehart lens fed with 1-to-4 power dividers forming a 3-port antenna with a scanning span of 91 and 16.2 dBi gain.

12:20 ***Transmit Lens Arrays for Broadband THz Power Distribution and Beam Steering***

Maria Alonso-delPino and Sjoerd Bosma (Delft University of Technology, The Netherlands); Cecile Jung-Kubiak (NASA-JPL, Caltech, USA); Juan Bueno (Delft

University of Technology, The Netherlands); Goutam Chattopadhyay (NASA-JPL/Caltech, USA); Nuria LLombart (Delft University of Technology, The Netherlands)

This paper presents a novel quasi-optical power distribution technique based on a transmit lens array that allows achieving an efficient multi-pixel LO power distribution for submillimeter-wave instruments. This method can distribute the power from one antenna to a multi-pixel lens array in a hexagonal configuration with a power coupling efficiency of nearly 60%. To maximize this coupling, we synthesize a top-hat radiation pattern using multi-mode leaky-wave feeds that feed silicon elliptical lenses. Moreover, the proposed transmit array architecture could be operated in a coherent mode for applications requiring beam steering of highly directive beams. We will present a prototype based on a transmit array of 7 pixels at 450-650 GHz with preliminary measurements showing a good agreement with simulations.

CS21: Enhanced Capabilities of Characteristic Mode Analysis for Novel Applications

T09 EM Modelling and Simulation tools/ / Electromagnetics

11:00 ***Characteristic Modes Analysis for the Design of a Wideband Circularly Polarized X-Band Antenna***

Simone Genovesi (University of Pisa, Italy); Francesco Alessio Dicandia (Università di Pisa, Italy)

Characteristic Mode Analysis (CMA) is exploited for the design of a metasurface (MS) able to convert a linearly polarized field into a circularly polarized one. A MS is adopted for the design of an antenna aiming to operate in the whole X-band for satellite communications (7.25 GHz-7.75 GHz, 7.9 GHz-8.4 GHz). CMA results provide useful insight for properly tuning the unit cell of the finite MS, which is based on a loop element. A comparison between two different solutions is addressed and an excitation strategy for stimulating the desired characteristic modes is envisioned.

11:20 ***Development of Robust CMA Tool for Efficient Modeling of Large PEC Structures***

Jihong Gu and Chao-Fu Wang (National University of Singapore, Singapore)

Characteristic mode analysis (CMA) of perfectly electrically conducting (PEC) bodies is very useful for many applications. To develop a robust CMA tool for efficient modeling of large-scale PEC objects, several technical aspects have been considered to systematically implement the tool. Their resultant generalized eigenvalue equations are solved using implicitly restarted Arnoldi method (IRAM) accelerated by multilevel fast multipole algorithm (MLFMA). A sparse approximate inverse (SAI) preconditioner is employed to improve the convergence of the iterative solution process. As an important application of the CMA tool, fast reconstruction of scattering cross-section of complex PEC objects has also been developed for obtaining electromagnetic scattering data.

11:40 ***Modified Equivalent Circuit Model for Modal Admittance of A Dipole with Dielectric Loads***

Zitong Wang and Qi Wu (Beihang University, China)

Characteristic mode analysis (CMA) is very useful for the design of antennas. Antenna performance can be optimized by characteristic mode (CM) manipulation. However, the mechanism of mode manipulation using dielectric materials has not been well revealed. In this paper, the equivalent circuit model (ECM) is used to predict the modal admittance (MA) of the antenna over a broad bandwidth. Parallel-connected lumped components can be used to modify the ECM to reflect the influence of dielectric material on the MA.

12:00 ***Spatial and Spectral Behavior of Characteristic Modes Within Periodic Unit Cells***

Kurt Schab (Santa Clara University, USA)

Notable sparsity, symmetry, and tracking properties of characteristic modes on periodic systems are discussed. A set of example calculations demonstrate sparsity in reconstructing the reflection tensor from characteristic modes, as well as the multidimensional parameterization of modal quantities infrequency and scan angle.

12:20 ***Understanding Single-Element Beamforming Using Characteristic Modes and a Change of Basis***

Leonardo Mörlein (Leibniz Universität Hannover, Germany); Dirk Manteuffel (University of Hannover, Germany)

An insightful approach to single-element beamforming is presented. In order to enhance the understanding of single-element beamforming, a change of basis is used to connect the characteristic modes of a single element to array theory. For the analyzed patch antenna, this allows not only the derivation of new explicit relationships for the excitation, but also enables the use of the array factor and other valuable tools from array theory.

P03: Propagation for radar and sensing

T07 Positioning, Localisation and tracking/ /Propagation

Chairs: Golsa Ghiaasi (Silicon Austria Lab, Austria), Franz Teschl (Graz University of Technology, Austria)

11:00 ***Numerical Analysis of Dispersion Compensation for Guided Electromagnetic Waves in Rectangular Microwave Waveguides***

Manuel E. Rao and Thomas Maetz (Goethe University Frankfurt, Germany); Jochen Moll (Goethe University Frankfurt am Main, Germany)

Guided electromagnetic waves have been proposed recently as a novel technique for surface damage detection in metallic structural components. One limiting factor is frequency dispersion, which causes an emitted pulse to spread out in space and time as the wave propagates. This paper presents a dispersion compensation technique, originally introduced in the field of guided ultrasonic waves, that significantly improves localization accuracy by nonlinear mapping from time to distance domain exploiting a-priori knowledge about the dispersion characteristics. The method compresses the dispersed signal to its original shape. An application of the technique is presented in this paper considering damage localization in a complex WR28 waveguide covering the frequency band from 20-40 GHz. Therefore, the fundamental dispersion relationships for phase and group velocity have been derived. The results show a strong compression of the waveforms through dispersion compensation leading to an improved localization with an error of less than 1%.

11:20 ***Angle of Arrival Estimation System for LoRa Technology Based on Phase Detectors***

Noori BniLam (University of Antwerp - imec, IDLab Research Group, Belgium); Samer Nasser (University Antwerp, Belgium); Maarten Weyn (University of Antwerp - imec, Belgium)

In this paper, we propose a comprehensive low-power and low-cost Angle of Arrival (AoA) estimation system. The proposed system consists of a hardware architecture and an AoA estimation algorithm. The proposed hardware captures the phase values of the received signal and transmits them to the nearest LoRaWAN gateway. In the cloud, an AoA estimation algorithm will be performed, and the AoA of the received signal will be estimated. The proposed hardware is generic, and it can estimate the AoA of any received signal that is operating at a frequency below 2.7GHz. However, we have validated its performance with LoRa signals that are operating at the 868 MHz frequency band. The experimental validation, which has been conducted in a controlled environment, reveals that the proposed system can estimate the AoA of the received signals from various azimuth angles with a median and maximum estimation errors of 4 and 14 degrees, respectively.

11:40 ***Receiver Structures for Phase Modulated FMCW Radars***

Utku Kumbul and Nikita Petrov (Delft University of Technology, The Netherlands); Cicero S Vaucher (NXP Semiconductors, Eindhoven & Delft University of Technology, The Netherlands); Alexander Yarovoy (TU Delft, The Netherlands)

Two receiver structures of phase modulated FMCW signals with low ADC sampling requirement are investigated, namely the matched filter of the dechirped signal and the group delay filter approach. The sensing performance of the investigated receiver strategies are analyzed in application to BPSK modulated chirp. Numerical simulations demonstrate that both techniques provide comparable performance for low to moderate bandwidth of the modulation signal. Matched filter outperforms the group delay receiver for the modulation waveform with large bandwidth, hence with the price of larger computational complexity.

12:00 ***Drop-By-Drop Radar Cross Section Calculations for S- and C-Band Weather Radar Frequencies***

Franz Teschl (Graz University of Technology, Austria); Merhala Thurai (Colorado State University, USA); Sophie Steger (Graz University of Technology, Austria); Michael Schönhuber (Joanneum Research, Austria)

Recent studies revealed that scattering calculations at weather radar frequencies using individual drop shapes result in better agreement between simulated and measured polarimetric weather radar parameters, than if established rotational symmetric shape models are used. In the present work, thousands of individual rain drops that were detected with a 2D Video Disdrometer during a tropical storm, were reconstructed and their individual radar cross sections (RCS) were calculated by automatizing a commercial EM solver software. The calculations were carried out at the common weather radar frequencies at 2.8 GHz and 5.625 GHz, both for horizontal and vertical polarization. It is evaluated to what extend the RCS can differ for drops with an equal volume, it is discussed how the scattering parameters of individual drops scale within S- and C-band frequencies, and it is shown for one sample drop what effect the modelling granularity has on determined radar cross section values.

12:20 ***SAR-Based Sensing of Harmonic Transponders***

Aman Batra (University of Duisburg-Essen, Germany); Maher Khaliel (Universität Duisburg-Essen, Germany & Benha Faculty of Engineering, Benha University, Egypt); Ahmed Elawamry (Faculty of Engineering, Benha University, Egypt); Abdelfattah Fawky (Institute of Digital Signal Processing, Germany); MD Jahangir Alam (University of Duisburg-Essen & Institute of Digital Signal Processing, Germany); Michael Wiemeler (Universität Duisburg-Essen, Germany); Diana Goehringer (Technische Universität Dresden, Germany); Thomas Kaiser (Universität Duisburg-Essen, Germany)

Harmonic transponders differ from linear transponders by offering higher clutter mitigation and especially when the transponders are placed on highly reflective items or present in reflective environments. This paper exploits the inherent non-linearity in order to clearly sense and localize these transponders. The employed transponder is completely planar with a small footprint of 2 cm \(\times \) 3 cm. Furthermore, the transponder consists of two bowtie dipoles that are directly matched to the harmonic generation element at a fundamental 2.45 GHz frequency and also at the corresponding second harmonic 4.9 GHz frequency. In this paper, the inherent non-linearity sensing is exploited with synthetic aperture radar (SAR) in a highly cluttered environment. The proposed

method benefits by providing precise information along range and cross-range directions.

CS12: Antennas for Radio Astronomy

T08 Space (incl. cubesat)/ /Antennas

Chair: David S Prinsloo (ASTRON & Netherlands Institute for Radio Astronomy, The Netherlands)

11:00 ***A Maximum Directivity Beamformer for an SKA-Low Prototype Station***

David B Davidson (Curtin University, Australia & Stellenbosch University, South Africa); Daniel Ung (Curtin University, Australia)

The current beamforming strategy for the SKA-Low prototype station AAVS2 is the standard geometric-based array factor approach, as used in traditional array analysis and design. This method is simple, but because it ignores both mutual coupling and the inter-element variation in radiation patterns, it becomes progressively less reliable as the operating frequency decreases and the scan angle off broadside (zenith) increases. In this paper, the maximum directivity beamformer is applied to a computational electromagnetic simulation of an AAVS2 station. This formulation leverages the embedded element patterns and the array mutual coupling matrix. This permits considerably improved beam steering, in particular at the bottom end of the SKA-Low band. The computational cost of the method is also discussed.

11:20 ***A Dual-Beam Analog Beamformer for LOFAR 2.0 Enabling Simultaneous Space Weather and Radio Astronomy Observations***

Mark Ruiter and Paulus Kruger (ASTRON, The Netherlands); Sangitiana Harison (Station de Radioastronomie de Nançay, The Netherlands); Bruno Da Silva, Severin Barth and Stephane Bosse (Station de Radioastronomie de Nançay, France); Christophe Taffoureau (Station de Radioastronomie de Nancay, The Netherlands)

A newly developed phased array concept for LOFAR 2.0 radio telescope makes simultaneous Space weather and Radio astronomy observations possible

11:40 ***First Order Design of a Quadruple-Ridged Flared Horn for the ngVLA Band 1***

Robert Lehmensiek (EMSS Antennas, South Africa); Dirk de Villiers (Stellenbosch University, South Africa)

The design of an all-metal quadruple-ridged flared horn (QRFH) feed antenna for the ngVLA optics is presented. The feed is required to operate over the 1.2 GHz - 3.5 GHz frequency band with an optimization goal of maximizing the receiving sensitivity (Ae/Tsys) at an elevation angle of 45° and minimizing the fundamental waveguide mode reflection coefficient over the specified frequency band. The initial optimization was done on an analytically defined profile for both the horn and ridges, which provided a good starting point for optimizing horns with spline-defined profiles. In the final optimizations, the maximum ridge length was constrained to be about three-quarters of the total horn's length to allow for the addition of thermal and vacuum breaks. The final design has an average sensitivity of 13.4 m2/K over frequency and tipping angles.

12:00 ***Design and Measurement of a Bandwidth Enhanced Quad-Ridged OMT***

Jacobus M Kotzé, Petrie Meyer and Werner Steyn (Stellenbosch University, South Africa)

Orthomode transducers form an integral part of any receiver system, especially for high sensitivity, wideband applications such as reflector feed antennas for radio astronomy. This paper presents an improvement on the quadruple-ridged OMT that has formed the basis for many high performance reflector feeds systems. The improvement relies on the freedom offered by SLM 3D-printing to design quadruple-ridged waveguides with a wider single mode bandwidth than conventional square/circular ridged waveguides. A prototype quad-ridged OMT is designed and manufactured to operate over 3.5 - 12.3 GHz, the ngVLA Band 2. The manufacturing and measurement of the prototype is discussed in detail with recommendations for future designs. The basic design of the proposed OMT can be customised to attain good performance over more than a decade bandwidth, or used as a basis for high performance narrowband applications.

12:20 ***Design of a Low Frequency and Wide Band Reflector Antenna Feed for Future Earth Observation Radiometers***

Rubén Caballero Nagore (EOSOL, Spain); Josep Closa Soteras (Airbus Defence & Space, Spain); Tamara Coello (Airbus Defence and Space, Spain); Kerlos Atia Abdalmalak and Luis Enrique García Muñoz (Universidad Carlos III de Madrid, Spain); Aitor Martinez (EOSOL, Spain)

A complete reflector antenna architecture solution has been developed for Cryorad mission operating from 400 MHz to 2 GHz. This paper analyzes the antenna feed requirements and proposes an array feed solution comprised of two different frequency feeds. The design and analysis of one the proposed conical logarithmic spiral feed have been carried out. More than 10 dB of directivity radiation pattern from 900 MHz up to 2 GHz with a directivity stability of ±0.5dB using only a 130 mm diameter feed has been developed. Single circular polarization is achieved with an axial ratio under 1 dB within the complete operating band. The proposed feed is ideal for use in satellite due to its reduced size and mass.

CS06: AMTA Convened Session: Recent Advances in Test Chamber and Range Modeling, Design, Echo Reduction and Characterizations

T09 EM Modelling and Simulation tools/ /Measurements

Chairs: Zhong Chen (ETS-Lindgren, USA), Stuart F Gregson (Queen Mary, University of London, United Kingdom (Great Britain))

11:00 ***Comparison of Echo Reduction Techniques for Omni-Directional Antenna Calibration in an Extrapolation Range***

Zhong Chen and Yibo Wang (ETS-Lindgren, USA)

Literature on antenna gain calibration using extrapolation method has mostly focused on antennas with moderate to high gains where chamber reflections are relatively small. The traditional technique to remove antenna-to-antenna multipath reflections is to apply a moving average over the antenna response before a polynomial fit is applied. For low gain antennas, multipath reflections from surroundings can be much more pronounced. The moving average approach may not provide enough echo suppression. In this study, we investigate two additional techniques for removing the multipath reflections. The first technique is to apply time domain gating. Another method is to use angular spectrum filtering. At each frequency, the antenna response is expanded to k-space, where a filter can be applied to retain the response from the direct path direction only. The three techniques are compared using a set of measured data of broadband dipoles in an anechoic chamber.

11:20 ***Comparison of Measurements and Simulations of Tapered Anechoic Chambers***

Vince Rodriguez (NSI-MI AMETEK & University of Mississippi, USA)

Recently the author presented two papers on the use of full wave numerical methods for the prediction of anechoic chamber performance. In the first paper [1] the author argued that full wave analysis while accurate is still dependent on the accuracy of the input parameters, one of which may be the material properties of the RF absorber. On the second paper [2] presented the author stated that full wave analysis should be reserved to evaluating the potential effects of defective absorber of location of lights in different areas of the range. In this paper the author compares the full wave analysis of a taper anechoic range with the measured performance of the implementation of said tapered range.

11:40 ***Spatial Distribution of Equivalent Echo Sources in Antenna Measurements with a Moving Antenna Under Test***

Josef Knapp (Technical University of Munich, Germany); Thomas F. Eibert (Technical University of Munich (TUM) & Chair of High-Frequency Engineering (HFT), Germany)

A possible spatial support for equivalent sources accounting for echoic distortions in measurement scenarios with a moving AUT and a fixed probe location is discussed. In a heuristic argument, an equivalent scenario is introduced, where an unphysical ghost AUT, which is identical to the original AUT except for a constant scaling factor, accounts for the no longer present echo fields. A toroidal ghost source region around the moving AUT is, thus, identified and confirmed by a simulated measurement campaign. In the simulated measurements, the fields from reconstructed sources in the proposed region usually deviate by less than -40 dB compared to the fields from reconstructed sources on a large sphere or an untruncated mode expansion. The newly found spatial interpretation of the additional echo sources adds valuable insights to the mechanisms of echo suppression techniques based on modal expansions or surface current reconstruction.

12:00 ***Efficient Optimization of the Blended Rolled Edge of a Rectangular Single Offset-Fed Compact Antenna Test Range Reflector Using Genetic Evolution***

Stuart F Gregson (Queen Mary, University of London, United Kingdom (Great Britain)); Marc Dirix (Antenna Systems Solutions, Spain); Rostyslav Dubrovka (Queen Mary, University of London, United Kingdom (Great Britain))

The physical and electrical size of the parabolic reflector largely determines the usable size of the CATR QZ, with the reflector edge treatment being hugely influential in terms of determining the overall quality and uniformity of the collimated, pseudo plane wave. Recently, it has been demonstrated that modern powerful digital computational simulation technology in combination with evolutionary optimization strategies can be successfully harnessed to optimize the serrated edge treatment of an offset-fed CATR as part of the design process. In this paper, a further enhancement is presented in which the evolutionary computing technique is applied to the more geometrically complex blended rolled edge (BRE) treatment of a rectangular CATR reflector. Results of the validation of this novel technique are presented together with optimized QZ performance that highlight the successful use of this design procedure.

12:20 ***Measurement Uncertainty Evaluation for Validating RF/EMC Chambers from 30 MHz to 1000 MHz***

Wei Du (Avic Chengdu Aircraft Industrial (Group) Co. Ltd., China); Meng Donglin (National Institute of Metrology, China); Yulu Huang and Rui Wang (Avic Chengdu Aircraft Industrial (Group) Co. Ltd., China)

The basic idea to validate an anechoic chamber from 30 MHz to 1000 MHz is discussed in brief, and then focus on the correction factor in normalized site attenuation method. A calculable biconical antenna is provided and experimentally verified. The difference of antenna factor between measurements and calculation is less than 0.2 dB. The correction factor of NSA is provided for 5 m range measurements. Finally, a measurement uncertainty example is shown for validating the semi-anechoic chamber with reference site method.

Friday, April 1 12:40 - 13:40

Closing Ceremony

Friday, April 1 14:00 - 18:00

Short Courses