AES 2023 Torremolinos - Spain

The 9th International Conference on Antennas and Electromagnetic Systems

June 5 Ð 8, 2023
Torremolinos - Spain

Proceedings

ISSN 2491-2417

aesconference.org

AES 2023 Torremolinos - Spain

The 9th International Conference on Antennas and Electromagnetic Systems

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Said Zouhdi | Paris-Saclay University, France

TABLE OF CONTENT

ORGANIZATION I COMMITTEES 4
PLENARY SPEAKERS 6
KEYNOTE SPEAKERS 12
TUTORIALS 21
GUIDELINES FOR PRESENTERS I IN-PERSON 22
GUIDELINES FOR POSTER PRESENTERS I ONLINE 23
USEFUL INFORMATION 24
TABLE OF CONTENTS 27

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UniversitŽ Paris-Saclayis ranked 1st in France and 16th in the world according to the Academic Ranking of World Universities (ARWU).

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PLENARY SPEAKERS

Shanhui Fan

Stanford University, USA

Electromagnetics for Energy Applications

Shanhui Fan is the Joseph and Hon Mai Goodman Professor in the School of Engineering, a Professor of Electrical Engineering, a Professor of Applied Physics (by courtesy), and a Senior Fellow of the Precourt Institute for Energy, at the Stanford University. He received his Ph. D in 1997 in theoretical condensed matter physics from the Massachusetts Institute of Technology (MIT). His research interests are in fundamental studies of solid state and photonic structures and devices, especially photonic crystals, plasmonics, and meta-materials, and applications of these structures in energy and information technology applications. He has published over 600 refereed journal articles, has given over 380 plenary/keynote/invited talks, and holds over 70 US patents. He has cofounded two companies aiming to commercialize high-speed engineering computations and radiative cooling technology respectively. Prof. Fan received a National Science Foundation Career Award (2002), a David and Lucile Packard Fellowship in Science and Engineering (2003), the U. S. National Academy of Sciences W. O. Baker Award for Initiatives in Research (2007), the Adolph Lomb Medal from the Optical Society of America (2007), a Vannevar Bush Faculty Fellowship from the U. S. Department of Defense (2017), a Simons Investigator in Physics (2021), and the R. W. Wood Prize from Optica (2022). He is a Web of Science Highly Cited Researcher since 2015, and a Fellow of the IEEE, the American Physical Society, the Optical Society of America, and the SPIE.

Electromagnetics for Energy Applications

Electromagnetic fields represent one of the most important carriers of energy. The ability to control electromagnetic fields therefore play an essential role in the generation, transport, and utilization of energy. In this talk, we review our efforts in advancing electromagnetic technology for energy applications. Examples include radiative cooling, nighttime power harvesting, and the use of non-reciprocity to reach the ultimate efficiency limit of solar energy harvesting.

Yongxin Guo

National University of Singapore, Singapore

Efficient Wireless Power Transfer for IoTs and Biomedical Applications

Yongxin Guo is currently a Full Professor at the Department of Electrical and Computer Engineering, National University of Singapore (NUS). Concurrently, He is Director, Center for Peak of Excellence on Smart Medical Technology at NUS Suzhou Research Institute and Co-Director, Center for Smart Sensing and Artificial Intelligence, NUS Chongqing Research Institute. He has authored or co-authored over 500 international journal and conference papers and 4 book chapters. He holds over 50 granted/filed patents in USA, China and Singapore. His current research interests include RF sensing, antennas and electromagnetics in medicine; wireless power for biomedical applications and internet of things; wideband and small antennas for wireless communications; and RF and microwave circuits and MMIC modelling and design. He has graduated 19 PhD students at NUS.

Dr. Guo is a Fellow of IEEE and a Fellow of Academy of Engineering, Singapore. He is serving as Editor-in-Chief, IEEE Journal of Electromagnetics, RF and Microwave in Medicine and Biology for the term of 2020-2023. He served as the IEEE Fellow Evaluation Committee for IEEE Engineering in Medicine and Biology Society (2019-2020). Dr Guo was the Chair for IEEE AP-S Technical Committee on Antenna Measurement in 2018-2020. He served as Associate Editor for IEEE Antennas and Propagation Magazine (2018-2020), IEEE Journal of Electromagnetics, RF and Microwave in Medicine and Biology (2017 – 2020), Electronics Letters (2015-2019), IEEE Antennas and Wireless Propagation Letters (2013-2018), and IET Microwaves, Antennas & Propagation (2014-2017). He has served as General Chair/Co-Chair for a number of international conferences. He was the recipient of 2020 IEEE Microwave and Wireless Components Letters Tatsuo Itoh Prize of the IEEE Microwave Theory and Techniques Society. He was elected as a Distinguished Lecturer of IEEE Antennas and Propagation Society for the term of 2022-2024.

Efficient Wireless Power Transfer for IoTs and Biomedical Applications

Wireless power transfer (WPT) plays an increasingly important role in internet of things (IoTs) and biomedical applications. With the rapid development of 5G and IoTs, the dense deployment of sensor nodes become more popular. Various wireless power application scenarios will be introduced. Our recent research progress on near-field inductive and capacitive WPT and far-field WPT will be reported. Adaptive rectifier design and reconfigurable diode topology will be explained. Waveform-optimized WPT together with reconfigurable diode topology will be further illustrated.

Yahya Rahmat-Samii

University of California - Los Angeles, USA

Yahya Rahmat-Samii is a Distinguished Professor, a holder of the Northrop-Grumman Chair in electromagnetics, a member of the U.S. National Academy of Engineering (NAE), a Foreign Member of the Chinese Academy of Engineering (CAE) and the Royal Flemish Academy of Belgium for Science and the Arts, the winner of the 2011 IEEE Electromagnetics Field Award, and the Former Chairman of the Electrical Engineering Department, University of California at Los Angeles (UCLA), Los Angeles, CA, USA. He was a Senior Research Scientist with the Caltech/NASAÕs Jet Propulsion Laboratory. He has authored or coauthored more than 1100 technical journal and conference papers and has written over 36 book chapters and six books and is the holder many patents. He has more than 20 cover-page IEEE publication articles.

Prof. Rahmat-Samii is a fellow of IEEE, AMTA, ACES, EMA, and URSI. He was a recipient of the Henry Booker Award from URSI, in 1984, which is given triennially to the most outstanding young radio scientist in North America, the Best Application Paper Prize Award (Wheeler Award) of the IEEE Transactions on Antennas and Propagation in 1992 and 1995, the University of Illinois ECE Distinguished Alumni Award in 1999, the IEEE Third Millennium Medal and the AMTA Distinguished Achievement Award in 2000. In 2001, he received an Honorary Doctorate Causa from the University of Santiago de Compostela, Spain. He received the 2002 Technical Excellence Award from JPL, the 2005 URSI Booker Gold Medal presented at the URSI General Assembly, the 2007 IEEE Chen- To Tai Distinguished Educator Award, the 2009 Distinguished Achievement Award of the IEEE Antennas and Propagation Society, the 2010 UCLA School of Engineering Lockheed Martin Excellence in Teaching Award, and the 2011 campus-wide UCLA Distinguished Teaching Award. He was also a recipient of the Distinguished Engineering Educator Award from The Engineers Council in 2015, the John Kraus Antenna Award of the IEEE Antennas and Propagation Society and the NASA Group Achievement Award in 2016, the ACES Computational Electromagnetics Award and the IEEE Antennas and Propagation S. A. Schelkunoff Best Transactions Prize Paper Award in 2017. Rahmat-Samii was the recipient of the prestigious Ellis Island Medal of Honor in 2019. The medals are awarded annually to a group of distinguished U.S. citizens who exemplify a life dedicated to community service. These are individuals who preserve and celebrate the history, traditions, and values of their ancestry while exemplifying the values of the American way of life and are dedicated to creating a better world. Among the receipts of this honor are seven US presidents to name the few. He is listed in WhoÕs Who in America, WhoÕs Who in Frontiers of Science and Technology and WhoÕs Who in Engineering. He has been a plenary and millennium session speaker at numerous national and international symposia. He has been the organizer and presenter of many successful short courses worldwide. Many of his students have won major theses and conference paper awards.

He has had pioneering research contributions in diverse areas of electromagnetics, antennas, measurements and diagnostics techniques, numerical and asymptotic methods, satellite and personal communications, human/antenna interactions, RFID and implanted antennas in medical applications, frequency-selective surfaces, electromagnetic band-gap and meta-material structures, applications of the genetic algorithms and particle swarm optimizations. He was the 1995 President of the IEEE Antennas and Propagation Society and 2009Ð2011 President of the United States National Committee (USNC) of the International Union of Radio Science (URSI). He has also served as an IEEE Distinguished Lecturer presenting lectures internationally.

The Art, Science and Engineering of Modern Antenna Measurements and Diagnostics : From MarconiÕs First Measurements to TodayÕs Incredible Advances

Starting with MarconiÕs Þrst antenna pattern measurements, we then discuss modern planar near-Þeld antenna measurements as a novel paradigm linking electromagnetic theory, sampling techniques, back projection and FFT. Based on the fundamental electromagnetic principles, the underlying concepts governing simulations, designs and operations of planar-near Þeld measurements and diagnostics techniques will be highlighted. Modern measurement systems such as plane-polar, bi-polar and robotics scanning systems will be presented. Representative measurement results of reflector, array, reflectarray and lens antennas will be presented for diverse applications including planetary missions, radars for remote sensing, and Cubesats. Finally, the topics of diagnostics and phaseless antenna measurement techniques and algorithms will be touched upon..

Eva Rajo-Iglesias

University Carlos III of Madrid, Spain

Eva Rajo-Iglesias was born in Monforte de Lemos, Spain, in 1972. She received the M.Sc. degree in telecommunication engineering from the University of Vigo, Spain, in 1996, and the Ph.D. degree in telecommunication engineering from the University Carlos III of Madrid, Spain, in 2002. She was a Teacher Assistant with the University Carlos III of Madrid from 1997 to 2001. She joined the Polytechnic University of Cartagena, Cartagena, Spain, as a Teacher Assistant, in 2001. She joined University Carlos III of Madrid as a Visiting Lecturer in 2002, where she has been an Associate Professor with the Department of Signal Theory and Communications since 2004. Since 2018 she is Full Professor in the same department. She visited the Chalmers University of Technology, Gšteborg, Sweden, as a Guest Researcher, in 2004, 2005, 2006, 2007, and 2008, and has been an Affiliated Professor with the Antenna Group, Signals and Systems Department, since 2009 to 2016. She has co-authored more than 75 papers in JCR international journals and more than 120 papers in international conferences. Her current research interests include microstrip patch antennas and arrays, metamaterials, artificial surfaces and periodic structures, gap waveguide technology and MIMO systems. Dr. Rajo-Iglesias was the recipient of the Loughborough Antennas and Propagation Conference Best Paper Award in 2007, the Best Poster Award in the field of Metamaterial Applications in Antennas, at the conference Metamaterials 2009, the 2014 Excellence Award to Young Research Staff at the University Carlos III of Madrid and the Third Place Winner of the Bell Labs Prize 2014. She is currently an Associate Editor of the IEEE Antennas and Propagation Magazine and has served as Associate Editor of the IEEE Antennas ans Wireless Propoagation Letters (2011-2017).

Designing Antennas with Gap Waveguide Technology : Exploring New Trends

A brief introduction to the foundational principles of gap waveguide technology, followed by an overview of traditional designs of directive antennas using corporate fed arrays will be presented. Subsequently, novel applications of this technology in the millimeter frequency bands will be explored, which include the implementation of alternate periodic structures replacing the conventional bed of nails. Finally, the potential of combining this technology with established technologies like microstrip, as well as the design of other types of antennas as leaky wave antennas, will be discussed. In this way, an overview of different on going research lines connected to this technology will be presented.

Wen Tong

Huawei Wireless, Canada

cmWave-MIMO : towards the 1K-element-array paradigm

Wen Tong is the CTO, Huawei Wireless. He is the head of Huawei wireless research. In 2011, Dr. Tong was appointed the Head of Communications Technologies Labs of Huawei, currently, he is the Huawei 5G chief scientist and leads HuaweiÕs 10-year-long 5G wireless technologies research and development.

Prior to joining Huawei in 2009, Dr. Tong was the Nortel Fellow and head of the Network Technology Labs at Nortel. He joined the Wireless Technology Labs at Bell Northern Research in 1995 in Canada.

Dr. Tong is the industry recognized leader in invention and standardization of advanced wireless technologies, he is the key contributor to 3GPP since its inception. Dr. Tong was elected as a Huawei Fellow and an IEEE Fellow. He was the recipient of IEEE Communications Society Industry Innovation Award for Òthe leadership and contributions in development of 3G and 4G wireless systemsÓ in 2014, and IEEE Communications Society Distinguished Industry Leader Award for Òpioneering technical contributions and leadership in the mobile communications industry and innovation in 5G mobile communications technologyÓ in 2018. He is also the recipient of R.A. Fessenden Medal. For the past three decades, he had pioneered fundamental technologies from 1G to 5G wireless and Wi-Fi with more than 450 granted US patents.

Dr. Tong is a Fellow of Canadian Academy of Engineering, Fellow of Royal Society of Canada, and he serves as Board of Director of Wi-Fi Alliance, he is the committee member for ÒIEEE Fellow CommitteeÓ.

cmWave-MIMO : towards the 1K-element-array paradigm

In this talk, we present the development of massive MIMO antenna technologies for the emerging 6G and associated challenges. The overall system performance and antenna design-choice in terms of spectrum and channel propagation properties are discussed. We explore the centimeter wave spectrum for the 6G massive MIMO. The candidate frequency range is from 7GHz to 15GHz, we discuss the new propagation properties and ultra-large antenna element array architecture, namely, the 1K-element-array paradigm for both base-station and user-equipment.

KEYNOTE SPEAKERS

Andrea Fratalocchi

KAUST, Saudi Arabia

Universal light encoders : artificial intelligent optical hardware for real-time hyperspectral imaging and ultrasensitive detection

Andrea Fratalocchi is a Full Professor (from Jan 2023) in the Computer, Electrical, and Mathematical Sciences and Engineering Division at KAUST University. He joined KAUST in January 2011 as Assistant Professor and was promoted to Associate Professor in July 2016. Before joining KAUST, Andrea Fratalocchi was a Research Fellow at the Sapienza University of Rome under a KAUST Fellowship Award. From 2007 to 2009, Andrea Fratalocchi worked as a post-doctoral researcher at Sapienza University under a "New Talent" Award from the research center "Enrico Fermi." In 2012 he was appointed as Editor of Nature Scientific Report. In 2017, he won the Middle East GCC Enterprise Award as the best electrical engineer of the year. In 2019, he became a Fellow of the Institute of Physics (IOP), a Senior Member of the IEEE, and a Fellow of the Optical Society of America (OSA) : "For pioneering innovations in the use of complex optical systems and the development of creative technologies in clean energy harvesting, bio-imaging, and advanced optical materials". According to the standardized citations index collected by Plos (https ://doi.org/10.1371/journal.pbio.3000918).

Andrea Fratalocchi is in the top 2% of Optics worldwide. Andrea Fratalocchi authored more than 200 publications, including three books and six patents. Andrea Fratalocchi is the co-founder of Pixeltra (www.pixeltra.com), a startup company implementing a revolutionary artificial intelligent hardware and software hyperspectral technology for security, food safety, and biomedical applications.

Universal light encoders : artificial intelligent optical hardware for real-time hyperspectral imaging and ultrasensitive detection
I will summarize present and future research in the field of universal light encoders (ULEs), which represent artificial intelligent optical hardware implementing arbitrary user-defined functionalities in ultrathin metasurfaces. ULEs process information at the speed of light and can be integrated into any conventional monochrome camera for machine vision, transforming the system into an optical neural network processor. I will discuss applications of ULEs in the implementation of HyplexTM, a high-resolution hyperspectral imaging camera and a universal platform for ultrasensitive detection.

Mona Jarrahi

University of California Los Angeles, USA

Hyperspectral Terahertz Imaging Using Plasmonic Detectors

Mona Jarrahi is a Professor of Electrical and Computer Engineering at the University of California Los Angeles. She has made significant contributions to the development of ultrafast electronic and optoelectronic devices and integrated systems for terahertz, infrared, and millimeter-wave sensing, imaging, computing, and communication systems by utilizing novel materials, nanostructures, and innovative plasmonic concepts. Her scientific achievements have been recognized by several prestigious awards including the Presidential Early Career Award for Scientists and Engineers; Friedrich Wilhelm Bessel Research Award from Alexander von Humboldt Foundation; Moore Inventor Fellowship from the Gordon and Betty Moore Foundation; Kavli Fellowship by the USA National Academy of Sciences, Grainger Foundation Frontiers of Engineering Award from the USA National Academy of Engineering; Breakthrough Award from Popular Mechanics Magazine; Research Award from Okawa Foundation; Early Career Award in Nanotechnology from the IEEE Nanotechnology Council; Outstanding Young Engineer Award from the IEEE Microwave Theory and Techniques Society; Booker Fellowship from the USA National Committee of the International Union of Radio Science; Lot Shafai Mid-Career Distinguished Achievement Award from the IEEE Antennas and Propagation Society; Early Career Award from the USA National Science Foundation; Young Investigator Awards from the USA Office of Naval Research, the Army Research Office, and the Defense Advanced Research Projects Agency. Prof. Jarrahi is a Fellow of IEEE, OSA and SPIE societies and has served as a distinguished lecturer of IEEE, traveling lecturer of OSA, and visiting lecturer of SPIE societies.

Hyperspectral Terahertz Imaging Using Plasmonic Detectors
This talk gives an overview of advancements in hyperspectral terahertz imaging systems, which utilize plasmonic photoconductive terahertz detectors to provide significantly higher signal-to-noise ratio levels.

Maria Kafesaki

University of Crete, Greece

Cylinder- and multi-coated-cylinder-systems as multifunctional metamaterials : An Effective Medium description

Maria Kafesaki is Associate Professor in the Dept. of Materials Science and Technology of the University of Crete and Adjunct Researcher at the Institute of Electronic Structure and Laser (IESL) of Foundation for Research and Technology Hellas (FORTH). She obtained her Ph.D. in 1997, at the Physics Department of the University of Crete, Greece, on elastic wave propagation in complex media. She has worked as a post-doctoral researcher in the Consejo Superior de Investigaciones Cientificas in Madrid, Spain, and in IESL of FORTH (1997-2001). Her current research is on the area of electromagnetic wave propagation in periodic and random media, with emphasis on photonic crystals and metamaterials, where she has large theoretical and computational experience. She has more than 110 publications in refereed journals (with more than 6500 citations and h-index=42, according to Web of Science), and more than 70 invited talks at international conferences and schools. She has participated in many European projects as well as in the organization of many international conferences and schools. She is a Fellow of the Optical Society of America. Figure : A simple PT-symmetric chiral bi-layer. Under oblique incidence of circularly polarized (CP) waves the bi-layer eigenvalues ! indicate the existence of a mixed phase and two exceptional points, highly tunable by the incidence angle.

Cylinder- and multi-coated-cylinder-systems as multifunctional metamaterials : An Effective Medium description

We discuss an effective medium approach for analyzing metamaterials composed of cylindrical scatterers/meta-atoms, either simple or coated/multi-coated. We demonstrate the potential of this approach in THz systems made of polaritonic cylinders as well as in graphene-based nanotubes. In both cases we demonstrate a reach palate of optical responses, including negative index and hyperbolic metamaterial response.

Enrica Martini

University of Siena, Italy

Recent advances in metasurface antennas design and modelling

Enrica Martini received the Laurea degree (cum laude) in telecommunication engineering from the University of Florence, Italy, in 1998. From 1998 to 1999 she worked at the University of Florence under a one-year research grant from the Alenia Aerospazio Company, Rome, Italy. In 2002, she received the PhD degree in informatics and telecommunications from the University of Florence and the Ph.D. degree in electronics from the University of Nice-Sophia Antipolis, under joint supervision. In 2002, she was appointed Research Associate at the University of Siena, Italy. In 2005, she received the Hans Christian Ørsted Postdoctoral Fellowship from the Technical University of Denmark, Lyngby, Denmark, and she joined the Electromagnetic Systems Section of the Ørsted DTU Department until 2007. From 2007 to 2017 she was a Postdoctoral Fellow at the University of Siena, Italy. In 2012, she co-founded the start-up Wave Up Srl, Siena, Italy, of which she was the CEO from 2016 to 2018. From 2019 to 2021 she was an assistant professor at the University of Siena, Italy. She is currently an Associate Professor with the Department of Information Engineering and Mathematics, University of Siena, Siena, Ital Dr. Martini coordinated tasks of various research projects funded by national and international governmental institutions, as well as by industry. Her research interests include metasurfaces and metamaterial characterization, metasurface-based antennas and microwave devices, electromagnetic scattering, antenna measurements and tropospheric propagation. Dr. Martini was a co-recipient of the 2016 Schelkunoff Transactions Prize Paper Award, of the Best Paper Award in Antenna Design and Applications at the 11th European Conference on Antennas and Propagation in 2017, of the Best Poster Award at the Metamaterials Congress in 2019 and of the Best Paper Award in Electromagnetics at the 15th European Conference on Antennas and Propagation in 2021.

Recent advances in metasurface antennas design and modelling

This contribution provides an overview of the recent advances in the field of modulated metasurface antennas. After reviewing the most advanced analytical and numerical models, different designs and realizations will be presented, including antennas with shaped pattern, dual polarized, multibeam and beam scanning antennas.

Taiichi Otsuji

Tohoku University, Japan

Graphene-based van der Waals 2D heterostructure materials and devices for terahertz wireless communications

Taiichi Otsuji is a Full Professor at the Research Institute of Electrical Communication (RIEC), Tohoku University, Sendai, Japan. He received the Dr. Eng. degree in electronic engineering from Tokyo Institute of Technology, Tokyo, Japan in 1994. From 1984 to 1999 he worked for NTT Laboratories, Kanagawa, Japan. In 1999 he joined Kyushu Institute of Technology as an associate professor, being a professor in 2002. He joined RIEC, Tohoku University, in 2005. His current research interests include terahertz electronic, photonic and plasmonic materials/devices and their applications. He has authored and co-authored 300 peer-reviewed international journal papers and more than 600 international conference proceedings including 210 invited presentations, and holds 13 Japanese and 8 US patents. He is the recipient of the Outstanding Paper Award of the 1997 IEEE GaAs IC Symposium in 1998, the Prizes for Science and Technology in Research Category, the Commendation for Science and Technology by the MEXT, Japan, in 2019, and the 59th Achievement Award of the IEICE (Institute of Electronics, Information, and Communication Engineers), Japan, in 2022. He has served as an IEEE Electron Device Society Distinguished Lecturer since 2013. He is a Fellow of IEEE, OPTICA (former OSA, Optical Society of America), and JSAP (Japan Society of Applied Physics).

Graphene-based van der Waals 2D heterostructure materials and devices for terahertz wireless communications
This paper reviews recent advances in the research and development of graphene-based van der Waals 2D heterostructure materials and devices for terahertz wireless communications.

Willie J. Padilla

Duke University, USA

Physics Informed Deep Learning In Metamaterials

Willie J. Padilla is a professor at Duke University with a masterÕs degree and doctorate in physics. He received a Young Investigator Award from the Office of Naval Research and a Presidential Early Career Award for Scientists and Engineers. Padilla is a fellow of the American Physical Society, Optical Society of America and Kavli Frontiers of Science. He is also a Web of Science Highly Cited Researcher in physics for 2018 and 2019. He heads a group working in the area of metamaterials with a focus on machine learning, computational imaging, spectroscopy and energy, and has published more than 200 peer-reviewed journal articles.

Physics Informed Deep Learning In Metamaterials
Deep learning has had profound impacts in electromagnetic metamaterials, however there are several,drawbacks including. Through incorporation of prior knowledge, physics informed deep neural networks (PINNs),have the capability to solve many of the outstanding problems in deep learning and may additionally learn new,physics of systems under study. We discuss three different studies using physics informed deep learning and,describe the future of the field is also given.

Atif Shamim

KAUST, Saudi Arabia

On-Chip Antennas - The Last Barrier to True RF System-on-Chip

Atif Shamim received his MS and PhD degrees in electrical engineering from Carleton University, Canada in 2004 and 2009 respectively. He was an NSERC Alexander Graham Bell Graduate scholar at Carleton University from 2007 till 2009 and an NSERC postdoctoral Fellow in 2009-2010 at Royal Military College Canada and KAUST. In August 2010, he joined the Electrical and Computer Engineering Program at KAUST, where he is currently an Associate Professor and principal investigator of IMPACT Lab. He was an invited researcher at the VTT Micro-Modules Research Center (Oulu, Finland) in 2006. His research work has won best paper awards in IEEE ICMAC 2021, IEEE IMS 2016, IEEE MECAP 2016, IEEE EuWiT 2008, first prize in IEEE IMS 2019 3MT competition and IEEE AP-S Design Competition 2022, finalist/honorable mention prizes in IEEE AP-S Design Competition 2020, IEEE IMS 2017 (3MT competition), IEEE IMS 2014, IEEE APS 2005. He has been selected as the Distinguished Lecturer for IEEE AP-S (2022-2024). He has won the Kings Prize for the best innovation of the year (2018) for his work on sensors for the oil industry. He was given the Ottawa Centre of Research Innovation (OCRI) Researcher of the Year Award in 2008 in Canada. His work on Wireless Dosimeter won the ITAC SMC Award at Canadian Microelectronics Corporation TEXPO in 2007. Prof. Shamim also won numerous business-related awards, including 1st prize in Canada's national business plan competition and was awarded OCRI Entrepreneur of the year award in 2010. He is an author/co-author of around 300 international publications, an inventor on more than 40 patents and has given close to 100 invited talks at various international forums. His research interests are in innovative antenna designs and their integration strategies with circuits and sensors for flexible and wearable wireless sensing systems through a combination of CMOS and additive manufacturing technologies. He is a Senior Member of IEEE, founded the first IEEE AP/MTT chapter in Saudi Arabia (2013) and served on the editorial board of IEEE Transactions on Antennas and Propagation (2013-2019), and as a Guest Editor for IEEE AWPL Special issue (2019), and is currently serving as an Associate Editor for IEEE Journal of Electromagnetics, RF and Microwaves in Medicine and Biology. He serves on numerous IEEE committees such IEEE Technical committees on Antenna Measurements (AP-S), Microwave Controls (MTT-S 13), and Additive Manufacturing (CRFID). Find out more details at (https ://cemse.kaust.edu.sa/impact).

On-Chip Antennas - The Last Barrier to True RF System-on-Chip

In the last decade, the increased level of integration provided by silicon technologies and emerging applications at millimeter wave frequencies has helped to achieve true System-on-Chip solutions bringing the antennas on the chip. This is because antenna sizes at these frequencies become small enough for practical on-chip realization. However, there are a number of challenges to overcome, for instance dealing with silicon substrate high conductivity and permittivity, metal stack-up and layout restrictions, and on-chip characterization through delicate probes, etc.

Fredrik Tufvesson

Lund University, Sweden

Channel modelling and characterization for communication and sensing in a 6G era

Fredrik Tufvesson received his Ph.D. in 2000 from Lund University in Sweden. After two years at a startup company, he joined the department of Electrical and Information Technology at Lund University, where he is now professor of radio systems. His main research interests is the interplay between the radio channel and the rest of the communication system with various applications in wireless systems such as massive MIMO, mm wave communication, vehicular communication and radio based positioning. Fredrik has authored around 90 journal papers and 140 conference papers, he is fellow of the IEEE and recently he got the Neal Shepherd Memorial Award for the best propagation paper in IEEE Transactions on Vehicular Technology and the IEEE Communications Society best tutorial paper award.

Channel modelling and characterization for communication and sensing in a 6G era
6G is expected to be based on distributed and co-located ultra-massive MIMO at frequencies ranging from one or a few GHz to hundreds of GHz. It will support both communication and sensing applications and should at the same time offer extreme reliability, enormous data rates, and ultra-low latencies. In this talk, we discuss channel characteristics, channel models, and the implications on 6G. Based on measurement examples, we point out possible directions and limitations and what we really can expect from the various frequency bands.

Ventsislav K. Valev

University of Bath, UK

Chiroptical harmonic scattering : predicted in 1979 and demonstrated four decades later

Ventsislav K. Valev is a Full Professor and a Research Fellow of the Royal Society, in the Physics Department of the University of Bath, where he serves as the Head of Department. He is also an Associate Fellow of Homerton College, in the University of Cambridge.

Valev was born in Bulgaria. He studied physics at the University of Western Brittany (France), with a final year at the University of Cardiff (Wales), as an Erasmus student. He received his PhD in 2006, from the Radboud University Nijmegen (the Netherlands). Subsequently, he was a post-doc and a Research Fellow at the KU Leuven University (Belgium). In 2012, he became a Research Fellow in the Cavendish Laboratory at the University of Cambridge and, in 2013, he joined Homerton College, as a Research Associate. Since 2014, he has been working at the University of Bath, where he arrived as a Reader and a Research Fellow of the Royal Society. In 2019, he was promoted to professor and in 2021 he became the Director of Research for the Department of Physics. He was appointed Head of Department in 2022.

Valev's research group focuses on the interaction between powerful laser light and nanostructured materials. He builds laser experiments to study novel materials, such as plasmonic nanostructures, metamaterials, 2D materials and quantum optical materials. He explores the physics of photons, electrons and magnetism confined to tiny volumes of space – nanoparticles or 2D sheets. He aims to discover new properties and to test theoretical predictions, seeking out new and useful intersections between classical electromagnetism and quantum mechanics. His investigations are both fundamental and applied, with potential benefits for the pharmaceutical, food, perfume, and agrochemical industries.

Chiroptical harmonic scattering : predicted in 1979 and demonstrated four decades later
Chiroptical harmonic scattering (CHS) was predicted in 1979, but an experimental observation of this effect remained elusive for 40 years. A first form of CHS was reported in 2019 ; it was demonstrated that light scattered at the second-harmonic from Ag nanohelices dispersed in water could reveal the chirality of the nanohelices. Observations in other systems (metal and semiconductor) and at the third-harmonic quickly followed. Now, we show the effect in high refractive index dielectrics.

TUTORIALS

Prof. Willie J. Padilla

Duke University, USA

Tuesday 6th June
15:00 - 16:00 — Playamar

Introduction to Deep Learning Techniques for Artificial Electromagnetic Materials

Willie J. Padilla is a professor at Duke University with a master’s degree and doctorate in physics. He received a Young Investigator Award from the Office of Naval Research and a Presidential Early Career Award for Scientists and Engineers. Padilla is a fellow of the American Physical Society, Optical Society of America and Kavli Frontiers of Science. He is also a Web of Science Highly Cited Researcher in physics for 2018 and 2019. He heads a group working in the area of metamaterials with a focus on machine learning, computational imaging, spectroscopy and energy, and has published more than 200 peer-reviewed journal articles.

Introduction to Deep Learning Techniques for Artificial Electromagnetic Materials
Deep neural networks (DNNs) have enhanced and transformed traditional research methods and are driving scientific advance. Deep learning has shown immense potential in the field of artificial electromagnetic materials (AEM) research, with applications spanning electromagnetic metamaterials, metasurfaces, photonic crystals, and plasmonics. In this brief tutorial we review the status of the field with a focus on recent advances, key limitations, and future directions. Strategies, guidance, evaluation, and limits of using deep networks for both forward and inverse AEM problems are presented.

GUIDELINES FOR PRESENTERS I IN-PERSON

In-person Oral Presentations

Each session room is equipped with a stationary computer connected to a LCD projector. Presenters must load their presentation files in advance onto the session computer. Technician personnel will be available to assist you.

Scheduled time slots for oral presentations are 15 mn for regular, 20 mn for invited presentations, 30 mn for keynote talks and 35 mn for plenary talks, including questions and discussions. Presenters are required to report to their session room and to their session Chair at least 15 minutes prior to the start of their session.

The session chair must be present in the session room at least 15 minutes before the start of the session and must strictly observe the starting time and time limit of each paper.

In-person Poster Presentations

Presenters are requested to stand by their posters during their session. One poster board, A0 size (118.9 x 84.1 cm), in portrait orientation, will be available for each poster. Pins or thumbtacks are provided to mount your posters on the board. All presenters are required to mount their papers 30mn before the session and remove them at the end of their sessions. Posters must prepared using the standard AES poster template (available on the conference website).

GUIDELINES FOR PRESENTERS I ONLINE

All Oral presentations will be in person with option for remote viewing via Zoom.

Poster sessions will be hybrid, consisting of both in person and virtual presentations. Instructions for virtual poster presenters can be found here : guidelines).

USEFUL INFORMATION

Venue

AES 2023 will be held at :
Palacio de Congresos y Exposiciones de la Costa del Sol
3 Calle Mexico, 29620 Torremolinos (Spain)

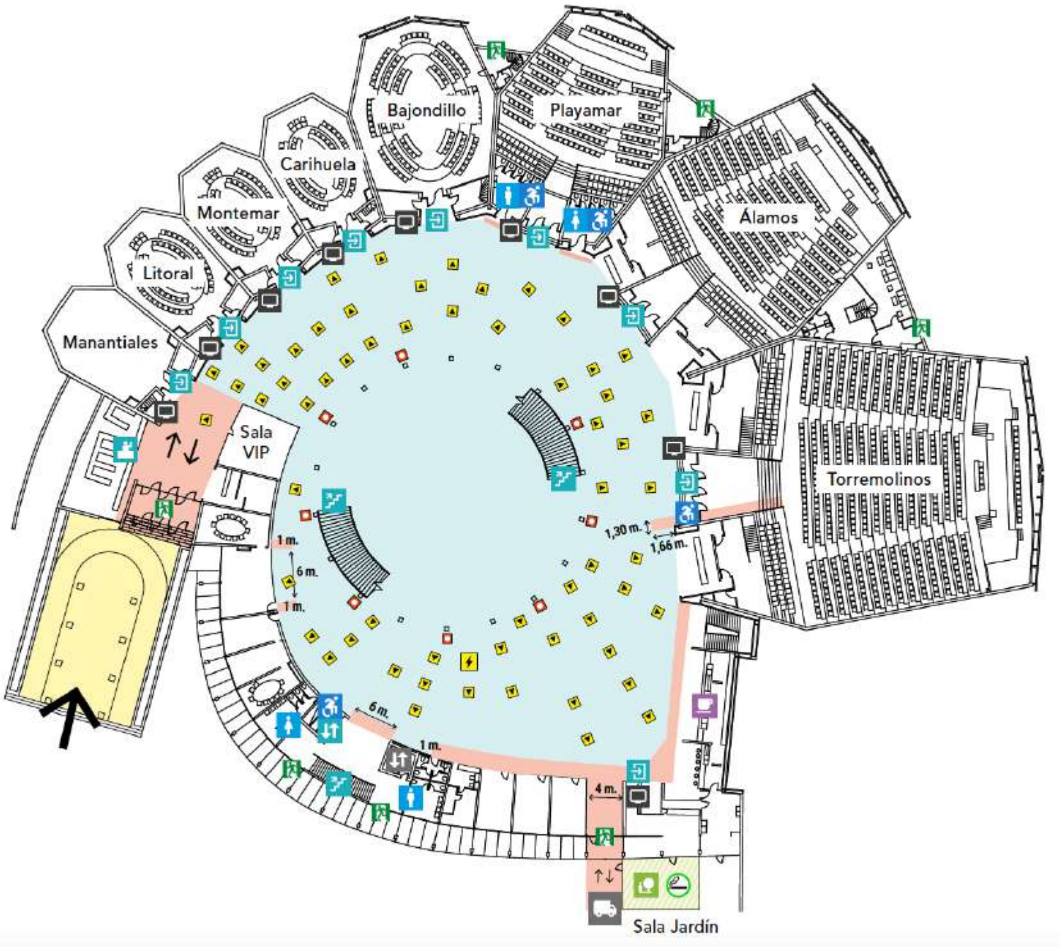
https://palacio-congresos.es

PALACIO DE CONGRESOS

Opened in October 1970, the Palacio de Congresos y Exposiciones de Torremolinos (Congress and Exhibition Centre) was the result of a project designed in 1967 by the architects Rafael de la Hoz and Gerardo Olivares James. The building, which became the state heritage property in 1971.

The complex is built on an estate of 70,000 square meters, of which 18,000 square meters are gardens. Situated in a privileged location in the municipality of Torremolinos and located in the upper area of the town on a hill overlooking the sea, the Congress Center is an icon of MalagaÕs coastal landscape.

The building is arranged in a circular format around which the various auditoriums, meeting rooms, administrative offices and annexed buildings are distributed. The central hall is presided over by its most iconic visual symbol, an emblem of convention and business tourism in Spain : a large translucent dome with an unprecedented crystal lamp hanging from the center of the exposed radial roof, falling like drops in a waterfall spilling over the center of the composition.



Getting to Venue

Getting to Torremolinos from Malaga Airport

Torremolinos is around 8km away from Malaga international airport. You can go from the airport to the city center by taxi, by train or by bus.

Taxi

The airport has a well-signposted taxi rank outside the arrivals area of Terminal T3. Make sure that the taxi driver has started the taximeter at the beginning of the journey (minimum fare). We recommend requesting a receipt for any complaint or claim.

Train

The new suburban train station in the new Terminal T3 building links the airport with Torremolinos city centre and other cities like Benalmadena and Fuengirola in one direction, and it links Malaga city center in the other direction.

The train station is situated underground and accessed via escalators. It is well signposted and can be reached via the square outside arrivals or outside departures. Before the station entry barriers you will see several self-service tickets machines on your right where you can buy your tickets.

The first train to Torremolinos leaves the airport at 05 :32, leaving every 20-30 minutes until the last train at 23.42. Line : C1. Estimated travel time : 10 minutes.

Bus

You will find the bus stop straight in front of you outside the arrivals area of Terminal T3 on the side of the road where there are a couple of shelters with seats. You will also see a ticket office in the left hand corner of the arrivals forecourt where you should purchase your tickets for the journey. Line : Torremolinos-Benalmadena-Airport. Estimated travel time : 30 minutes.

Getting to Torremolinos from Malaga train station

There are two train stations in the centre of Malaga : Maria Zambrano and Centro Alameda. Maria Zambrano station provides high-speed (AVE) and long-distance links to many Spanish cities like Barcelona, Cordoba, Madrid, Santiago de Compostela, Seville, etc, as well as local and regional routes.

You can take Line C1 from any of the two stations to reach Torremolinos. The estimated travel time is 20 minutes. You can check the timetables on the website of the national rail company RENFE

Getting to Torremolinos from Malaga bus station

Malaga bus station is located at the street "Paseo de los Tilos" very near Maria Zambrano train station. So it will be very easy to take a bus or a train from this station. You can take bus line Malaga-Torremolinos. Estimated travel time : 20 minutes.

TABLE OF CONTENTS

Plenary presentation

Electromagnetics for Energy Applications (pp. 39)
Shanhui Fan,

Efficient Wireless Power Transfer for IoTs and Biomedical Applications (pp. 40)
Yongxin Guo,

cmWave-MIMO : towards the 1K-element-array paradigm (pp. 41)
Wen Tong,

Designing Antennas with Gap Waveguide Technology: Exploring New Trends (pp. 42)
Eva Rajo-Iglesias,

The Art, Science and Engineering of Modern Antenna Measurements and Diagnostics: From Marconi's First Measurements to Today's Incredible Advances (pp. 43)
Yahya Rahmat-Samii,

Keynote presentation

Universal light encoders: artificial intelligent optical hardware for real-time hyperspectral imaging and ultrasensitive detection (pp. 45)
Andrea Fratalocchi,

Recent advances in metasurface antennas design and modelling (pp. 46)
Enrica Martini,

On-Chip Antennas: The Last Barrier to True RF System-on-Chip (pp. 47)
Atif Shamim,

Graphene-based van der Waals 2D heterostructure materials and devices for terahertz wireless communications (pp. 48)
Taiichi Otsuji,

Cylinder- and multi-coated-cylinder-systems as multifunctional metamaterials: An Effective Medium description (pp. 50)
Charalampos Mavidis, Anna Tasolamprou, Maria Kafesaki,

Chiroptical harmonic scattering: predicted in 1979 and demonstrated four decades later (pp. 52)
Ventsislav Valev,

Physics Informed Deep Learning In Metamaterials (pp. 54)
Willie Padilla, O. Khatib, S. Ren, C. Nadell, J. M. Malof,

Hyperspectral Terahertz Imaging Using Plasmonic Detectors (pp. 56)
Mona Jarrahi,

Channel modelling and characterization for communication and sensing in a 6G era (pp. 57)
Fredrik Tufvesson,

Tutorial

Introduction to Deep Learning Techniques for Artificial Electromagnetic Materials (pp. 59)
Willie J. Padilla,

Spatiotemporal effects in multimode optical fiber

Light by light manipulation in multimode fibers (pp. 61)
Tigran Mansuryan, Alessandro Tonello, Yago Arosa Lobato, Mario Ferraro, Mario Zitelli, Fabio Mangini, Yifan Sun, Benjami Wetzel, Katarzyna Krupa, Stefan Wabnitz, Vincent Couderc,

Twists and turns of light propagation in periodically modulated waveguide arrays (pp. 63)
Alejandro Aceves,

Stabilization of light bullets in multimode graded-index fibers: Analytical versus numerical characterization (pp. 65)
Pedro Parra-Rivas, Yifan Sun, Mario Ferraro, Fabio Mangini, Mario Zitelli, Stefan Wabnitz,

Random lasing in multimode diode-pumped graded-index fiber with fs-inscribed 3D refractive-index structures (pp. 67)
Alexey G. Kuznetsov, Alexey A. Wolf, Zhibzema Munkueva, Alexander V. Dostovalov, Sergey A. Babin,

Reduced model for nonlinear multimode dynamics in photonic crystal structures (pp. 69)
Francesco Rinaldo Talenti, Alfredo De Rossi, Stefan Wabnitz,

Controlling optical thermalization via spectral engineering: A Kinetic Equation Approach (pp. 71)
Tsampikos Kottos,

Two-waves thermalization and calorimetry experiments in nonlinear multimode optical fibers (pp. 73)
Mario Ferraro, Fabio Mangini, Fan O. Wu, Mario Zitelli, Demetrios N. Christodoulides, Stefan Wabnitz,

Thermodynamic fluctuations in optical nonlinear systems (pp. 75)
Konstantinos Makris, Georgios Pyrialakos, Fan Wu, Demetri Christodoulides,

Multimode dissipative spatiotemporal solitons in coherently driven passive nonlinear cavities with parabolic potentials (pp. 77)
Yifan Sun, Pedro Parra-Rivas, Carles Milian, Yaroslav Kartashov, Mario Ferraro, Fabio Mangini, Mario Zitelli, Raphael Jauberteau, Francesco Rinaldo Talenti, Stefan Wabnitz,

Additive manufacturing for electromagnetic devices

Iterative correction of phase errors in flat distributed dielectric lenses using full-wave modeling (pp. 80)
Carey Rappaport, Ann Morgenthaler,

Advanced Computational Electromagnetics Code for Efficient Synthesis and Design of Coupled-Resonator Microwave Circuits (pp. 82)
Valentin de la Rubia,

Review of patch antennas for wireless applications using ink-jet printing technique (pp. 84)
Mohamad Hosein Rasekhmanesh, Asrin Piroutiniya, JosŽ Luis Masa-Campos, Enrique Marquez-Segura, Eduardo Garcia-Ma Juan Corcoles, Jorge A. Ruiz-Cruz,

Stereolithography to generate OAM waves using dielectrics (pp. 86)
Miguel Angel Balmaseda-Marquez, Salvador Moreno-Rodriguez, Angel Palomares-Caballero, Carlos Molero, Juan Francis Valenzuela-Valdes, Pablo Padilla,

3D-Manufacturing of Reflectarrays through the process of Stereolithography plus Metallization (pp. 88)
Ignacio Parellada-Serrano, Jaime Velasco, Angel Palomares-Caballero, Carlos Molero, Pablo Padilla, Juan Francisc Valenzuela-ValdŽs,

The manufacturing methods comparison fo a Ka-band slotted waveguide antenna (pp. 90)
Alicja Schreiber, Bernd Gabler,

Antennas, EM and Smart Sensing Technologies for Biomedical and Healthcare Applications

Millimeter-Waves for Breast Cancer Detection: State-of-the-Art and Perspectives (pp. 96)
Simona Di Meo, Giulia Matrone, Marco Pasian,

A systematic study of the electromagnetic occupational exposure in healthcare applications (pp. 98)
Simona D'Agostino, Micol Colella, Micaela Liberti, Francesca Apollonio,

Antenna / body interactions at mmWaves (pp. 100)
Maxim Zhadobov,

A Radar And Camera-based Cuff-less And Calibration-free Blood Pressure Estimation Method (pp. 101)
Bo Wang, Zhi Zheng, Haotian Shi, Yongxin Guo,

Design and Optimization of Transmission Coils for Magnetic Resonance Coupling Human Body Communication (pp. 103)
Ziliang Wei, Yupei Zheng, Bingheng Chen, Yueming Gao, Yadong Yin, Jiejie Yang, Sio Hang Pun, Mang I. Vai,

Bioimpedance-based Muscle Activity Monitoring (pp. 105)
Pan Xu, Wanting He, Wei Ma, Ting Liu, Yipeng Liao, Zeljka Lucev Vasic, Mario Cifrek, Yueming Gao,

Space-Division-Based Stroke Classification and Localization Using Wearable Microwave Sensing Technique (pp. 107)
Zheng Gong, Yifan Chen,

Advances in Sensor Technologies Involving Electrodynamics and Magnetism

Giant Magnetoimpedance effect in amorphous microwires: from phenomenology to non-destructive composites monitoring (pp. 110)
Arkady Zhukov, Paula Corte-Leon, Mihail Ipatov, Juan Maria Blanco, Valentina Zhukova,

Sensing carbon fiber composites with continuous ferromagnetic microwires -electromagnetic and mechanical characterization (pp. 112)
Rafael Garcia-Etxabe, Diego Pineda, B. Muniozguren, Johan Malm, Christer Johansson, Valentina Zhukova, Mihail Ipatov, Arka
Zhukov,

Magnetic properties and applications of glass-coated ferromagnetic microwires (pp. 114)
Valentina Zhukova, Paula Corte-Leon, Mihail Ipatov, Juan Maria Blanco, Arkady Zhukov,

Non-plane Surface Magnetic Structures in Cylindrical Magnetic Microwires (pp. 116)
Alexander Chizhik, Paula Corte-Leon, Valentina Zhukova, Julian Gonzalez, Przemyslaw Gawronski, Arkadi Zhukov,

Smart Electromagnetic Skins and their Applications

Preliminary study of reconfigurable Orbital Angular Momentum beams with Liquid Crystal metasurface at mmWave (pp. 119)
Pablo de la Rosa del Val, Robert Guirado, Gerardo PŽrez-Palomino, Manuel Ca–o-Garcia, Eduardo Carrasco,

Reflection Loss Assessment of Reflecting Intelligent Surfaces (pp. 121)
Filippo Costa, Michele Borgese,

Preliminary Results on Conformal Reflective Surfaces for Urban Scenarios (pp. 123)
Michele Beccaria, Agnese Mazzinghi, Andrea Massaccesi, Angelo Freni, Paola Pirinoli,

Smart Skin-Enabled Communications Exploiting Surface Waves (pp. 125)
Talha Arshed, Stefano Maci, Enrica Martini,

Some Notes on the Electromagnetic Field Processing in the Deep Physical Layer (pp. 127)
Marco Donald Migliore,

Characterization and Optimization of Intelligent Reflective Surfaces in mm-wave Band including the Reflection produced by the Building Structure (pp. 130)
çlvaro F. Vaquero, Eduardo Martinez-de-Rioja, Manuel Arrebola, Jose A. Encinar,

Nanoscale Electrodynamics

Terahertz Waveforms in the Atom-Scale Gap of a Scanning Tunnelling Microscope (pp. 136)
Lukas Kastner, Dominik Peller, Carmen Roelcke, Thomas Buchner, Alexander Neef, Johannes Hayes, Franco BonafŽ, Dor
Sidler, Michael Ruggenthaler, Angel Rubio, Jascha Repp, Rupert Huber,

First-principles electromagnetics simulation for nonlinear nanophotonics: method and applications (pp. 138)
Mitsuharu Uemoto, Kazuhiro Yabana,

Terahertz Scanning Tunneling Microscopy: Exploring Ultrafast Dynamics in Materials down to the Atomic Scale (pp. 140)
Frank Hegmann,

In situ control and nanofocusing of extreme ultraviolet (pp. 142)
Aleksey Korobenko, Sabaa Rashid, Christian Heide, Andrei Naumov, David Reis, Pierre Berini, Paul Corkum, Giulio Vampa,

Thermodynamic limits for radiative heat engines (pp. 144)
Maxime Giteau, Michela Florinda Picardi, Georgia Papadakis,

Antenna theory and design

Antenna Design Optimization Using Machine Learning (pp. 147)
C. J. Reddy,

Applications of reflectarray antennas using frequency and polarization independent beamforming (pp. 148)
Jose Antonio Encinar, Daniel Martinez-de-Rioja,

Multiband Substrate Integrated Waveguide Dielectric Resonator Antenna for 4G and 5G Applications (pp. 150)
Irene Kong Cheh Lin, Mohd Haizal Jamaluddin,

On The Performance of Minkowski Fractal Resonator for Ku-Band Applications (pp. 152)
Mustafa Mahdi, Taha Elwi, Enrique M‡rquez Segura,

Investigation of Compact Antenna Test Range Symmetry Requirements (pp. 156)
Marc Dirix, S. F. Gregson,

Investigation of the textile technology impact's on the RF performances of a fully textile offset parabolic antenna design (pp. 159)
L. Mercier, B. Agnus, Y. Herve, S. Carras,

Review on Dual BP-NGD Phase Shifter Application for Beam Steering Antenna Design (pp. 161)

Blaise Ravelo, Samuel Ngoho, Fayu Wan, Taochen Gu, Fayrouz Haddad, Mathieu Guerin, Wenceslas Rahajandraibe,

Optimizing a pyramidal horn together with a dielectric lens for an airborne X-band transmitter (pp. 163)
Jonathan Kuster, Florent Christophe, Annick Penarier, Philippe Nouvel,

Array antennas, active, adaptive and reconfigurable antennas

Deep-learning-assisted reconfigurable metasurface antenna for real-time holographic beam steering (pp. 169)
Hyunjun Ma, Jin-soo Kim, Jongho Choe, Q-Han Park,

Origami foldable and deployable reflectarray antennas for CubeSats (pp. 170)
Takashi Tomura,

Wideband SIW Antenna Arrays for 5G Applications (pp. 171)
Huanhuan Huang, Yanzhong Yu, Xuehua Lin, Jing Tian,

Broadband Anti-Reflection Moth-Eye Structures in the Terahertz Region Fabricated by Ultrashort-Pulsed Laser Processing (pp. 175)
Kuniaki Konishi,

A Simple mm-Wave Chipless Pressure Sensor (pp. 176)
Sandra Rodini, Simone Genovesi, Giuliano Manara, Filippo Costa,

Improved Foreign Object Detection Method for Wireless Charging using Balanced and Synchronous Coils (pp. 178)
Sehwan Choi, Seunggu Nam, Churlseung Lee, Youngkee Ryu,

Analytical, Computational and numerical techniques

A spectral element modal method for the analysis of crossed binary gratings (pp. 181)
Gerard Granet, Kofi Edee,

Exploring the Thermally Activated Delayed Fluorescence Performance for a Phenothiazine Derivative via TD-DFT (pp. 182)
Lucia Cascino, Antonio Maggiore, Ivan Rivalta, Gian Paolo Suranna, Roberto Grisorio, Daniele Conelli, Vincenzo Maioran
Stefania D'Agostino,

Modelling Technique for Finite Length Microstrip Periodic Structures for MMW Filters (pp. 184)
Abdolreza Divsalar, D. Mirshekar-Syahkal,

A hybrid wavelet-based method to model the electromagnetic propagation above a polluted sea surface (pp. 186)
Thomas Bonnafont, Ali Khenchaf,

Higher-order Modes by Misalignment in Transition from Hollow Metallic Waveguides to Dielectric Waveguides (pp. 192)
Nikolaos Xenidis, Serguei Smirnov, Joachim Oberhammer, Dmitry Lioubtchenko,

Imaging, inverse scattering and remote sensing

Measuring Free-Space Light Beams with On-Chip Circuitry (pp. 196)
Peter Banzer, Varun Sharma, Johannes BŸtow, Dorian BrandmŸller, Jšrg Eismann,

The Behaviour of PolInSAR Coherence as a Parameter for Backscattering Analysis and Target Characterization (pp. 197)
Sofiane Tahraoui, Foued Cherchour, Mounira Ouarzeddine,

Metamaterials, metasurfaces, FSS and EBG

Roles of spatial symmetries in metamaterials (pp. 205)
Karim Achouri,

Topologically protected plasmonic edge states in metallic nanostructures (pp. 207)
Yuto Moritake,

Design and Experimental Demonstration of Optical Cloaking (pp. 209)
Kotaro Kajikawa,

Mechanically tunable multiplexed holographic metasurfaces (pp. 211)
Jianling Xiao, Robert I. Hunter, Duncan A. Robertson, Graham M. Smith, Simon Horsley, Sebastian A. Schulz, Andrea Di Falco,

Polarization manipulation and multiplexing in optical metasurfaces (pp. 213)
Ruwen Peng, Mu Wang,

Complete control of microwave transmission with double-layer metasurfaces (pp. 215)
Jonghwa Shin, Joonkyo Jung, Taeyong Chang,

Control of the Scattering Properties of a Complex Enclosure by Means of Nonlinear Metasurfaces (pp. 217)
Jared Erb, Steven Anlage,

Electromagnon Excitations and Microwave/Optical Device Functions in Multiferroic Materials (pp. 218)
Masahito Mochizuki,

3D chiral metasurface composed of bidirectional folded split ring resonators (pp. 220)
Changzhi Gu,

Ultra-sensitive THz biosensors based on metasurfaces (pp. 221)
Teun-Teun Kim,

Nonlinear Metasurfaces: Third order Nonlinearities of amorphous Composites and structure-induced Second order Surface Nonlinearities (pp. 223)
Christin David,

Photonic Metamaterial Continuous Time Crystal (pp. 225)
Tongjun Liu, Venugopal Raskatla, Jun-Yu Ou, Kevin MacDonald, Nikolay Zheludev,

Advanced wavefront engineering for 6G wireless communications (pp. 227)
Sotiris Droulias, Giorgos Stratidakis, Angeliki Alexiou,

Machine learning in nanooptics and phonics (pp. 229)
Mehdi Keshavarz Hedayati,

Microwave Discrete Time Crystal Oscillator (pp. 230)
Kyungmin Lee, Minwook Kyung, Jagang Park, Yung Kim, Hyuckjoon Cho, Joonhee Choi, Bumki Min,

Spoof terahertz surface plasmon polaritons on metasurface pathways for network and sensing applications (pp. 231)
Sven Becker, Tassilo Fip, Marco Rahm,

Weyl Physics and Electromagnetic Metamaterials (pp. 232)
Amirullah Mamedov,

Multichannel Distribution and Transformation of Polarization-Entangled Photons with Metasurfaces (pp. 234)
Yajun Gao, Ru-Wen Peng, Mu Wang,

FSS-Backed Reflectarray for Millimeter-Wave 5G Applications at the 28 GHz band (pp. 236)
Roman Soroka, Eduardo Martinez-de-Rioja, Ana Arboleya, Jose A. Encinar,

Soil Moisture Detection Using Metamaterials Based Absorber (pp. 238)
Mohammed Bait-Suwailam, Yaseen Al-Mulla,

One-way Complete Polarization Conversion at the Non-Hermitian Chiral Degeneracy of a Null-eigenvalue (pp. 240)
Soojeong Baek, Donghak Oh, Sangha Lee, Kyungmin Lee, Jagang Park, Teun-Teun Kim, Bumki Min,

Bi-hyperbolic and tetra-hyperbolic isofrequency topologies in a gyroelectromagnetic medium (pp. 242)
Volodymyr Fesenko, Dmytro Vavriv, Patrizia Savi, Vladimir Tuz,

Tunable THz graphene metasurface beam splitter (pp. 244)
Hyeongi Park, Sodam Jeong, Soojeong Baek, Teun-Teun Kim,

Nanophotonics, plasmonics and quantum optics

Chiro-optical microscopic imaging of plasmonic materials and chiral near-field interaction with molecules (pp. 247)
Hiromi Okamoto,

Realization of true perfect absorber metasurfaces for perfect thermal radiation in midinfrared wavelength (pp. 249)
Yoshiaki Nishijima,

Reconfigurable nanoantennas based on conducting polymer plasmonics (pp. 251)
Shangzhi Chen, Magnus Jonsson,

Mode synchronization in GaN ridge polariton lasers (pp. 252)
Hassen Souissi, Maksym Gromovyi, Thiaka Gueye, Christelle Brimont, Laetitia Doyennette, Dmitry Solnyshkov, Guillau
Malpuech, Edmond Cambril, Sophie Bouchoule, Blandine Alloing, Jesus Zuniga-Perez, Thierry Guillet,

Nonlocal theory of tip-enhanced type microscopies (pp. 254)
Hajime Ishihara, Mamoru Tamura, Yoshitsugu Tomoshige, Hiroyuki Ikagawa, Tomohiro Yokoyama,

Near-field manipulation of light via nanoantennas: analytical tools for electromagnetic fields design and potential for photonic integration (pp. 256)
Michela Florinda Picardi, Cillian McPolin, Jack J. Kingsley-Smith, Xudong Zhang, Shumin Xiao, Anatoly Zayats, Francisc
Rodriguez-Fortu–o,

Distinguishing Polaritonic from Charge Transfer Excitations in a Metal-Molecule System (pp. 258)
Lucia Cascino, Stefano Corni, Stefania D'Agostino,

Symmetry and topology in photonic crystals (pp. 260)
Thomas Christensen,

Enhanced and Tunable Kerr effect on InSb/graphene hybrid magnetoplasmonic structure at Terahertz waves (pp. 261)
Maha Ben Rhouma, K. Edee, B. Guizal,

Hybrid Anapole States: Theory and Applications (pp. 263)
Alexander Shalin, Alexey Kuznetsov, Vjaceslavs Bobrovs,

Collective effects in periodic arrays of plasmonic antennas (pp. 265)
Juan R. Deop-Ruano, Alejandro Manjavacas,

Chiral sensing with semiconductor nanophotonics (pp. 266)
Alberto Curto,

Plasmonics in a variable-temperature thermodynamic bath (pp. 267)
Michele Magnozzi, M. Ferrera, L. Mattera, M. Canepa, F. Bisio,

Plasmonic Sensing and Switching: FANO, PIT and MIM Resonnances (pp. 269)
Zouheir Sekkat,

Quasi-BIC on a hybrid anapole regime in silicon metasurfaces (pp. 270)
Alexey Kuznetsov, V. Bobrovs, A. S. Shalin,

Resonant hot carrier generation due to coherent coupling between plasmon and electron-hole pairs in nano metal array (pp. 272)
Soshun Inoue, Tomohiro Yokoyama, Hajime Ishihara,

Pure broadband toroidal source (pp. 274)
Dmitrii Borovkov, Adriˆ Valero, Mikhail Sidorenko, Aleksandr Kalganov, Pavel Dergachev, Egor Gurvitz, Lei Gao, Vjaceslav Bobrovs, Andrey Miroshnichenko, Alexander Shalin,

Optothermal non-contact surface cleaning (pp. 276)
Denis Kislov, Daniel Ofer, Andrey Machnev, Hani Barhom, Vjaceslavs Bobrovs, Alexander Shalin, Pavel Ginzburg,

Analysis of tip-enhanced photoluminescence image for allowed and forbidden transition of single molecule based on nonlocal response theory (pp. 277)
Yoshitsugu Tomoshige, Mamoru Tamura, Tomohiro Yokoyama, Hajime Ishihara,

Nonlocal Formulation of Coherent Anti Stokes Raman Scattering for Tip-Enhanced Microscopy (pp. 279)
Hiroyuki Ikagawa, Mamoru Tamura, Tomohiro Yokoyama, Hajime Ishihara,

Simultaneous transfer of energy and angular momentum in a pair of rotating nanostructures (pp. 281)
Juan R. Deop-Ruano, Alejandro Manjavacas,

Optics and Photonics

Detection of concealed reagents using THz parametric generator (pp. 284)
Kodo Kawase, Sota Mine, Kosuke Murate,

Symmetry aspects of patterns produced by optical scanners with Risley prisms (pp. 286)
Virgil-Florin Duma, A.-L. Dimb,

Fictitious, Physical and Stochastic Sources within Multilayer Optics (pp. 288)
Claude Amra, Paul Rouquette, Myriam Zerrad, Gabriel Soriano, Michel Lequime,

Low threshold mode-locking close to the exceptional point in coupled microcavitie (pp. 290)
Takasumi Tanabe, Riku Imamura, Shun Fujii,

Galaxy-shaped structures fabricated by irradiation of hybrid vortex modes (pp. 292)
Takashige Omatsu,

Optical manipulation and fusion of gold particle assemblies by two focal lasers (pp. 294)
Tomohiro Yokoyama, Yukihiro Tao, Hajime Ishihara,

Theoretical analysis of luminescence-induced optical force exerted on micromechanical membranes (pp. 296)
Hideki Arahari, Sota Konishi, Seiji Akita, Hajime Ishihara,

Diffractive Optical Elements through Reshaped Photosensitive Materials Platform (pp. 298)
Sara Moujdi, M. De Oliveira, S. L. Oscurato, F. Borbone, A. Ambrosio,

Comparison between the optical force by the microscopic model of chiral molecules and that based on the phenomenological chiral susceptibility (pp. 300)
Takao Horai, Hajime Ishihara,

Optoelectronics, Photonic Materials and Devices

VCSEL-based optical Ising solver (pp. 303)
Aaron Danner, Soon Thor Lim,

Discovering new high-refractive-index dielectric materials (pp. 304)
Soren Raza,

Integration of Mid-index Silicon Nitride Platforms for CMOS Photonic Circuits (pp. 306)
Thalia Dominguez Bucio, Valerio Vitali, Ilias Skandalos, Stefan Tudor Ilie, Teerapat Rutirawut, J. M. Luque Gonzalez, WangŸemert PŽrez, A. Ortega Mo–ux, I. Molina Fernandez, P. Cheben, J. Schmid, C. Lacava, P. Petropoulos, F. Y. Gardes,

Steering light in flat-optics 2D semiconducting layers (pp. 307)
Maria Caterina Giordano, Francesco Buatier de Mongeot,

Magnonic antenna effect for strong magnon-polariton in magnetic thin layer (pp. 308)
Tomohiro Yokoyama, Kenta Kato, Hajime Ishihara,

Scattering and diffraction

Diffraction of Plane Waves by a Junction between Magnetically Conductive and PMC Co-Planar Half-Sheets (pp. 311)
Giovanni Riccio, Gianluca Gennarelli, Flaminio Ferrara, Claudio Gennarelli, Rocco Guerriero,

Complex Time Delay of Short Pulses in Scattering Systems (pp. 313)
Isabella Giovannelli, Steven Anlage,

Propagation theory

On the Implementation of Large Intelligent Antenna Systems without Equalization (pp. 315)
Mario Marques da Silva, Rui Dinis,

Review on Ladder Topological Based Microstrip BP-NGD Design (pp. 318)
Samuel Ngoho, Blaise Ravelo,

Analysis of Propagation Mechanisms in Different Tunnel Environments for LOS and NLOS Scenarios (pp. 320)
Enes Aksoy, Allan Wainaina Mbugua, Yun Chen, Haroon Khan, Leszek Raschkowski, Lars Thiele, Slawomir Stanczak,

Amplitude-time characteristics of mobile phone emissions in 5G versus 4G networks (pp. 322)
Delia Deaconescu, David Vatamanu, Ana-Maria Buda, Paul Bechet, Simona Miclaus,

Classification of IEEE 802.11ax Emissions by Using YOLOv7 Real-Time Detection Algorithm (pp. 326)
Ana-Maria Buda, Delia Deaconescu, David Vatamanu, Simona Miclaus,

Material Characterization and non-destructive testing

Ultra-wideband graphene-based absorbers for THz integrated waveguide systems (pp. 330)
N. Xenidis, A. Przewloka, A. Krajewska, P. Drozdz, J. Oberhammer, Dmitri Lioubtchenko,

Intelligent Testing Environments for the Over-The-Air Characterization of Intelligent Wireless Devices (pp. 332)
AndrŽs Alay—n Glazunov,

Non-Axial Aligned Biaxial Material Characterization Using a Focus Beam System (pp. 334)
Nicholas O'Gorman, M. J. Havrilla,

Artificial intelligence optical hardware for ultra-sensitive detection (pp. 336)
Qizhou Wang, Ning Li, Zhao He, Arturo Lopez, Fei Xiang, Andrea Fratalocchi,

Plenary presentation

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'L! Z@JE$@($#L$,9D@$9=B$"L$,9:;@=@($7;7$*87=#;>8I9=B$#J88:7EE@>=$?>:$!=@E>;:>8@D$,>BJH9;7B$,7;9EJ:?9D
#D9==@=A$)C:>JAC$ U:>9BE@B7($#8&00"&9, *"&0"'!&#%"!:, '0$, %", /'&#4#)#!:, <!&0'#!:$, 4%', =%>0:, ?!>0,
190"%@0"!,A<0&!@!&0'#!:$B@7=9($.;9HG($%&%'($][($88L]$a$

!"#$%&%'($)*++",*-./*#$ 0$#1!./($2$ 3$4$56/"$%&%$ $ $ $ $ $ $$ $ $ $ $

!" #$%&'()"*+"",-.(/%+(0,-*(1,22&+2(*3(/24+(56(78-*+9 #3" #$%&'((

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!"#$%&'()#) %%

!"#$%&'()**+,%-#"./01"23%45%67"/#7/%+#(%8/79:&*-6$3 ;%+)("%&0+"+%

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!"#$%&'$()!"#$""%&'%($')"#$*(%+',%(#'-.'/)($+$&&'0-112")0%#)-"'3$4)0$&'%"3'#(%3)#)-"%++5'6%4$'($1%)"$3'-..'#
7"#$*(%#$3'8)(02)#&'9:;06"%($'%+&-'0-11-"+5':"-/"'%&'06),&;'($&2+#)"*')"'+%(*$'&)<$3'1-32+$&='7"'#6$'+%&#'
3$0%3$>' #6$')"0($%&$3' +$4$+' -.')"#$*(%#)-"' ,(-4)3$3' ?5' &)+)0-"' #$06"-+-*)$&' %"3' $1$(*)"*' %,,+)0%#)-"&'
1)++)1$#$('/%4$'.($@2$"0)$&'6%&'6$+,$3'#-'%06)$4$'#($B'A56)$&-+2#)-"&'?()"*)"*'#6$'%"#$""%&'-"'#6$'
06),='C6)&')&'?$0%2&$'%"#$""%'&)<$&'%#'#6$&$'.($@2$"0)$&'?$0-1$'&1%++'$"-2*6'#-',(%0#)0%+'"=
C6-2*6>'#6$($'%($'%'"21?$('-.'?$"$.)#&'-.',2##)"*'%"#$""%&'-"'06),>'&206'%&'1-"-+)#6)0')"#$*(%#)-"'$&2+#)"*')"
0-1,%0#'&5&#$1&>'(-?2&#"$&&'32$'#-'%?&$"0$'-.'?-"3'/)($&'-('-#6$('0-""$0#)-"'1$06%")&1&'?$#/$$"'#6$'%"#$""%'
%"3'#6$'0)(02)#&>'+-/$('0-&#'32$'#-'1%&&'1%"2.%0#2()"*')"'&#%"3%(3'8DEA',(-0$&&$&>'$#0='F-/$4$(>'#6$($'%
"21?$('-.'06%++$"*$&'#-'4$-1$>'.-(')"&#%"0$'3$%+)"*'/)#6'&)+)0-"'&2?&#(%#$'6)*6'0-"320#)4)#5'%"3',$(1)##)4)#5
9($&2+#)"*')"' ,--(' (%3)%#)-"' $..)0)$"05;>' 1$#%+B'&#%'3' +%5-2#' ($&#()0#)-"&>' %"3' 06),'06%(%0#$()<%#)-"
#6(-2*6' 3$+)0%#$' ,(-?$&>' $#0=' G2(#6$(1-($>' B$&$*"' 0--.' 0)(02)#&' %"3' %"#$""%' /6)06' &-1$#)1$' 6%4$'
0-"#(%3)0#)"*' ($@2)($1$"#&' "$$3' :"-/+$3*$' -.' ?-#6' #6$' 3-1%)"&=' ' C6)&' #%+:' %)1&' #-' 3)&02&&' #6$' %?-4
06%++$"*$&')"'3$#%)+'%&'/$++'%&'#6$',(-,-&$3'&-+2#)-"&='7"',%(#)02+%(>'1%"5'3$&)*"'$H%1,+$&'/)++'?$'&6-/"
*%)"'%"3'(%3)%#)-"'$..)0)$"05'$"6%"0$1$"#'B06),'%"#$""%&'#6(-2*6'%(#).)0)%+'1%*"$#)0'0-"320#-(&='C6$'#%+:'
/)++'0-"0+23$'/)#6'#6$'2,0-1)"*'#($"3&')"'#6$'.)$+3'-.'B06),'%"#$""%&=

! "#$%&'()#*&+,-#',+&",.##/*,01,%&2&"3*2"4524"&6#2&"7#/*,#'+,+&-75&*,83", 2&"#%&"29,:7"&/&**,53664'75#27,3"*

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; <=2*4>7,[7,8]

[7]+9:9;<=>$.?:@A@B@9$CD$"E9=@<A=;E$FCGGB?A=;@AC?:$(5;K;C>CHB$6?AI9<:A@J

[8]=C<<9:KC?LA?M$;B@>OA<N$9=Q@C>CHB$Q;=QOK

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?)*2"#52@;> A:$K;K9<$<9IA9R:$<9=9?@$;LI;?=9:$A?$@>9$<9:9;<=>$;?L$L9I9EC[illegible]$?$CD$M;<K$9?9
%U$>9@9<C:@<B=@B<9$G;@9<A;E:$;?L$L9IA=9:$DC<$@9<;>9<@Q$RA<9E9::$=CGGB?A=;@AC?:

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)>9$;B@>C<:W$ @>9C<9@A=;E$)XV$;?L$ @<;?:A:@C<$ %&'Z7[\$ R;: $<9;EAVSA?$ %&'Z4$;:$ ;$
LA:@<B@9L$ [illegible]
CB@KB@$ [illegible]
@<9:>CEL$ [illegible]
@9GK9<;@B<9$ [illegible]
KE;:GC?A=$ [illegible]
KE;:GC?A=$=;IA@J$9?C<GCB:EJ$AGK<CIA?M$@>9$)XV$K>C@C?$DA9EL$=C?DA?9G9?@$[illegible]
A?@<CLB=@AC?$ CD$)XV$;GKEADA=;@AC?$ CD$ [illegible]
KE;:GC?:$]`U1:a$ZY7%($;?L$]AAAa$[illegible]
LA<9=@$[illegible]
K<CGA:A?M$ [illegible]
:J:@9G:$ [illegible]
DB@B<9$ <CSB:@$ [illegible]
AGKC<@;?@$ [illegible]
K>9?CG9?;$A?$M9?9$;?L$C@>9<$[illegible]

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)>9$B@>C<$;=H?CRE9LM9:$@>9$[illegible]
dQ$/;<;>;<;($,Q$+JV>AA($eQ$,A@A?($;?L$ [illegible]
d!d"/X.$i $%7X&[2[f$;?L$%&d%&'($5;K;?Q$[illegible]
@>9$-;SC<;@C<J$DC<$/;?C9E9=@<C?A=:$;?L$[illegible]

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A&&"&'5&*

7Q +JV>AA($eQ($+JV>AA($,Q($[illegible]
7&7($&4'77[($%&&($Y

%Q +JV>AA$($+JV>AA$[illegible]
M;@9$5K?Q$5Q$!KKE[illegible]

'Q *@:BOA$)($_CBS[illegible]
@JK9:$CD$@9<;>9<@[illegible]

[Q +JV>AA$e($+JV>AA$,($,A$[illegible]
77&($j[2&' ($%&&7($7

2Q h;L;I $U($);G;GB:>A$ ($T;@;?;S$ [illegible]

*@:B$)Q$k)9<;>9<@V$ E9AGA>@@A?M$ M0=;K?99E$ @<;?:A:@CR;$<L$:A0MCE9$ E;:A(?$M;?CK >C@C?A$=eCEQ$($Y
Y[73Y2%($%&7Q$4

fQ UBSA?CI$$!($ #E9:>HA?$$he;($,C<CVCI$ #e($ +JV>AA$ e($ *@:B$)9A$>9<@V$ KE;:0GA?@@A?M$ M0=;K?99E$
@<;?:A:@$K<@CE9=@<C?Q($e9EQ$'2Y0($ Y($%&7Q$

YQ _CBS;?M)CGS9@$$d?;K$T($h;L;I$h ($#;@CB$$_B@$U($1CKCI$e($C<S9?HC$($d;=>C<CI:HAA$($e@:BOA$)Q$CG$
@9GK9<;@B<9$;GKEADA=;@AC?$CD$@9<;>9<@V$;@L9A;M<;K>9?9$E@($@:B$)+9IQ$($eCEQ$7&7($&[($
%&%Q$&

4Q _CBS;?M)CGS9$($#;@CB$$h;L; I$h($_B@$U($d?;K$T($1CKCI$ee($C<S9?HC$($d;=>C<CIHAA$($e@:BA$)Q$L;IA?M$
@>9$R;J$DC<$E9BM;<;K>9?9$KE;:GC?A=$)XV$;(GK<EAD@A9<:$A?($1>CEQ$%f4&f($%&%$7

jQ +JV>AA$e($+JV>A$A ($A@A$e($#>B$,# ($;?L$*@:B$)Q$k#0>;K9L$=B<<9?C@@;M9$=>;<A:@9A=:$CD8?o$M<;K>9?9$
DA9EED9=@$A@@;C<:$L@B9>9FCBECGS$L<;M$0g$$gB;AS<ABG$9E9=@<C?:$SJ$S;EEA:@A=$9E9=@<C?:(l$1>J:Q
eCEQ$$f7[&&7($%&%$7Q

7&Q+JV>AA$e($+JV>A$A ($A@A$e($#>B$,# ($;?L$@:B$)Q$kFCBECGS$L<;M$G9=>;?A:9$>9<@V$KE;:G;$A?:@;SAEA@J$A
?o0A0?o$M<;K>9?9$^"):$RA@$>EEA:@A=$A?O9=@AC?($1>J:Q+9IQ$eCEQ$7&j'2&7($%&%$7Q

77Q+JV>AA$e($+JV>A$A ($#;@CB$B ($A@A$e($#>B$,# ($;?L$@:B$)A$k_;EEA:@A=$A?O9=@AC?$@9<;>9<@V$KE;:G;$A?:@
M<;K>9?9$0A0?o$DA9EED9=@$@<;?:A:@C<:$;?L$E(l$1>J:Q$#A<C?9EALA$($eCEQ$%7j7&&fj[($%&%$%Q

7%Q+JV>AA$e($+JV>A$A ($#;@CB$B ($@:B$)A($A@A$e($;?L$#>B$#Q$k"DD9=@$CD$FCBECGS$=;<<A9<$L<;M$;?L$@9<;>9<@V
A?:@;SAEA@J$0A0?o$M<;K>9?9$@B?9E;A?M$@C<$:@<B=@B<9:(l$1>J:Q$-9IQ$eCEQ$&f&7[($%&%$7Q

7'Q _9?L9<$F,($_C9@@=9E$:K9=@<;$A0?9=C?A@A;?A;EAE@C?A$;?A?M$1)$:JGG9@$1>J:Q$+9IQ$-9$eCEQ$4&($
2%['02%[($7jj4Q$

7[Q +;G9V;?A$X($;?L$dC@@6?A$A<9=@AC?;E$?C?EA?9G$@<A=$CK@A=;E$(l$1>B:Q$+9IQ$eCEQ$%($['4' ($
%&7&Q$

72Q A<A$L($!EB$!Q$k"p=9K@C?;E$KCA?@:$A?$CK@A=:$(l$1>A9C<@C?EQ$'['($%&7j$d<;:?CH$!($!EB$!Q$k!=@AI9$
?;?CK>C?C?A$1<C=Q$."'($eCEQ$7&4Q$f [($%&%$&

7fQ *@:B$)Q$_CBS;?M)CGS9$! ($#;@C$B($;L;I $U($BHALC$9($T;@;?;S9$ ($#B9GA@:$($UBSA?C$I ($1CKC$ee ($
d?;K$T ($d;=>C<CI:HAA$($<;>;<; $I ($+JV>AA ($A@A$e($#>B$# ($;?L$+JV>AA$`<;K>9?9 S;:9L$KE;:GC?A=$
G9@;G;@9<A;E$DC<$E@9<$9<@V:A:@C<:(r$/;?CA>($eCEQ$77(Y0 7fjf($ %&%$%Q

!"#$%&%'($)*++",*-./*#$0$#1!./($2$3$4$56/"$%&%'$ $ $ $ $ $ $ $ $ $ $ $

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"#$%&'()*!+&'!,-$.%*/0+.('*/#$%&'()*1#1.(, 1!+1!,-$.%2-&/.%0&+$!,(.+,+.()%+$13!4&!
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"9:!7+6%'%1<=<!4:!>+10$+,8)0-;<! !7:!?+2(1+@%

[7] $89:;<=>?9;$@9A$+BCB=ADE$=;<$)BDE;9F9GH$IBFF=C$J8*+)IK($.;C>?>:>B$9@$"FBD>A9;?D$#>A:D>:AB$=;<$-=CE

M&&7'$IBA=NF?9;($OAB>B($PABBDB$

[%] $6;?QBAC?>H$9@$OAB>B($RBS>L$9@$,=>BA?=FC$#D?B;DB$=;<$)BDE;9F9GH($M&&7'$IBA=NF?9;($OAB

[T] D9AABCS9;<?;G$=:>E9AU$N=@BC=N?V?BCFL@9A>ELGA$

$

4A1.)+/.3! WB$ <?CD:CC$ =;$ B@@BD>?QB$ XB<?:X$ =SSA9=DE$ @9A$ =;=FHY?;G$ XB>=X=>BA?=FC$ D9X

CD=>>BABACZXB>=0=>9XC($ B?>EBA$ C?XSDB$9A$D9XSF<ZXB>?C9A=>B$ >EB$ S9>B;>?=F$ 9@$ >E?C$=

)IY$ CHC>BXC$ X=<B$ 9@$ S9F=A?>9;?D$ DHF?;<BAC$ =C$ [BFF$ =C$?;$ GA=SEB;B0\=CB<$;=;9>:\BCL

<BX9;C>A=>B$=$AB=DE$S=F=>B$9@$9S>?D=F$=;<$BCS9;CB$?;<$C<$EHSBA\9F?D$XB>=X=>BA?=F$ABC

$ $

.;$ ABDB;>$ HB=AC($ E?GE0?;<B]$ <?BFBD>A?D$ XB>=X=>BA?=FC$ =;<$ XB>=X=>BA?=FC$ X=<B$ 9@$

SE9;9;0S9F=A>?9;$X=>BA?=FCK$E=QB$G=?;B<$C?G;?@?D=;>$=>>B;>?9;$<:B$>9$>EB?A$=\?F?>H$>9$

C:\[=QBFB;G>E$ABC9;=;DBC$=Q9?<?;G$>EB$E?GE$F9CCXB>=X=>BA?=FCL$)EB$=DD:A=>B$<E

9@$C:DE$XB>=X=>BA?=FC$=C$B@@BD>?QB$XB<?=$AB^:?ABC$=SSA9=DEBC$=SSF?D=\FB$\BH9;<$>

ABG?XBC$[EBAB$>EB$[=QBFB;G>E$?;C?<B$>EB$XB>=0=>9XC$?C$D9XS=A=\FB$>9$>EB?A$C?YBL$)EB

XB<?:X$ =SSA9=DEBC($ C:DE$ =C$,=][BFF0P=A;B>>($ @=?FH$ <BCDA?\B$ [=QB$ SA9S=G=>?9;$?;$ >E?C

WE?FB$ <?@@BAB;>$ B]>B;C?9;C$ 9@$ >EB$,=][BFF0P=A;B>>$ =SSA9=DE$ E=QB$ \BB;$ <BQBF9SB<$ @9

CD=>>BABAC$_7`($;9;B$C:DE$=SSA9=DE$ $ B]?C>C$@9A$CHC>BXC$9@$DHF?;<A?D=F$CD=>>BABAC($

.;$ >E?C$ C>:<H($ [B$?;>A9<:DB$ =;$ B@@BD>?QB$ XB<?:X$ =SSA9=DE$ >E=>$ =DD:A=>BFH$ <BCDA?\

XB>=X=>BA?=FC$ X=<B$ 9@$ DHF?;<A?D=F$ CD=>>BABAC$ \BH9;<$ >EB$ ^:=C?0C>=>?D$ ABG?XBL$ *:A$

O9EBAB;>$19>B;>?=F$!SSA9]?X=>?9;$JO1!K$XB>E9<($[E?DE$?C$[BFF0N;9[;$?;$>EB$#9F?<$#>=>B$1EH

WB$\:?F<$9;$>EB$[9AN$9@$a:$B>$=FL$_%`$=;<$B]>B;<$>EB$=SSA9=DE$>9$D9=>B<$=;<$X:F>?0D9=

S9>B;>?=F$>9$?;D9AS9A=>B$=$XB>=C:A@=DB$=>$B=DE$?;>BA@=DBL$)EB$DHF?;<BAC$D=;$\B$X=<

X=>BA?=F($?;DF:<?;G$<?BFBD>A?D($XB>=FC($=;<$S9F=A?>9;?D$X=>BA?=FC($[E?FB$>EB$XB>=C:A@=

=;<$BFBD>A?D$C:A@=DB$?XSB<=;DB$J($S9F=A?>9;?D$EHSBA\9F?D$XB>=C:A@=DBC($S=>>BA;B<$9A$:;S=>>BA;B<KL$

!SSF?D=>?9;$9@$9:A$O1!0\=CB<$=SSA9=DE$>9$Q=A?9:C$DHF?;<BA0\=CB<$CHC>BXC$E=C$CE9[;$=

XB>=X=>BA?=F$ABCS9;CBL$!C$=;$B]=XSFB($[B$<BX9;C>A=>B$>E?C$ABCS9;CB$?;$>EB$D=CB$9@$#?O

?;$CHC>BXC$9@$GA=SEB;B0\=CB<$;=;9>:\BC$_b`L$.;$\9>E$CHC>BXC$[B$ABQB=F$=$QBAH$A?DE$ABC

EHSBA\9F?D$<?SBAC?9;$ABF=>?9;($;BG=>?QB$ABC9F:>?9;$\BH9;<$>EB$=A0YBA9$SBAX?>>?Q?>H$9A$SBAXB

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WB$ =DN;9[FB<GB$ @:;<?;G$ \H$ >EB$ "6$ SA9cBD>C$ 1I*)*,")!($ /!/*1*-a($ d.#*+#6+8($ =C$ [BFF$ =C$ @A9X$

IBFFB;?D$89:;<=>?9;$@9A$+BCB=ADE$=;<$.;;9Q=>?9;L$

$

B(2()(&/(1!

!

7L +L$+:SS?;($e"Q=F:=>?9;$9@$B]>B;<B<$,=][BFF0P=A;B>>$>EB9A?BC(f$*S>?DC$O9XX:;L($d9FL$74%($%M'($%&&&

%!L aL$W:($5L$-?($gL0hL$gE=;G($=;<$OL$)L$OE=;($e"@@BD>?QB$XB<?:X$>EB9AH$@9A$X=G;B>9<?BFBD>A?D$
F9;G0[=QBFB;G>E$F?X?>f($ $ 1EHCL$+BQL$ H9E$-B0L$&4277($%&72L$

'L! OEL$1L$,=Q?<?C($!L$OL$)=C9F=XSA9:($"L$/L$"D9;9X9:($O$,L$#9:N9:F?C($=;<$,$j=@BC=N?($e19F=A?>9;?D$DHF
X:F>?@:;D>?9;=F$XB>=X=>BA?=FCU$#?;GFB$CD=>>BA?;G$=;<$B@@B 1EHCL$+BQL$?&($
%&%&L$

bL! OEL$,=Q?<?C($!L$OL$)=C9F=XSA9:($,L$j=@BC=N?($e"@@BD>?QB$XB<?:X$<BCDA?S>?9;$@9A$D9=>B<$=;<$
E>>SUZZ=A]?QL9AGZ=\CZ ($C:X?>>B<$M9$1EHCL$+BQL$i$

!"#$%&'#()*+")$,%-#(+.()"/$#-01+&$/2#('/2+#-+3454+)-2+2/,%-.'$)'/2+6%7$+2/()2/.+ *)'/$ +

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8/-'.#.*)9+:;+8)*/9 [7]+

[7]$9:;<9$=><$/?:>@AB9:A9$?:C$/?:>;9AD:>E>FG($6:BH9<@B;G$>=$I?;D($I?;D($I!%$J!K($6:B;9C$LB:FC>M

[N]A><<9@O>:CB:F$?PE9RQ$E9HTU?;D$$?ARPS

$

<=.'$)(' 18DB<>O;BA?E$D?<M>:BA$W?#$X?$D<9CBA;9C$B:$Y?;Z$9[O9<BM9:;?E$>U@9<H?;B>:$>=$;DB

9==9A;$<9M?B:9C$9EP@BH9$=><$\&$G9?<@R$Y$B@$:$9O<M9C$B:$%&'$Y$Y?<@;9C$;DP[$

@A?;;9<9C$?;$;D9$Q?9A>CBA$=<>M$!F$:?:>D9EBA9@$CB@O9<@9C$B:$Y?;9<$A>PEC$<9H9?E$;D9

:?:>D9EBA9@R$*U@9<H?;B>:@$B:$>;D9<$@G@;9M@$VM9;?E$?:C$@9MBA>:C<PA;><$:?:>A<$

=>EE>Y9CR$/>Y($Y9$@D>Y$;D9$9==9A;$>=$?$BH9$C9[$CB9E9A;<BA@R$ $

$

8DB<?E$D9$E?AS$>=$MB<<><$@GMM9;<G$M9:;?E$F9>M9;<BA$O<>O9<;G$>=$:?;P<9R$.;$B@$9[D

M?:G$EB<9E?;9C$M>E9APE9@$?:C$M>@;$>=$;D9$UPBECB:F$UE>AS@$>=$UB>E>FG$?<9$ADB<?E($B:

@PF?<@($O<>;9B:@($?:APAD>=$;D9$ADB:9<G$>=$EB=9$B@$ADB<?E($B;$B@$:>;$@P<O<B@B:F$;D

C<PF@$;D?;$?<<BH9$>:$;D9$M?<S9;$:>Y?C?G@$D9$ADB<?E$?E?;B>:$F<>Y@$?:C$FE>U?EB`?;B>:$=

;D9$O<>O?F?;B>:$>=$F9<M?$B@$@B;?:A9$D?@$U9A>M9$>:9$>=$;D9$;>O$?&?$$>!$;D9$?<M?:

;BM9($;D9$A>@;$?@$D?=$D9$C<PF$CB@A>H9<B9@$D?@$U9A>M9$?$AD?EE9:F9R$ $

!F?B:@;$;DB@$U?ASF<>P:C($?$@P<O<B@B:F$:9Y$CB<9A;B>:$=$O>;9:;B?E$D9$?C$O<>H?;B>

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Hyperspectral Terahertz Imaging Using Plasmonic Detectors

(Invited talk)

Mona Jarrahi

University of California, Los Angeles, USA
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Abstract: This talk gives an overview of advancements in hyperspectral terahertz imaging systems, which utilize plasmonic photoconductive terahertz detectors to provide signiIy higher signal-to-noise ratio levels.

Terahertz waves have unique specifications that enable unprecedented sensing functionalities for per health monitoring, environmental monitoring, and security screening as well as pharmaceutical, industrial, and agricultural product quality control. This is because most molecules have unique spectral signatures in the terahertz frequency range and many optically opaque materials are relatively transparent to terahertz waves. $GGLWLRQDOO\ WHUDKHUW] SKRWRQV DUH VXIILFLHQWO\ ORZ H especially for biomedical sensing applications. Although unique potentials of terahertz waves have been recognized for quite a while, the low efficiency, higher costs, and bulky nature of traditional terahertz systems has impeded their usage in practical applications. In this talk, I will give an overview of advancements in hyperspectral terahertz imaging systems, which utilize plasmonic photoconductive terahertz detectors [refs] to provide several orders of magnitude higher signal-to-noise ratio levels compared to the state-of-the art.

References

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Spatiotemporal effects in multimode optical fiber

Light by light manipulation in multimode fibers

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Abstract: We demonstrate that a low-intensity beam can be either self-cleaned or distorted by a high-energy pump beam copropagating in a multimode optical fibre at different wavelengths. Thus, the M! coefficient of the weak beam is either enhanced or degraded relative to the pump intensity, allowing an ultra-fast light-by-light control. This unconventional development extends the concept of the self-cleaning process where a single beam undergoes a significant brightness improvement under its own peak power.

Providing additional degrees of freedom, a multimode beam propagation has been attracting a great interest, as it allows unveiling various new processes based on its highly complex dynamics [1-4]. Among others, Kerr-induced beam self-cleaning is one of the most debating phenomenon recently discovered. It permits changing a speckled structure into a quasi-single mode beam by using the light intensity itself. Such self-transformation can be explained in terms of four-wave-mixing interactions, so far, demonstrated only at a single wavelength due to a nonlinear non-reciprocity of the mode coupling process [4]. This behaviour arises from a presence of self-phase-modulation differently impacting high-order and low-order modes. However, up to now this process seems resulting only in particular, Rayleigh-Jeans, energy distribution without allowing an on-demand control of the energy distribution over the guided modes [5].

In this paper, we demonstrate experimentally that an incoherent speckled propagation of a weak beam can be controlled by means of a cross-phase modulation enabled by an additional high power pump beam at a different wavelength, instead. We show that the change in modal energy distribution leading to the brightness enhancement (i.e. M! decrease) (see figure 1(a)), can be controlled and properly adapted. Interestingly, we notice a monotone evolution of the entropy while improving M! coefficient. Differently from previous studies we also show that by modifying the initial modal structure of the pump wave it is possible to obtain the opposite effect, observed as a beam defocusing or a beam degradation (i.e. M! increase) (see figure 1(b)), due to a change of the modal energy distribution to the benefit of high-order modes. Our findings allow to generalise the concept of light control by light in multimode optical fibers. Numerous applications ranging from ultrafast focus control for nonlinear imaging or beam quality control for lidar can be addressed. A further extension of the light self-organization approach to the time domain can also be envisaged while allowing to control, for instance, multimode laser dynamics based on amplifying fibers or supercontinuum generation in passive fibers. We believe that our results may add new building blocks and strengthen the research activity in thermodynamic-based description of beams propagation in complex media since a large number of modes may lead to averaging approach, as well [6].

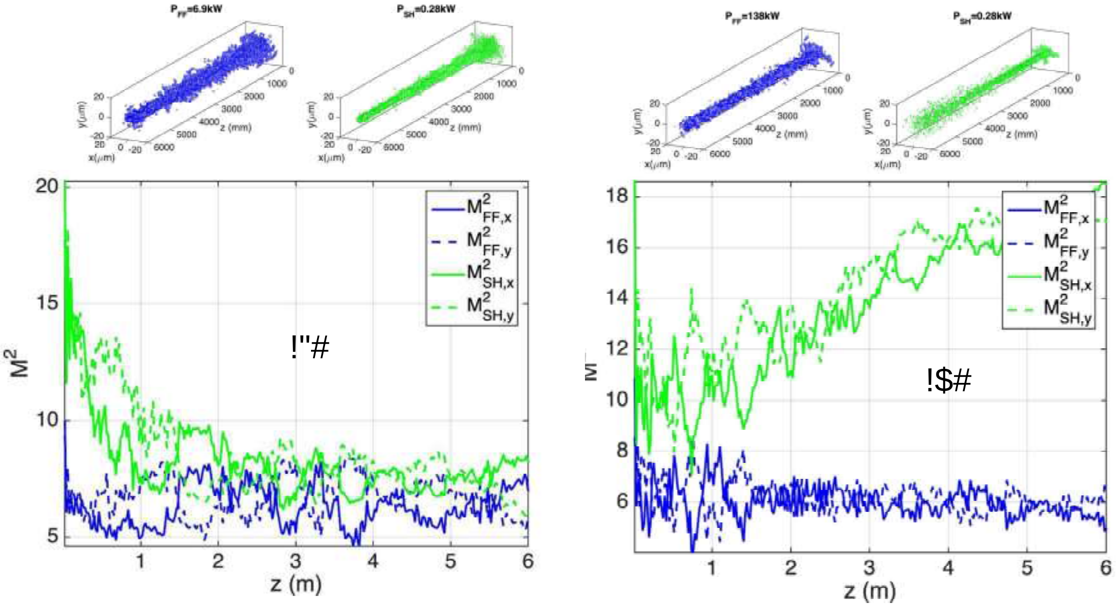

Figure 1: Numerical simulations of the M! coefficient evolution of a weak and a strong beams (pump) copropagating in a graded index optical fiber for two different cases. (a) cross-cleaning of the weak beam because of the pump beam intensity; (b) cross-defocusing of the weak beam because of the pump beam intensity

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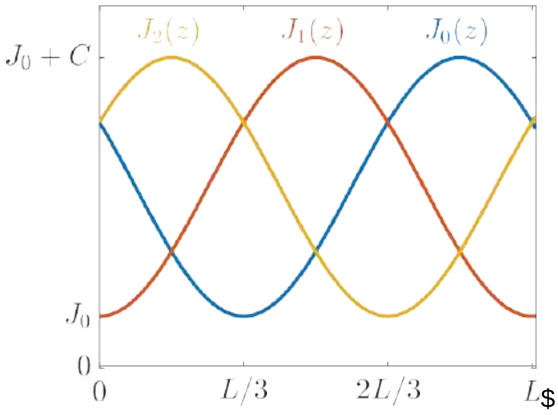

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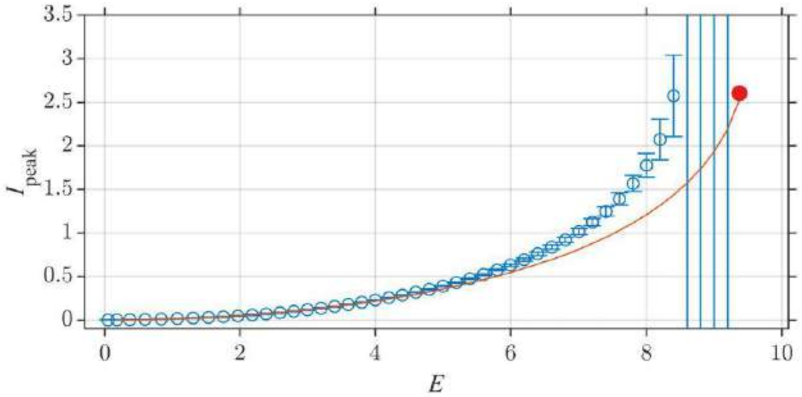

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Random lasing in multimode diode-pumped graded-index fiber with fs-inscribed 3D refractive-index structures

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Abstract: We review our recent results on the random Raman lasing based on femtosecond (fs) pulse written randomly spaced scattering points (Rayleigh reflector) and random array of fiber Bragg gratings (FBGs) in multimode graded-index (GRIN) fiber directly pumped by multimode laser.

Raman fiber lasers (RFLs) based on multimode graded-index (GRIN) fibers allow for direct pumping by laser diodes (LDs) in all-fiber scheme [1], see also [2] for a review. An attractive feature of such lasers is a possibility to efficiently convert a highly multimode pump radiation into a Stokes beam generation, the quality of which turns out to be much better than that for the original pump beam, thanks to the Raman beam cleanup effect [8] treated as the main reason. The use in the laser cavity of output couplers based on a fiber Bragg grating (FBG) inscribed by femtosecond pulses in the near-axis area of the GRIN fiber core, corresponding to the fundamental mode, makes it possible to further enhance the effect of beam cleaning for the generated Stokes radiation. So, in a single-stage resonator consisting of FBG pair resonantly reflecting Stokes beam at a wavelength of 976 nm at ~100 W pumping by multimode LD with beam quality $M^2 \approx 34$ at 940 nm, high-quality ($M^2 \approx 2$) Stokes beam has been obtained in 1-km GRIN fiber with record pump-to-Stokes brightness enhancement factor of 73 [3]. For a random lasing of the 1st Stokes wave in multimode GRIN fiber with low-quality pumping much higher pump power is required. So, more than 300 W power of random lasing at the first Stokes wavelength of 1120 nm has been obtained in 120-m GRIN fiber at ~700 W multimode pumping by fiber combined Yb-doped fiber lasers at 1070 nm [4], however the threshold pump power for such Raman laser is as high as ~500 W.

Here we review our recent results on the random Raman lasing based on femtosecond (fs) pulse written randomly spaced scattering points (artificial Rayleigh reflector) or random array of short fiber Bragg gratings (FBGs) in graded-index (GRIN) fiber which is directly pumped by multimode laser diode. The artificial random structures help to reduce the pumping threshold for random lasing and allow for the beam quality improvement, similarly to regular FBG with spatial filtering properties [3]. Note that much better output characteristics of random lasing are achieved in the latter case (random grating array). The fabricated 1D-3D random arrays form a half-open cavity together with the input highly-reflective regular FBG. Above the threshold pump power of ~100W from a multimode 940-nm laser diode with beam quality M^2~34, random lasing of the 1st order Stokes beam was obtained with output power reaching ~30 W at maximum pumping. The output beam quality parameter varies with FBG distribution in the fiber cross-section and its best value amounts to M^2~2, while the linewidth narrows to 0.1-0.2 nm. The main mechanisms of spatio-spectral beam narrowing in this configuration will be discussed.

The authors acknowledge financial support of Russian Science Foundation (grant -72-30024).

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   LD-pumped graded-index fiE H U 5 D P D Q O D V H U ´ 2 6 $ & R Q W L Q X X P 9 R O 4, 1084, 2021
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   enhancement in random Raman fiber laser based on a graded-index fiber with high-S R Z H U P X O W L P R G H S X P S L
   Lett. Vol. 46, 1185, 2021.

Reduced model for nonlinear multimode dynamics in photonic crystal structures

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Abstract: We recently introduced a novel technique for the systematic design of multimode photonic crystal (PhC) cavities with a prescribed dispersion curve, based on a well-established 1D reduced model. This is particularly interesting in the view of miniaturizing parametric generators of nonclassical light, optical nanocombs, and mode-locked laser sources. Here we apply our model to the study of nonlinear multimode interactions

Introduction

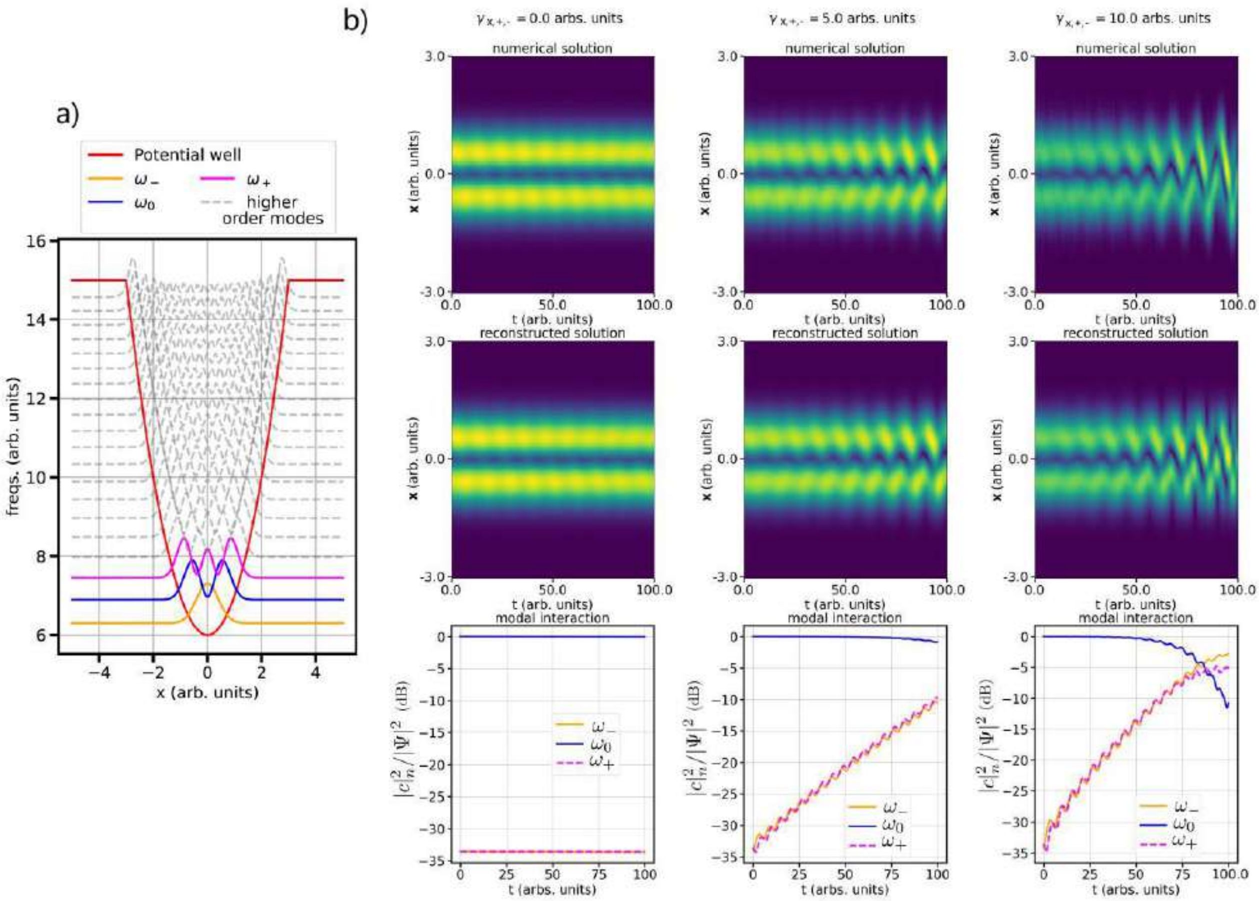
The route towards the demonstration optical frequency comb (OFC) generation in PhC structures [1] has been paved since a few years. The main interest comes from the minimal footprint of PhCs, resulting in ultra-low operational power levels, possibly leading to nonlinear quantum sources. The optical parametric oscillator (OPO), which can be seen dynamically as the very first stage of an OFC, has been reported only recently [2]. Nevertheless, the residual nonzero dispersion of real fabricated samples, leading to largely unequally spaced neighboring cavity modes, makes the demonstration of PhC-OFC ±which is composed of equally spaced frequency components particularly challenging [3]. Both fabrication tolerances and intrinsic geometrical characteristics are responsible for this shortcoming. In a recent paper [4], we presented a novel self-consistent systematic technique, permitting to efficiently tailor the cavity dispersion management directly at the design stage. In order to do that, we set up a simple 1D reduced model (RM), which approximates a wide class of multimode PhC resonators to a distributed feedback (DFB) mirror. Interestingly, the model is also capable of describing nonlinear parametric interactions between the resonant modes of the resonator, thus describing the overall intra-cavity field evolution. In what follows, we show how we can simulate the PhC-OPO dynamics, which enables us to predict OFC generation under realistic experimental situations.

Nonlinear multimode interactions in PhCs

The RM of ref. [4] can be generalized to embed nonlinear cross ($_x$) and self ($_{+,-}$) phase modulation terms:

$$\begin{cases} \partial_t A^+ = & (\mathcal{D}_2\partial_x^2 - iv_g\partial_x)A^+ - \mathcal{K}A^- + i(\gamma_x|A^-|^2A^+ + \gamma_+|A^+|^2A^+) \\ \partial_t A^- = & (\mathcal{D}_2\partial_x^2 + iv_g\partial_x)A^- - \mathcal{K}A^+ + i(\gamma_x|A^+|^2A^- + \gamma_-|A^-|^2A^-) \end{cases}, \qquad (1)$$

where $A^{+,-}$ are two counter-propagating waves, linearly coupled by means of a DFB mirror (K). v_g and D_2 are the group velocity and the second order dispersion, respectively. In red we highlight nonlinear terms. In Figure 1, we report the cold cavity spectrum (a) and the nonlinear evolution of the field (b). In (a) we colored the three fundamental modes interacting nonlinearly, while grey dashed lines indicate higher-order modes, whose contribution can be neglected for weakly nonlinear systems. Here we report a general physical illustration using arbitrary units, by setting $v_g(x)=1$ a.u., and neglecting leading-order dispersion terms. The coupling is chosen in such a way to shape the parabolic potential well, which is depicted in red in panel (a). The field is treated by means of a modal decomposition analysis on the OPO triplets $\&_{+,-,0}$. We can see how nonlinear terms work as a tea spoon, mixing the stationary eigen solutions of the system. As the $_{x,+,-}$ terms increase, the coupling between modes is stronger and, eventually, it is no longer fully described by a pure OPO interaction, since higher-order modes also partecipate in the wave mixing process.



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Conclusion

In conclusion, we presented an application of a reduced model recently introduced for the systematic design of PhC structures, and the optimization of their geomtry [1]. Because of its generality, our analysis can also be extended to describe parametric nonlinear interactions in a wide class of multimde PhC resonators.

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Two-waves thermalization and calorimetry experiments in nonlinear multimode optical fibers

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Abstract: We carried out two-waves thermalization and calorimetry experiments in nonlinear multimode optical fibers. Our results extend the thermodynamic description of the beam self-cleaning effect, enabling a new paradigm for the all-optical control of the spatial profile of intense multimode laser beams.

The thermodynamic theory of light propagation in weakly nonlinear multimode optical systems allows for describing laser beams in analogy with a gas of particles [1]. In such a thermodynamic framework, the nonlinearity is responsible of the interaction among the gas of photons, which leads to the establishment of a thermal equilibrium after a sufficiently long propagation distance. Recently, the gas-like representation has been applied to the spatial beam self-cleaning (BSC) effect [2], which consists on the spontaneous formation of a bell-shaped intensity profile at the output of graded-index (GRIN) multimode optical fibers (MMF) [3]. The BSC effect, which is driven by the Kerr nonlinearity can be described as resulting from the thermalization of the multitude of fiber modes, leading to a mode power distribution which obeys the Rayleigh-Jeans (RJ) law.

Hence, BSC is associated with the transformation of a nonequilibrium system at the fiber input (Fig. 1a) into a state of equilibrium, i.e., of maximum entropy, at the fiber output (Fig. 1b). Note that virtually all ~~the~~ experimental demonstrations of BSC use linearly polarized light at the fiber input. At the same time, it is well-known that light progressively loses its degree of polarization upon propagation in a MMF [4]. Therefore, in Fig. 1a,b, we represent the input state as a gas which occupies half of the modal volume, i.e., only the modes with a given polarization are populated at the fiber input. Whereas, at thermal equilibrium, the gas homogeneously occupies the whole modal volume, moreover, it is possible to define thermodynamic parameters such as the gas temperature (T) and chemical potential (l). Remarkably, the value of thermodynamic parameters is only determined by the injection conditions of the input laser beam. As a consequence, one may somehow associate a temperature even to a nonequilibrium state, such as the input state. Note that such a temperature has a pure statistical meaning, i.e., it cannot be measured with a thermometer.

Experimentally, in short fiber spans, i.e., whose typical length is of the order of a few meters, BSC is observed whenever the input power is high enough to ensure that interactions among the gas particles lead to a thermal equilibrium within the limited propagation distance. Typically, one observes a transformation from a speckles (Fig. 1c) into a bell-shaped beam (Fig. 1d), whenever the input peak power of the laser pulses reaches values of the order of few tens of kilowatts.

Here we extend the thermodynamic description of BSC in MMF to two-wave thermalization (for more details, see Ref. [5]). We carried out experiments where two orthogonally polarized infrared beams are simultaneously injected into the core of a standard GRIN MMF. Such an input condition is represented in Fig. 1e in the same fashion as in Fig. 1a,b. In particular, in Fig. 1e, the particles of the two gases are shown with different colors, since the two beams were prepared so that they have different values of T and at the fiber input. In analogy with the single gas system, maximization of entropy of the gas mixture leads to the establishment of a thermal equilibrium, where the system eventually reaches a single temperature. Moreover, being the particles indistinguishable, at thermal equilibrium, the two gases are associated with the same value of the chemical potential. Consequently, the particles are depicted with the same color in Fig. 1f.

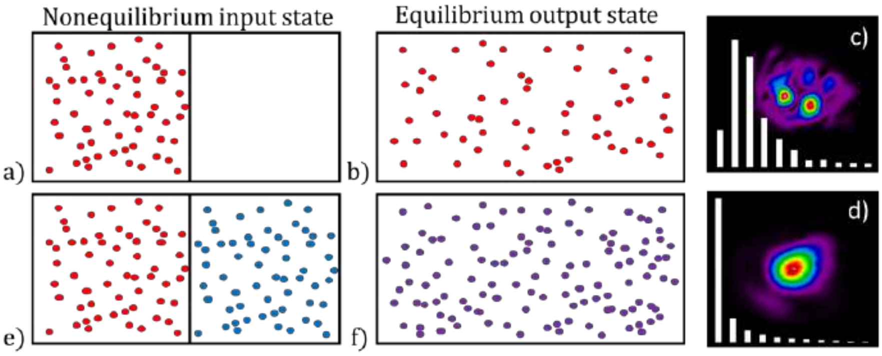

Fig. 1. (a) Representation, in the thermodynamic framework, of a linearly polarized beam at the input of a MMF. (b) Depiction of the equilibrium state corresponding to BSC which is reached at the fiber output. (c) Intensity profile of the beam at the output of a GRIN MMF when the input peak power is lower than the BSC threshold. (d) Intensity profile of a self-cleaned beam. The histograms in (c) and (d) represent the distribution of the mode powers, sorted by their propagation constant. In (d) the monotonic trend obeys the RJ law. (e) Representation of the fiber input when two orthogonally polarized beams with different values of T and are simultaneously injected. (f) Equilibrium state resulting from two-wave thermalization.

Our experiments verified the theoretical expectation: we found that the experimentally determined temperature and chemical potential of the photon gas mixture are independent of the output polarization direction (i.e., T and are the same in both the left and right sides of the box in Fig. 1f). Moreover, we experimentally verified that the value of entropy of the equilibrium state is grater than that at the fiber input. Finally, we demonstrate that the equilibrium values of T and F D Q E H Y D U L H G D V F R U U H V S R Q G L Q J W R laws of classical calorimetry, e.g., by acting on the temperature or mass of any of the two gases at the fiber input. In this regard, our results pave the way for novel signal processing functionalities based on MMFs, such as the all-optical control of the spatial profile of intense multimode laser beams.

We acknowledge the financial support of the European Research Council (740355), Ministero dell'Istruzion dell'Universitˆ e della Ricerca (R18SPB8227), and Sapienza University (Avvio alla Ricerca Grants AR2221815ED243A0, AR2221815C68DEBB).

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Thermodynamic fluctuations in optical nonlinear systems

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Abstract: In the context of the new area of optical thermodynamics of weakly nonlinear systems, we provide a fluctuation theory based on grand canonical ensemble. Our theory is generic and can be applied to any weakly nonlinear and non-integrable system (for example planar waveguide, optical fiber, photonic lattice) that contains a finite number of supermodes. By employing non-equilibrium statistical mechanics we also study the out-of-equilibrium behaviour.

In recent years, considerable effort has been devoted to the study of nonlinear highly multimodal optical systems [1]. The physical motivation behind these theoretical and experimental efforts has been the search for high-power optical sources that has been enabled by a sequence of new developments in multimode technologies p taining to both guided-wave structures and optical cavities. Understanding and predicting the complex nonlinear response of such systems especially when hundreds or thousands of modes are involved, is a challenging task the best case, all relevant approaches are mostly based on complicated nonlinear optical simulations, that make the description of realistic multimode fibers a formidable task. Thus a theory that explains and predicts such a complex behavior is still missing.

Quite recently however, a self-consistent theoretical framework has emerged, what we call ÓOptical Thermodynamics Ó [2Ð6]. In particular, optical thermodynamic theory is capable of describing such complex phenomena by means of thermodynamics of the systemÕs supermodes. A complete set of thermodynamical variables was determined and thus was able to describe and accurately predict the equilibrium behavior of the multimode system. The equation of state, the entropy and the Rayleigh-Jeans modal occupancies distribution was derived axiomatically either on thermodynamical grounds [2Ð4] or equivalently on statistical mechanical foundations [5, 6]. Such an approach is universal since it can be applied to any weakly nonlinear optical multimode system o finite number of supermodes that involves a finite number of conserved quantities. We can derive the fundamental relations that govern the grand canonical ensemble through maximization of the Gibbs entropy equilibrium. In this classical picture of statistical photo-mechanics, we obtain analytical expressions for the probability distribution, the grand partition function, and the relevant thermodynamic potentials.

The first part of the talk is devoted to the understanding of the role of equilibrium fluctuations and the second part to develop a non-equilibrium description of the system. In order to achieve our first goal we are going to rely on the grand canonical formalism [5] and directly calculate the relevant fluctuations based on the grand partition function expression. For states far from equilibrium, we develop a Langevin type of approach for the projection modal coefficients and derive effective stochastic equations that govern every supermode. Ou analytical expressions are compared with direct numerical results of system-bath simulations, in all cases, and the agreement is excellent.

In conclusion, by means of statistical mechanics, we have established a solid foundation for the optical the modynamics for equilibrium and non-equilibrium states. This formulation was carried out in the grand canonical ensemble picture and is applicable to any nonlinear arrangement involving conserved quantities such as th power, Hamiltonian, and a finite set of distinguishable modes. The equilibrium expressions for the fluctuation of power, Hamiltonian and modal occupancy number were found in excellent agreement with direct bath-system simulations. Even more interestingly, we were able to apply a Langevin type of formalism in order to understan the non-equilibrium behavior of our system. Our results universally apply to any other weakly nonlinear highly multimoded bosonic arrangement.

Acknowledgements: This project was funded by the European Research Council (ERC-Consolidator) under the grant agreement No. 101045135 (Beyond Anderson).

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,QVWLWXWH RI 6SHFWURVFRS\ 5XVVLDQ $FDGHP\ RI 6FLHQFHV 7URLWVN 0RVFRZ 5XVVLD
&15 ,12 ,VWLWXWR 1D]LRQDOH GL 2WWLFD 9LD &DPSL)ODJUH 3R]]XROL ,WDO\
FRUUHVSRQGLQJ DXWKRU \LIDQ VXQ#XQLURP D LW

$EVWUDFW: :H VKRZ WKH SUHVHQFH RI VWDEOH KLJK RUGHU OLJKW EXOOHWV LQ D FRKHUHQWO\ GULYHQ SDVVLYH P XOWLP RGH .HUU FDYLW\ ZLWK D WKUHH GLP HQVLRQDO SRWHQWLDO 7KHVH VWDWHV KDYH YHU\ ULFK P XOWLP RGH IHDWXUHV ZKLFK DUH XQYHLOHG E\ GHFRP SRVLQJ WKH QRQOLQHDU VROXWLRQV RQ WKH WKUHH GLP HQVLRQDO OLQHDU HLJHQP RGHV RI WKH FDYLW\

6ROLWDU\ ORFDOL]HG VWUXFWXUHV LQ GLVVLSDWLYH V\VWHPV ... WKUHH GLP HQVLRQDO ... / %V ... [illegible]

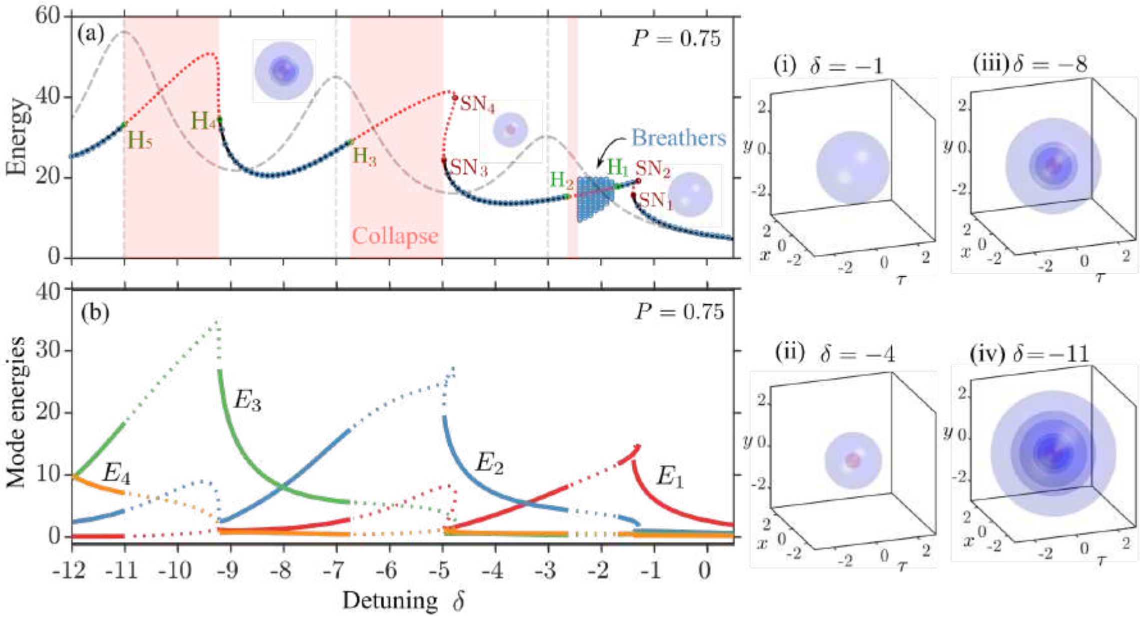
,Q WKLV ZRUN ZH XQFRYHU WKH H[LVWHQFH RI D ULFK YDULHW\ RI / %V RI GLIIHUHQW RUGHUV LQ WKH FRQWH[W RI P XOWLP RGH H[WHUQDOO\ GULYHQ .HUU FDYLWLHV ZLWK WKH DGGHG LQIOXHQFH RI SDUDEROLF SRWHQWLDOV : H H[DP LQH WKH VWDELOLW\ RI YDULRXV KLJK RUGHU / %V DQG FODVVLI\ WKHP LQ WHUP V RI WKHLU ELIXUFDWLRQ GLDJUDP %\ GHFRP SRVLQJ WKH / %V LQWR WKUHH GLP HQVLRQDO OLQHDU HLJHQP RGHV ZH FDQ REWDLQ WKH HYROXWLRQ RI WKH P RGDO HQHUJLHV RI KLJK RUGHU / %V : H DWWULEXWH WKH RULJLQ RI WKH KLJK RUGHU / %V SULP DULO\ WR WKH FRUUHVSRQGLQJ KLJK RUGHU P RGHV

,Q WKH P HDQ ILHOG DSSUR[LP DWLRQ WKH G\QDP LFV RI WKH HOHFWULF ILHOG HQYHORSH $A(x, y, \tau, t)$ SURSDJDWLQJ ZLWKLQ WKH FDYLW\ LV JRYHUQHG E\ DQ H[WHQGHG GLP HQVLRQOHVV / XJLDWR / HIHYHU // HTXDWLRQ ZLWK D ' SDUDEROLF SRWHQWLDO

$$\frac{\partial A}{\partial t} = \mathrm{i}\left(\nabla_\perp^2 + \frac{\partial^2}{\partial \tau^2}\right)A - \mathrm{i}\left(x^2 + y^2 + C\tau^2\right)A + \mathrm{i}|A|^2A - (1 + \mathrm{i}\delta)A + P,$$

ZKHUH δ LV WKH FDYLW\ GHWXQLQJ SDUDP HWHU P LV WKH SXP SLQJ UDWH $\nabla_\perp^2 = \partial_{xx} + \partial_{yy}$ DFFRXQWV IRU GLIIUDFWLRQ $\partial_{\tau\tau}$ DFFRXQWV IRU GLVSHUVLRQ $(x^2 + y^2)$ LV WKH WUDQVYHUVH SDUDEROLF LQGH[SURILOH RU VSDWLDO SRWHQWLDO DQG $C\tau^2$ RULJLQDWHV IURP V\QFKURQRXV SKDVH P RGXODWLRQ

)LJXUH D VKRZV WKH ELIXUFDWLRQ GLDJUDP RI / % HQHUJ\ YV GHWXQLQJ δ)RXU H[DP SOHV RI / % VWDWHV IRU WKH QHJDWLYH GHWXQLQJ YDOXHV $\delta = -1, -4, -8, -11.5$ DUH SORWWHG LQ)LJ L LY UHVSHFWLYHO\ 7KH WZR VKHOOV LQ LVRVXUIDFHV ZLWK GLIIHUHQW FRORUV UHSUHVHQW GLIIHUHQW ILHOG LQWHQVLWLHV $I_1 = 3$ UHG DQG $I_2 = 0.1$ EOXH 7KH IRXU VWDWHV WKDW ZH FRQVLGHU UHSUHVHQW WKH ILUVW WKH KLJK RUGHU / %V 7KH\ DUH VHSDUDWHG E\ WKH WKUHH SHDNV YLVLEOH LQ WKH ELIXUFDWLRQ GLDJUDP $ SDUW IURP WKHVH / %V ZH DOVR REVHUYH ZDYH FROODSVH DQG WKUHH GLP HQVLRQDO EUHDWKHUV LQ WKH UHG DQG EOXH UHJLRQV UHVSHFWLYHO\ 1XP HULFDO FRQWLQXDWLRQ DQG GLUHFW QXP HULFDO VLP XODWLRQ DUH XVHG WR FDOFXODWH WKHVH VWDWHV %\ GHFRP SRVLQJ WKHVH VROXWLRQV RQ WKH WKUHH GLP HQVLRQDO OLQHDU HLJHQP RGHV ZH REWDLQ P RGDO HQHUJ\ E_n $n = 1, 2, \ldots$ ZKLFK LV SORWWHG LQ)LJ E $V WKH GHWXQLQJ δ GHFUHDVHV IRU HDFK QWK RUGHU EXOOHW LWV P RGDO HQHUJ\ E_n LQFUHDVHV XQWLO LW UHDFKHV D SHDN YDOXH ZKHUH D SKDVH WUDQVLWLRQ RI / % RUGHU RFFXUV



)LJXUH DE %LIXUFDWLRQ GLDJUDP V VKRZLQJ WKH ILHOG HQHUJ\ RI WKH EXOOHW $E(t)$ LQ D DQG WKHLU PRGDO HQHUJ\ $E_n(t)$ LQ E YV δ IRU WKH SXPS $P = 0.75$ LQ D 6ROLG EODFN GDVKHG UHG OLQHV UHSUHVHQW VWDEOH XQVWDEOH VROXWLRQV REWDLQHG E\ QXPHULFDO FRQWLQXDWLRQ %OXH FLUFOHV VXSHULPSRVHG RQ VROLG OLQHV DUH VROXWLRQV IURP GLUHFW QXPHULFDO VLPXODWLRQV 7KH FROODSVH UHJLRQV DUH PDUNHG E\ UHG DUHDV DQG EUHDWKHU DPSOLWXGHV DUH PDUNHG E\ VSDUVH EOXH FLUFOHV 7KH JUD\ GDVKHG FXUYH FRUUHVSRQGV WR WKH OLQHDU VWDWHV RI WKH FDYLW\ +HUH $C = 1$

7KLV ZRUN UHYHDOV WKH SUHVHQFH RI D GLYHUVH UDQJH RI / %V ZLWK KLJK RUGHUV LQ PXOWLPRGH H[WHQGDOO\ GULYHQ . HUU FDYLWLHV ZLWK SDUDEROLF SRWHQWLDOV 7KURXJK RXU DQDO\VLV ZH HYDOXDWH WKH VWDELOLW\ RI PXOWLSOH KLJK RUGHU / %V DQG FDWHJRUL]H WKHP %\ SURMHFWLQJ WKH / %V LQWR OLQHDU WKUHH GLPHQVLRQDO HLJHQPRGHV ZH WUDFH WKH RULJLQ RI WKH KLJK RUGHU / %V WR WKHLU FRUUHVSRQGLQJ KLJK RUGHU PRGHV

: H DFNQRZOHGJH WKH ILQDQFLDO VXSSRUW RI WKH (XURSHDQ 5HVHDUFK &RXQFLO 0 LQLVWHUR GHOO,VWUX]LRQH GHOO8QLYHUVLWj H GHOOD 5LFHUFD 5 63% 0 DULH 6NáRGRZVND &XULH $FWLRQV * UDQW3,' 1%& 0 &,1 $(, DQG ³(5') $ ZD\ RI PDNLQJ (XURSH DQG 6DSLHQ]D 8QLYHUVLW\ $YYLR DOOD 5LFHUFD * UDQWV $5 (' $ $5 & ' (%%

5HIHUHQFHV

< 6LOEHUEHUJ 2SW/ HWW
< 9 . DUWDVKRY * ($VWUDNKDUFKLN %$ 0 DORP HG DQG/ 7RUQHU 1DW5HY 3K\V
& 0 LOLiQ < . DUWDVKRY DQG/ 7RUQHU 3K\V 5HY / HWW
2 9 6KWLUOLQD 0 3) HGRUXN < 6 . LYVKDU DQG6 . 7XULWV\Q 3K\V 5HY $
9 / . DODVKQLNRY DQG6 : DEQLW] / DVHU3K\V / HWW
$. 7XVQLQ $ 0 7LNDQ DQG7 - . LSSHQEHUJ 3K\V 5HY $
1 (QJKHEHUW1 * ROGP DQ 0 (UNLQWDOR 1 0 RVWDDQ 6 3 * RU]D) / HR DQG-) DWRP H DU;LY
< 6XQ 3 3DUUD 5LYDV 0) HUUDUR) 0 DQJLQL 0 =LWHOOL 5 -DXEHUWHDX) 5 7DOHQWL DQG6 : DEQLW] 2SW/ HWW

< 6XQ 3 3DUUD 5LYDV & 0 LOLiQ < 9 . DUWDVKRY 0) HUUDUR) 0 DQJLQL 0 =LWHOOL 5 -DXEHUWHDX) 5 7DOHQWL DQG6 : DEQLW] DU;LY

Additive manufacturing for electromagnetic devices

,WHUDWLYH FRUUHFWLRQ RI SKDVH HUURUV LQ
XVLQJ IXOO ZDYH PRGHOLQJ

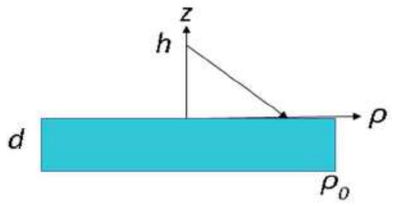
&DUH\ 5DSSDSRUW DQG $QWRQ 0RUJHQWKDOHU

1RUWKHDVWHUQ 8QLYHUVLW\ %RVWRQ 0$ 86$
UDSSDSRUW#QHX HGX

$EVWUDFW 'LVWULEXWHG GLHOHFWULF OHQVHV RIIHU VLJQLILFDQW
FRQYHQWLRQDO XQLIRUP GLHOHFWULF OHQV DQWHQQDV EXW R
EDVHG GHVLJQ 7KH FXUUHQW LQYHVWLJDWLRQ FRQVLGHUV DQ L
ZDYH SURSDJDWLRQ WKURXJK D OHQV WKDW PHDVXUHV WKH SKD
SURILOH RI WKH OHQV 7KH GHVLJQ SURFHVV SURFHHGV LWHUDW
IRU WKH RSWLPDO OHQV DQWHQQD

'HVLJQ 0HWKRG

$VVXPH WKH GHVLUHG OHQV LV IODW DQG FLUFXODU GLHOHFWULF FRQ
U IHG E\ D SRLQWVRXUFH DW KHLJKW DQG D IODW GLHOHFWULF OHQ
KDYH UHODWLYH GLHOHFWULF FRQVWDQW RI WKH OHQV WR EH GHWHU
VLPSOLILHG FRQGLWLRQ WKDW UD\V IURP WKH WRS VLGH RI WKH OHQV
WUDFH VWUDLJKW GRZQ WKURXJK WKH OHQV DQG DOZD\V UD\ UH

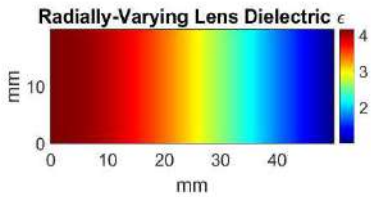


)LJXUH)ODW FLUFXODU OHQV JHRPHWU\

7R JHQHUDWH D SODQH ZDYH RXWSXW ZLWK
DOO H[LWLQJ UD\V PXVW EH WKH VDPH (T
OHQJWK WKURXJK WKH OHQV WR WKH RXWHU VXUIDFH
FRQVWDQW ZKLFK RFFXUV ZKHQ

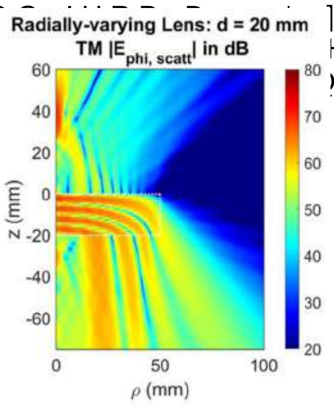
LQVLGH WKH OHQV 1RWH WKDW WKH GLVWD
RI WKH OHQV DQG WKDW SRLQW

)RU D *+] U PP GLDPHWHU PP WKLFN OHQV ZLWK PP KHLJKW SRLQW
GLHOHFWULF FRQVWDQW SURILOH LV VKRZQ LQ)LJ [LPL]LQJ LQ WKH



)LJXUH)ODW FLUFXODU OHQV
GLHOHFWULF FRQVWDQW SURILOH

7KH HOHFWULF ILHOG
SRLQW VRXUFH WKD
GLVWULEXWHG GLH
PRGHOHG ZLWK
'LIIHUHQFH)UHTXH
)')' PHWKRG DQG
)LJ 7KHUH LV
EDFNVFDWWHU ZLW
ZDYHV OHDYLQJ WKH



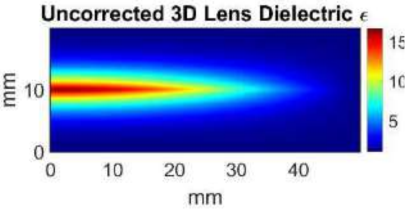
)LJXUH)LHOG VFDWWHUHG
FLUFXODU DQG DFFXPXODWH

HG E\ WKH
V LV
QVLW\
XSSHU
ULJKW

7KH EDFNVFDWWHU FDQ EH DPHOLRUDW WKH GLHO
WKLFNQHVV DV ZHOO DV GLVWULEXWLQJ
UD\V WUDFH VWUDLJKW WKURXJK WKH OHQV

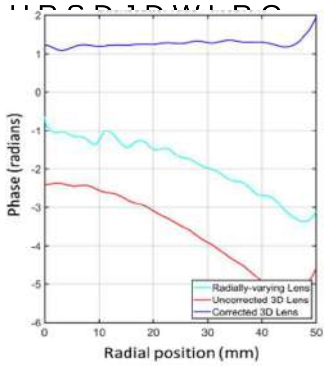
WKH LQGH[RI UHIUDFWLRQ KDV D WDSHUHG SURILOH JLYHQ E\ ... PDWFKHG DW WKH WRS VXUIDFH ... QLW\ DW WKH ERWWRP VXUIDFH DW

7R GHWHUPLQH WKH LQGH[RI UHIUDFWLRQ ... IURP 7KH VROXWLRQ ... 7KH UHVXOWLQJ GLVWULEXWLRQ ZLWK ... DQG PD[LPXP ... SUHVHQWV D PDWFK WR IUHH VSDFH VXUIDFHV ZKLOH NHHSLQJ WKH SKDVH FKDQJH YHUWLFDOO\ VWU... DV WKH SUHYLRXV OHQV



)LJXUH ')ODW FLUFXODU OHQV GLHOHFWULF FRQVWDQW SURILOH

7KH)')' PRGHOHG SURSDJDWLRQ ... WKURXJK WKLV ... LQGLFDWHV QHDU SO... DYLRU RQ H[LWLQJ WKH OH... LV VWLOO SKDVH HUURU DFURVV ... WKH DSHUWXUH 7KH UHG ... LQGLFDWHV ... IURP ... WR ... 8VLQJ ... GHWDLOHG SKDVH LQ... DEOHV D FRUUHFWLRQ WR WKH GLHOHFWULF FRQ... LEXWLRQ ... LQ)LUVW ILW D IRXUWK RUGHU ... DO LQ)LJ WKHQ VHW LW HTXDO WR WKH ... SKDVH HUURU IRU ... DQG VROYH IRU ... WKH PRGHOLQJ ZLWK ... RULJLQDO DQG WKH FRUUHFWHG ... WKH SKDVH YDULDWLRQ LV PLQLPL]HG VHH)LJ EOXH FXUYH ZLWK ... UDGLDQ SKDVH YD... K U WKH FRUUHFWHG ... ZLWK ... JLYHQ LQ

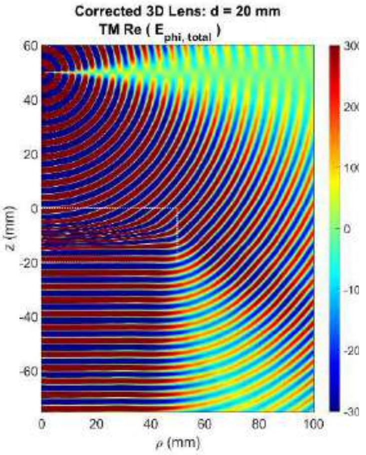


)LJXUH ... 3KDVH HUURU IRU ... YDU\LQJ ' XQFRUUHFWHG D... FRUUHFWHG IODW OHQVHV

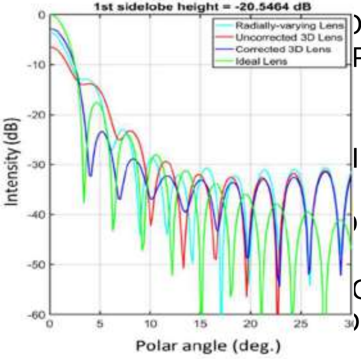
5HVXOWV DQG &RQFOXVLRQV

7KH FRPSXWHG ZDYH SDWWHUQ LQ)LJ VKR... IURQWV EHORZ WKH ERWWRP H[LW VXUIDFH RI ... IDUILHOG SDWWHUQV RI WKH WKUHH OHQVHV ... ' FRUUHFWHG DUH ... DORQJ ZLWK WKH ... H[FLWHG DSHUWXUH ... FLUFXODU GLPHQVLRQ ... 7KH SDWWHUQ RI ... OHQV EOXH DSSURDFKHV ... ZLWK OHVV WKDQ ... UHGXFWLRQ EXW ZL... OREHV

,W KDV EHHQ VKRZQ ... ZDYH PRGHOLQJ RI ... GLVWULEXWHG GLHOHFWULF ... LW LV SRVVLEOH WR FRPSXWH ... GLVWULEXWLRQ WR FRUUHFW SKDVH HUURUV DQG JHQHUDWH QHDU SHUIHFW SDWWHUQV



)LJXUH 5HDO SDUW RI ILHOG H[FLWHG E\ D ... FLUFXODU SRODUL]HG SRLQW VRXUFH DW ... ZLWK ' SKDVH FRUUHFWHG OHQV ZLWK



)LJXUH 0RGHOHG IDUILHOG S... UDGLDOO\ YDU\LQJ XQFRUUH... FRUUHFWHG SKDVH DQG L...

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G:C8><A>H@8C:;FIA:JF9=H8D

!@4.2$&A(B8/4(=*2C('"$04(=/.8($(%'=(+'.8*"*0*37(5*2(&*-,0'":2'4*%$.*2(+/&2*=$#'(&/2&-/.4?(B8' 52'D-'%&7(2'4,*%4'(*5(.8'(/+,'"$%&'(+$.2/E(*5(.8'('"#/&'(-%'"2($%$074/4(/4(*@.$/%'"(/%(,*0':2'4/"-'(5*2+ @7(+'$%4(*5($(5-00:=$#'(4*0#'2F(%$+'07F(.8'(5/%/.'('0'+'%.(+'.8*"(GH1<IF(=/.8($(+*'"0(*2'"2(2'"-&./*% G<J;I(0$7'2(*%(.*,(*5(/.(.*(3'.(.8'(52'D-'%&7(2'4,*%4'(=/.8('$4'? B8/4(/+,'"$%&'(+$.2/E(4.$%"4(5*2('0'&.2*+$3%'./&4F(/?'?F(%*(&/2&-/.($,,2*E/+$./*%(/4(.$C'%(/%.*($&&*-%.(.* 4*0#'(<$E='00K4('D-$./*%4?(L2$,,/%3(.8'(,874/&$0(/%5*2+$./*%(/%&0-'""(/%(.8'(,*0':2'4/"-'(2',2'4'%.$./*% *5(.8'(/+,'"$%&'(+$.2/E(5*2(.8'(+/&2*=$#'(5/0.'2(-%'"2($%$074/4F($(0/%'$2("7%$+/&$0(474.'+(&$%(@' /'"%./5/'"F(=8/&8(,2*#/'"4(#$0-$@0'('"4/3%(/%5*2+$./*%?(B*(4*+'('E.'%.F(/%(.8'(%$22*=@$%"(0/+/.F(.8/4 "7%$+/&$0(474.'+(/4(4/+/0$2(.*($(&/2&-/.(2',2'4'%.$./*%? B8/4(%'=("7%$+/&$0(474.'+(4.$%"4(-,*%('0'&.2*+$3%'./&4F(3/#/%3(2/4'(.*($%('0'&.2*+$3%'./&$007(3'%'2$.'" &*-,0/%3(+$.2/E(5*2(&*-,0'":2'4*%$.*2(+/&2*=$#'(&/2&-/.4?(6'#'2$0($,,0/&$./*%4F(4-&8($4(+/&2*=$#'(5/0.'24F "/,0'E'24($%"($%.'%%$4F(=/00(48*=(.8'(&$,$@/0/./'4(*5(.8/4(%'=(.'&8%/D-'?

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Review of patch antennas for wireless applications using inkjet printing technique

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Abstract: This study focused on a double-stacked array antenna with patch elements disposed linearly and circularly. Using the inkjet printing method, the single patch antenna was created for the 5 GHz band. The goal is to print conductive silver ink on a thin Kapton film to produce microstrip lines. High-impact polyester (HIPS) is utilized as a substrate to secure the Kapton layers, which increases the impedance bandwidth while also enhancing mechanical stability

Antenna design

Fig. 1 shows the suggested method for introducing a double-stacked patch antenna that is described in [1]. Although this technique increases overall thickness, it improves antenna bandwidth in terms of impedance matching, which makes it worthwhile to use. As per the manufacturer [2], the electric constant of the HIPS and Kapton substrates are 2.4 and 3.4 respectively.

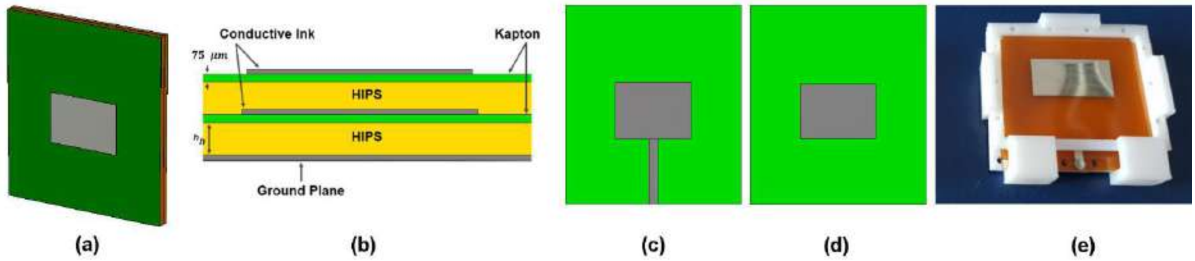

Fig. 1) Stacked patch antenna configuration a) Perspective view, b) side view of the antenna including ground plane, conductive ink, Kapton and HIPS substrate, c) front view of the bottom layer and d) top layer, e) manufactured antenna.

In a subsequent step, the idea of designing a stacked linear array antenna was discussed based on the proposed design principles. The proposed antenna's ultimate design is displayed in Fig. 2. As shown in this figure, the first layer includes the feeding network, which is intended to excite eight radiating patches. In order to obtain a compact design and enhance the impedance matching, double quarter-wavelength (ã¤v) transmission lines with a corner-cut T-junction power divider were used in each step of this feeding network.

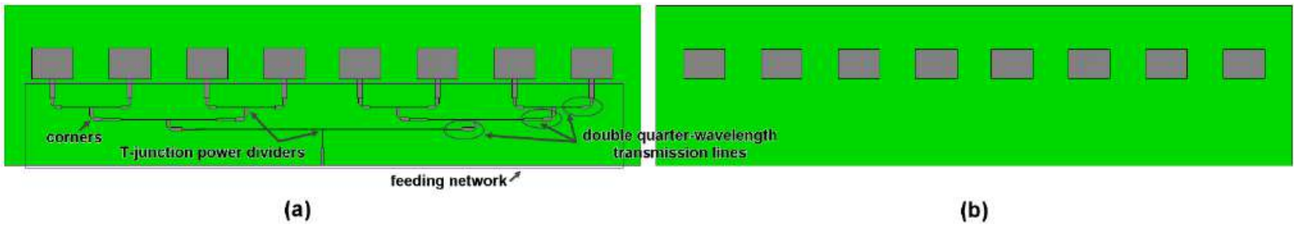
corners
T-junction power dividers
double quarter-wavelength transmission lines
feeding network
(a)
(b)

Fig. 2) Front view of the stacked linear array antenna including the a) bottom and the b) top layers.

So far, the concept of a directional stacked antenna design employing a combination of the inkjet printing method to put the silver conductive ink on Kapton films and the 3D printing method to manufacture the HIPS has been presented. This approach has a lot of potential, so it might be extended to include more complex structures. An example is the omnidirectional antenna design, which is covered in more detail in this section.

It has always been fascinating to think of conformal array antennas as small, inexpensive structures. The orientation of the elements, as the primary distinction between conformal and linear array antennas, makes it feasible to obtain an omnidirectional radiation pattern in the azimuth plane with this arrangement of the radiating elements. The formulation for an N-faced prism is taken from [3] and is as follows:

$$E_{conf}(\theta,\varphi) = \sum_{n=1}^{N} E_n(\theta,\varphi) I_n e^{j\left(\frac{2\pi}{\lambda} r \sin\theta\cos(\varphi-\varphi_n)+\alpha_n\right)}$$

Where $E_{conf}(\theta,\varphi)$ shows the conformal array antenna's radiated-field E, $E_n(\theta,\varphi)$, I_n, and α_n represent, respectively, the radiated-field, feeding amplitude, and phase of the n-th single radiating element and N is the radius of the circle, which also points to the distance between the center of the circle and the center of each element. Accordingly, an initial idea of presenting a conformal array antenna by bending the concept that is presented in Fig. 2 based on designing a linearly stacked array antenna with eight elements has been shown in Fig. 3.

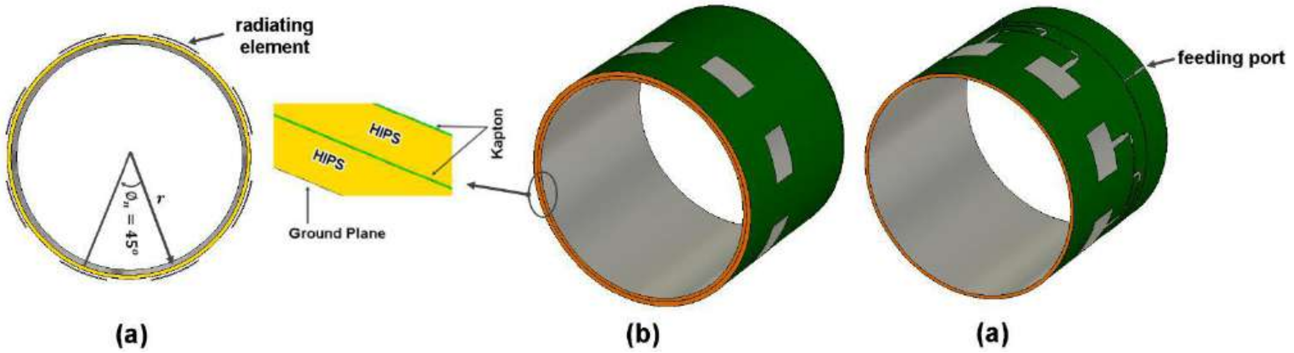

Fig. 3) Stacked conformal array configuration. a) front view, b) perspective view of the top layer and c) perspective view of the bottom layer.

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Stereolithography to generate OAM waves using dielectrics.

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Abstract: Metal prototypes has always played an important role, with low tolerances and fulfilling the high standards of investigation [1]. 3-D printing is emerging as an alternative with technologies such as stereolithography. In this work it will be seen the application of this technique in the fabrication of dielectric transmitarrays (TA) with the capability of producing orbital angular momentum waves (OAM).

Summary:

Orbital angular momentum waves were proposed by Allen et al. [2] in 1992. This type of wave has different modes, which are orthogonal one to another when the mode differs. Since then, the generation of this modes have been pursued, being the multimodal generation the principal target. Many ways of creation have been achieved in previous years using high-cost systems as multi-arrays antennas or monolithic metallic prototypes [3]. Stereolithography emerged as a solution to create 3D printed devices in dielectric with the capability of generate OAM.

Stereolithography (SLA) emerged during the 1970s as a system that can build 3D objects by two intersecting radiation beams through both photochemically cross-linking or degrading polymers [4]. The process begins with an STL file, by slicing it the 3D model is converted to 2D slices that contain the information needed to generate each layer. The fundament of this process is the curing reaction of resins, this reaction is initiated by supplying the energy of UV light and it occurred two stages during the curing: gelation and vitrification [5]. The gelation is a transition between the liquid resin to a rubber state. Then, the vitrification occurred, being a thermoreversible process that leads to the transition from rubber to a glassy solid resin [6].

The choice of this technique to our problem is not trivial. After a careful design studying the phase shift introduce by each part of the cell, the unit cell presented in Fig.1 is developed:

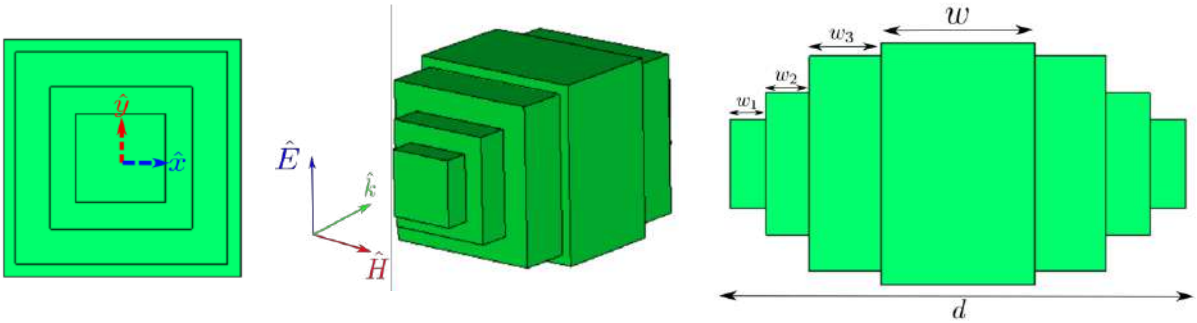

Fig.1 Front (left), perspective (center) and side (right) view of the unit cell proposed.

While the dimension & FDQ YDU\ IURP 4.2mm to 4.38mm (to introduce different phase shifts) GLPHQVLRQV & & DUH ILI[HG, being its function to adapt the impedance to the dielectric. The goal was to obtain four different phase shifts in order to have a 2-bit configuration. With this unit cell we create a transmitarray (40x40) which has the ability to generate OAMs. Our choice of material was the Grey V4 with a permittivity of Er = 2,6.

Once the final design is decided and the STL file is generated, it is used the Formlabs 3 [7] to 3D print our model. The WROHUDQFH RI RXU SULQWHU (XY plane) and the layer thickness is about P50m. This kind of machine use low force stereolithography. In this type of SLA, the printer uses a flexible film which bows gradually as the part is lowered, reducing the pressure in the overall system. It is important to set a correct arrangement of supports depending on the type of geometry we have. For example, if the structure has gaps or bulky parts, it is needed to correct the possible deviations of the printing. When the printing is done, a post-processing must be carried out, depending on the material used. First of all, the prototype must be washed to remove any resin residues. Then, the curing occurred, leaving it the time needed to entangle the polymer. Some pictures of final results can be seen in Fig.2. We expect to obtain a flat TA with the capability of generate a certain OAM mode.

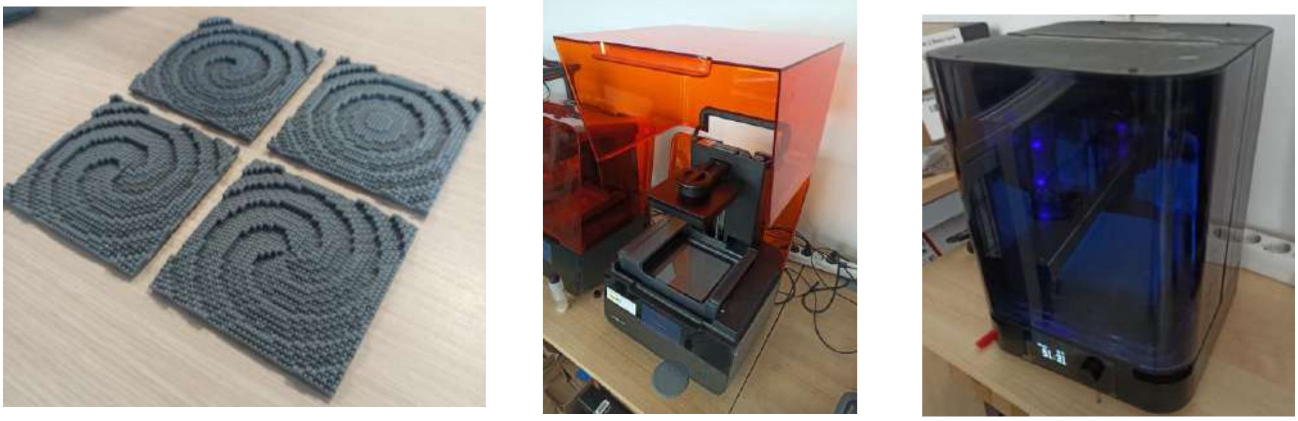

Fig.2. Several OAMs lenses (left). Formlabs 3 (middle) and curing machine (righ

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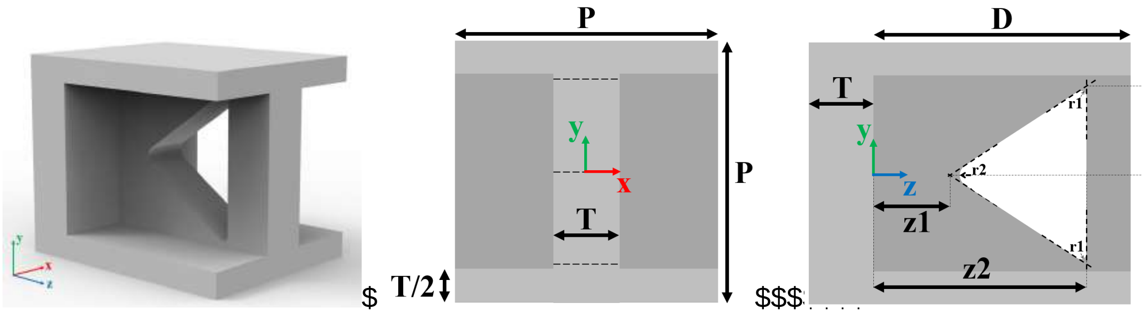

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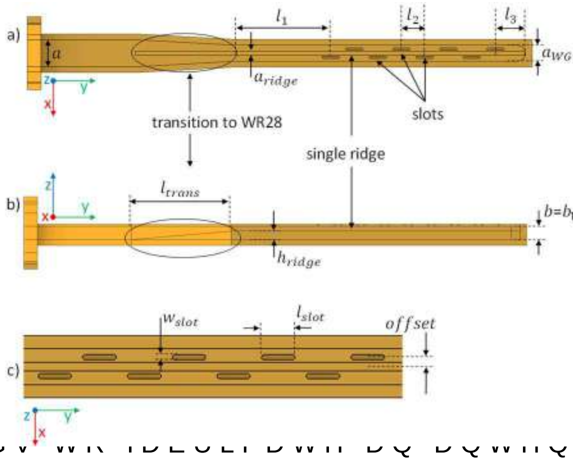

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,Q RUGHU WR YHULI\ WKH XVDELOLW\ RI WKH ' SULQWLQJ SURFHVV IRU DQWHQQDV LQ KLJKHU IUHTXHQF\ EDQGV D VLQJOH ± D EDQG VORWWHG ZDYHJXLGH DQWHQQD 6:$ LV GHVLJQHG DQG IDEULFDWHG XVLQJ WKH ' VHOHFWLYH ODVHU VLQWHULQJ 6/6 SURFHVV ZLWK D EUDVV SURWRW\SH DQG V\QWKHWLF PDWHULDO DQG FRPSDUHG WR WKH PDFKLQHG ZDYHJXLGH LQ FRQFOXVLRQ

$QWHQQD XQGHU WHVW

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7DEOH 7KH SDUDPHWHUV RI VLPXODWHG DQWHQQD PRGHO

3DUDPHWHU	9DOXH	'HVFULSWLRQ
=	PP	6WDQGDUG ZDYHJXLGH :5 ZL
>		6WDQGDUG ZDYHJXLGH :5 KHL
=ÐÀ	PP	:DYHJXLGH ZLGWK
>ÐÀ	PP	:DYHJXLGH KHLJKW
=åÜ×ÚØ	PP	5LGJH ZLGWK
[åÜ×ÚØ	PP	5LGJH KHLJKW
æßâç	PP	6ORW OHQJWK
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lÐÕßß	PP	:DOO WKLFNQHVV
KBB	PP	6ORW RIIVHW WR WKH PLGGOH RI
ξ	PP	,QSXW OHQJWK
ϵ		'LVWDQFH EHWZHHQ WZR VC
;		'LVWDQFH WR WKH ZDYHJXL(
çåÔáæ	PP	7UDQVPLVVLRQ OHQJWK

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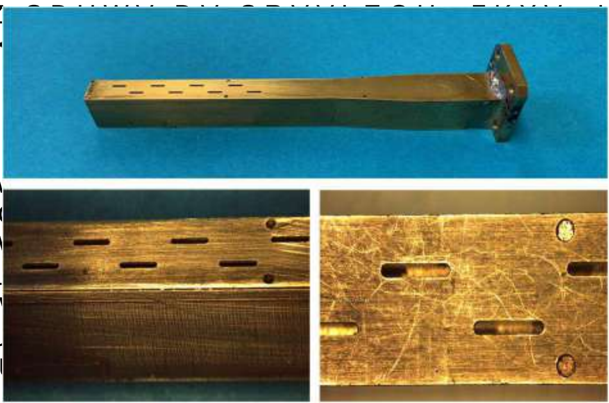

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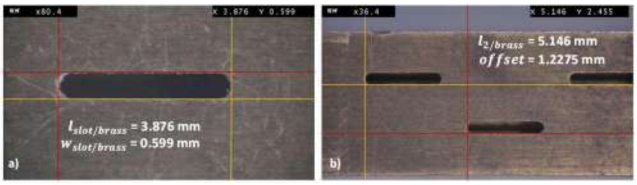

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' 6/6 0HWDO 3ULQW

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7DEOH 7KH PRGLILHG SDUDPHWHUV IRU ' SULQW SURFHVV

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æßâç	PP	6ORW OHQJWK
Sæßâç	PP	6ORW ZLGWK
KBB	PP	6ORW RIIVHW WR WK OI
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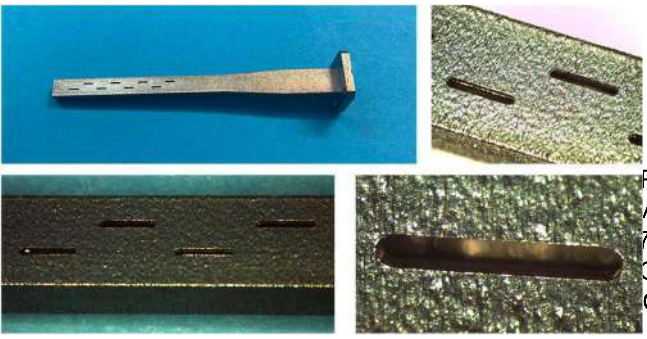

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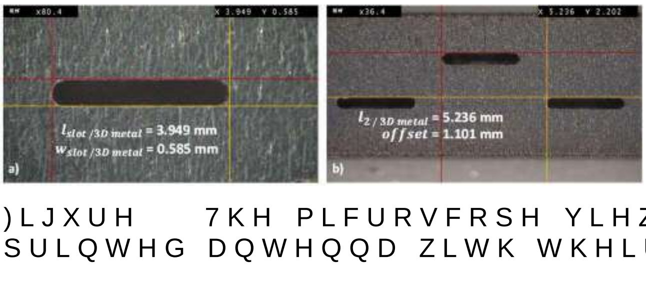
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X 3.949 Y 0.585
$l_{slot/3D\ metal}$ = 3.949 mm
$w_{slot/3D\ metal}$ = 0.585 mm
a)
x36.4
X 5.236 Y 2.202
$l_{2/3D\ metal}$ = 5.236 mm
$offset$ = 1.101 mm
b)

)LJXUH 7KH PLFURVFRSH YLHZV RI SULQWHG DQWHQQD ZLWK WKHLU JHR

' 6/6 6\QWKHWLF 0DWHULDO 3ULQW

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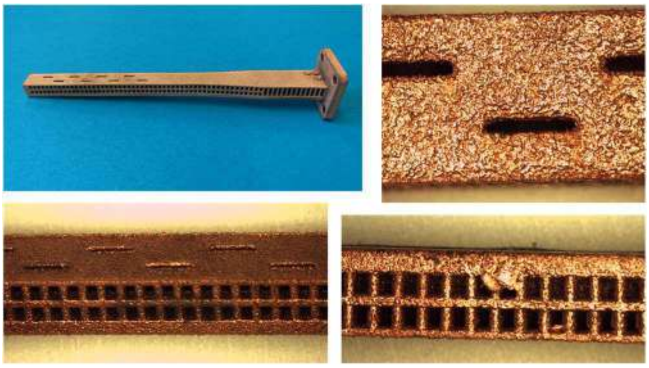

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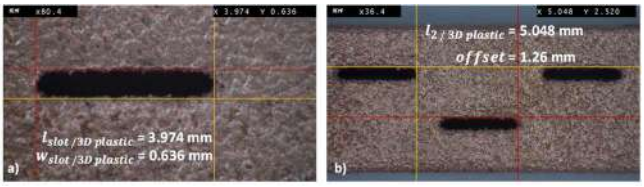
x80.4
X 3.974 Y 0.636
$l_{slot\,/3D\,plastic}$ = 3.974 mm
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x36.4
X 5.048 Y 2.520
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offset = 1.26 mm
b)

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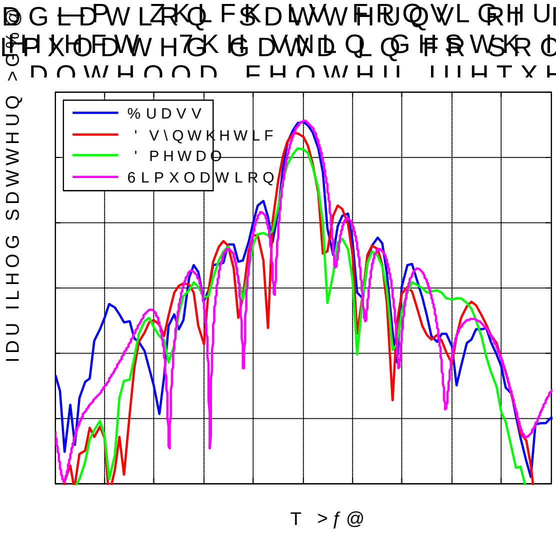

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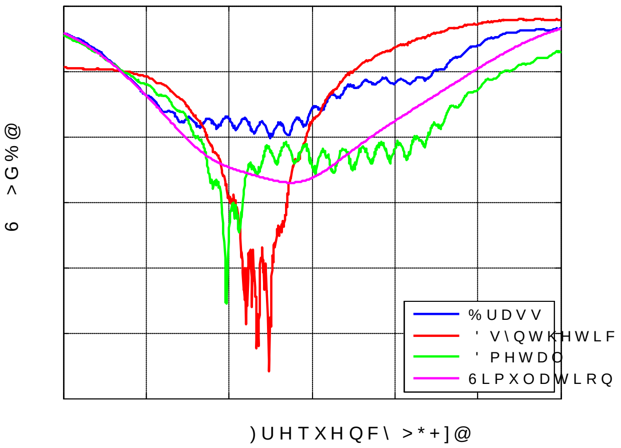

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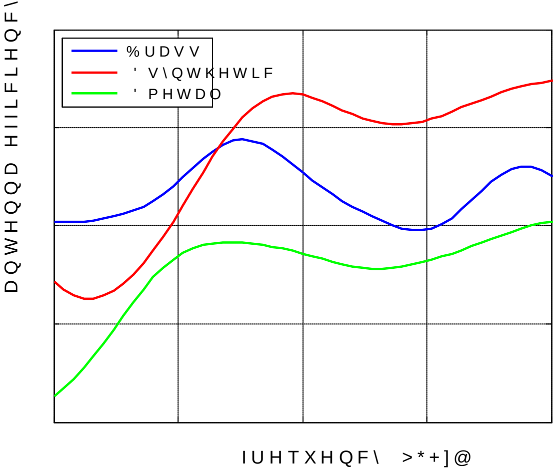

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Antennas, EM and Smart Sensing Technologies for Biomedical and Healthcare Applications

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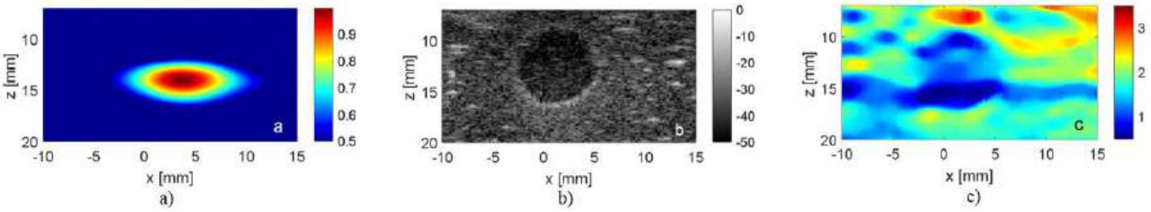

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A systematic study of the electromagnetic occupational exposure in healthcare applications

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Abstract: This paper aims to study how to improve occupational health and safety conditions in the healthcare environment; in particular we will focus on a systematic evaluation of the exposure to the variable magnetic field produced during a transcranial magnetic stimulation (TMS) treatment. Four exposure conditions are provided based on two virtual human body models, in the case of a circular coil applicator. Results of the induced electric field inside the human body models show that in some cases exposure limits are exceeded and lead us to possible safety suggestions.

Introduction

The study began by carefully reviewing real exposure scenarios of clinicians, as the reference material used is company user manuals, websites, papers, and measurement campaigns[1]. We collected approximately 70 images of these scenarios to identify all the possible positions assumed by clinicians during TMS treatments. Furthermore, since the coil must be held in place in proximity of the patient's head, the operator often uses hands to hold it during treatment. This can potentially introduce critical issues with operator's limb exposure that were confirmed by some results obtained in a previous study[1,2]. To reduce these local risks, a dosimetric approach to provide useful suggestions is carried out, as no technical standard devices are currently available for TMS

Models and methods

As a source model, it is considered a circular coil model 9784-00 of Magstim powered with Magstim 200[1] and BiStim system, at the maximum stimulator output (100% MSO): the two systems deliver current pulses assimilated to pure sinusoids at equivalent frequencies of 3 kHz (5.6 kA) and 1 kHz (9.7 kA), respectively. The Human models used to reproduce the operator, are two posable versions of the male models, called Duke (34-year-old, 1.77 m, 70.2 kg) and Jeduk (33-year-old, 1.62 m, 64.5 kg), both members of the Virtual Population (ViP., v.3.0)[3]. Concerning the exposure scenario, in order to conduct a local analysis of the exposure of the clinician's hand, two different way of gripping the coil are considered for each human model. For Duke, the clinician is assumed to hold the coil with one hand (right and left assessed separately) with two different ways of gripping (defined as Closed and Open). For Jeduk model, a more realistic conditions are evaluated, with both hands involved in the exposure, as well as two different holding modes (related to the orientation of the right hand and named defined as "Alfa" and "Beta"). Finally, the 99th percentile of the induced electric (E-) field in the human model was assessed by comparing it with the limit of ICNIRP 2010[4] guidelines (i.e., 1.13 V/m for these frequencies).

Results

First, we have evaluated the local maps of the induced E-field due to the TMS exposure of the hands, considering the four conditions described before (Figure 1).

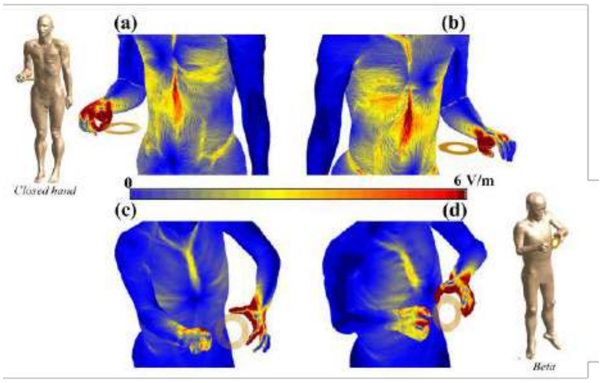

Figure 1. E-field maps (a) Duke right Closed hand, (b) Duke left Open hand, (c) Jeduk Alfa with coil handle perpendicular to the body surface, and (d) Jeduk Beta with the handle parallel to the body surface.

These distributions of the E-field show how, in all the cases, a large portion of the hand exceeds the limit confirming the criticality of the proximity in use of the device. The extent of the exposure becomes clearer by analyzing the 99th percentiles of the E-field evaluated in the hand and forearm, as reported in Table I.

Table 1. 99th percentiles of induced E-field (V/m)

	Duke		Jeduk			
	Closed	Open	Alfa		Beta	
Hand	right	left	right	left	right	left
70% MSO	21.36	15.17	7.33	15.88	6.97	21.67
50% MSO	15.26	10.84	5.23	11.34	4.98	15.48
30% MSO	9.15	6.50	3.14	6.81	2.99	9.29

Discussions

For all the exposure conditions here considered, the circular coil causes an induced E-field that exceeds the suggested limits, also considering the lowest level of MSO used in practice in clinics (30% MSO). Excluding the implausible 100% MSO[5], the percentage variation respect the limits ranges between +164.6% up to +1790%. These results indicate the need to explore new method for shielding the hand by using for example a dedicated glove. In conclusion, we demonstrate how risk assessment in healthcare workplace can be effectively approached using computational methods with ultimate goal to identify possible flaw of knowledge and suggesting new protocol for assessing exposure to devices such as TMS, which currently lack standardizations.

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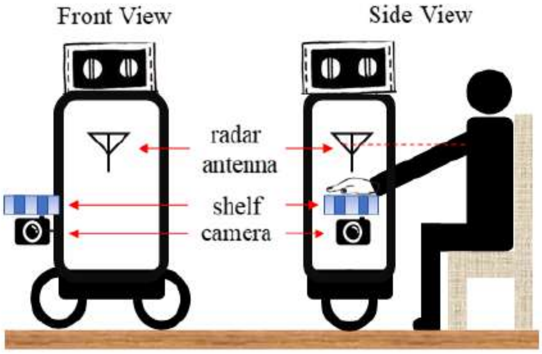

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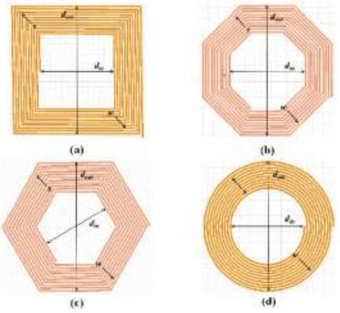

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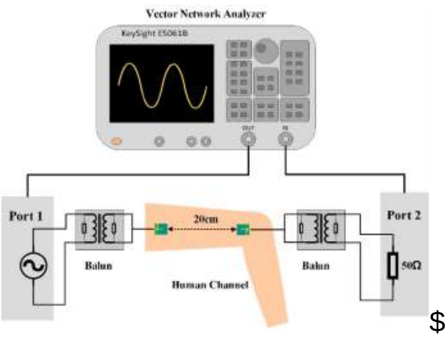

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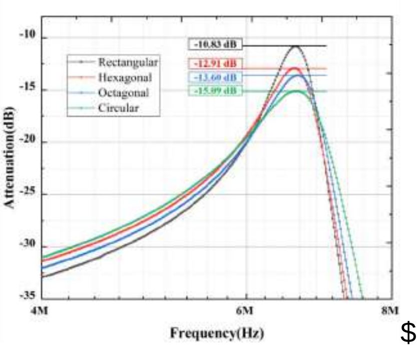

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&ROOHJH RI 3K\VLFV DQG ,QIRUPDWLRQ (QJLQHHULQJ)X]KRX 8QLYHUVLW\ &KLQD
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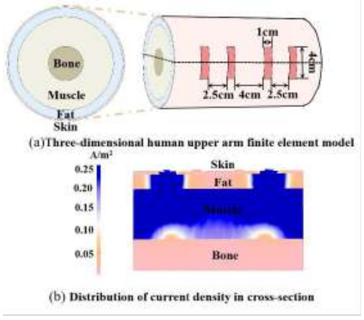
$EVWUDFW 7KLV VXPPDU\ SURSRVHG D QHZ PHWKRG IRU FRQWLQXRXV PRQLWRULQJ RI ILQJHU IOH[RU DFWLYLW\ 7KH ELRLPSHGDQFH PHDVXUHPHQW VFKHPH IRU PXVFOH G\QDPLF PRQLWRULQJ LV GHWHUPLQHG E\ DQDO\VLV RI ILQLWH HOHPHQW HOHFWURPDJQHWLF VLPXODWLRQV ZLWK DQ XSSHU DUP PRGHO ,Q YLYR H[SHULPHQWV ZHUH FRQGXFWHG WR YHULI\ WKH DFFXUDF\ RI WKH VLPXODWLRQ IROORZHG E\ FRQVWUXFWLQJ D ORQJ DQG VKRUWWHUP PHPRU\ QHWZRUN WR FKDUDFWHUL]H WKH PXVFOH DFWLYLW\ OHYHO E\ ELRLPSHGDQFH 7KH UHVXOWV LQGLFDWH WKDW WKH ELRLPSHGDQFH WHFKQLTXH KDV WKH SRWHQWLDO WR WUDFN PXVFOH DFWLYLW\ FRQWLQXRXVO\

0XVFOH IDWLJXH LV D SK\VLRORJLFDO SKHQRPHQRQ FKDUDFWHUL]HG E\ D GHFOLQH LQ PXVFOH VWUHQJWK DQG DQ LQDELOLW\ WR PDLQWDLQ HVWDEOLVKHG PRYHPHQWV >@ ,W RFFXUV FRPPRQO\ LQ VSRUWV ILWQHVV DQG UHKDELOLWDWLRQ WUDLQLQJ >@ $SSURSULDWH H[HUFLVH SURPRWHV KHDOWK EXW IUHH UDGLFDOV SURGXFHG E\ H[FHVVLYH H[HUFLVH ZLOO FDXVH DQ LPEDODQFH LQ WKH ERG\ V R[LGDWLYH DQG DQWLR[LGDQW FDSDFLW\ >@ &RQWLQXRXV PRQLWRULQJ RI PXVFOH DFWLYLW\ LV DQ HIIHFWLYH PHWKRG RI DYRLGLQJ PXVFOH LQMXU\ DQG GHYHORSLQJ SURSHU WUDLQLQJ SODQV 6KLQ HW DO >@ XVHG ELRLPSHGDQFH %, GDWD DW PXOWLSOH IUHTXHQFLHV WR WUDFN PXVFOH FKDQJHV LQ SDWLHQWV ZLWK VWURNH /L HW DO >@ PHDVXUHG ORFDO %, FKDQJHV GXULQJ WKH SURJUHVVLRQ RI PXVFOH IDWLJXH WR YHULI\ WKDW %, FDQ EH D ELRPDUNHU RI PXVFOH VWDWXV 1RQH RI WKH DERYH VWXGLHV KDYH YDOLGDWHG ZKHWKHU %, KDV WKH SRWHQWLDO WR WUDFN PXVFOH DFWLYLW\ FRQWLQXRXVO\ 7KLV VXPPDU\ GHVLJQV PXVFOH VXVWDLQHG FRQWUDFWLRQ H[SHULPHQWV EDVHG RQ HOHFWURPDJQHWLF VLPXODWLRQV WR DFKLHYH PDSSLQJ IURP %, WR PXVFOH DFWLYLW\


Bone
Muscle
Fat
Skin
1cm
4cm
2.5cm 4cm 2.5cm
(a)Three-dimensional human upper arm finite element model
A/m²
0.25
0.20
0.15
0.10
0.05
Skin
Fat
Muscle
Bone
(b) Distribution of current density in cross-section

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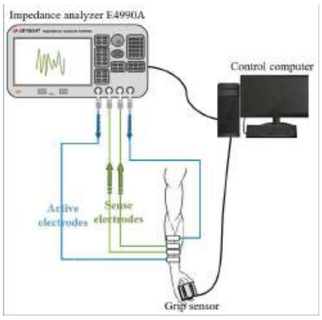

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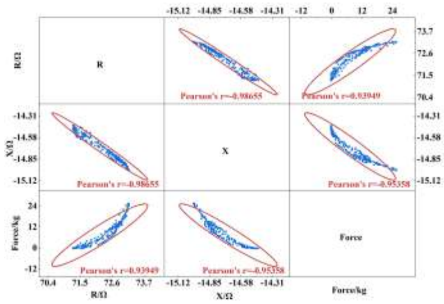

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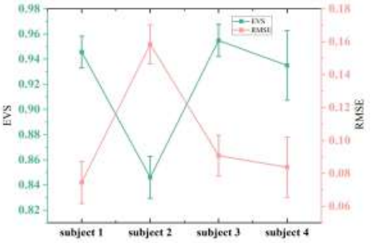
7KH HOHFWURGH FRQILJXUDWLRQ LV DQ LPSRUWDQW LQIOXHQFH RQ PHDVXULQJ VXUIDFH %, ,W LV QHFHVVDU\ WR FRQGXFW DQ HOHFWURPDJQHWLF VLPXODWLRQ RI WKH HOHFWURGH DUUDQJHPHQW WR GHWHUPLQH WKH DYDLODELOLW\ RI WKH VFKHPH)LUVWO\ ZH XVHG 9,112 SRUWDEOH XOWUDVRXQG 4 / 6X]KRX &KLQD WR FROOHFW WKH WKLFNQHVV RI HDFK WLVVXH OD\HU RI WKH VXEMHFWV IRUHDUP IURP WKH ZULVW MRLQW WR WKH HOERZ MRLQW DQG FDOFXODWHG WKH DYHUDJH YDOXH DV D EDVLV IRU PRGHOLQJ :H FRQVWUXFWHG D KXPDQ IRUHDUP ILQLWH HOHPHQW)(0 HOHFWULF ILHOG PRGHO LQ &2062/ 0XOWLSK\VLFV 7KH IRUHDUP ZDV HTXDWHG WR D IRXUOD\HU F\OLQGHU ZKHUH WKH WKLFNQHVV RI HDFK WLVVXH OD\HU ZDV VHW DV IROORZV VNLQ FP IDW FP PXVFOH FP DQG ERQH FP 7KH GLHOHFWULF SDUDPHWHUV RI HDFK WLVVXH OD\HU ZHUH REWDLQHG IURP WKH GDWDEDVH >@ @ 7KH)(0 PRGHO LV VKRZQ LQ)LJ D 7R WUDFN WKH FKDQJHV LQ ILQJHU IOH[RU PXVFOH JURXS DFWLYLW\

FDXVHG E\ ILQJHU IOH[LRQ DQG H[WHQVLRQ HOHFWURGHV ZHUH SDVWHG WR WKH VNLQ RI WKH ILQJHU IOH[RU PXVFOH ZLWK WKH WZR H[WHUQDO HOHFWURGHV DV H[FLWDWLRQ HOHFWURGHV DQG WKH WZR LQWHUQDO HOHFWURGHV DV VHQVLQJ HOHFWURGHV 7KH HOHFWURPDJQHWLF VLPXODWLRQ IROORZV WKH IROORZLQJ SULQFLSOHV 0DNH WKH H[FLWDWLRQ FXUUHQW IORZ WKURXJK WKH WDUJHW DUHD EXW QRW DIIHFW WKH VHQVLQJ HOHFWURGHV ZRUN 0DNH WKH H[FLWDWLRQ VLJQDO IORZ WKURXJK WKH PXVFOH OD\HU DV PXFK DV SRVVLEOH :H ILQDOO\ GHVLJQHG WKH HOHFWURGH DUUDQJHPHQW DV VKRZQ LQ)LJ D ,Q WKH HOHFWURPDJQHWLF VLPXODWLRQ WKH H[FLWDWLRQ FXUUHQW VLJQDO DPSOLWXGH LV P$ WKH IUHTXHQF\ LV N+] $IWHU HOHFWURPDJQHWL FDOFXODWLRQV WKH FXUUHQW GHQVLW\ GLVWULEXWLRQ LQ WKH WUDQVYHUVH VOLFH RI WKH PRGHO L VKRZQ LQ)LJ E 7KH UHVXOWV VKRZHG WKDW PRVW RI WKH FXUUHQW SDVVHG WKURXJK WK PXVFOH OD\HU ZKLOH DOPRVW QR FXUUHQW SDVVHG WKURXJK WKH ERQH OD\HU 7KHUHIRU WKLV HOHFWURGH FRQILJXUDWLRQ VFKHPH PHHWV WKH H[SHULPHQWDO UHTXLUHPHQWV DQG WK PHDVXUHG LPSHGDQFH LQIRUPDWLRQ PDLQO\ RULJLQDWHV IURP WKH PXVFOH OD\HU



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Space Division-Based Stroke Classification and Localization Using Wearable Microwave Sensing Technique

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Abstract: A novel microwave medical sensing method is proposed for fast stroke classification and localization, which utilizes space division of the region under examination (i.e., the head). The space division is enabled by the generalized scattering matrix theory and incorporates the brain anatomy. Then a novel decision tree learning method is proposed, which facilitates efficient stroke feature identification for classification. The classification accuracy and localization efficiency are shown to be greatly improved compared to the traditional method.

In microwave medical sensing (MMS), signals scattered from a region under examination (RUE) such as the huPDQ KHDG DUH UHODWHG WR WKH 58(¶ geometric shape, internal structure, and electromagnetic properties. A wearable MMS system is shown in Fig. 1(a). The RUE structure is often highly complex, and it is difficult to characterize the spatial property of an anomaly without reconstructing the image. To solve this problem, we propose a novel space-division-based stroke classification and localization method. As shown in Fig. 1(b), the RUE is an enclosed area A, whereas the receiving antennas are outside A. Assume that there is an anomaly in the RUE; this feature will influence the electromagnetic responses at the receiving antennas. According to medical knowledge and anatomical structure, RUE is divided into multiple subareas by spatial partitioning. The generalized scattering matrix (GSM) theory is utilized to conduct an electromagnetic analysis on the space division, merging some of the subareas. The merging aims to ensure that the electromagnetic responses of different subareas are independent of each other. Thus, any anomaly present in a certain subarea will introduce highly location-selective signatures. Subsequently, if the RUE A is divided into several subareas, $A = \{A_1, « A_i « A_I\}$. Each subarea separately satisfies the electromagnetic independence requirement based on GSM [1]. When an anomaly occurs in a certain A_i, this feature will produce a specific electromagnetic response. Based on this response, we can obtain the location information of the disease.

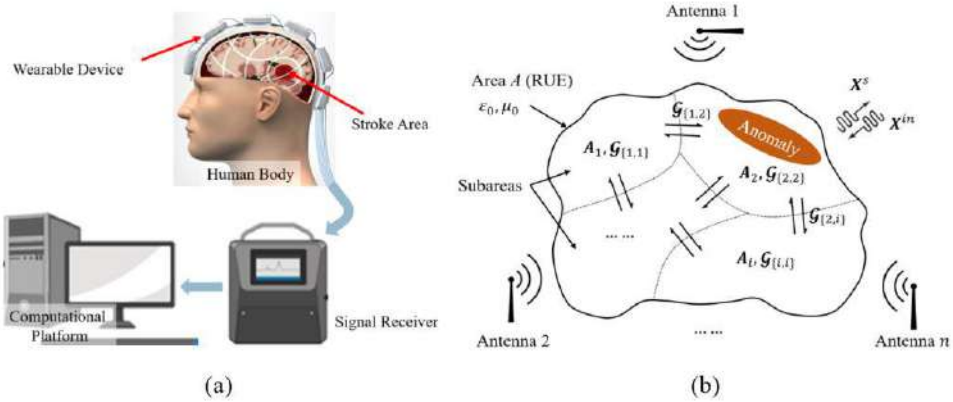

Fig. 1. (a) Architecture of the proposed system. (b) Pictorial illustration of the space-division-based method.

For each A_i, a stroke incidence probability is assigned according to expert knowledge, where the risk set of A is $. = \{ ._1, ..., ._i, ..., ._I\}$. Without loss of generality, let us assume that the subareas are sorted in risk, so that A_1 has the highest risk in A and $._1 • ._2 • « • ._I$. We now proceed to construct a decision-tree-based classifier. The criterion for decision-making is the incidence probability, where the highest-risk subarea should be selected.

Thus we first check A_1 for stroke classification. In this case, the root node has two branches, which are $\{A_1\}$ and $\{A_2, ..., A_i, ..., A_I\}$. If the stroke area is not in A_1, we would continue to the subarea with the second highest incidence probability A_2. As such, the detection sequence is obtained based on the incidence risks. Next, as there are two types of stroke, intracranial haemorrhage (ICH) and ischemic stroke (IS). Linear discriminant analysis is utilized to distinguish ICH from IS due to its efficiency.

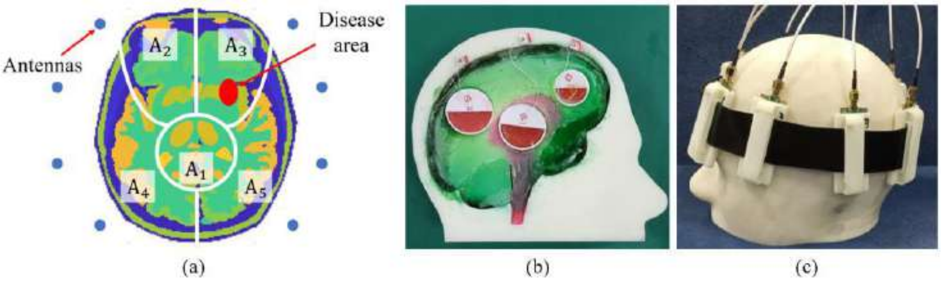

Fig. 2. (a) Brain structure and space division. (b) Head-mimicking phantom. (c) Wearable antenna array.

The brain area is divided into five subareas based on GSM brain anatomy: basal ganglia region (BGR) A_1, left forebrain A_2, right forebrain A_3, left hindbrain A_4, right hindbrain A_5, as shown in Fig. 2(a). Then we define the incidence probabilities of these subareas as $_1 = 46\%$, $._2 = 20\%$, $._3 = 20\%$, $._4 = 7\%$, $._5 = 7\%$ [2]. The disease area is randomly introduced to these subareas according to their corresponding incidence probabilities. Half of the manufactured human brain is shown in Fig. 2(b), and the experimental system setup with the wearable antenna array is shown in Fig. 2(c).

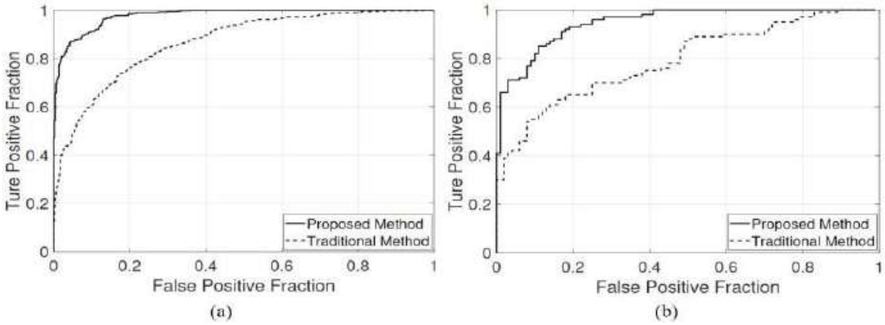

Fig. 3. (a) Simulation and (b) experimental results for proposed and traditional methods.

There are 1000 and 200 groups of simulation and experimental results in the database, respectively, and half of those are IS and the other half are ICH. The training set accounts for 70% of the database, whereas the test set accounts for 30%. For the classification performance, the receiver operating characteristic (ROC) curves of the proposed and traditional methods are shown in Fig. 3. For simulation results, the areas under the curve (AUCs) for the proposed and traditional methods are 0.97 and 0.85, respectively, which exhibits a 14.1% performance improvement. The localization accuracy of the proposed method is 94.2%. For experimental results, the AUC for the proposed and traditional methods are 0.93 and 0.78, respectively, which exhibits a 19.2% performance improvement. The localization accuracy of the proposed method is 90.5%. In addition, due to the decision tree learning method, the diagnosis time is significantly reduced, with a 21.1% efficiency improvement.

References

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Advances in Sensor Technologies Involving Electrodynamics and Magnetism

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PDJQHWLF EVWDELOLW\ ,Q WKH FDVH RI JODVV FRDWHG PLFURZL
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LQGXFHG PDJQHWLF ELVWDELOLW\ 7KHUHIRUH VLPLODUO\ WR DQ
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PDJQHWLF DQLVRWURS\ KDV EHHQ REWDLQHG E\ VWUHVV DQQHDO
7KH WUDQVIRUPDWLRQ RI WKH PDJQHWLF VWUXFWXUH ZDV I
DQQHDOLQJ DW GLIIHUHQW WHPSHUDWXUHV)LJ &KDQJH
WZR W\SHV RI WKH LQYHVWLJDWHG PLFURZLUHV 7KH IRUPD
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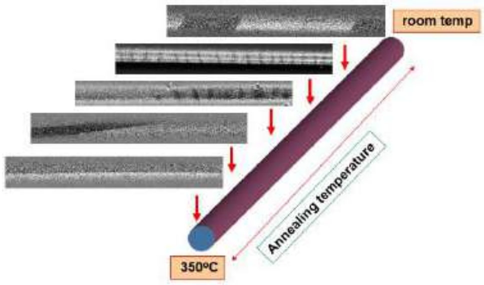

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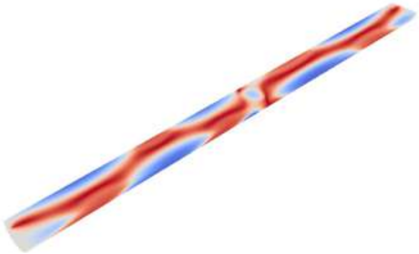

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Smart Electromagnetic Skins and their Applications

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$$E(r,\theta) = A(r)\cdot e^{jl\theta}$$

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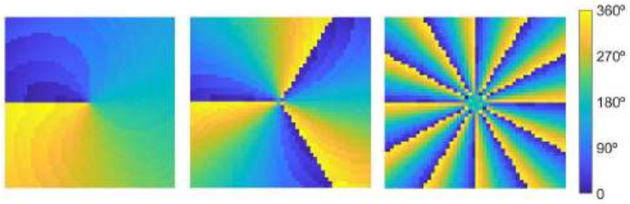

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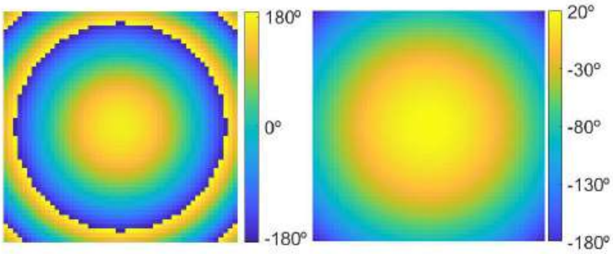

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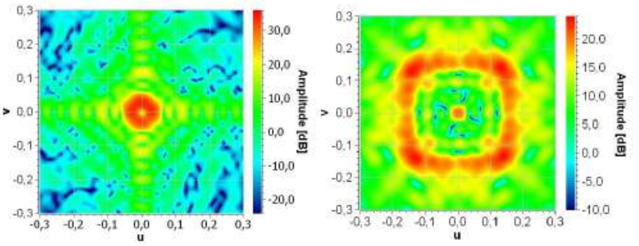

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AES 2023, TORREMOLINOS - SPAIN, 5 ±8 JUNE 2023

Reflection Loss Assessment of Reflecting Intelligent Surfaces

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Abstract: Reconfigurable Reflecting Intelligent Surfaces represent a valid solution for future 6G communications but face practical implementation challenges such as limited tuning range of diodes and losses caused by their presence. The paper focuses on the impact of diode series resistor on RIS performance, highlighting the importance of minimizing losses.

In recent years, Reflecting Intelligent Surfaces (RISs) have become a highly investigated solution for wireless communication systems [1]. The concept behind RISs is to manipulate the phase and amplitude of incident signals by adjusting the impedance of the surface [2], [3]. This can be achieved by using reconfigurable RISs, which allow for dynamic changes to the impedance and reflectivity in real-time [4], [5].

The reconfigurable nature of RISs brings numerous benefits to wireless communication systems, such as improved spectral efficiency, increased coverage, and reduced interference [6]. There are various methods to achieve reconfigurability in RISs, including using Varactor Diodes [7] ±[9], PIN Diodes [10], [11], and MEMS [12].

By applying a varying bias voltage to varactor diodes, the impedance of the surface can be adjusted, resulting in a range of reflection coefficients for incident signals. However, there are also challenges associated with reconfigurable RISs. One of these challenges is the limited tuning range of varactor diodes, which restricts the range of impedances that can be realized by the RIS [13]. Additionally, the high series resistance of the diodes can result in substantial reflection losses, which can negatively impact the overall performance of the RIS.

In addition to losses caused by the presence of diodes, there are other factors that affect the efficiency of Reflecting Intelligent Surfaces (RISs). For example, the use of materials such as glass-reinforced epoxy laminate (FR4), which are cost-effective but also have high loss properties, can result in losses. Furthermore, the flow of current on imperfect conductors and losses in the active components can lead to ohmic losses. Minimizing the effect of these losses is critical, and it has been found that a small periodicity of the lattice is an effective way to achieve this [14]. In fact, designing the pattern with a small period not only reduces losses but also leads to a wider bandwidth for the RIS, thus improving its overall performance [15], [16]

Studies in the literature have investigated the behavior of varactor diodes, the key components of RISs, at microwave frequencies. However, it has been discovered that the actual resistor value of the diodes is significantly different from the one specified in the data sheet, and the series resistance is often much higher than expected [17]. Given these findings, it is critical to assess the reflection losses of RISs when the series resistor exceeds 2 ohms

This paper aims to provide a comprehensive evaluation of the reflection losses of RISs, focusing on the impact of the diode series resistor on the performance of the RIS.

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Preliminary Results on Conformal Reflective Surfaces for Urban Scenarios

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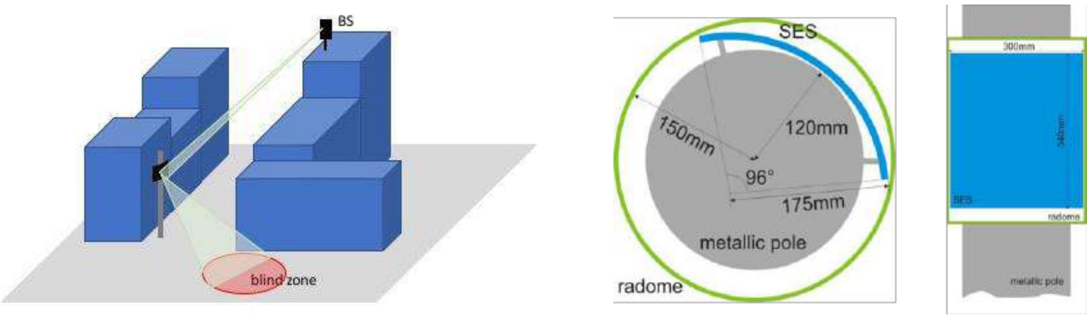
Abstract: In this communication, the results of a preliminary analysis on the possibility to use a curved passive smart electromagnetic skin working at millimeter waves to be mounted on street light or stop light poles are presented. In particular, the radiation properties of the curved surface are studied and compared with those of a planar solution, taking also into account the visual impact and the possibility to rotate the surface around the supporting pole.

The need for the next generation of communication systems to provide huge data rates with very low latency, ubiquitous mobile ultra-broadband connectivity, seamless coverage, and reduced power consumption pushed research interest to find new solutions to satisfy these requirements. If, on one side, the use of the mm wave frequencies presents several advantages, on the other, the larger attenuation and stronger interaction with obstacles along the propagation path can cause a degradation of the services in those regions that are not in the line-of-sight of the base station antennas. To limit their spread, Smart Electromagnetic Skins (SESs) can be introduced in the environment in which the propagation occurs [1-2]. They are very thin surfaces, consisting of many elements with resonant or subwavelength size, able to provide anomalous reflections. Depending on the scenario in which they are introduced, they could be passive structures [3], but, if necessary, they could also include active elements to provide coverage reconfigurability [4]. Usually, SESs are assumed planar to be integrated on walls of buildings. However, this solution is not always feasible, as for example, in historical city centers or on buildings with plenty of windows. Thus, other supporting structures must be used, such as the street light or the stop light poles (see the scheme in Fig. 1a). For the latter cases, the use of a curved instead of a planar reflecting surface seems convenient to reduce its visual impact and allow the SES to be illuminated by the field arriving from different base stations.



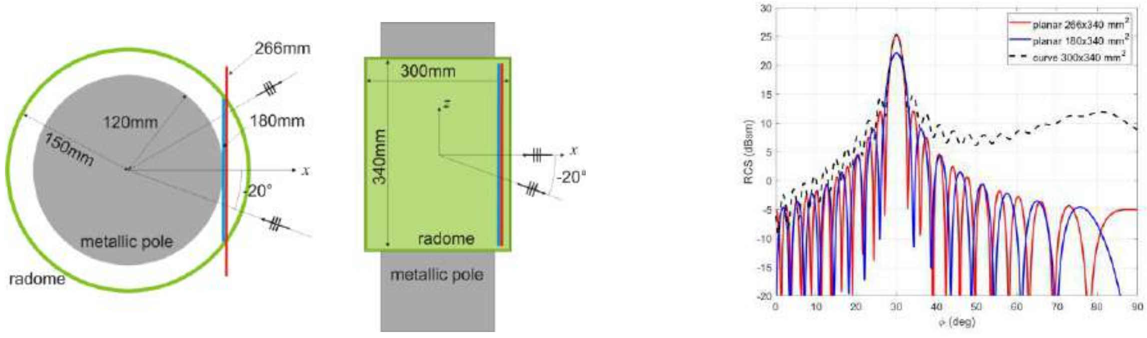
(a) (b)

Figure 1: (a) Example of the considered environment, where the SES is used to cover blind zones for the base station antenna. (b) Top and side view of the SES.

To assess the feasibility and the performance of a curved SES, a configuration as the one shown in Fig. 1b, designed to be mounted on a light pole with a diameter of 240 mm and protected by a radome concentric to the pole, with a diameter of 300 mm, is considered. Note that in the present analysis the effect of the radome on the performance of the SES is assumed negligible, but it is used to have an indication of the size of the reflecting surface that can be introduced between it and the pole.

Even if SESs can be realized either with resonant or subwavelength unit-cells, here the first choice is adopted. Moreover, since the required bandwidth is less than 10%, a simple re-radiating element is selected, i.e., a square patch printed on a single layer of Dicald527, with thickness h = 0.8 mm, relative dielectric constant Bp L tä w w and losses characterized by – ƒ A L r ä s y The unit-cell has a size equal to l ¤ t at the upper bound of the considered frequency range f = 27.5 GHz. The surface, that has size of 300 mm u 340 mm, is therefore discretized with 55 u 62 elements.

The performance of the curved SES is compared with that of two different planar reflecting surfaces with the same height of the curved one. The first one has a width of 180 mm to stay between the pole and the radome. The width of the second configuration is instead fixed in such a way that the reflected main beam has the same HPBW of the curved SES, and it is equal to 266 mm. In Fig. 2a the top and side views of the two planar SESs are shown. The three configurations are designed to provide a reflection in the direction (àå L s s rÜ âå L urÜ) with respect to the coordinate system indicated in Fig. 2a, when an incident plane wave is impinging on the surface with angles (àÜáÓ L {rÜ âÜáÓ L Ftr Ü) and then their radar cross section (RCS) is evaluated. The obtained patterns in the plane àå L s srÜ are plotted in Fig. 2b. It is worth noting that the curved SES has a maximum RCS comparable to that of the larger planar SES, which however is too large to stay behind the radome.



(a) (b)

Figure 2 (a) Top and side view of the planar SESs. (b) Evaluated RCS in the àå L s s rÜ plane.

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Some Notes on the Electromagnetic Field Processing in the Deep Physical Layer

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Abstract

Antennas and Electromagnetic field Processing Devices (EPD) are discussed, considering their role in the OSI stack of the next generations of personal communication systems. The physical layer is divided into two layers, the ÔSurface Physical LayerÕ, which will be called simply the Physical Layer (PL), and the ÔDeep Physical LayerÕ (DPL). According to this Ôextended OSIÕ model, antennas are Ôcross-laye devices, while EPDs are Ôsignal processingÕ devices operating at the DPL, wherein the ÔsignalÕ is the electromagnetic field configuration.

1. Introduction

The challenging objectives of the next generation of personal communication systems require extremely aggressive use of the communication channel with active control of it. In this new vision, the communication channel becomes a resource that can be dynamically optimized, with a great impact on the performance of the communication system. Radiating systems interact intelligently with the environment, playing an active role in the communication system.

The starting point of the analysis carried out in this presentation is to use a physical approach to information theory [1] for the analysis of such structures. The basic idea is to split the Physical Layer, introducing a layer below the physical layer, called the Deep Physical Layer, wherein information is not yet an abstract quantity, but a physical quantity, defined as the number of distinguishable configurations of the observable (in the specific case the electromagnetic field) in the presence of noise at the receiver side [2].

This opens new challenges in the study of the physical processing of information in the communication channel and the analysis of the impact of these systems on the communication process.

2. The Deep Physical Layer

The OSI model (Fig. 1) gives a complete view of the communication process. In the OSI model the data stream is divided into seven layers starting from the highest level, the ÓapplicationÓ layer, down to the lowest level, the Óphysical layerÓ (PL), which describes the implementation of the transmission of bits through the communication channel. Each intermediate layer represents a conceptual ÔdiscontinuityÕ in the complex procedures required for communication.

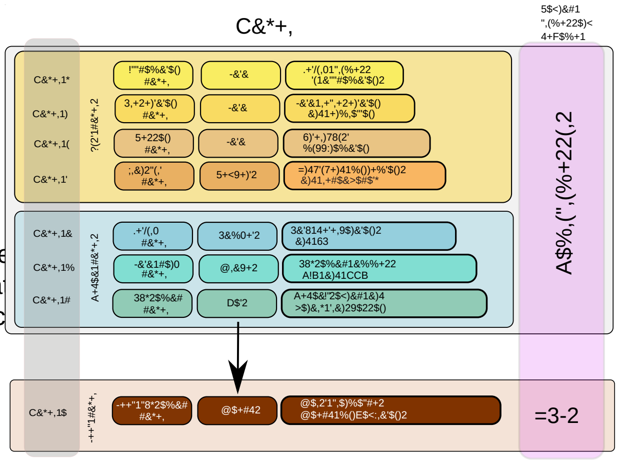

Figure 1: In the extended OSI layer, antennas are Ôcross layerÕ devices, while RISs (Reflecting Intelligent Surfaces) are special EPDs (Electromagnetic field Processing Devices) able to perform signal processing at the Deep Physical Layer level

If we look at the physical layer, we can note that the analysis of the communication process at this level is performed using statistical models. This is a well-established approach, routinely applied by the signal processing community with great success.

However, the first step that any communication system does before starting the communication is to identify the channel state. In practice, this changes the perspective of the communication systems from a statistical approach to a deterministic approach, ÔobservingÕ the actual state of the channel. This indicatedn that inside the physical layer, there is a ÔconceptualÕ discontinuity.

Loosely speaking, in the physical layers two ÔworldsÕ coexist. In a world, information is an abstract concept related to the Shannon mutual information. This is the world of the mathematical theory of information. However, there is a further world where information is encoded in a physical observable, that obeys the rule of physics. Loosely speaking, this is the world of the physical theory of information. Here, limitations are fixed by the laws governing our universe and hence are unbreakable.

All this suggests dividing the physical layer into two parts, an upper part, the Òsurface physical layer,Ó which in the following will be called simply the Physical Layer (PL)

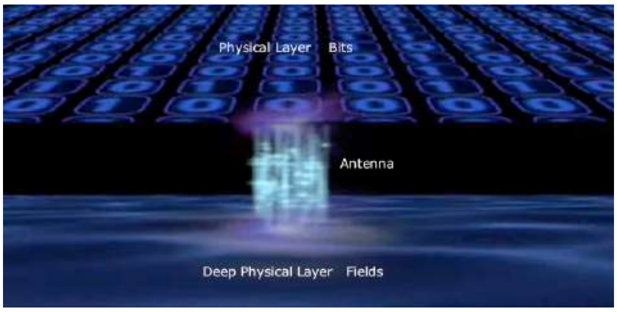

Figure 2: A prictorial view of the roel of the antennas in the extended OSI layer; antenna is the ‘gate’ between the Physical Layer (PL) and the Deep Physical Layer (DPL). In this sense, antennas can be seen as ‘cross-layer’ devices.

for the sake of simplicity, and a lower part, the “Deep Physical Layer” (DPL) [1]. While in the upper part, information is represented by abstract quantities, at the DPL, information is associated with physical observables. In particular, the amount of information is defined as the number of distinguishable electromagnetic field configurations on the receiver.

In this ‘extended’ OSI model the DPL is treated the same way as the other layers of the stack. In particular, as in the other layers, also in the DPL it is possible to do some ‘signal processing’ to optimize the communication process [4]. The only difference is that at the DPL the ‘signal’ is the electromagnetic field configuration, and the devices at the DPL directly modify the electromagnetic field configuration. We will call these devices Electromagnetic field Processing Devices (EPDs) [3]..

3. The role of Antennas in the DPL

As discussed above EPDs directly modify the electromagnetic field configuration in the DPL. In this view, antennas can be seen as quite special EPDs.

Indeed, the role of the antennas is to ‘connect’ the PL with the DPL (Fig. 2). In this sense, they ‘translate’ bits in different electromagnetic field configurations and vice-versa [4].

All this also suggests a bottom-up vision of the communication systems.

The DPL contains all the resources regarding space/time/polarization degrees of freedom of the electromagnetic field that the communication system can use to encode information [1]. EPDs allow the maximization of these resources by increasing the number of possible distinguishable field configurations by the receiver.

The different distinguishable configurations of the field must be converted into ‘bits’ to be processed by the layers above the DPL. The antenna does this conversion.

As a consequence, while before the use of EPD the propagation channel was the bottleneck, the use of EPD shifts such a bottleneck toward the antennas. It is worth noting that this view also suggests a ‘cross-layer’ approach for antenna synthesis, in which the radiating system is designed considering a double goal: controlling the distribution of the radiated power density in the space and maximizing the channel capacity [4].

Figure 3: A pictorial view of an EPD; it consists of an array of electromagnetic controllable scattering elements optimized to maximize the capacity of the wireless system. The DPL contains all the resources regarding space/time/polarization degrees of freedom of the electromagnetic field that the communication system can use to encode information while EPDs allow the maximization of these resources by increasing the number of possible distinguishable field configurations by the receiver, acting as ‘lenses’ for physical information.

4. The role of EPDs in the DPL

As noted above, the role of the EPD is to maximize the resources the DPL makes available to the upper layers [3].

An EPD consists of several electronically controllable scattering elements. The general architecture is similar to the one used in the Reflecting Intelligent Surfaces (RIS) [5]. However, there are some differences.

The goal of EPDs is the maximization of the channel capacity, and their synthesis is driven by information-based goals [6]. The solution maximizes the number of MIMO spatial subchannels [7], giving quite complex field configurations on the EPD. Instead, the main goal of the RIS is extending the wireless connection to overcome the limitations of the high-frequency communication systems, as in 5G FR2 or in the THz band that will be used in the next-generation 6G communication systems. RIS is based on reflection, allowing more classic synthesis methods to be used.

Also, the field of application of EPDs and RISs is different. RISs are highly effective in mmW and THz frequencies, where their use at lower frequencies, where scattering mitigates the coverage problems, is more attractive at the lower frequencies, where increasing the MIMO spatial subchannels allow increasing the capacity balancing the narrower bandwidth available, while is less appealing. at very high frequencies, where extremely large bandwidth allows very high bit rates.

EPDs and RISs share the use of controllable devices. Indeed, EPDs can also be obtained as an array of RISs, i.e., of reflecting controllable surfaces [7] organized to maximize the capacity of the wireless system [3] (Fig. 3).

Loosely speaking, RIS devices give optimal field processing when field configurations have only one spatial degree of freedom, [4]. More complex field elaboration must be carried out to maximize the channel capacity if more than one degree of freedom is available.

5. Conclusions

Introducing the Deep Physical Layer in the OSI model allows for quantifying the amount of information transmitted by the communication systems in terms of electromagnetic field configurations. Put simply, in the DPL, information is physical

In this model, the role of the antennas is to ÔconnectÕ the upper layer of the physical layer with the DPL, ÕmappingÕ bits in different configurations of the electromagnetic field and vice-versa.

Processing at the DPL is made by devices called Electromagnetic Field Processing Devices (EPDs), which consist of arrays of controllable reflecting devices organized to maximize the capacity of the wireless system [3]. They act as ÔlensesÕ instead of Ômirrors,Õ as in RIS devices, for information.

A simple Óproof of conceptÓ of EPD is the ADAM architecture, in which several controllable scattering elements are placed in proximity of a MIMO antenna, obtaining a 6 bits local controllable environment [6]. Experiment tests confirmed the effectiveness of the use of EPD. In particular, the prototype allowed almost half the transmitted power without reducing the performance in terms of channel capacity, with a positive impact not only on the communication network, reducing energy consumption, but also on the environment, lowering the level of the electromagnetic field [7]. The ADAM architecture is the starting point for developing new devices under investigation in the microwave laboratory of Cassino University.

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[7] :;<=>?@;A?!BC!#D;E?>FE=D!#AGFA;;>FAG(!3AFH;>IFJ=J!J;!*HF;JB(!$<=FA

[%] AI?F?K?B!J;!);D;EB@KAFE=LM;I(!3AFH;>IFJ=J;!J;!-FINB±(!1B>?KG=D

:;<O!BC!$FGA=D!)P;B>Q!=AJ!RB@@KAFE=?FBAI!=AJ!);D;@=?FE!$QI?;@I!=AJ!RB@<K?FAG(!3AFH;>IFJ=J!+;Q!2K=A

[9] .ACB>@=?FBA!1>BE;IIFAG!=AJ!);D;EB@@KAFE=?FBAI!R;A?;>(!3AFH;>IFJ=J!1BDF?SEAFE=!J;!,=J>FJ(!$<=

[8] RB>>;I<BAJFAG?PB>T;NBU=KAFBHFO;I

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I>9'%$&!

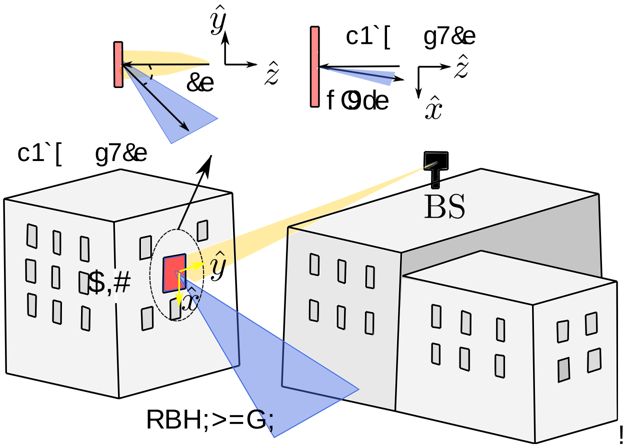
)PFI!VB>W!<>;I;A?I!?P;!J;IFGA!=AJ!B<?F@FX=?FBA!BC!= .A?;DDFG;A?!+;CD;E?FH;!$K>C=E;!Y.+$Z!N=I;J!BA!=!>;C ?;EPABDBGQ! ?B! F@<>BH;! ?P;! EBH;>=G;[!=FA!4!! @@ IE;A=>FBO! "! <>;DF@FA=>Q! J;IFGA! FI! <;>CB>@;J! ?B! = VFJ;!N;=@!FA!=XF@K?P!=AJ!;D;H=?FBAO!)P;!.+$!FI!<D=E NKFDJFAG! C=L=J;! =AJ! FE?!! ;EC;D;E?>B@=GA;?FE=I EP=>=E?;>FX;J! CB>! JFCC;>;A?! @=?;>F=DIO!)P;! J;IFGA F@<>BH;J!NQ!B<?F@FXFAG!?P;!.+$!EBAIFJ;>FAG!?P;!V F?!FI!<D=E;JO

KA 2,'%+-8&')+,!

.A! ?P;! >;E;A?! Q;=>I(! $@=>?! #D;E?>B@=GA;?FE! $WFAI P=H;!N;;A!<>B<BI;J!?B!BH;>EB@;!?P;!FIIK;!I>;D=?;J!?B!IFGA <>B<=G=?FBA! N;E=KI;! BC! ?P;! <PQIFE=D! N=>>F;>I J;<DBQ@;A?! BC! ABH;D! VF>;D;II! A;?VB>W[!=FA! @@ IE;A=>FBI^O!/=@;DQ(!.A?;DDFG;A?!+;CD;E?FH;!$K>C=E;!Y.+$Z =>;! KI;J! ?B! ;AP=AE;! 4\! _+%! EBH;>=G;! =HBFJFAG! E?BIO FAI?=DDFBA!BC!@KD?F<D;!N=I;!I?=?FBAI!Y`$ZO!"A!.+$!FI!<D=E IK>C=E;! @=J;! K<! BC! <PFIFC?FAG! ;D;@;A?I! ?P=?! >;CD;E?FBA F@<FAGFAG!IFGA=D!>=JF=?;J!C>B@!?P;!`$!FA?B!=!J;IF>;J! Y<;EKD=>!B>!=AB?P;>!JF>;E?FBAZO!)P;!>;CD;E?;J!CF;DJ!EBKDJ ;F?P;>!=!N;=@FAG!B>!;H;A!=!IP=<FAG!N;=@O!"E?K=D@FX=?FBA!< <=IIFH;!<P=IPFC?FAG!;D;@;A?I!E=A!N;!KI;J!FA!?P;!<=A;D(! @=FADQ!J;<;AJFAG!BA!?P;!>;EBACFGK>=?FBA!>;aKF>;J!NQ!?P; EBH;>=G;O!,B>;BH;>(!.+$!P=I!N;;A!=!DIB!<>B<BI;J!?B!FA?>BJKE;! N;=@!?FD?FAG!FA!=!<BFA?FAG!B>!E=>P!?P;!EBH;>=G;!IPBKDD;J! NDFAJ!XBA;I(!VPFEP!=>;!J;CFA;J!=I!=A!=>;=!BC!<BB>!B>!)P;!AAKDD EBH;>=G;O!)P;!?P;!.+$!FI!N=I;J!BA!=!<=IIFH;!;D;@;A?I!F?!FI E=DD;J!$,#O

.+$!P=H;!N;;A!<>B<BI;J!CB>!NB?P!K>N=A!=AJ!FAJBB>!IE;A=>FBI]' ^(!9^O!.A!NB?P!E=I;I(!?P;!V=DDI!=>;!KIK=DDQ!?P;!@BI?!EBHF?;>;G!K <D=E;@;A?I!CB>!FAI?=DDFAG!?P;!>;CD;E?FH;!IK>C=E;O!!#A!=!?GK ;?@ IE;A=>FB(!?P;!`$!FI!C=>!=V=Q!C>B@!?P;!.+$(!?P;>;CB>;!;D;E?>B@ I@=DD!C>=E?FBA!BC!?P;!>=JF=?;J!<BV;>!<>BHFJ;J!NQ!?P;!`$!FI! E=<?K>;J!NQ!?P;!.+$O!)PFI!I@=DD!C>=E?FBA!@KI?!N;!<>BHFJ;J!N @=A=G;J!?B!;AP=AE;!?P;!EBH;>=G;O!*VFAG!?B!?P;!`$!?B!E?>;IIFE =V=Q(! ?P;! IK>>BKAJFAG! BC! ?P;! .+$! =>;! =DIB! I?>BAGDQ! FDDK@FA=?;J!IB!?P=?!?P;!I<FDDBH;>!BA!?P;!NKFDJFAG!C=E;I!=>;! N;!A;GDFGFND;O!

)P;!>;CD;E?FBA!<>BJKE;J!NQ!?P;!IK>>BKAJFAG!V=DD!N;PFAJ!?P;! EP=>=E?;>FX;J!=AJ!EBAIFJ;>;J!CB>!=!=EEK>=?;!@BJ;DFAG!BC!?P; EBH;>=G;!<>BHFJ;J!NQ!?P;!J;HFE;!BC!?P;!KI;>!=I!_FGK>;!7O



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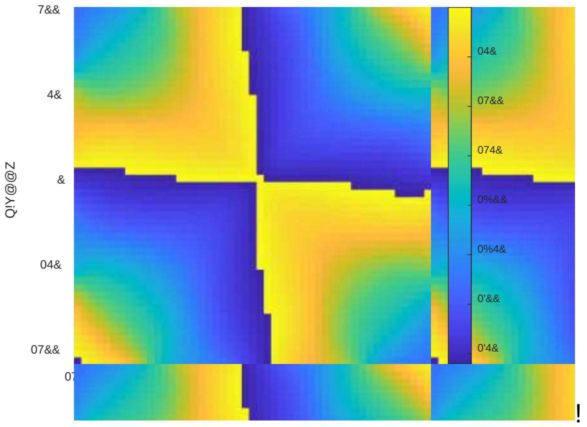
LA 70$%'!F3(&'%+0$4,(')&!7M),!N(9)4,

LAKA &(,$%)+!$,-!70$%'!F3(&'%+0$4,(')&!7M),!./')&9!

)P;!AAKDDFG;A?!+;CD;E?FH;!$K>C=E;!FI!N=I;J!BA!=!<=IIFH;!<=A;D(!IB!?P=?!F?!FI!E=DD;J!=!$@=>?!#D;E?>B@=GA;?FE!$WFA!Y$,#ZO!)P;!IFGA=D!C>B@!?P;!`$!FI!>;CD;E?;J!=AJ!IPBKDJ!N;!=!IK>C=E;!=!!?P;!<D=E;@;A?!BC!?P;!$,#!=AJ!?P;!KI;>!=!<D=E;!FA!=!NKFDJFAG!C=E;!=!?B!=AJ!KI;>!=!=!EBH;>=G;O!"!IF@<D;!@BJ;D!BC!?P;!.+$!=!?P;!IK>C=E;!IPBKDJ!N;!EBAIFJ;>;J!=AJ!=!?P;!<=A;D!IPBKDJ!N;!KI;J!?B!?P;!BN?=FA!?P;!=!<=A;D!IPBKDJ!N;!J;IFGA;J!=AJ!?P;!IFGA=D!?B!=!EBH;>=G;!IPBKDJ!N;!=!<BV;>!=AJ!;D;E?>B@=GA;?FE!CF;DJ!=!IPBKDJ!N;!N=I;J!BA!?P;!EBAIFJ;>;J!VPFEP!FI!=!?P;!EBH;>=G;O!)P;!IK>C=E;!IPBKDJ!N;!>;CD;E?FBA!=!?P;!@BJ;D!=AJ!?P;!I;>H;J!=!?P;!FA!=AJ!IFGA=D!=!?P;!=!N;=@!VF?P!?P;!<FIFC?FAG!=!>;CD;E?FH;!=!?P;!IFGA=D!=!=!BAD!?P;!.+$!=AJ!?P;!<=A;D!FI!J;IFGA;J!=AJ!KI;J!?B!=!?P;!IFGA=D!FA!?P;!J;IF>;J!JF>;E?FBA!=AJ!?P;!KI;>!<BV;>!FI!EBAIFJ;>;J!=!<=A;D!F?!FI!=!$,#!?B!BN?=FA!=!EBH;>=G;!?P;!_FGK>;!7O!,BJ;D!=!DFA;O!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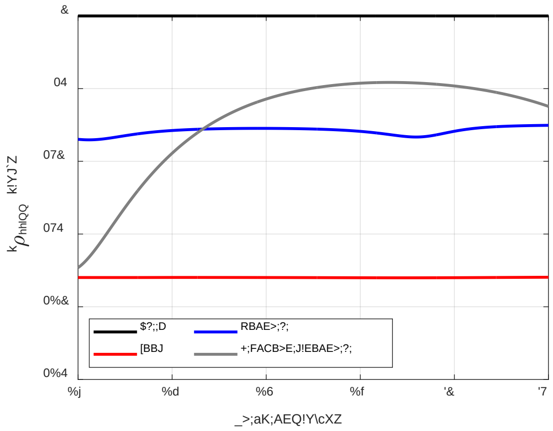
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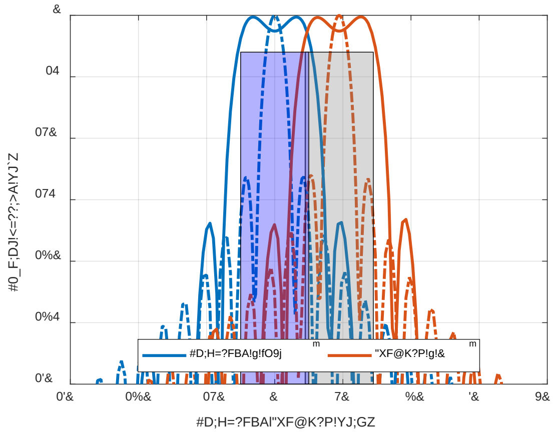
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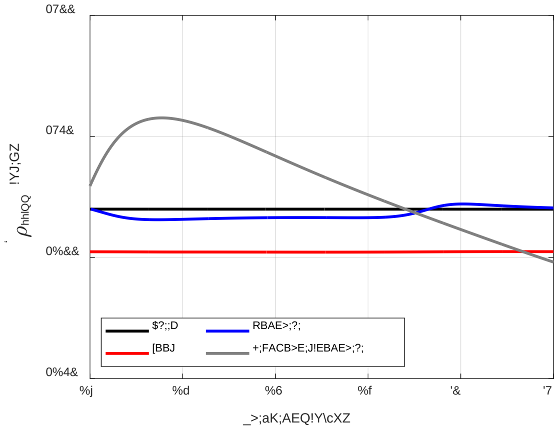
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FAEFJ;A?!V=H;!FI!>;CD;E?;J!FA!?P;!I<;EKD=>(!?P;!BK?GBFAG!=>;!fO9de!FA!;D;H=?FBA!=AJ!&e!FA!=XF@K?PO!

)P;!<=A;D!FI!JKDD;=>DQ!<BD=>FX;J!EBAIFJ;>FAG!?B!?P;!PB>FXBA?=D!<BD=>FX=?FBA!YcZ!J;CFA;J!=I!EBAIFJ;>FAG!?B!?P;!VPFD;!?P;!H;>?FE=D!<BD=>FX=?FBA!YiZ!FI!J;CFA;J!FA!?P;!)B!=EPF;H;!?P;!J;IF>;J!I<;EFCFE=?FBAI!?P;!>;CD;E?FH;!$#!FI!EB@<>FI;J!BC!4&!h!4&!;D;@;A?I!BC!<;>FBJFEF?Q!9O%!h!9O%!@@O!

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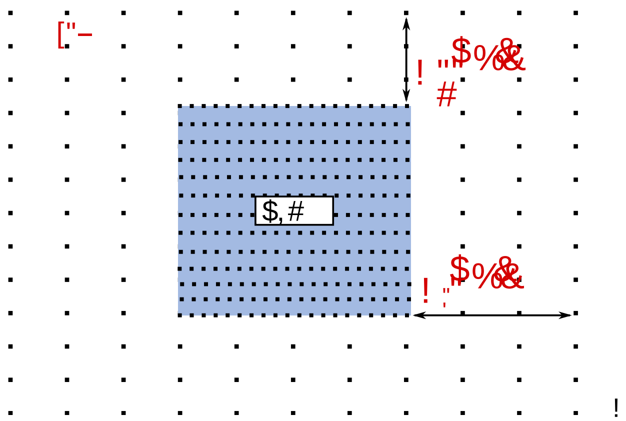

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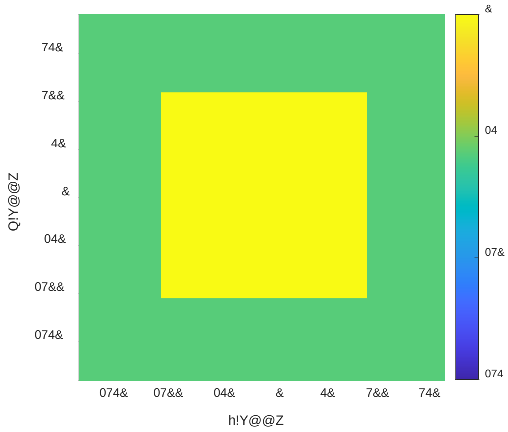

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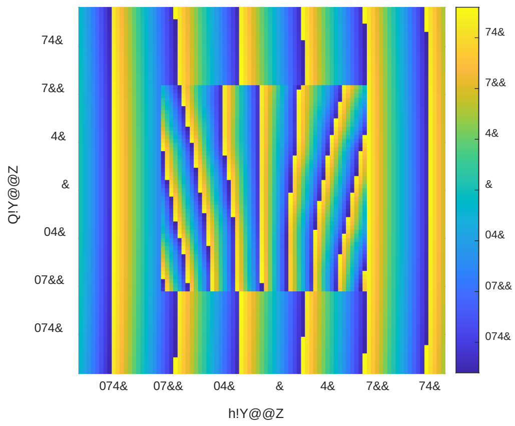

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)P;!$,#!FI!J;IFGA;J!CB>!=A!BK?JBB>!IE;A=>FB(!IB!?P=? <=A;D!VFDD!N;!FAI?=DD;J!FA!=!NKFDJFAG!C=L=J;O!RBAI ?P;!`$!FI!C=>!=V=Q!<>BHFJ;I!=!N;=@!VF?P!VFJ;!c1`[!YFA! ?PFI!E=I;!=NBK?!7!?P;!FAEFJ;A?!CF;DJ!VFDD!P=H;!=!I FDDK@FA=?FBA!=DIB!FA!?P;!IK>>;AJ;>I!BC!?P;!$,#(!<>B PFGP!I<FDDBH;>O!RB@<=>FAG!?P;!;D;E?>FE=D!IFX;!BC ?P;!C=L=J;(!?P;!$,#!VFDD!BADQ!E=<?K>;!=!DBV!C>=E?F >=JF=?;J!<BV;>(!VPFD;!?P;!I<FDDBH;>!PFGPO!)P;>;CB> ?P;!>;CD;E?FBA!<>BJKE;J!NQ!?P;!V=DD!IPBKDJ!N;!=A ;H=DK=?;!F?!FACDK;AE;I!BA!?P;!EBH;>=G;O!

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?P;!<>;I;AE;!BC!I?;;D!YB>!B?P;>!@;?=DIZ(!?P;!G>;=?;>!? ;CD;E?FBA! <>BJKE;JO!)P;! >;I<BAI;! BC! I?;;D! E=A! N ;>=GA;?FE! NQ! ?P;! >;CD;E?FBA! <>BJKE;J! NQ! =! 1;> #D;E?>FE=D! RBAJKE?B>! Y1#RZ(! VPFD;! ?P;! VBBJ! @FGP EBAIFJ;>;J!=I!?P;!=I<=>;A?!IFAE;!F?!N=>;DQ!>;CD;E?I!?P;!V=H;! D;=I?!VF?PFA!?PFI!N=AJ!VFJ?PZO!

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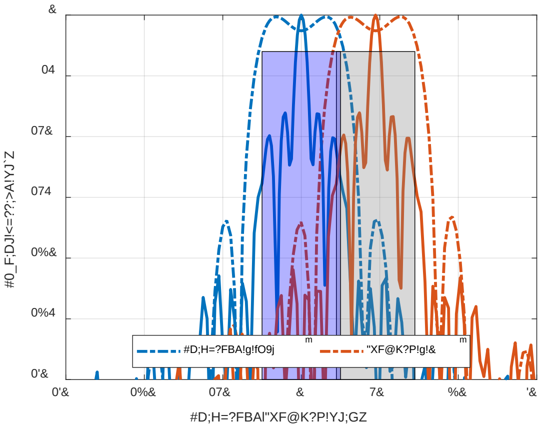

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Nanoscale Electrodynamics

Terahertz Waveforms in the Atom-Scale Gap of a Scanning Tunnelling Microscope

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Abstract: Measuring ultrafast, near-field waveforms on atomic length scales has remained an open challenge. Using a molecular switch as a local field sensor, we sample the temporal shape and strength of atomically confined light field transients. This allows us to quantitatively determine the instantaneous field strength in units of V/m with sub-cycle precision.

Tailored nanostructures like antennas, nanoparticles and tips confine and enhance electromagnetic waveforms in sub-wavelength volumes. Such nanoscale optical fields have revolutionized (bio)chemical and medical detection[1], augmented photoenergy harvesting[1], and allowed for femtosecond scanning tunneling microscopy (STM)[2,3], with real-space resolution down to the sub-molecular level[3]. However, when light interacts with nanostructures, a complex interplay of plasmonic propagation, near-field screening, geometrical phase retardation and antenna enhancement determines the time-dependent near fields making a priori prediction of local waveforms extremely challenging. Moreover, non-classical femtosecond dynamics such as tunneling has been predicted to shape local fields[4]. Far-field transients can be directly sampled in the time domain by electro-optic detection. In contrast, quantitative measurements of ultrafast atom-scale near fields have remained a major challenge. Since light-matter interaction crucially depends on the absolute strength of local fields as well as their temporal evolution, a parameter-free method to directly measure and calibrate atom-scale waveforms has been highly desirable.

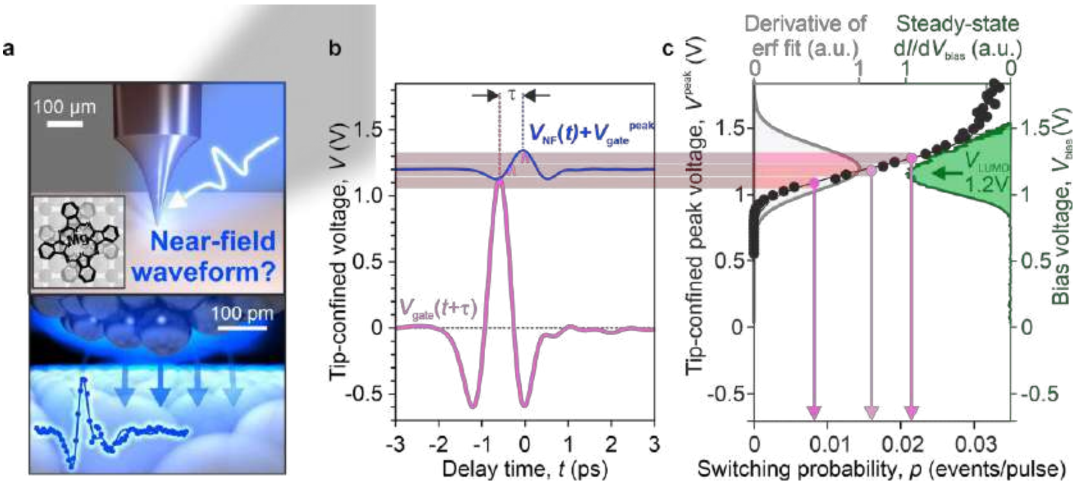

Fig. 1. a, A THz waveform is coupled into an STM junction where the ultrafast voltage applied by the near-field waveform is detected using a single molecule switch (inset) as an atom-scale voltage gauge. b, A test transient, $V_{NF}(t)$, is superimposed with a gate waveform, $V_{gate}(t)$, (pink curve) for different delay times, τ. Thereby, the field crest at the maximum of the interference sum samples the test waveform (blue curve). c, Calibration scheme. The switch¶s reaction rate depends on the local THz-induced peak voltage (data points). Comparing the derivative of this error function (gray curve) with steady-state tunnel spectroscopy (green curve) gauges the THz-induced voltage quantitatively.

We demonstrate a direct quantitative detection of atomic-scale near-field waveforms with femtosecond precision in a novel pump-probe sampling scheme[5]. A single-cycle pulse in the terahertz (THz) range of the electromagnetic spectrum is focused onto the Ångström-scale junction of an STM, where the light fields induce an ultrafast voltage[2,3,5,6]. The idea is to use the field crest of a second THz pulse as a sub-cycle gate. When we vary the delay time between the two pulses, the peak voltage of the interference transient directly traces the test waveform. Hence, we can stroboscopically resolve the time evolution of our test waveform, if we manage to measure the local instantaneous peak voltage. To this end, we employ a bistable molecule as a high-precision, atom-scale and quantitative voltage sensor and build on state-selective lightwave-driven STM[3,7]. Using the voltage-dependent switching rate of the molecular rotor, we directly sample the temporal shape and strength of atomically confined light-field transients quantified in units of volts[5]. The far-field waveform (Fig. 2a, red) focused on the STM junction differs markedly from the atomic near-field transient (datapoints). The 1/f scaling of the field enhancement redshifts the central frequency and a clear phase shift can be observed. These and more subtle features of the transfer from the far field to the near field are reproduced by a classical numerical calculation (Fig. 2b). First principles TDDFT simulations[8] corroborate assumptions made in our analysis and confirm that the instantaneous peak voltage can be extracted very accurately by our atomic-scale sensor.

Our ultrafast, local sampling technique opens the doors to explore the validity limits of classical nano-optics directly on sub-Å and femtosecond scales. Moreover, this lays the foundation for calibrated simulations, which connect macroscopic light and Å-scale waveforms. Moreover, atomically defined and calibrated waveforms can now be utilized to shed light on the dynamics of single molecules, atomic defects or novel quantum materials by means of ultrafast nanoscopy and spectroscopy.

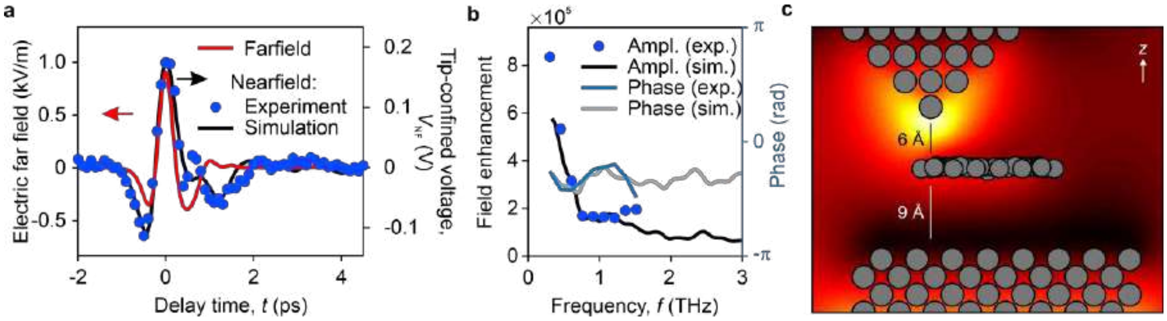

Fig. 2. a, Far-field waveform coupled into the junction (red). Resulting tip-confined voltage transient (datapoints) and a scaled classical simulation of the near-field waveform (black curve). b, Transfer function for amplitude an phase determined experimentally and using a classical simulation. c, First principles TDDFT simulations[8] of the dynamical Hartree potential

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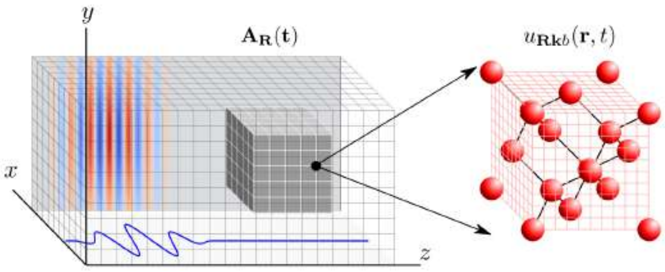
C"%&,3,/%),(*)('(".(#,&)'5%.$,")52#('-#(,).(*0$#*)0(*#&).(%#(/#)",/#&)50"/#/)2,=#)1##(),()#//#(%.,")%'5.$).()%2#)$0&&#(%)3&'(%.#&)'3)'5%.$,")/$.#($#)@(*#&)"#$%&'(.#*)3(,('52'('(.$/ <)&%.3.$.,")(,('/$,"#)/%&0$%0&#/<)5,&%.$0",&"+)%2#)/#-.$'(*0$%'&)D,"4".#"#$%&.$D)(,('5,&%.$"#/),(*)-#%,/0&3,$#/<)2,=#)1##().(%#(/.=#"+)/%0*.#*).()&#$#(%)+#,&/),)(#@)5",%3'&-)3'&)('(".(#,&)'5%.$/<)/0$2),/)2,&-'(.$)B#(#&,%.'()'3)E'-50%,%.'(,")#"#$%&'-,B(#%.$/)/.-0",%.'(/)1,/#*)'()F,G@#""H/)#I0,%.'(/<)/0$2),/)%2#)4%&.(#3.(.%#)*.33#&#($#)69878:)-#%2'*<)2,=#)1#$'-#),().(*./5#(/,1"#)%"") .()%2#)*#/.B()'3)(,('52'%'(.$/)*#=.$#/)$789:;:<($ %2#)$'(=#(%.'(,")-#%2'*)&#I0.&#/)#-5.&.$,")'5%.$,")$'(/%,(%/)'3)-#*.,),(*)%/),55".$,%.'(/)".-.%#*)%')=#(%/)$,0/#*)1+)@#,A).(%#(/.%+)".B2%)@.%2)".(#,&)&#$5'(/#>)

J#) .(=#/%.B,%#)%2#'&#%.$,"),(*)$'-50%,%.'(,")-#%2'*/)3'&)#"#$%&'()*+(,-.$/)1,/#*)'()%2#)4##5#(*#(%)*#(/.%+)30($%.'(,")%2#'&+)678897:<)@#)$'-1.(#)()*#(/.%+)'3)(,('5,&%.$"#/) ,55"+)%')=,&.'0/)-,%#&.,")/+/%#-/)K4C4)/0$2),/)%'-/<)-"#$0"#/<),(*)10"A)/"*.*/>)72#)78897$,()/0$$#//30""+)5&#*.$%)".(#,&)*.#"#$%&.$)3(.$%.'(/),(*)'5%.$,"),1/'&5%.'(<)K(CM ,(*)('(4#5#&%0&1,%.=#)('(".(#,&)52#('-#(,)/0$2),/)%0((#").'(.;,%.'(</,%0&,1"#),1/'&5%.'(<),(*)2.B2)2,&-'(.$)B#(#&,%.'()6RRS/)>J #)30&%2#&-'&#"5),)$'05"#*)-#%2'*)$'-1.(.(B) %2#)3.4#%5&.($.5"#/)78897),(*)%2#)#"#$%&'-,B(#%.$)/.-0",%.'(,")%2,%)@#)$,""+#2#)F,G@#""U78897)-0"%./$,"#)-#%2'*<)%'#/$&.1#)".B2%4%%#&)(%#&,$%.'().()%2#)(,('/$,"#)-,%#&.,"/)K(CM)>


y
x
z
$\mathbf{A}_{\mathbf{R}}(\mathbf{t})$
$u_{\mathbf{Rk}b}(\mathbf{r},t)$

)

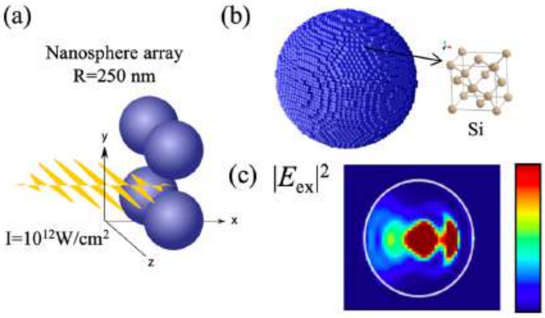
) !"#$%&' ($=>?:$8@$,>A9:BBC)DDE)$=FBGHIJ>B:$=,<K8IJ8NHJ$:B:JG<8=>?O:GHJ$
) @H:BL$HI$I8B;:L$FIHO?$J8F<I:$?<HL$IPIG:=$QB:@GR$9KHB:$=HJ<8IJ8NHJ$:B:
) J>BJFB>G:L$FIHO?$?<HL$IPIG:=$Q<H?KGRM
)

72#)$'($#5%0,")."0/%&,%.'()3)'0&)F,G@#""U78897)$'05".(B)./)2'@().()9.B>)()%2#)$'0&/#)B&.*)/+/%#-<)%2#)-,$&'/$'5.$)#"#$%&'-,B(#%.$)3.#"*)#/$&.1#*)1+)%2#)F,G@#"")#I0,%.'(/)3'&)%2#)=#$%'&)5'%#(%.,")W

!" R #" R # A R (t) + 1/c2 !2/!t2 A R (t) = c/4" J R (t))

@2#&#)./)%2#)-,$&'/$'5.$)$"&*.(,%#>)72#)/'0&$#)%##G))&#5&#/#(%/)$0&&#(%)*#(/.%+).(*0$2#))(,<)
@2.$2)./)B.=#()1+)%2#)-.$&'/$'5.$)#"#$%&'()*+(,-X$%)$2)B&.*)5'.(%)<)%2#).(*.=.*0,")#"#$%&'()*+(,-.$/)
B'=#&(#*)1+)%2#).-#*#5#(*#(%)Y'2(4Z2,-)678YZ:)#I0,%.'(W))

i ! / ! t u bkR (r, t) = 1/2 ! i" r + k + 1/c A R (t) #2 + V R (r, t) u bkR (r, t))



! "#$%&'W$Q>R$HBBFIG<>GH8O$8@$N:<I$
$QXR$ =FBGHIJ>B:$ =8L:B$ QJR$ N<8@HB
:O:<?PGGYS4M$$Z@I[M

@2#&#)),&#%2#)["'$2)'&1.%,"/)'3)#"#$%&'(/#(*)/)%2#)
#33#$%.=#)5'%#(%.,"0*.(B)%2#).'(.$<)R,&%&##),(*)
#G$2,(B#$'&&#",%.'()%#&E/>$0",%.'()'3)%2#05"#*)
#I0,%.'(/)5&'=.*#/)%2#)".B2%)5&'5,B,%.'(),(*)-,%#&.,"/)
&#/5'(/#)/.-0"%,(#'0/"+>)
)))X/),)*#-'(/%&,%.'()'3)%2#)G@#""U78897)
-0"%./$,"#)$,"$0",%.'(<)@#)$'(/.*#()(%#(/#)",/#&)
#G$.%,%.'()'3)%52&)'*.$),&&,+)'3)-.$'(*0$%.(B)6/.".$'(:)
(,('/52#&#/)@.%2).,-#%#&)]NO^)(-) K/##9.B>)N6461M))
72#).($.*#(%)",/#&0I0#($+).)/#%/)L>OO)#_<)@2.$2)./)
/-,""#&)%2,()%2#)*.&#$%)1,(*)B,5)'3)/.".$'(>)C(*#&)%2#)
/%&'(B).(%#(/.%+)Ja$- :)50"/#<)%@')52'%'())
%2&##)52'%'()&5%.'()5&'$#//)"#*/)%2#)$,&&.#&)#G$./%,%.'($,")&#B.'(>)KZ##)9.B)N6$%)$)1"0#)$#/"
/2'@().()9.B>)N61)78897)$,"$0",%.'()'3)/.".$'().)/$,&&.#*)'0%T-,$&'/$'5.$)B&.*)5'.(%/V>)Z.($#%2#&#),&#)
,1'0%)Lb<^^^)-,$&'/$'5.$)B&.*)5'.(%/)%2#)$,"$0",%.'(I0.&#/)20B#)$'-50%.(B)&#/'0&$#/>
)X"%#&(,%.=#".%).)5'//.1"#)%'&3'&-%2#)#"#$%&'*+(,-.$/)$,"$0",%.'(B)#-.$'(*0$%.(B)["'$2)
#I0,%.'()%2,%).(="=#/%2#*#(/.%+)-,%&.G %B&'0(*)/%,%#)#.B#(#(#&B.#/)%&,(/.%.'()*.5"'#)-'-#(%/)())

i ! / ! t " (k,R) bb' (t) = [# b (k) ! # b' (k)] " (k,R) bb' (t) + 1/c A R (t) á # " $ % j p bj (k) " (k,R) jb' (t) ! " (k,R) bj (t) p jb' (k) & ( ))

[+)0/.(B).%$'-50%,%.'(,")$'/%)$,()1#)/.B(.3.$,(%"+)&#*0$#*)$'-5,&#*)%78897 >)??'@/)0/)%)*#/$&.1#)
30&%2#&)$'-5"#G$#//#/).($"0*.(B)&#,"./%.$)4"#"#$%&.$)(,('52'%'(.$/)*#=.$#/72#)-#%2'*/)@#)2,=#)1##()
#=#""5.(B),&#).-5"#-#(%#).(,()'5#(4'0&$#)5&'B&,-)5,$A,B#)ZXcFdeV)6Z$,",1"#)X1).(.%.')c.B2%F,%%#&
/.-0",%'&)3'&)d5%.$/),(*)e,('/$.#($#:)K4gM)J#)#G5#$%@.."")5&'=.*#),)0/#30")5",%3'&-" .(B)%')B,.(),)
##5#&)0(#&/%,(*.(B)'3)%2#)0(*#&"+.(B)52+/.$/(.B2%%2,%)./)0/#30")%2#)*#/.B()'3)0%0&#)'5%.$,")*#=.$#/>
)

*,-,%,.',#)
S!M ,C)F4(1"2),C)7O)9O)3%*;)2G6<;)E":C)H"&'C2)IIJ)KLIMN)O
%!M7O)P$8$($)2)3O)Q)R"%&;.6)2G6<;)E":C)R)!# 2NNM)KLIISO)
'M 3O)Q)R"%&;.6)2DT)TU$&$2VCF4')7O)P$8$($)2G6<;)E":C)R)$"2)JIIM)KWXX)XO
T!M YO)9""*&*2PC)74U$8$%)ZO)V)5$&*2)7O)P$8$($)2=C>6"'C)G6<;)C%!&)2XINLX)KWXLI)D)
2!M 7O)P$8$($)2?O)541/<$'$2)PC)56/(*6$%)2O)Z&*8"2)3O)Q)R"%&;.6)2G6<;)E":C)R)! 2XN[L\N)KWXL)WO
U!M Y C)]*0$)"#$%2)>*'#4&C)G6<;C)>*"C)(! 2)\[SDS[)KWXL)O
V!M 5VHYZ])?!!Q?)#%*E".&)*++/./$-)U"8;/&"A&&#;A^^;$-'T&00+&)CE#^

!"#$%"#&'()*$++,+-(!.++"/,+-(0,*#12*1345(673/1#,+-(8/&#$9$2&(:4+$;,*2(,+(0$&"#,$/2(<1=+(&1(&%"(>&1;,*()*$(/"

$

?@@(A"-;$++B(

789:;<=8><$?@$1ABCDEC($6>DF8;CD<B$?@$!GH8;<:($"I=?><?>($!GH8;$:$)JK$%"L($M:>:I: NE?;;8C9?>ID>O$:P<A8?Q$>>RP:GH8;<:$E:

$

>C2&$*&()8;:A8;<T$CE:>>D>O$<P>>8GD>O$=DE;?CE?9BUVTD=:OD>O$?@$PG<;:@:C<$9A8>?=8>:$
=:<8;D:GC$I?X>$<?$<A8$:<?=DE$CEOG8$UGEGG8W$DE?C8E?9P;:<D?>$)VT$9PGC8C$:><8>>:E?P9G8I$<?$<A8$
CA:;9$=8<:G$<D9$?@$:>$#),($:>I$<A8$;8CPG<:><$EP;;8><$YP>E<D?>$9;?IPE8C$:$E8CEP
<;:>CD8><$<P>>8G$EP;;8><$<A:<$E:>$H8$PC8I$<?$9;?H8$PG<;:@:C<$IB>:=DEC$?@$XA:<8(?$CE:G8S$
;8E8><$8[98;D=8><C($:>I$@P<P;8$ID;8E<D?>C$;8$IDCEPCC8IS$

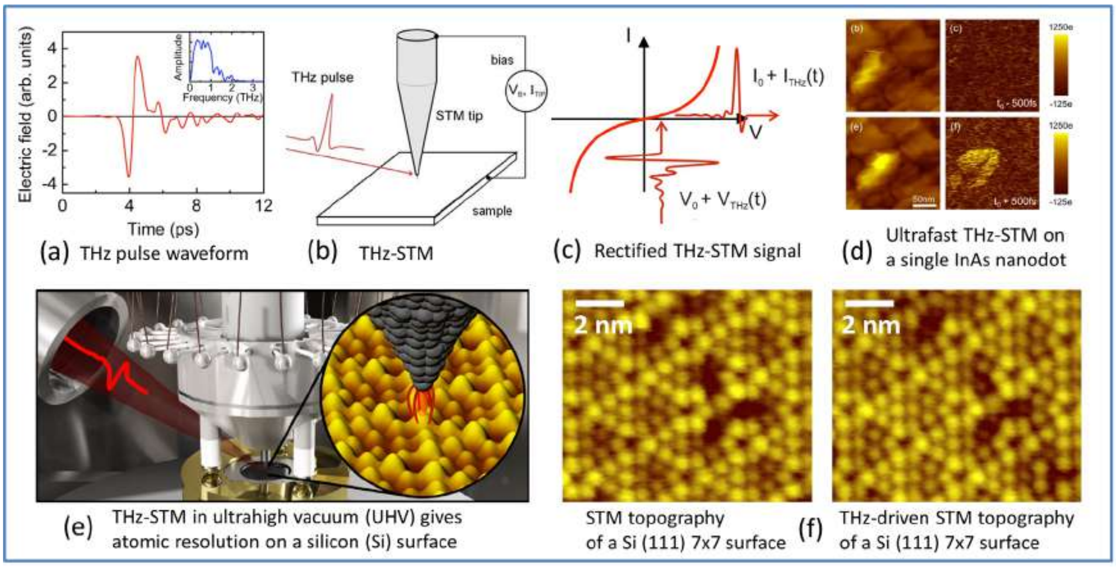
$

$

)A8$:HDGD<B$<?$ID;8E<GB$9;?H8$PG<;:@:C<$>:>?CE:G8$DC$8CC8><D:G$<?$?P;$P>I8;C<
8[ED<:<D?>$IB>:=DEC$D>$=:<8;D:GC$:>I$D>$<A8$I8F8G?9=8><$?@$>8X$I8FDE8$<8EA>?G?OD8CS$V
E:9:HDGD<B$A:C$H88>$EA:GG8>OD>O$:>I$DC$<A8$@?EPC$?@$;8C8:;EA$I8$<?$:$C8;D8C$?@$<P>>D>O$
<P>>8GD>O$=DE;?CE?9B$UVT$:$9?X8;@PG$>8X$<8EA>D\P8$<A:<$8>:HG8C$ID;8E<$@?$C
IB>:=DEC$D>$=:<8;D:GC$I?X>$<?$<A8$:<?=DE$CE:G8

.>$)VT#),($<8;:A8;<T$9PGC8C$U_DOS$L:W$:;8$@?EPC8I$?@$:>$#),$U_DOS$LHW($XA
H8A:F8C$GDZ8$:>$:><8>>:$<A:<$O;8:<GB$8>A:>E8C$<A8$)VT$9PGC8$8G8E<;DE$@D8GI$<A:<$DC$E?P
YP>E<D?>S$)A8$;8CPG<D>O$<8;:A8;<T$F?G<:O8$<;:>CD8><$:E;?CC$<A8$YP>E<D?>$9;?IPE8C$:$CPH
<A:<$E:>$A:F8$:>8<$;8E<D@D8I$E?=9?>8><$IP8$<?$<A8$D>A8;8><$>?>GD>8:;D<B$?@$<A8$EP;;8
?@$<A8$<P>>8G$YP>E<D?>$U_DOS$LEW($XADEA$E:>$H8$=8:CP;8I$:C$:$@P>E<D?>$?@$<A8$<D=8$I
X8GG$:C$8G8E<;?>$E?>E8><;:<D?>$IP8$<?$9A?<?8[ED<:<D?>$8@@8E<C$D>$<A8$C:=9G8S$

$


Electric field (arb. units)
4
2
0
-2
-4
0
4
8
12
Time (ps)
Amplitude
0 1 2 3
Frequency (THz)
(a) THz pulse waveform
THz pulse
STM tip
bias
V_B, I_TIP
sample
(b) THz-STM
I
I_0 + I_THz(t)
V
V_0 + V_THz(t)
(c) Rectified THz-STM signal
(b)
(c)
(e)
(f)
1250e
-125e
t_0 - 500fs
t_0 + 500fs
50nm
(d) Ultrafast THz-STM on a single InAs nanodot
(e) THz-STM in ultrahigh vacuum (UHV) gives atomic resolution on a silicon (Si) surface
2 nm
2 nm
STM topography of a Si (111) 7x7 surface
(f) THz-driven STM topography of a Si (111) 7x7 surface

$

?,-.#"(D@VT9PGC8$U8W$P9G8I$<?$:$#),$UHW$$$;8E<D@D8><$<P>>8G$EP;;8><C$UEW$$$IW$)VTG8$
.>!C$>:>?I?<$$$>I$U8(@W$$GDE?>$CP;@:E8$$<?=DE$;8C?GP<D?>S$

)VT 0#),$ X:C$ @D;I8<$ >C<;:<8I$ HB$ M?EZ8;$ 8<$:GS$]L^($ CA?XD>O$ <A8$ 9A?<?8[ED<:<D?>$ IB>:=DE

.>!C$>:>?I?<$XD<A$CD=PG<:>8?PC$&S2$9C$<D=8$;8C?GP<D?>$:>I$%$>=$C9:<D:G$;8C?GP<D?>$P>I8;$:

LIWS$ *98;:<D?>$ D>$ POA$ FAEPP=$ U_DOS$ L8W$:GG9RGSS>?P;E)8I$ <P>>8G$ EP;;8><C$ E?>@D>8I$ <?$ CD

:<?=C$U_DOS$L@W($:C$;89?;<8I$@@$ 'CVVGDE?>$CP;@:E8C$]%^$:>I$CD>OG8$98><:E8>8$ =$?G8EPG8C$

A:C$;8E8><GB$H88>$PC8I$<?$C<PIB$=8<:G$CP;@:E8C$]aH($?C($?2(9%$:>I$bD%#8'$]J^($:>I$

MJ&$ @DG=C$]c^($:C$ X8GG$:C$ @?;$:99GBD>O$ G?E:GDT8I$ @?;E8C$ <?$ CD>OG8$ =?G8EPG8C$]4^$ :

=:<8;D:GC$]d^S$ ,PEA$ X?;Z$ A:C$ @?EPC8I$?>$ EA:;:E<8;DT8D>O$ X:A8$ D>$ 8G8E<;?>$ E?A8;8><$ E?G$?@$

<P>>8G$ EP;;8><C$]%(J(L'(La^($=?I8GD>O$<A8$)VT$]%(a(LJ^($ D>E;8:CD>O$ H:>IXDI<A$]L2^$:>I$ 8@@D

]Lc^($ A8;=:G$:>I$>?><A8;=:G$ 8GD@@8;8E<C$]L4(Ld^$ D8FD>O$:<<?C8E?>I$<D=8$;8C?GP<D?>$]%&(%L^S$

A:C$:GC?$H88>$<A8$CPHF8E<$?@$C8;8FD8X$:;<DEG8C$]%'$

_P>ID>O$CP99?;<$@;?=$/#"+M($M_.($!GH8;<:$.>>?F:<8C($:>I$5?>G8IO8I$

$$

E"9"#"+*"2(

L$)S$-S$M?EZ8;($`S$58GDE($,S$KP9<:($#S$5S$,?G8CZB($5S$!S$5S$bP;O8CC($KS$78$-?C$+8B8C($-S$`S$)D<?F:($

_;88=:>($:>I$_S$!S$V8O=:>>($/:<S$1A?<?>S$c($J%$U%&L'WS

%!S `S$58GDE($,S$1ABCS$L'($2dL$U%&LcWS

'S!)S$-S$M?EZ8;($8<$:GS($/:<P;8$2'd($%$J'$U%&LJWS

a$ eS$-P?($`S$58GDE($1ABCS$+8FS$b$L&%($%&2acU%&%&WS

2$ #S$"S$!==8;=:>($8<$:GS($($/:<S$M?==P>S$L%(Jda$U%&%LWS

J$ #S$e?CADI:($8<$:GS($!M#$1A?<?>DEC$J($L'2J$U%&LdWS

c$ #S$e?CADI:($8<$:GS($1A?<?>DEC$4($'L2$U%&%LWS

4$ 7S$18GG8;($8<$:GS($/:<P;8$242($24$U%&%&WS

d$ fS$fD=P;:($8<$:GS($!M#$1A?<?>DEC$4($4%$U%&%LWS

L&S 1S$VS$/OPB8>($8<$:GS($1ABCS$M:>S$L($L2c$U%&L2WS

LLS 7S$18GG8;($8<$:GS($1A?<?>S$L2($La'$U%&%LWS

L%S 5S$):Z8I:$:>I$.S$f:<:B:=:($/:<S$1A?<?>S$L2($c&$U%&%LWS

L'S fS$e?CAD?Z:($8<$:GS($/:<S$1A?<?>S$L&$cJ%$U%&LJWS

LaS fS$e?CAD?Z:($8<$:GS($/:>?$-8<<S$L4($2Ld4$U%&L4WS

L2S ,S$,gGG8;($8<$:GS($!M#$1A?<?>DEC$c($%&aJ$U%&%&WS

LJS #S$"S$!==8;=:>($8<$:GS($1ABCS$+8FS$b$L&2($LL2a%c$U%&%%WS

LcS ,S$!HI?($8<$:GS($!M#$1A?<?>DEC$4($&%$U%&%LWS

L4S /S$,S$#:H:>C($8<$:GS($!M#$/:>?$LJ($Laacd$U%&%%WS$

LdS ,S$K:;O$:>I$fS$f8;>($#ED8>E8$'Jc($aLL$U%&%&WS

%&S ,S$K:;O($8<$:GS($/:<S$1A?<?>S$LJ(dJU%&%%WS

%LS)S$-S$M?EZ8;($`S$58GDE($,S$:>I$!S$V8O=:>>($/:<S$1A?<?>S$L2($%4$U%&%LWS

%%S)S$-S$M?EZ8;$:>I$_S$!S$V8O=:>>($D>$5P:><P=$($8<$:G($i)A8$%&%L$PG<;:@:C<$C98E<;?CE?9DE$9;?H8C$?@$E?

=:<<8;$;?:I=:9j($5?P;>:G$?@$1ABCDECQ$M?>I8>C8I$,:<<8;$"($'2$&&L$U%&%LWS

%'S)S$):EADT:Z8($8<$:GS($!1-$,:<8;S$d($&J&d&'$U%&%LWS

%aS -S$KP<TG8;($8<$:GS($/:<S$+8FS$1ABCS$'($aaL$U%&%LWS

%2S ,S$189G?X($/:<P;8$2aa($a&4$U%&LcWS

%JS eS$)D:>($8<$:GS($#P;@S$+8FS$-8<<S$%2($L4aL&&'$U%&L4WS

In situ control and nanofocusing of extreme ultraviolet

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Abstract: We integrate coherent short-wavelength high-order harmonics from a MgO crystal, with a nanostructured element etched onto the surface of the crystal itself, allowing us to control the emitted extreme ultraviolet light. Using this technique, we achieve focusing of the radiation down to 150 nm waist radius. Future developments may demonstrate nanoscale laser ablation and miniaturization of extreme ultraviolet coherent sources on a chip.

Modern technology heavily relies on the processes occurring on a length scale of 10 nms. Addressing this length scale with light requires operating in the extreme ultraviolet (XUV) as dictated by the diffraction limit. Using the traditional, *ex situ* approach, where the XUV generation and control are separated, is complicated by the need of bulky and expensive equipment.

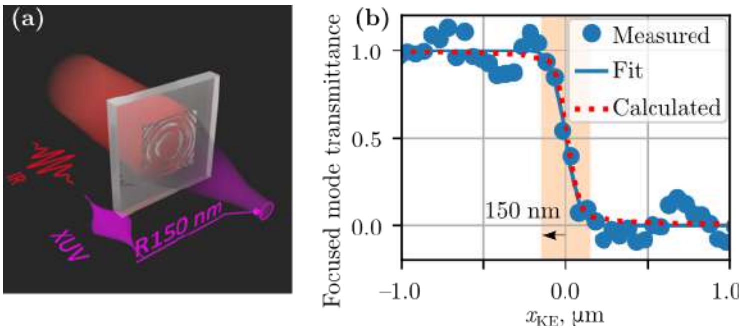

Figure 1. (a) High-NA in situ focusing of XUV from a structured dielectric. (b) Knife-edge measurement of a waist siz

Here we report on a different, *in situ* approach, with both generation and control of the XUV taking place in a single, chip-scale device. We fabricate a structure on the surface of a magnesium oxide crystal. When illuminated by the femtosecond laser, it emits coherent radiation in the extreme ultraviolet spectral range through a high harmonic generation process. The phase and amplitude profile, imprinted by the structure onto the generated light, leads to the rapid focusing of the latter with unprecedentedly high numerical aperture of 0.35, and to its eventual convergence down to a waist radius of 150 nm.

In the future, shorter wavelength harmonics and higher numerical aperture structures will bring the size of focal spot achieved with our technique, down to the sub-100 nm scale. The unique combination of short wavelength, small focus and high intensity, inherent to the method, will enable many applications, such as direct laser nanostructuring and nonlinear imaging with chemical specificity, element-specific imaging, and photoelectron spectro-nanoscopy.

We acknowledge the support from the W. M. Keck Foundation, the Alexander von Humboldt foundation, the Joint Center for Extreme Photonics, the U.S. Defense Threat Reduction (Grant No. 1-19-1-0026), U.S. Air Force Office of Scientific Research (Grant No. FA9550-15-1-0109) and the Natural Sciences and Engineering Research Council of Canada.

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Thermodynamic limits for radiative heat engines

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Abstract: The efficiency of any heat engine is bounded by the well-known Carnot efficiency. While achieving high efficiency is of interest for energy production, engines that operate close to the Carnot efficiency usually have vanishing power output. Operating at maximum power, however, leads to significantly degraded efficiencies, thus imposing a trade-off between power and efficiency. In this talk, we evaluate this trade-off for heat engines that exchange heat radiatively with a hot source, which includes thermophotovoltaic systems.

Thermodynamic limits set the bounds for any heat engine operating between thermal sources. Particularly, the maximum efficiency of a heat engine that operates between a hot source and a cold bath is given by the Carnot limit [1]. Among heat engines, a peculiar example is given by radiative heat engines, which receive heat in the form of thermal radiation. One practical implementation of such engines is thermophotovoltaic systems, where a photovoltaic cell converts the thermal radiation emitted by a hot source into electricity. Thermophotovoltaics is a very active and promising research field, with many impressive results reported recently, both in terms of efficiency [2], [3] and power density [4]. Aside from solar radiation, thermophotovoltaics can convert heat from any other source, which results in a large applicability of this technology in waste-heat recovery. Therefore, it is becoming increasingly important to determine figures of merit in order to compare experimental results between each other, as well as to evaluate their performance relative to optimal configurations.

We consider a hot emitter at temperature $6_Á$ and a cold bath at temperature $6_¼$ exchanging power through a heat engine in steady-state condition. The emitter and the converter exchange energy radiatively, while the converter is in thermal contact with the cold bath. We call $2_Á$ and $2_¼$ the power densities emitted by the hot source and by the engine, respectively. The heat engine generates an output power density 9 with an accompanying heat flux Q. The general system is schematically represented in Fig. 1 (a).

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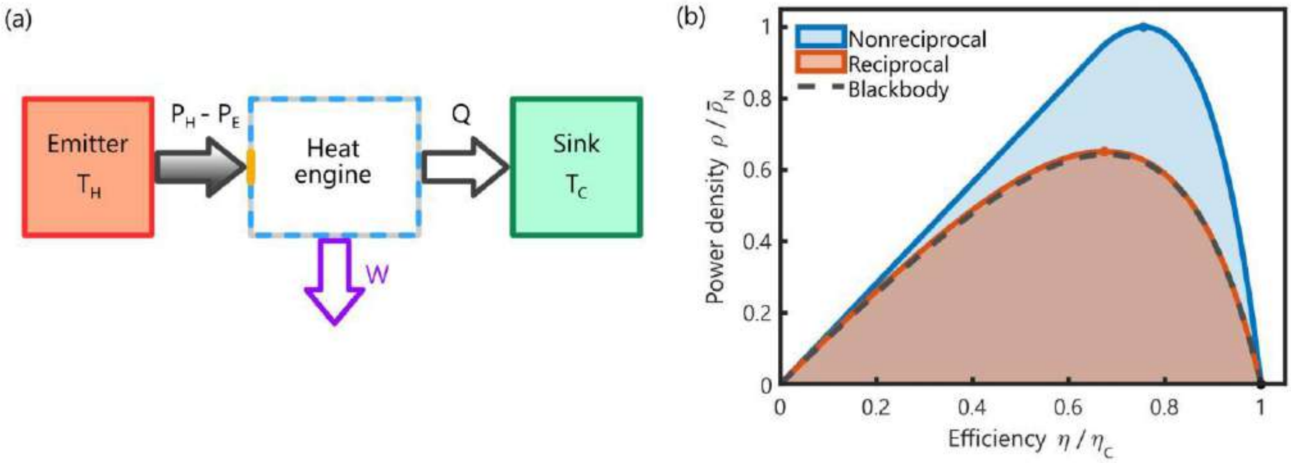
We define a first figure of merit é L 9 ¤ê$6_Á^8$ as the output power density normalized to the power density emitted by a blackbody emitter at temperature $6_Á$, where ê is the Stefan-Boltzmann constant. Meanwhile, the second figure of merit is the efficiency ß L 9 ¤:$2_Á$ F $2_¼$;, where the denominator accounts for the net heat drawn from the emitter. We aim at maximizing the é for any given value of ß, once $6_Á$ and $6_¼$ are fixed, to estimate the maximum power output attainable when operating at a given conversion efficiency.

In doing so, we derive three general thermodynamic bounds for radiative energy conversion (Fig. 1(b)). The first is the absolute limit, corresponding to an isentropic conversion process and requiring an infinite number of engines connected non-reciprocally (analogous to the Landsberg limit for sunlight conversion [6]). This is indicated, in)LJ E DV ³1RQ-UHFLSURFDO´. The second is obtained by combining an infinite number of engines without breaking reciprocity (in analogy to what in solar energy conversion is called multicolor limit [7]), in Fig. 1(b) this

LV UHSRUWHG . Finally, ³5HFLSURFDO the third corresponds to the performance bounds using a single engine (endoreversible or blackbody limit for solar conversion [8]) GHQRWHG DV ³%ODFNERG\´ LQ)L. We observe that the introduction of nonreciprocity leads to significantly higher upper bounds, while the difference between one engine and an infinite number of reciprocal engines is marginal



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References

1. 1 6KLUDLVKL . 6DLWR DQG 7DVDNL Trade-off Relation between Power and Efficiency ³8QLYHUVDO 7UDGH RII 5HODWLRQ EHWZHHQ 3RZHU DQG (IILFLHQF\ IRU +HDW (Q Phys. Rev. Lett., vol. 117, no. 19, p. 190601, Oct. 2016, doi: 10.1103/PhysRevLett.117.190601.
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6. 3 7 /DQGVEHUJ DQG * 7RQJH ³7KHUPRG\QDPLF HQHUJ\ FRQYHUVLRQ HIILFLHQFLHV Journal of Applied Physics, vol. 51, no. 7, pp. R1–R20, Jul. 1980, doi: 10.1063/1.328187.
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8. $ ' 9RV ³5HIOHFWLRQV RQ WKH SRZHU GHOLYHUHG E\ HQGRUHYHUVLEOH HQJLQHV)HE GRL

Antenna theory and design

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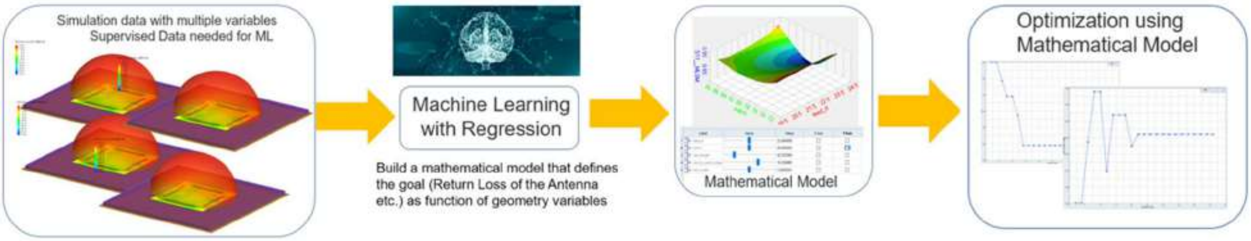
Simulation data with multiple variables
Supervised Data needed for ML
Machine Learning
with Regression
Mathematical Model
Optimization using
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Build a mathematical model that defines the goal (Return Loss of the Antenna etc.) as function of geometry variables

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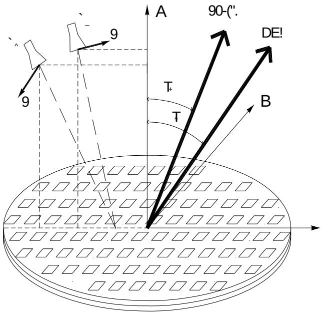
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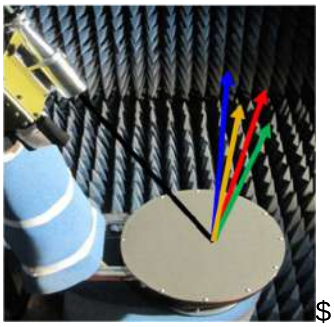

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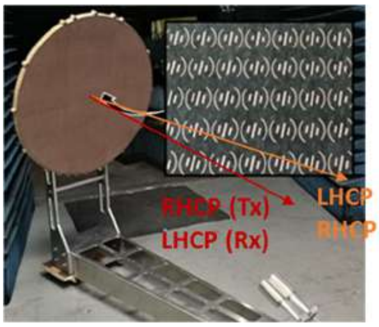
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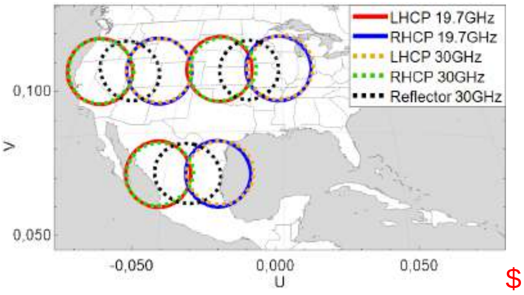
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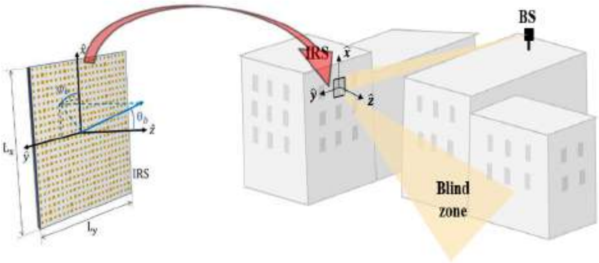
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!8>A88=B$=8D$1;:I=C=>?:8($H:EM$2e($8:M$a&($IIM$%4%h0%4'h($*@>M$%&&jM$

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'M ,=;>?8AT0DA0+?:L=($\M$A>$=EM($W);=8B<?>3+A@A?HA$1=;=O:E?@$+A9EA@>=;;=P$>:$YA8A;=>A$)R:$]A=<B$IA

#=>AEE?>A$!8>A88=B$?8$g=0]=8D(X$."""$);=8BM$:8$!8>A88=B$=8D$1;:I=C=>M($H:EM$jf($8:M$2($IIM$%jh'0%j42($

eM ^=SFA;:(IM`M$A>$=EM($k+A9EA@>=;;=P0O=BAD$.8>AEE?CA8>$+A9EA@>?8C$#F;9=@A$>:$.<I;:HA$<<0m=HA$

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2M YF?;=D:($+M$A>$=EM($k\P8=<?@$,:DAE?8C$:9$-?SF?D$G;PB>=E0]=BAD$,A>=BF;9=@AB$=8D$.>B$!IIE?@=>?:8$

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Multiband Substrate Integrated Waveguide Dielectric Resonator Antenna for 4G and 5G Applications

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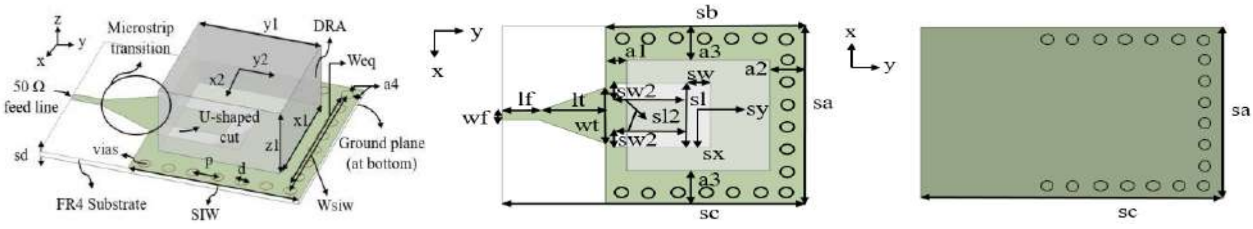
Abstract: In this work, Substrate Integrated Waveguide with a Dielectric Resonator Antenna is introduced in a more compact size to operate in the 4G bands for LTE Band 3 (1.8 GHz), LTE Band 7 (2.6 GHz) and covers 5G Band n77 (3.7 GHz). A U-shaped slot cut is introduced in order to produce multiple frequency of operation. Simulation is done using Ansys HFSS (High Frequency Structure Simulator) version 2019. Simulated impedance bandwidths are 21.51% (1.67-2.07 GHz) at 1.8 GHz, 4.63% (2.53-2.65 GHz) at 2.6 GHz and 7.57% (3.56-3.84GHz) at 3.7 GHz and good radiation pattern performance were obtained.

I. Introduction

A compact multiband antenna is favored in todD\¶V ZLUHOHVV FRPPXQLFDWLRQ HUD [1]. A multiband resonance can be obtained by the multiple slots [2] using Substrate Integrated Waveguide (SIW). In this paper, a rectangular Dielectric Resonator Antenna (DRA) excited by a U-shaped slot using Substrate Integrated Waveguide is proposed in this paper for 4G and 5G applications to have higher bandwidth and higher gain.

II. Research Methodology

The 3D model view of a single port SIW fed DRA is shown in Fig. 1. A FR4 substrate with a permittivity of 4.6, a loss tangent of 0.019 and with a thickness of 1.6 mm is used. $'5$¶V SHUPLWWLYLW\ RI and loss tangent of 0.0019 is used in this work. Its dimensions for 1.8 GHz are calculated in [1]. It is excited in respective mode by the U-shaped cut configuration, located in the top wall of SIW operating in TE10 mode. The SIW and microstrip transition design parameters are calculated from a conventional waveguide WR 430 in [3], [4], [5].



(a) (b) (c)

Fig. 1 Single port SIW with a DRA geometry (a) Overall 3D view (b) Top view (c) Back view

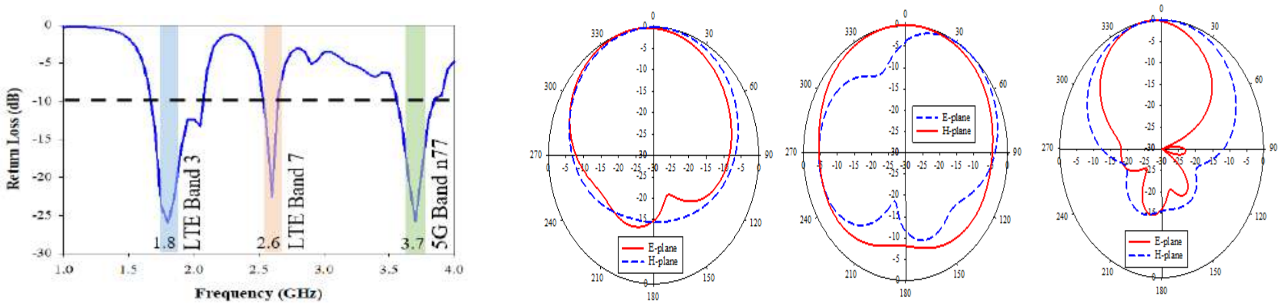
Table 1 Optimised design parameters

Parameter	sa	sb	sc	sd	x1	y1	z1	x2	y2	lf	lt	wf	wt	sw
Value (mm)	64	56	85	1.6	40	40	21	0	-2	10	19	2.95	20	7

Parameter	sl2	sw2	sx	sl	sy	d	p	a1	a2	a3	a4	Weq	Wsiw
Value (mm)	20	6	0	23	-2	4	8	6	10	12	2	52	56

III. Result and Discussion

The simulated results of the proposed antenna are discussed. The simulated impedance bandwidths are 21.51% (1.67–2.07 GHz) at 1.8 GHz, 4.63% (2.53–2.65 GHz) at 2.6 GHz and 7.57% (3.56–3.84 GHz) at 3.7 GHz, as shown in Fig. 2(a). Less than -22 dB of return loss is found within the bands of interest. Simulated normalised radiation patterns of E-plane and H-plane for each frequency are depicted in Figs. 2(b), 2(c) and 2(d).



(a) (b) (c) (d)

Fig. 2 Simulated antenna performance (a) return loss (b) normalised radiation patterns at 1.8 GHz (c) normalised radiation patterns at 2.6 GHz (d) normalised radiation patterns at 3.7 GHz

IV. Conclusion

A multiband SIW singly fed with a DRA and a U-shaped cut is presented in this paper. The antenna exhibits good characteristics where impedance bandwidths are 21.51% at 1.8 GHz, 4.63% at 2.6 GHz and 7.57% at 3.7 GHz. More than 4.5 dBi of gain and at least 74% of antenna efficiency are found within the bands of interest. The proposed antenna can be a good candidate for 4G and 5G applications.

Acknowledgements

This study was supported by the Fundamental Research Grant Scheme (FRGS) awarded by the Ministry of Education of Malaysia (Investigation of Low Cost Substrate-Based Antenna Using Three-Dimensional Printing Technology for Fifth Generation Wireless Systems FRGS/1/2021/TK0/UTM/02/60).

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2. $VKUDI 1 2 +DUD] 0 $ $VKU 8-GHz quad-band millimeter wave SIW array antenna with (%* VWUXFWXUHV IRU * DSSOLFDWLRQV ´ LQ ,QWHUQDWLRQDO &RQIH
Research (ICTRC), 5-8, 2015.
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4. Kumar, P., S. Dwari, S. Singh DQG 1 . $JUDZDO ³'HVLJQ ,QYHVWLJDWLRQ RI D Dual-Band /DP DRA for Mil LWDU\ $SSOLFDWLRQV ´)UHTXHQ] 9RO 1R 1–14, 2018.
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IOSR J Electron Commun Eng, Vol. 3, No. 5, 36–40, 2012.

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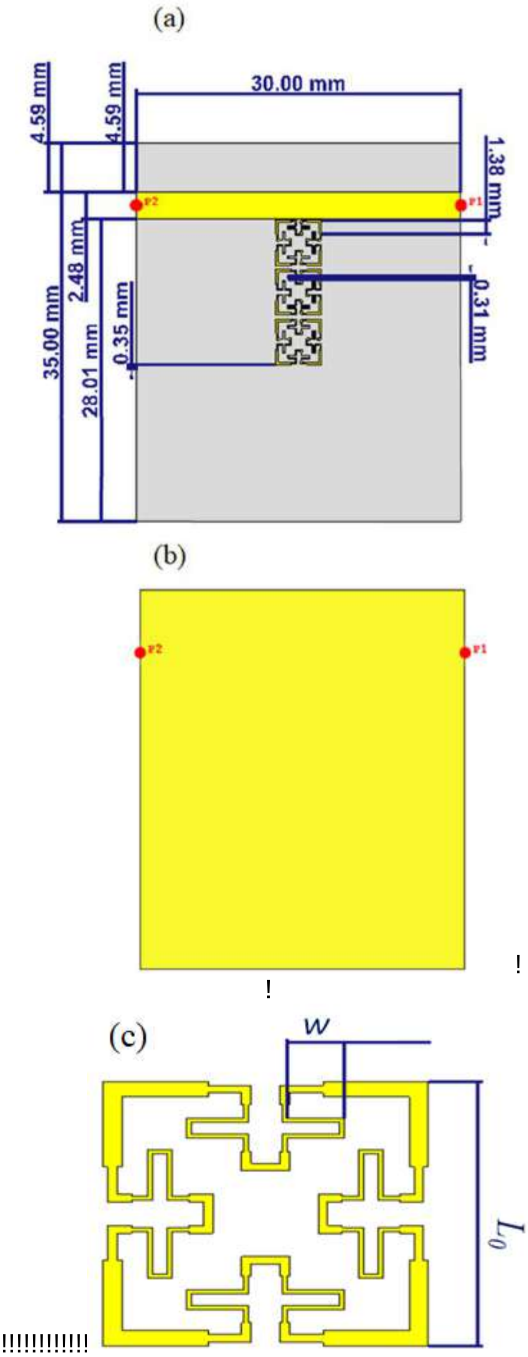

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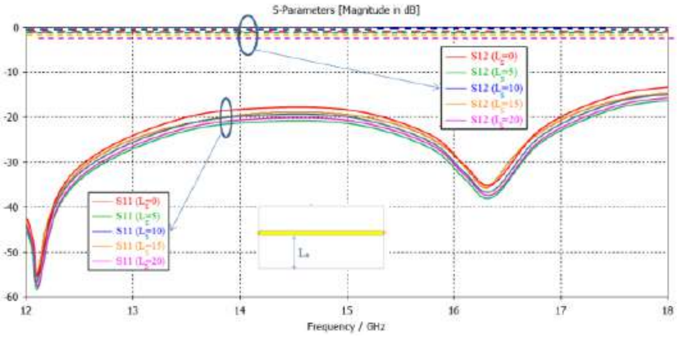
CA>GA8I24(,4&#5&"H#4%

)D8! NC;N;B8J! @>B<?BB?;>! 9?>8! BAC=:A=C8! ?B! J8B?H>8 REWDLQ D FORVH YDOXH DURXQG ?<N8J@>:8G!)D8! :@>! Y8! :@9:=9@A8J! J?C8:A9R! QC;< @>@9RA?:@99R!Y@B8J!;>!AD8!AC@>B<?BB?;>!9?>8!Z?JA AD8!@=AD;CB!8L@9=@A8J!AD8!N8C?<8A8CB!?>!A!C@>H8!;Q! $7%! ADC;=HD! Q@99! @>@9RB?B! Y@B8J! ;>! :;<<8C:?@ B;QAZ@C8!N@:[@H8!;Q!P$)!<?:C;Z@L8!BA=J?;!f7%gG!)D8C8 AD8!8QQ8:A!;Q!B=YBAC@A8!J?<8>B?;>!?B!:D@>H8J!Z?AD!@ ;Q!B=YBAC@A8!98>HAD!E-BF!BA@CA?>H!QC;<!&<<!A;!%&< AD8! ?>?A?@9! B=YBAC@A8! ?B! 74<<G! .>! B=:D! :@B8! AD8! 8QQ8:A?L8! J?<8>B?;>! Z;=9J! Y8! @::=<=9@A?L89R! L@C?8 74<<! A;! '4<<! Z?AD! BA8N! ;Q! 4<<G! .A! ?B! Q;=>J! QC;<! AD8 ;YA@?>8J! C8B=9AB! ?>B?H>?Q?:@>A! L@C?@A?;>! ;Q! AD8 J=8!A;!AD8!Q@:A!;Q!Q?89J!QC?>H?>H!Z?AD!AD8!Q=9 9?>8!?B!<=:D!98BB!AD@>!AD8!B=YBAC@A8!J?<8>B?;>B!f7 BD;ZB! AD8! ;YA@?>8J! C8B=9AB! QC;<! AD8! NC;N;B8J! N@ BA=JR!?>!A8C<B!;Q!$77!@>J!$7%!BN8:AC@G



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b?H=C8! %W!L@9=@A8J!N@C@<8A8CB!Y@B8J!L@CR?>H!AD8!B= J?<8>B?;>!?>!A8C<B!;Q!$77!@>J!$7%!QC8S=8>:R!C8BN;>B8G

CA@A@A>G2#+&(#B))&-42 #

)@B8J! ;>! AC@>B<?BB?;>! 9?>8! AD8;CR! AD@A! Z@B! 8\N9 f74g(! AD8! @=AD;CB! 8L@9=@A8J! AD8! N8C?<8A8CB! QC;<! J N@C@<8A8CBG!)D8B8! N@C@<8A8CB! J8B:C?Y8! AD8 :D@C@:A8C?BA?:B! ;Q! AD8! NC;N;B8J! QC@:A@9! BAC=: C8B;>@>:8!QC8S=8>:R!Y@>JG!)D8C8Q;C8(!AD8!@=AD;CB!

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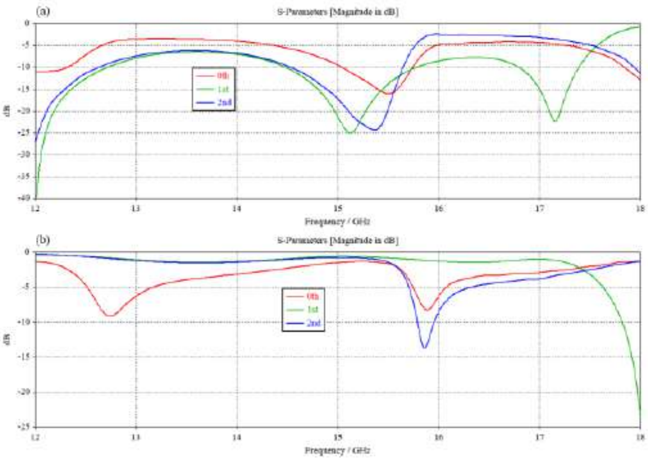

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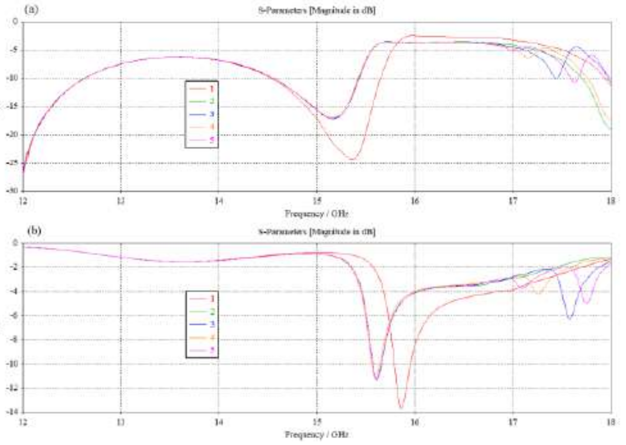
8QQ8:A!?>!A8C<BW!E@F!$77!@>J!EYF!$7%!QC8S=8>:



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b?H=C8!W#L@9=@A8J8JC@<8A8CB!Y@B8J!L@CR?>H!AD8!
:899!>=<Y8C!?>!A8C<BW!E@F!$77!@>J!EYF!$7%!QC8S
C8BN;>B8G

!

?>! A8C<B! ;Q! $77! @>J! $7%! BN8:AC@9! =9D8B?;>B! @
@NN9?8J!A;!AD8!NC;N;B8J!,?>[;ZB[?!BA@CA?>H!QC;<!A
=N!A;!AD8!B8:;>J!;CJ8CG!.>!AD?B!@>@9RB?B!AD8!@=A
AD8! NC;N;B8J! =>?A! :899! ;>! @! B=YBAC@A8! 8>:9;B
AC@>B<?BB?;>! 9?>8! A;! 8L@9=@A8! AD8! C8B=9AB
)D8C8Q;C8(!AD8!H8>8C@A8J!Z@L8B!?>B?J8!B=:D!AC@>B
@C8!8\:?A8J!QC;<!AZ;!Z@L8!H=?J8B!N;CAB!A;!8@!)#,
QC88! BN@:8! 8>L?C;><8>A! f74gG!)D=B(! AD8! 0=>?A
N@C@<8A8CB! Z;=9J! Y8! =B8J! A;! :D@C@:A8C?`8!
NC;N8CA?8B!?>!A8C<B!;Q!Y@>JZ?JAD(!8Q:?8>:R!@>J
9;BB8B!@B!BD;Z>!?>!b?HG'G

!

.A! ?B! Q;=>J! QC;<! AD8! NC;N;B8J! C8B=9AB! ;Q! $7%! BN
B8:;>J! ;CJ8C! NC;L?J8B! @! QC8S=8>:R! C8B;>@>:8! @A
AD@A!8QQ8:A?L89R!89?<?>@A8J!AD8!Q?CBA!<;J8!;Q!A
@>J! AD8! C8B;>@>:8! Y@>J! ;Q! AD8! Q?CBA! ;CJ8C! AD8!
;YL?;=B!AD@A!AD8!B8:;>J!;CJ8C!:;<Y?>8J!AD8B8!Y@>J
>8Z! <;J8! H8>8C@A?;>G!)D?B! C8L8@9B! >;! >88J! A;!
:;<N98\?AR! ;Q! AD8! J8B?H>! A;! :;>B?J8C! AD8! AD?CJ! ;C
D?HD!:;<N98\?AR!@>J!?<N98<8>A@A?;>!J?QQ?:=9ARG

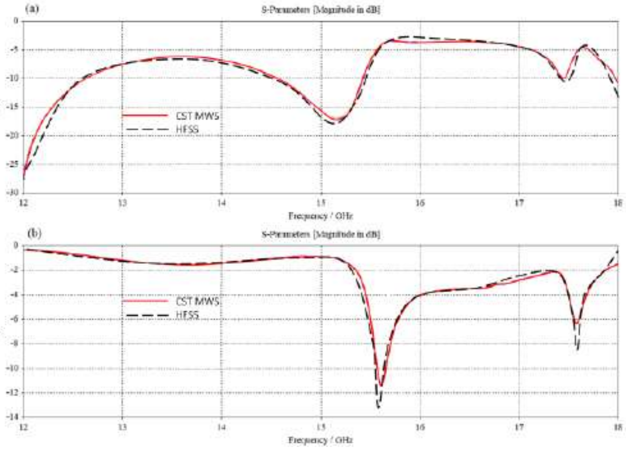
CAC&8+I&(#*)#8"/4#-&5#52

)D8! NC;N;B8J! C8B;>@A;C! ?B! :;>BAC=:A8J! QC;<! >=<Y8C! ;Q!
NC;N;B8J!=>?A!:899BG!)D8C8Q;C8(!?A!?B!L8CR!9;H?:@9!A;!B8@C:D
8QQ8:A! ;Q! ?>:C8@B?>H! AD8! >=<Y8C! ;Q! =>?A! :899B! ;>! AD8
N8CQ;C<@>:8! ;Q! NC;N;B8J! C8B;>@A;CG! .>! B=:D! :@B8! ?>! A8C<B! ;Q!
L@C?@A?;>! ?>! AD8! >=<Y8C! Z?AD! C8BN8:A! A;! AD8! =>?A! :899!
>=<Y8C! ?>:C8@B8! QC;<! 7! A;! 4! Z?AD! BA8N! ;Q! 7! ?B! C8N;CA8J! @B
8@:D!:@B8!?>!b?HG!cG!.A!D@B!Y88>!Q;=>J!QC;<!B=:D!B8AAC?>HB!AD@A!AD8
?>:C8@B?>H! AD8! =>?A! :899! C8N8A?A?;>! Z;=9J! ?>:C8@B8! AD8!
NC;N;B8J!C8B;>@A;C!Y@>JZ?JAD!Z?AD!H@?>?>H!A;!AD8!Y@>JZ?JAD
AD8! B@<8! :;>A8\A(! 8@:D! ?>J?L?J=@9! =>?A! :899! ?B! @J
B8N@C@A89R!@BBY@9?>:Dj!AD8C8Q;C8(!?>:C8@B?>H!AD8!@>J
:899!>=<Y8C!?>:C8@B8B!AD8!>=<Y8C!;Q!D8B!f77gG

!

OLA P,5/;,4/*"#,";#L/2-822/*"

"QA8C!@CC?L?>H!A;!AD8!;NA?<@9!J8B?H>!@=<Y8C!;Q!=>?A!:899B!?>
B;QAZ@C8!N@:[@H8!Y@B8J!;>!_b$$!B?<=9@A?;>B!Q;C!L@9?J@A?;>G



b?H=C8!4W)D8!NC;N;B8J!C8B;>@A;C!C8B=9AB!L@9?J@A
Y@B8J!;>!P$)!,a$!@>J!_b$$!B;QAZ@C8!B?<=9@A?;>BG

a8!Q;=>J!QC;<!AD8!;YA@?>8J!C8B=9AB!@>!8\:8998>A!@HC
Y8AZ88>! AD8! C8B=9AB! ;Q! P$)! @>J! _b$$! B?<=9@A?;>B(! =
J?QQ8C8>A!>=<8C?:@9!@9H;C?AD<B!A;!@BB8BB!AD8!<;J89
AD8!NC;N;B8J!C8B;>@A;C!BD;Z!@>!8\:8998>A!Y@>JZ?JAD
Z?AD!BAC;>H!8>D@>:8<8>A!@>J!<@\?<=<!AC@>B<?BB?;>!@C;
74G}"_!AD8!AD!$7%!Y8>JZ?JAD!Y@!<@\?<=<!C8Q98:A?;>!
@>J! AD8! C8B;>@>:8! ?>! A8C<B! ;Q! $77! ?B! Q;=>J! A;! Y8! AD8!
QC8S=8>:R!Y@>J!;Q!?>A8C8BAG!$=:D!C8B=9AB!@C8!AD8!
NC;N;B8J!C8B;>@A;C!Y8D@L8B!@>!8\:8998>A!N@BBY@>J
BA;NY@>J!A;!AD8!;YA@?>8J!C8B=9AB!QC;<!AD8!P$)!@>J
_b$$!A;;9B!@>J!AD@A!@C8!NC8B8>A8JG!.A!?B!Q;=>J!AD8!@:D8
;QQ8C!;Q!;YA@?>?>H!@!Y8AA8C!C8B=9AB!A;!AD8!NC;N;B8J!Z8!
@>J!@9B;!L@9?J@A?;>!@!:;<N@C?B;>!Y8AZ88>!AD8?C!NC;N;B8J!C8B;>@
;AD8C! N=Y9?BD8J! C8B=9AB! A;! ?>J?:@A8! AD8! @
@JL@>:8<8>AB! ;L8C! ;AD8C! C8B;>@A;CB! D@B! Y88>! :@CC
)D8! NC;N;B8J! C8B;>@A;C! ?B! Q;=>J! A;! BD;Z! <?>?<=<
C8Q98:A?;>!:;8QQ?:?8>A!?>!A8C<B!;Q!$77!?B!A;!AD8C!
N=Y9?BD8J! C8B=9AB! $=:D! @:D?8L8<8>A! ?B! @AAC?Y=
@JL@>A@H8B!;Q!=B?>H!,?>[;ZB[?!QC@:A@9!=>?A!:899!B
)D8!:;<N@C?B;>!?B!8\A8>J8J!Y8AZ88>!J?QQ8C8>A!N=Y9

!

C8B=9AB!?>!A8C<B!;Q!$77!@>J!$%7!N@C@<8A8CB!@A!AD8C;B8S=8>:R!
C8B;>@8!E@F!@B!BD;Z>!?>!)@!Y98!7G
!

)@Y98!7W!N@C?B;>!Y8AZ88>!AD8!NC;N;B8J!C8B;>@A;C!
C8B=9AB!@>J!;AD8C!N=Y9?BD8J!C8B=9AB
!

6&)A#	G>>Q;:#	G>@Q;:#	)(QKRF#
f7g!	07G!]	074!	%G!7
f%!g	0%G!4	0&!	4G!h
f'g!	04G!&	0c&!	%Gi!4
fcg!	0G]!	0%&	%!
fcg!	07G!	074!	7G!c
f4g!	0%G!c	06!	cG&!4
f]g!	0cG!4	07%!	'G4
fhg!	0%G!i	07'e0%7!	&Gh4e7!G%
f6g!	07G!i	07i!	%G7!c
fig!	07G!]	07]!	'Gh4
f7&g!	07G!7	0&!	cG!7
f77g!	07G!%	0c&!	&G!6
f7%!g	0%G!'	0%%	7G!7
f7'g!	0G&!	076!	%Gi!]
f7cg!	07G!6	07i!	%G!%'

!
!

SA! T*"-582/*"

)D8! NC;N;B8J! Z;C[! ?B! J8B?H>8J! Y@B8J! ;>! @! NC?>A8J! <?:C;Z@L8! C8B;>@A;C! ZD?:D! ?B! J8L89;N8J! Q;@!>X!G! .A! ?B! J8B?H>8J! Y@B8J! ;>! @! B?>H98! :;9=<>! @CC@R! ;Q! '! =>?A! :899B! ;Q! ,?>[;ZB[?!QC@:A@9!J8B?H>G!)D8C8Q;C8(!AD8!NC;N;B8J!J8B?H>!?B! Q;=>J! A;! NC;L?J8! @! N@BB! Y@>J! @C;=>J! 74G]^_`! Z?AD! $7%! @Y;=A!7%JTG! )D8! NC;N;B8J! Z;C[! ?B! J8B?H>8J! =B?>H! P$)! ,a$! A;! ;NA?<?`8! AD8! C8B;>@A;C! Y@>JZ?JAD! N@C@<8AC?:@99RG!)D8! NC;N;B8J! C8B;>@A;C! ;::=N?8B! @>! @C8@! @Y;=A! '4d'&<<%! ZD8>! NC?>A8J! ;>! +;H8C! 644&! B=YBAC@A8! ;Q! &G6<<! AD?:[>8BBG!)D8! NC;N;B8J! Z;C[! ?B! Q;=>J! A;! BD;Z! @>! 8\:8998>A! +8:;>Q?H=C@Y98! ,?:C;Z@L8! T@>JN@BB! b?9A8C(m N8CQ;C<@>:8! ?>! :;<N@C?B;>! A;! ?B;9@A?:@9! C8B;>@A;CB! AD@A! Z8C8! J8B?H>8J! ?>! AD8! 9?A8C@A=C8G! b;C! L@9?J@A?;>B(! AD8! NC;N;B8J! C8B;>@A;C! N8CQ;C<@>:8B! @C8! 8L@9=@A8J! =B?>H! _b$$G! b?>@99R(! AD8! C8B=9AB! QC;<! P$)! ,a$! @>J! _b$$! @C8! Q;=>J! A;! @HC88! A;! 8@:D! ;AD8C! 8\:8998>A9RG

6&)&(&"-&2#

f7g! $G! "C@?>(! 1G! >?C!J8B(! ,G! "G! TG! "YY@B?(! "G! U=JJ?;=B(! ,G! "G! ">A;>?@J8B! @>J! $G! /?[;9@;=(! m+8:;>Q?H=C@Y98! T@>JZ?JAD! T@>JN@BB! b?9A8C! a?AD! #>QQ@>:8J! *=A! T@>J! +8n8:A?;>! 3B?>H! Œ 0$8:A?;>! 9;@J8J! +?>H! +8B;>@A;C(m! "###! $%&'()*+,! *-.! /%',0,11! 2(34(-,-51! 6,55,'1! (! L;9G! %6(! >;G! 7(! NNG! 2%6(! >G! %&76G

f%!g!)G! PD8>H! @>J! 0G! XG!)@<(! m"! a?J8Y@>J! T@>JN@BB! b?9A8C! a?AD! +8:;>Q?H=C@Y98! T@>JZ?JAD! T@B8J! ;>! PC;BB! $D@N8J! +8B;>@A;C(m! "###! $%&'()*+,! *-. ! /%',0,11! 2(34(-,-51! 6,55,'1 (! L;9G! %h(! >;G! 7&(! NNG! 7i(! *:AG! %&7!hG

f'g! oG! 0XG! T?(! oG! pD@>H(! $G! a;>H(! $G! 0_G! ^=;! @>J!)G! q=@>(! mO8B?H>! ;Q! /;AD8J! Y@>J! T@>JN@BB! b?9A8CB! Z?AD! +8:;>Q?H=C@Y98! T@>JZ?JAD! T@B8J! ;>!)8C<?>@A8J!

fcg! P8C;B8S=8>:R! +8B;>@A;C(m! "###! 7&&,11! (! L;9G! 6(! NNG! 'hc7]! 0hc%h(! %&%!b&G

fcg! ,G! "G! $@>:D8`$;C?@>;(! +G! ^;<8`^@C:?@(! ^G!);CC8HC;B@! 18>@9L@(! r+8:;>Q?H=C@Y98! Y@>JZ?JAD! Y@>JN@BB! Q?9A8C! Z?AD! ;>! "###! $%&'()*+,! 7-5,--*! (! L;9G! h(! NNG! 54&%(! /;LG! %&7%G

f4g! "G! -G! T;Cn@(! 2G! P@CY;>899(! 2G! -G! r,'@CA?>8`(! :;>AC;99@Y98! Y@>JZ?JAD! Q?9A8C! @B8J! ;>! <8A@<@A8C?@9! C8J! AC@>B<?BB?;>! "###! 8Bt! 7-5,--! *1! /%',0,11! 9'! (4*:*5%(-;! L;9G! 7&(! NNG! 54h4 74h6(! ,@RG! %&7'G

f]g! /G! PD8>(! $G! XG! 28>H(! r+8:;>Q?H=C@Y98! Y@>JN@BB! Z?AD! B8N@C@A89R! C89;:@A@Y98! 8H8N@BB! Y@> $%&'()*+,! /%',0,11! 2(34(-,-51! 6,55,'! (! L;9G! %%(! NNG! 44i! 54]7(! $8NG! %&7%G

fhg! oG! ,G! a@>H(! oG! XG! T?(! $G! _G! ^=;G! r$R>AD8B?B! J8B?H! 8S=@C?NN98! @>J! !B99?BA?:! Z?J8Y@>J! T1bB! Z?AD! ?>J8N8>J8>A9R! C8:;>Q?H=C@Y98! 9;Z8C! N@BBY@>J! "###! 7&&,11! (! L;9G! 6(! NNG! h]64h]6]](! *:AG! %&%!&G

f6g! +G! ^;<8`^@C:?@(! "G! PG! ^=R8AA8(! OG! 1BR:D;H?;=! rU=@B?99?NA?:! <Y9@>J! Q?9A8CB! Z?AD! QC8S=8>:R! @>J! Y@>JZ?JAD! A8>!@Y?9?AR! "###! $%&'()*+,! /%',0,11! 2(34(-,-51! 6,55,'! (! L;9G! %](! NNG! 57i%(! O8:G! %&7iG

fig! TG! PG! _=@>H(! /G! aG! PD8>(! $G! XG! 28>H(! r C8:;>Q?H=C@Y98! Y@>JN@BB! Q?9A8C! @>J! C;>! @ N8CA=CY8J! (BD)@N8J! J<@98! C8B;>@A;C! "###! $%&'()*+,! /%',0,11! 2(34(-,-51! 6,55,'1! (! L;9G! %c(! NNG! %ih5%ii(! 2=>G! %&7hG

f7&g! G! $@>:D8`+8>8J;(! +G! ^;<8`^@C:?@(! 2G! -G! "9;>B;(! r)=>@Y98! :;<Y?>8! Q?9A8C! Z?AD! :;>A?>=;=B! :;>AC;9! ;C :8>A8C! QC8S=8>:R! @>J! Y@>JZ?JAD! "###! 8'*-1*&5%(-1 $%&'()*+,! 8<,('=! *-.! 8,&<-%>?,1! (! L;9G! 4'(! NNG! 7i7 7ii(! 2@>G! %&4G

f77g! [C8BB@G! a;>H! @>J! .G! PG! _=>A8C(! m#98:AC;>?:@9 +8:;>Q?H=C@Y98! ,?:C;Z@L8! T@>JN@BB! b?9A8C(m! "###! 8'*-1*&5%(-1! (-! $%&'()*+,! 8<,('=! *-.! 8,&<-%>?,1;! ! L;9G! 4h(! NNG! &(! O8:G! %&&iG

f7%g! G! 2G!)B@*(! 0G! PD8>! @>J! XG! 28>H(! mP8>A8C! bC8S=8>:R! @>J! T@>JZ?JAD! P;>AC;99@Y98! ,?:C;BA T@>JN@BB! b?9A8C! O8B?H>! 3B?>H! N8NO@8! +8B;>@A;C(m! "###! 8'*-1*&5%(-1! (-! $%&'()*+,! 8<,('=! *-.! 8,&<-%>?,1! (! L;9G!]7(! >;G! 7&(! NNG! 0]4i&(! *:AG! %&7'G

f7'g! _G! ^=;(! 2G! /?! @>J! 2G! _;>H(! ml@0C@8A;C=@9J8! T@>JN@BB! b?9A8C! a?AD! ;>C<! U! O?BAC?Y=A!?;> "###! $%&'()*+,! *-.! /%',0,11! 2(34(-,-51! 6,55,'1! (! L;9G! %6(! >;G! 77(! NNG! 7&&c(! /;LG! %&76G

f7cg! PG! $:D=BA8C(! "G! a?8>B(! bG! $:D<?JA(! r18CQ;C<@>@>@9RB?B! ;Q! C8:;>Q?H=C@Y98! Y@>JN@BB! Q? :;>A?>=;=B9R! A=>@Y98! :8>A8C! QC8S=8>:R! @>J! Y@>J "###! 8'*-1*&5%(-1! (-! $%&'()*+,! 8<,('=! *-.! 8,&<-%>?,1! (! L;9G!]4(! NNG! 54h4 5c4%'(! $8NG! %&7hG

)G! "G! #9Z?(! m"! b=CAD8C! .>L8BA?H@A?;>! ;>! AD8! 18CQ;C ;Q! AD8! TC;@JB?J8! P;=N98J! +8:A@>H=9@C! $N9?A! +8B;>@A;CB(m! ,11! %-#0,&5'(3*:-,5%&1! @,1,*'&<! 6,55,'1! (! L;9G! 'c(! NNG! 6(! *:AG! %&7%G

c!

!

,QYHVWLJDWLRQ RI &RPSDFW $QWHQQD

0 'LUL[DQG 6) *UHJVRQ

$QWHQQD 6\VWHPV 6ROXWLRQV 6SDLQ
1H[W 3KDVH 0 86$4XHHQ 0DU\ 8QLYHUVLW\ /RQGRQ 8.
FRUUHVSRQ PGLUL[#DV\VRO FRP

$EVWUDFW7KH RSWLPDO FRPSDFW DQWHQQD LV FRQVWUDLQHG E\ HOHFWULFD
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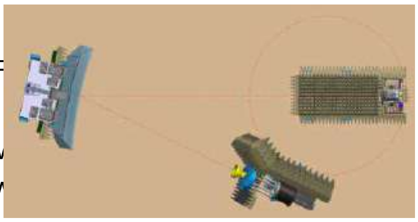
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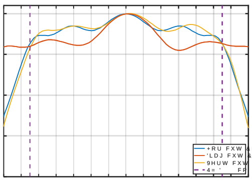

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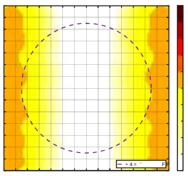

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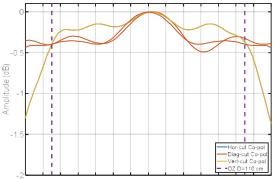

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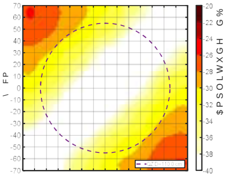

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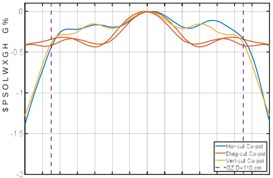

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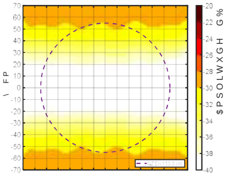

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Review on Dual BP-NGD Phase Shifter Application for Beam Steering Antenna Design

(Invited talk)

B. Ravelo[1*], S. Ngoho[2], F. Wan[1], T. Gu[1], F. Haddad[3], M. Guerin[3], and W. Rahajandraibe[3]

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[2]$VVRFLDWLRQ)UDQoDLVH GH 6FLHQFH GHV 6\VWqPHV $)6&(7
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Abstract: Recent study reveals an application of dual bandpass (BP) type negative group delay (NGD) circuit for beam steering antenna array (BSAA) design. The innovative BSAA is based on frequency independent microwave phase shifter. The operation principle in function of the BP-NGD center frequency and bandwidth is described. An illustrative recent result showing simultaneous steering in two different directions by means of NGD value in dual-band frequency is reviewed. The proposed dual BP-NGD microwave function is particularly useful in the future for 5G and 6G communication system.

1. Introduction of BP-NGD description for microwave signal synchronization

An unfamiliar electronic circuit susceptible to operate with NGD effect was investigated [1]. Thanks to the behavioral analogy with filter theory, a BP type NGD microwave function was identified [1]. The NGD can be analytically understood by means of GD definition from f-frequency dependent transmission coefficient S_{21} associated to PS expression ¥(f)= arg[S_{21}(jf)]:

$$2 S \, GD(f) \,\tilde{}\, \frac{w/(f)}{wf} \qquad (1)$$

The outstanding BP-NGD circuit can be used to synchronize microwave signals for 5G communication system [2]. The proposed dual BP-NGD can be potentially employed for WSN Tx-Rx system performance improvement owing to the principle illustrated by Fig. 1. In this scenario, a tri-band NGD circuit having center frequency and bandwidth $(f_k, \hat{u}f_k)_{k=\{1,2,3\}}$ is expected to synchronize signals transmitted by WS_k by reducing propagation from distance d_k.

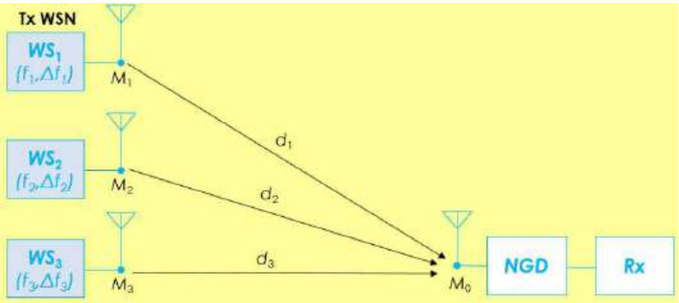

Fig. 1: Illustrative Tx-Rx multi-WSN scenario of synchronization by using BP-NGD circuit [2].

By assuming that $GD(f \;\; [f_k • \;\; f_k / 2]) \;\; 0'$, the following equation explains how the synchronization can be performed:

$$t_k \quad d_k / \text{velocity} \quad GD(f_k) \qquad (2)$$

2. BSAA design principle with dual BP-NGD frequency independent PS

The unfamiliar BP-NGD circuit was also used for frequency-independent PS design [3-4]. We remind that the classical BSAA operating through bandwidths B_1 and B_2 at two frequencies f_1 and f_2 which are associated to PS values ¥$_1$ = ¥(f_1) and ¥$_2$ = ¥(f_2), respectively, can be represented by Fig. 2(a). The BP-NGD PS was recently exploited to design BSAA with outstanding control of radiation center frequencies and bandwidths as illustrated by Fig. 2(b) [5].

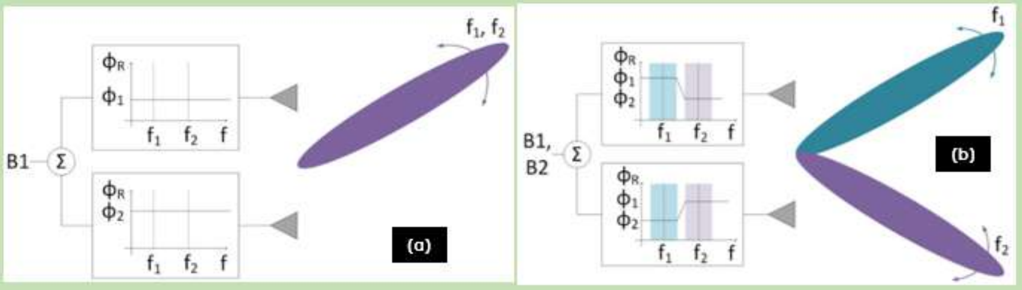

Fig. 2: Illustration of (a) classical and (b) dual band NGD BSAA [5].

The BSAA BP-NGD design principle of the multi-beam phased array is described. The design feasibility is illustrated with dual BP-NGD circuit. A proof-of-concept (PoC) of BP-NGD circuit is simulated and analyzed. Based on the PoC, simulations with separate beam steering positions at different frequencies are also analyzed. The innovative SBAA behavior is discussed.

3. Conclusion

An innovative application of dual BP-NGD circuit for BSAA design is reviewed. After description of BP-NGD unfamiliar microwave function, the design principle is illustrated. Simulations with dual BP-NGD PoC explain the feasibility of the SBAA design. The developed concept is useful in the future for designing SAA-NGD system of innovative multi-beam antenna for the improvement of RF and microwave system.

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Optimizing a pyramidal horn together with a dielectric lens for an airborne X-band transmitter

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Abstract

The design of a pod-mounted transmitter is subject to specific radiation pattern constrains, to be fulfilled in a strongly limited volume. The step-by-step definition of the antenna is described.

1. Introduction

The antenna will be housed in a pod of internal diameter 250 mm and protected by a radome to be optimized separately.The antenna to be designed has to cope with radiation pattern requirements as indicated below:

Table 1:Radiation pattern requirements

Frequency band (GHz)	Beamwidth horizontal	Beamwidth vertical	Gain (dBi)	Near SLL (dB)	Far SLL (dB)
8.5-9.6	<10¡	>30¡	>20	<-15	<-25

The horizontal beam width requires the width of the antenna to be close to the pod diameter. A further requirement is the capability of the main beam to be mechanically scanned from the axis of the pod up to at least 40¡ laterally, which adds a constrain to the length of the antenna, see figure 1. Due to power handling capability, the antenna has to be fed by a waveguide, chosen to be flexible to avoid rotary joint issues.

First, in terms of antenna selection, a pyramidal horn of thickness smaller than width - close to a sectoral horn - appears to approach the radiation pattern requirements [1]. Nevertheless, the criteria of quasi-plane wave front at the DSHUWXUH GRHVQ¶W DSSHDU DFKLHYDEOH ZLWKRXW D QHQ1WK RI WKH horn prohibiting wide enough angular scan, (see figure 1a) [1]. Therefore, compensating the spherical wave front of a reduced length horn through a plano-convex dielectric lens was selected [2]. Secondly, since mechanical scan remained still insufficient (figure 1b), the next improvement was to add a dielectric prism to deflect the main beam out of the plane of symmetry of the horn (figure 1c). Numerical simulations with a 3D electromagnetic commercially available code implementing Finite Integration Method with the Perfect Boundary Approximation were performed.

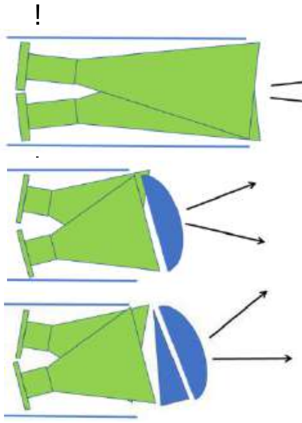

Figure 2 : Principles for mitigating the size limited angular scan (radome not shown)

This article presents the different steps to achieve an antenna that meets the different constraints imposed by the specifications.

2. Preliminary antenna selection

Without taking into account the size of the antenna, a preselection of several kinds of antennas has been made. For the realization of this project, high peak power was considered, to be generated by a magnetron. This leads to feed the antenna through a waveguide. In the literature [1], several types of antennas can be found which meet this criterion. From radiation pattern and footprint considerations, sectoral horn antennas were first selected

Because of its simplicity of construction and dimensioning, the horn antenna is the most widely used antenna for microwaves [1], fed by a waveguide. At the end of this waveguide, the edges are flared to obtain a larger opening. The angle, cross-section and length of the flare play an important role in the radiation pattern. This gradually increasing aperture also prevents mismatch from guided to free space propagation.

2.1. Sectoral E plane

The sectoral horn in E plane corresponds, on the one hand, to the flaring of the guide sections perpendicular to the E field. On the other hand, the edges of the guide parallel to the E field keep the same dimension, as shown below.

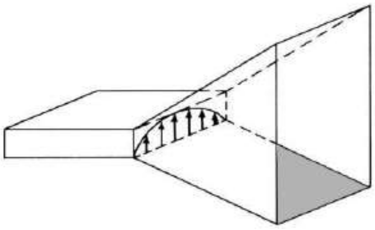

Figure 3 : Geometry of a sectoral E horn antenna [1]

Thanks to this aperture, the radiation in the E plane is thin and wide in the H plane. We have dimensioned a sectoral E plane horn from a WR112 guide (12.63 x 28.50mm).
First, we considered that the horn will be installed in a 250 mm diameter cylinder: this leads us to choose an aperture width of 240 mm. In a second phase, following the main laws of illumination for a rectangular aperture and assuming that the plane E follows a uniform and equiphase law [2], we obtain :

* 2 $ 9 L w ræ –ₒ á (1)

With the wavelength, º the aperture width of the horn and * 2 $ 9 is the half-power beamwidth in degrees. Taking an average frequency of 9 GHz, we obtain HPBW = 7¡, with a peak side lobe at -13.2 dB. We are now interested in the distance Re from the center of phase of the horn to the center of its aperture. We seek the smallest possible length, while having secondary lobes lower than -15 dB. From the universal E-plane radiation pattern [1], for an E-plane sectoral antenna, we derive a parameter s of one eighth and side lobes less than -15 dB for angles greater than ¡15
This parameter corresponds to a coefficient given in the literature[1].

OL o. / < Ë Ø , (2)

Thus, depending on this parameter, and using relationship (2) we obtain a length Re of 172 cm.

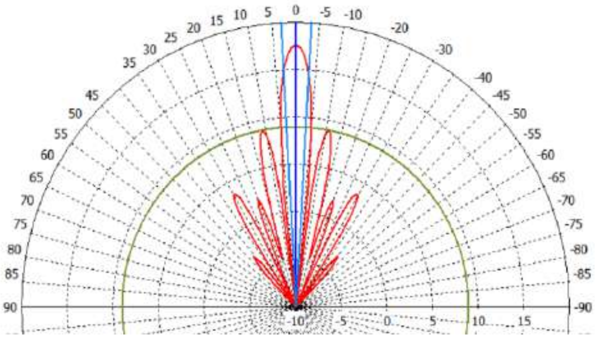

Figure 3 : Radiation diagram in E-plane (in blue the half-power beamwidth, in green the peak side lobe level)

We carry out a simulation with the dimensions determined previously, the result is presented in figure 3. The simulation results show parameters in agreement with those obtained analytically. Nevertheless, the side lobes are too high (-8 dB peak value) and do not meet the specifications. In addition, the length of the horn does not allow for the expected angular deflection.

2.2. Sectoral H plane

The H-plane sectoral horn is defined by flaring the guide sections parallel to the H-plane, with constant dimension in the perpendicular plane, resulting in a wide beam in the E plane and a thin beam in the H plane

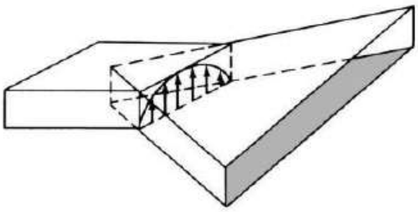

Figure 4 : Geometry of a sectoral H horn antenna [1]

We start from a WR112 guide to shape the horn and we keep an aperture width of 240 mm. Since the illumination now follows a cosine law [2], we obtain in a first step a -3 dB beamwidth of 9.6¡, as well as a peak side lobe equal to -23dB for a frequency of 9 GHz. In a second step, reference is made to the universal H-plane radiation pattern for an H-plane sectoral antenna: a parameter s of one quarter is determined for same conditions as in E-plane, this parameter s is also obtained from the literature [1]. A length Rh of 86 cm is now required to reduce the side lobes below -15 dB.
The simulation of the horn is shown in figure 5. The cross-sectional plane is this time quite conclusive at the level of the side lobes. It also matches the data obtained theoretically. Nevertheless, the vertical aperture has to be adjusted, which is performed in the next section.

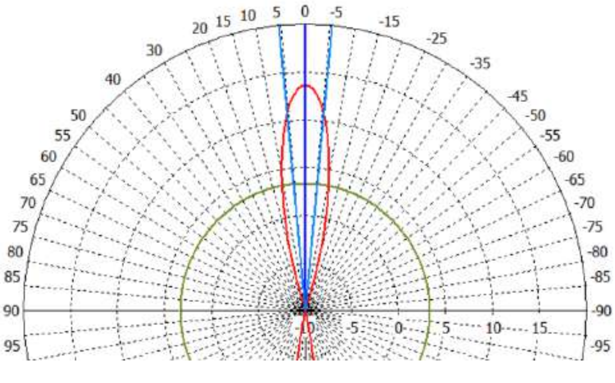

Figure 5 : Radiation diagram in H plane (In blue the half power beamwidth, in green the peak side lobe level)

It is now clear that H-plane sectoral horn is preferred to E plane not only for side lobes level but also for horn length consideration.

2.3. Transition from a sectoral horn to a pyramidal horn

In parts 2.1 and 2.2 we studied the radiation pattern in the horizontal plane parallel to the flared sides of the horn. But the above defined H-plane sectoral horn has a gain of only 13.7 dBi due to its very wide but unnecessary beamwidth of 111¡ in the vertical plane. We therefore have to consider increasing the vertical aperture to increase the gain, i.e. turning the sectoral into a pyramidal horn. Following [1], the gain equation for a non-equiamplitude aperture is given by:

$$) \; L \frac{8}{.} \; \hat{U}5\,\hat{U}B_{\acute{o}} \qquad (3) $$

With G the gain of the antenna, S the aperture surface, $B_{\acute{o}}$ the gain factor depending on the illumination law of the aperture (in our case, this coefficient is 0.81). Thus, for a gain of 22 dBi at 9 GHz and an horizontal aperture of 240 mm, a vertical aperture of 55 mm is obtained. The simulation figure 6 shows the resulting vertical radiation pattern with 32¡ of half power beamwidth.

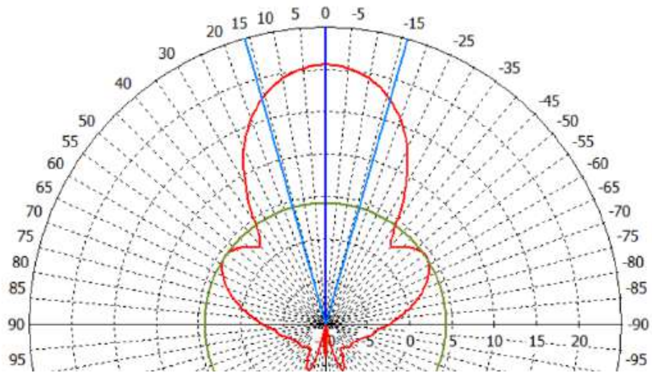

Figure 6 : Section of the radiation pattern in E-plane

3. Reduction of the length of the horn

As seen in the previous section, the length of the horn becomes our main problem to meet the specifications. To reach the angular deflection, a shortening of the horn length is necessary. We first performed a simulation by reducing the length of the horn down to 200 mm, while keeping the same aperture. The degradation on the beam in the horizontal plane is such that the main lobe widens to 16.9 degrees: this leads to a loss of 4 dB on the gain of the antenna. In order to compensate for these degradations, we now add a lens. The objective of this lens is to compensate the spherical phase front at the aperture, therefore thin the beam and increase the gain. By pure geometric rule, if we place ourselves in the H plane and look in the direction of propagation, we determine that the wave at the center of the aperture travels 17.6 mm further than on the edges of the horn. This distance difference generates a phase shift of 190¡ at a frequency of 9 GHz. We consider using rexolite (refractive index 1.59) for the lens, for its low loss at microwave frequencies and high resistance to environmental constraints. With these different data, geometrical considerations show that a planospherical lens of radius Rh = 332.3 mm and as center, the center of phase of the horn, is able to achieve the required phase front compensation at the aperture of the horn. To avoid reflections generated by the refractive index of the lens, matching layers a quarter wavelength thick and refractive index 1.26 are also included in the overall simulation presented in the figure below.

The results are quite satisfactory: when we look at the line-of-sight section, the compensation of the phase shift by the lens is obvious This compensation is reflected in the radiation diagram, with a thinning of the main beam and a gain greater than 21 dBi.

To conclude, the lens fulfills its objective by compensating for the shortening of the horn. With such horn dimensions, angular scanning becomes feasible. However, practical implementation of the matching layers is now to be considered

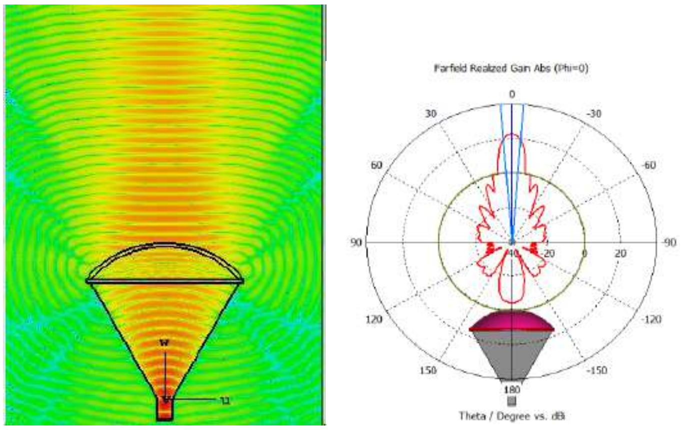

Figure 7 : Electric field inside and outside the device (left) and radiation diagram at 9 GHz for phi 0¡ (right)

4. Corrugated matching layers

The matching layers realized in the previous simulations are ideal, but not realizable in homogeneous rexolite. A solution is to create an artificial dielectric material, i.e. make periodic holes or grooves within the dielectric structure.

In order to be equivalent to an homogeneous medium, the period of the corrugations must not exceed the spacing p defined by the following equation:

$$ L \; L \frac{/}{á_{Þ}>á_{\hat{O}}\hat{u}q\;g:l\;\hat{\ddot{O}}} \; ''!!\#\$\% $$

With $J_{æ}$ the refractive index of the rexolite, $J_{Ü}$=1 the refractive index in free space and $\grave{a}_{Ü}$ the maximum angle of incident radiation, we find a spacing that must be less than 16 mm. There are two choices since corrugation can be achieved by periodic material substitution in 1 or 2 dimensions. For practical reasons we chose to dig cylindrical holes in the lens according to spacing p.

Following this, an optimization was made through computation of the effect of varying the diameter and

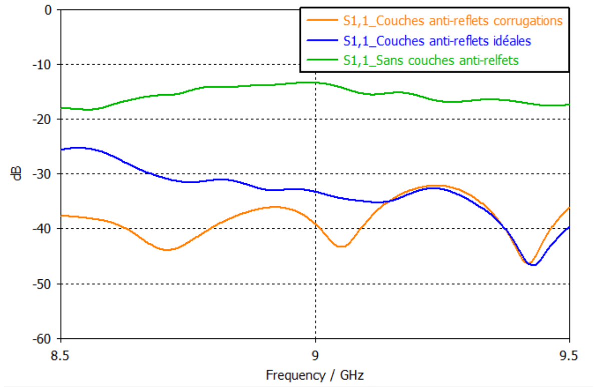

Figure 8 : Reflection coefficient without matching layer (green), with periodic holes (blue), with periodic grooves (orange)

spacing of the holes, in order to obtain the structure with the lowest reflection coefficient. Below we can see a comparison of the coefficient for a simulation without matching layers, and with layers of periodic holes or grooves.

Figure (8) confirms the advantages of the matching layers. Moreover, we observe that we obtain slightly better results with corrugated grooves.

5. Beam deflection

Having achieved the design of a compact, high peak power antenna meeting the required radiation pattern, we further want to extend the potential beam deflection. Such a 15¡ beam deflection should allow a mechanical scan of +/- 25¡ of the antenna to create a beam scan of -10/+40¡ with respect to the axis of the cylinder, meeting a further requirement for the system. Such beam deflection could result from the insertion of a dielectric prism into the horn. Like the lens, the prism is expected to be made of rexolite.

A representation of the antenna is given figure 9 with lens, prism and matching layers assembled. Obviously, prism and lens may be implemented from a single piece of rexolite, with matching layers at the input of the prism and the output of the lens.

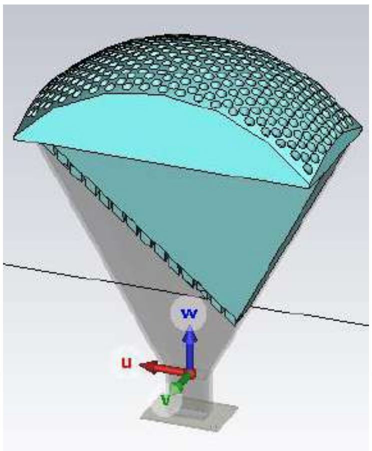

Figure 9 : Final design of pyramidal horn

Again the sizing of the prism is done by simulation, starting with a thin prism, allowing to observe jointly beam deflection and potential radiation pattern degradation, and further increasing the thickness of the prism. The figures below shows the final result: we obtain a 15¡ beam deflection without changing the main characteristics of the radiation pattern.

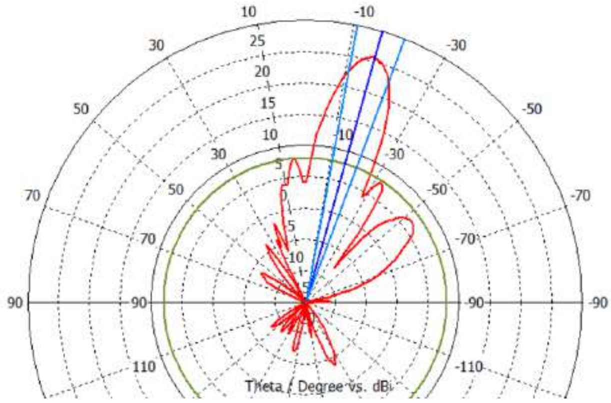

Figure 10 : Radiation diagram at 9 GHz for phi 0¡

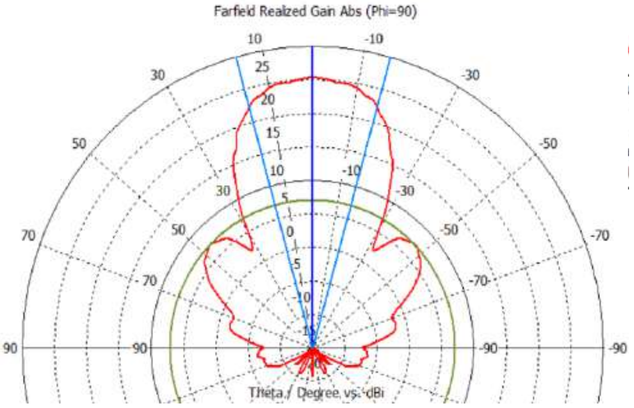

Figure 11 : Radiation diagram at 9 GHz for phi 90¡

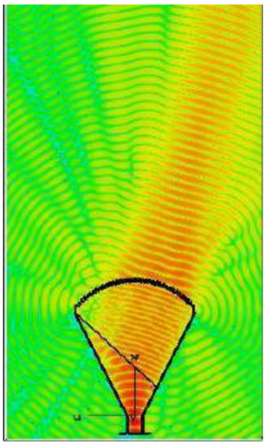

Figure 12 : Electric field inside and outside the device combining horn, lens and prism

6. Conclusion

To conclude, the step-by-step design of a horn and dielectric antenna has been shown theoretically to meet the specifications, taking into account various practical constraints. A physical realization of this antenna is underway.

Acknowledgements

The authors would like to thank RŽgion Occitanie / PyrŽnŽes-MŽditerranŽe (HERMES platform) and the European Regional Development Fund (FEDER) for partial funding of this work.

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Array antennas, active, adaptive and reconfigurable antennas

Deep-learning-assisted reconfigurable metasurface antenna for real-time holographic beam steering

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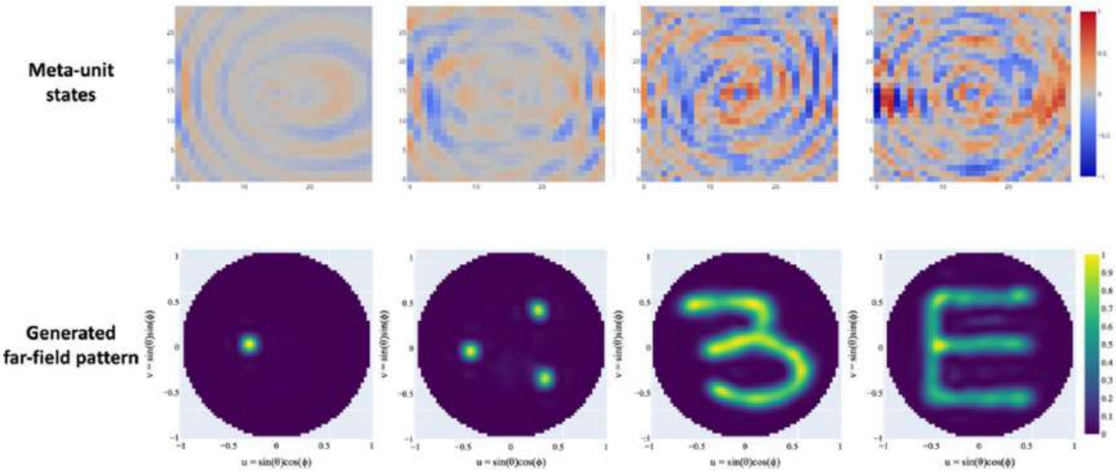
Abstract: We propose a deep-learning-based method for the control of a reconfigurable metasurface antenna. We modeled the metasurface as a collection of dipoles with states of varying polarizability and used a deep autoencoder neural network combined with a scattering equation and Born approximation to generate on-demand far-field maps. Our proposed autoencoder exhibits higher accuracy and a much faster speed compared with the conventional GA approach and allows for the real-time operation of a reconfigurable metasurface antenna for beam steering.

We propose a metasurface antenna capable of real-time holographic beam steering. An array of reconfigurable dipoles can generate on-demand far-field patterns of radiation through the specific encoding of meta-atomic states i.e., the configuration of each dipole. Suitable states for the generation of the desired patterns can be identified using iteration, but this is very slow and needs to be done for each far-field pattern. Here, we present a deep-learning-based method for the control of a metasurface antenna with point dipole elements that vary in their state using dipole polarizability. Instead of iteration, we adopt a deep learning algorithm that combines an autoencoder with an electromagnetic scattering equation to determine the states required for a target far-field pattern in real-time. The scattering equation from Born approximation is used as the decoder in training the neural network, and DQDO\WLF *UHHQ¶V IXQFWLRQ FDOFXODWLRQ is used to check the validity of Born approximation. Our learning-based algorithm requires a computing time of only around 100 V to determine the 900 meta-atomic states, thus enabling the real-time operation of a holographic antenna.



State patterns generated by the neural network, and the calculated far-field map from the *UHHQ¶V IXQFWLRQ

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Origami foldable and deployable reflectarray antennas for CubeSats

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Abstract: This paper presents origami foldable and deployable reflectarray antennas for CubeSats. To enable the reflectarray antennas, there is two key technology: creaseless reflection elements and deformation compensation reflectarray. In this paper, these technologies are shown in detail with design and measurement results.

Folding patterns are shown in Fig. 1 and are composed of mountain and valley folding lines. Array lattice is shown in the same figure and designed so that the boundaries coin with the folding lines. Most of them match with the array lattice but some cross the array element[2]. Figure 2 shows the shape of the reflection element which does not cross the folding lines and it is composed of four triangular patches with notches. Changing the dimension of the patch and the notch reflection phase can be tuned. These reflection elements enable creaseless design of reflectarray antennas.

Figure 3 shows the deformation compensation reflectarray antennas and the reflection elements are composed of a rectangular patch and a varactor diode. Depending on the deformation amount, bias voltage to the varactor diode is controlled to compensate for the deformation. Using a solid reflectarray prototype, the gain increment is confirmed[3].

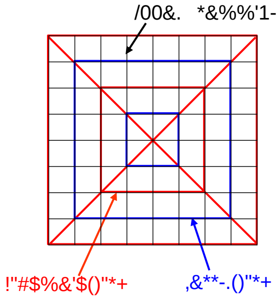

Fig. 1 Folding patterns

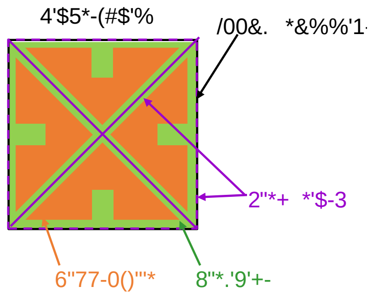

Fig. 2 Creaseless patch shap

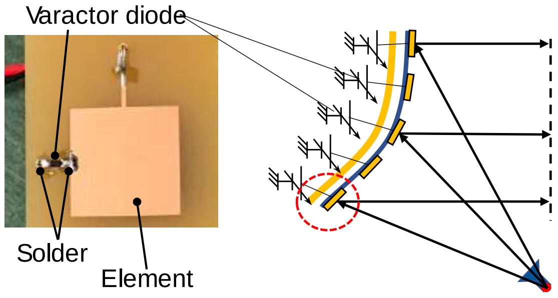

Fig. 3 Deformation compensation reflectarray

This work was supported in part by the Telecommunications Advancement Foundation, the Japan Society for the Promotion of Science (JSPS) KAKENHI under Grant JP20H00281 and Grant JP20H02146, DLab Challenge 2022 of Tokyo Institute of Technology.

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7KHUHIRUH PLOOLPHWHU ZDYH WHFKQRORJ\ KDV DWWUDFWHG PXFK DWWHQWLRQ IURP FRPPXQLFDWLRQ UHVHDUFKHUV 7KH UH> @ KDV SURSRVHG D î PLOOLPHWHU DUUD\ ZLWK D JDLQ RI G% LDQG D V\PPHWULFDO SDWWHUQ $ FRPSDFW GXDO EDQG DQWHQQD WKDW ZRUNV DW WKH PP ZDYH IUHTXHQF\ IURP *+] WR *+] LV SUHVHQWHG LQ UH> @ 7R PHHW WKH UHTXLUHPHQWV RI * WKH DQWHQQD DOVR QHHGV WR EH ZLWK KLJKHU JDLQ DQG D ZLGHU ZRUNLQJ EDQG

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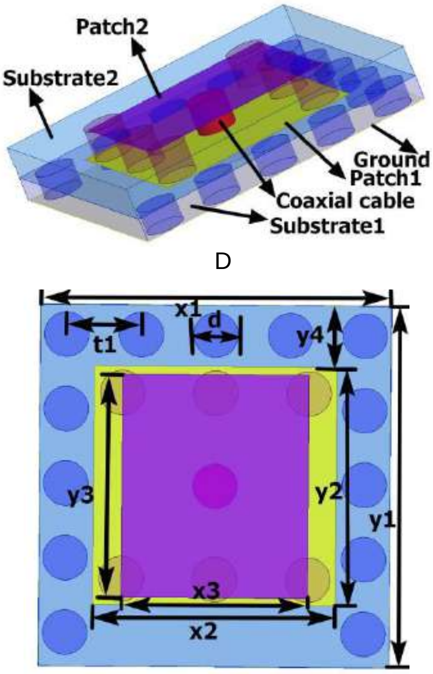
6LPXODWLRQ RI VWUXFWXUH

7KH PDWHULDO RI WKH VXEVWUDWH LV 5RJHUV 7KH HOHPHQW LV IRUPHG E\ VXEVWUDWH PP VXEVWUDWH PP JURXQG SDWFK SDWFK FRD[LDO FDEOH FRSSHU F\OLQGHUV DQG VHF F\OLQGHUV DV SUHVHQWHG LQ)LJXUH 7KH IHHGLQJ PHWKRG RI WKH DQWHQQD HOHPHQW LV FRD[LDO FDEOH 7KH GLPHQVLRQ SDUDPHWHUV RI WKH HOHPHQW DUH JLYHQ LQ 7DEOH



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E

)LJXUH &RQILJXUDWLRQV RI WKH DUUD\ HOHPHQW D SHUVSHFWLYH YLHZ E WRS YLHZ

7DEOH 7KH 3DUDPHWHUV 2I 7KH (OHPHQW

3DUDPHWHUV	9DOXH PP	3DUDPHWHUV	9DOXH PP
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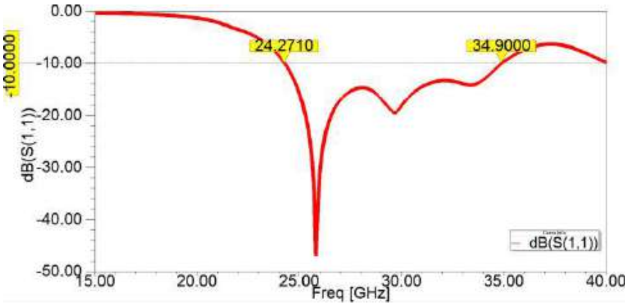
7KH VLPXODWLRQ UHVXOWV RI WKH HOHPHQW DUH JLYHQ LQ)LJXUH 7KH ZRUNLQJ IUHTXHQF\ RI WKH DQWHQQD HOHPHQW LV IURP *+] WR *+] ZKLFK FRYHUV WKH &KLQHVH * PP ZDYH EDQG RI *+] WR *+] 7KH UHWXUQ ORVV RI WKH HOHPHQW FDQ UHDFK G% DQG WKH = SDUDPHWHU RI WKH HOHPHQW LV LDW WKH FHQWHU IUHTXHQF\ SRLQW *+] $ JDLQ RI G% LV REWDLQHG DW WKH FHQWHU IUHTXHQF\ RI *+] 7KH 96:5 EDQG RI OHVV WKDQ LV IURP

* +] WR * +] ZKLFK FDQ FRYHU WKH HQWLUH ZRUNLQJ EDQGZLGWK 7KH GHVLJQHG HOHPHQW KDV JRRG LPSHGDQFH PDWFKLQJ DQG JDLQ



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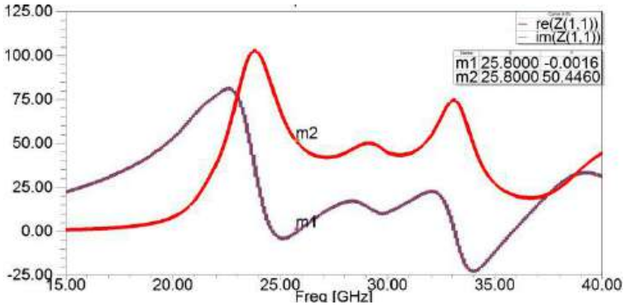

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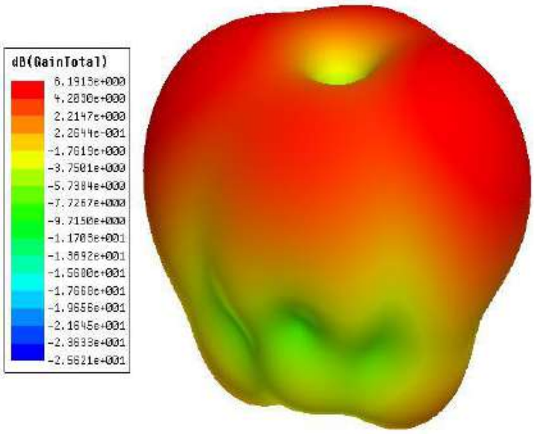
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-1.7619e+000
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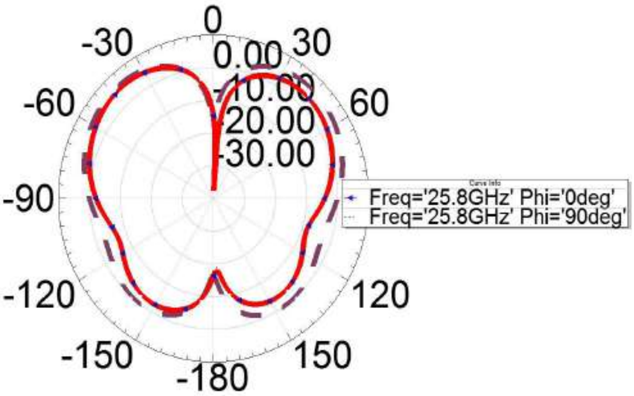
F



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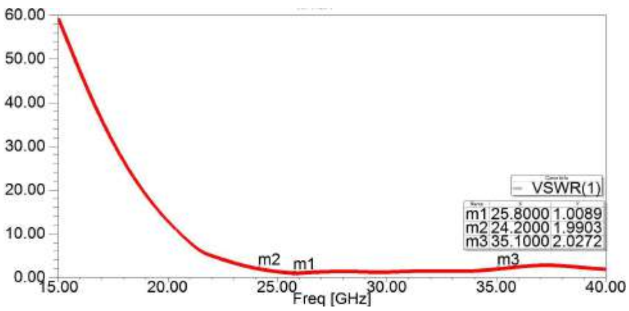

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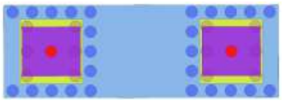
)LJXUH 7KH VLPXODWLRQ UHVXOWV RI DUUD\ HOHPHQW D6 E= SDUDPHWHU F ' UDGLDWLRQ SDWWHUQ G (SODQH DQG + SODQH UDGLDWLRQ SDWWHUQV H96:5

1XPHULFDO5HVXOWV

7ZR NLQGV RI GLIIHUHQW OLQHDU 6,: DUUD\V DUH GHYLVHG IRU EHWWHU SHUIRUPDQFH LQ WKLV VHFWLRQ ,W FDQ EH VHHQ IURP)LJXUH WKDW WKH DQWHQQD DUUD\ LV FRPSRVHG RI WKH DQWHQQD HOHPHQW SURSRVHG LQ WKH SUHYLRXV VHFWLRQ WKURXJK WKH OLQHDU DUUDQJHPHQW RI \8 DQG \8



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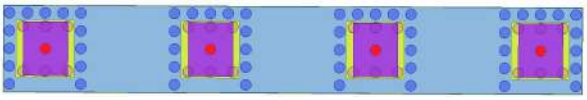

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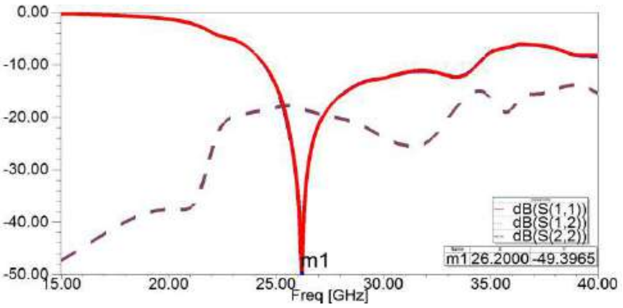
)LJXUH 7KH VWUXFWXUHV RI WZR GLIIHUHQW DUUD\V D \8 DQWHQQD DUUD\ E \8 DQWHQQD DUUD\

7KH î DUUD\ KDV DFKLHYHG D JDLQ RI G% ZLWK LVRODWLRQ RI PRUH WKDQ G% DW WKH ZRUNLQJ IUHTXHQF\ DV LOOXVWUDWHG LQ)LJXUH D DQG)LJXUH E)LJXUH G DQG)LJXUH H VKRZ WKH UHWXUQ ORVV DQG WKH JDLQ RI WKH î DUUD\ 7KH î DUUD\ KDV D JDLQ RI G% DQG DQ LVRODWLRQ RI PRUH WKDQ G% ZKLFK PHDQV WKH LQWHUIHUHQFH EHWZHHQ GLIIHUHQW HOHPHQWV LV ORZ 7KH (SODQH DQG + SODQH UDGLDWLRQ SDWWHUQV RI WKH î DUUD\ DQG î DUUD\ KDYH JRRG V\PPHWU\



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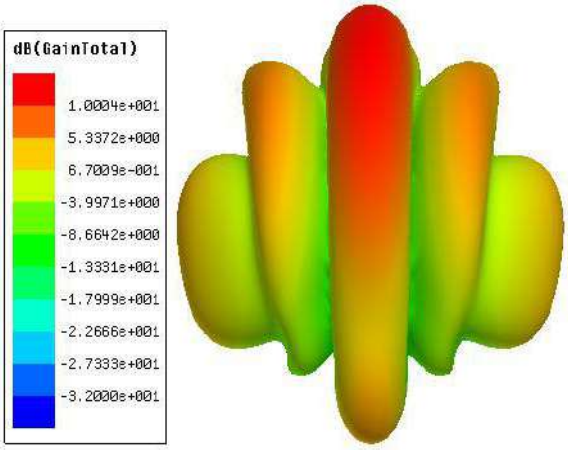
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-2.7333e+001
-3.2000e+001

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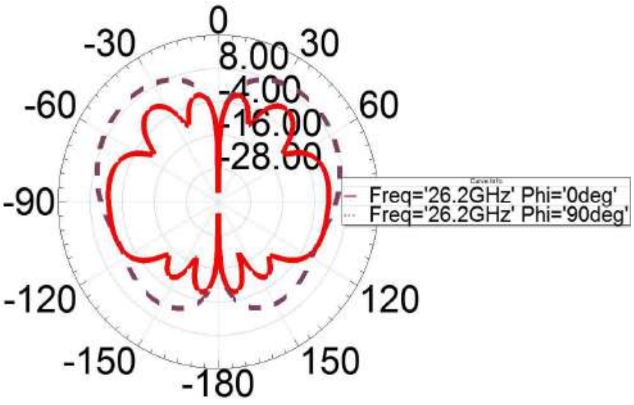

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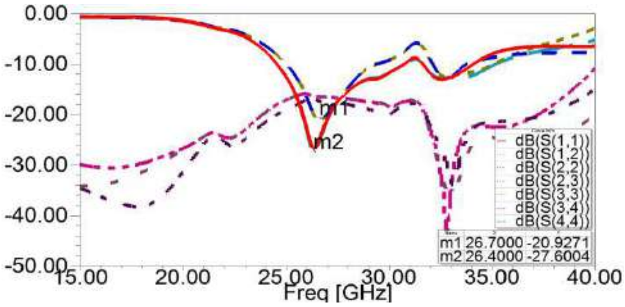

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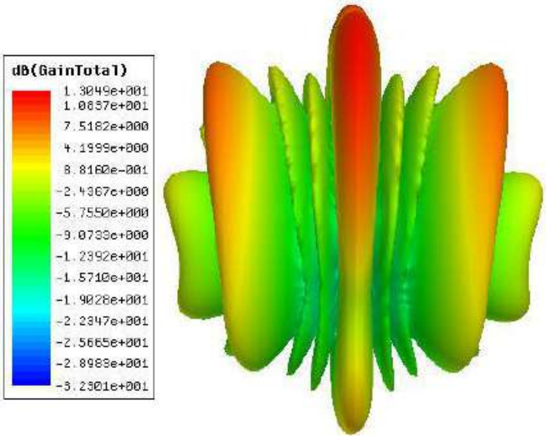
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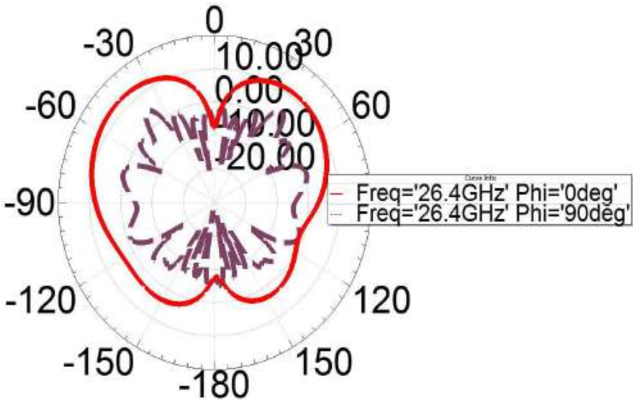
-3.2301e+001

H



I

)LJXUH 7KH VLP XODWLRQ UHVXOWV RI WZR DUUD\ V D 5HWXUQ ORVV RI WZR HOHP HQW DUUD\ E ' UDGLDWLRQ SDWWHUQ F (SODQH DQG + SODQH UDGLDWLRQ SDWWHUQV G 5HWXUQ ORVV RI IRXU HOHP HQW DUUD\ H ' UDGLDWLRQ SDWWHUQ I (SODQH DQG + SODQH UDGLDWLRQ SDWWHUQV

& RQFOXVLRQV

6HYHUDO OLQHDU 6,: P LOOLP HWHU DQWHQQD DUUD\ V ZLWK KLJK JDLQ DQG V\ P P HWULF SDWWHUQV DUH SURSRVHG LQ WKLV DUWLFOH 7R LP SURYH WKH SHUIRUP DQFH RI WKH DQWHQQD HOHP HQW 6,: WHFKQRORJ\ LV DSSOLHG LQ WKH HOHP HQW GHVLJQ 7KH VLP XODWLRQ UHVXOWV LOOXVWUDWHG WKDW WKH GHVLJQHG DUUD\ KDV JRRG FKDUDFWHULVWLFV $ JDLQ RI G% Z LWK WKH LVRODWLRQ RI P RUH WKDQ G% EHWZHHQ GLIIHUHQW HOHP HQWV DW WKH Z RUNLQJ IUHTXHQF\ KDV EHHQ REWDLQHG LQ WKH î DQWHQQD DUUD\ E\ VHWWLQJ WKH DSSURSULDWH DUUDQJHP HQW DQG WKH LQWHUYDOV RI DQWHQQD HOHP HQWV 7KH î DQWHQQD DUUD\ KDV WKH DGYDQWDJHV RI EURDG EDQGZ LGWK KLJK JDLQ DQG JRRG V\ P P HWU\ RI WKH SDWWHUQ Z KLFK P DGH LW VXLWDEOH IRU * FRP P XQLFDWLRQ DSSOLFDWLRQV

$ FNQRZ OHGJHP HQW

7KLV Z RUN LV VXSSRUWHG E\ WKH 1 DWLRQDO 3URMHFW RI ,QQRYDWLYH (QWUHSUHQHXUVKLS RI 8 QGHUJUDGXDWH 1 R

5 H HUHQFHV

> @0 6KDIL $) 0 ROLVFK DQG 3 M6P LWK ³ * $ 7XWRULDO 2YHUYLHZ RI 6WDQGDUGV 7ULDOV &KDOOHQJHV ' HSOR\ P HQW DQG 3UDFWLFH´ ,(((-RXUQDO RQ 6HOHFWHG $ UHDV LQ &RP P XQLFDWLRQV SS

> @: + RQJ . + %DHN DQG 6 . R ³0 LOOLP HWHU: DYH * $ QWHQQDV IRU6P DUWSKRQHV 2YHUYLHZ DQG ([SHULP HQWDO ' HP RQVWUDWLRQ´ ,(((7UDQVDFWLRQV RQ $ QWHQQDV DQG 3URSDJDWLRQ

> @0 DUFXV DQG 0 - ³ * $ 1 ' ,0 7) 2 5 $ 1 ' %(< 2 1 ' ´ ,(((: LUHOHVV &RP P XQLFDWLRQV

> @) $ OEDJGDOL DQG $ $ \ GLQ ³' XDOEDQG P P : DYH * DQWHQQD´

> @< & &KDQJ ³$ 1 RYHO' XDO3RODUL]HG : LGHEDQG DQG 0 LQLDWXUL]HG / RZ 3URILOH 0 DJQHWR(OHFWULF ' LSROH

$QWHQQD $UUD\ IRU PP:DYH * $SSOLFDWLRQV´ ,(((
2SHQ -RXUQDO RI $QWHQQDV DQG 3URSDJDWLRQ

> @< /L ³6LPXODWLRQ DQG H[SHULPHQW RQ 6,: VORW DUUD\
DQWHQQDV´ ,(((0LFURZDYH DQG :LUHOHVV &RPSRQHQWV
/HWWHUV SS

> @0 %R]]L $ *HRUJLDGLV DQG . :X ³5HYLHZ RI
VXEVWUDWH LQWHJUDWHG ZDYHJXLGH FLUFXLWV DQG DQWHQQDV´
,(7 0LFURZDYHV $QWHQQDV 3URSDJDWLRQ SS

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$HH>7:8@:J:I89K8K;09>HF>KBAKLI$

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)&8*"$1*B.(9$:8$C<MB7C<C$9>$?<C;A<$8:E7BD$D>88$C;<$9>$N?<87<D$?<=D<A9:>78$9@B9$>AA;?$>7$9@<$8
8;A@$B8$D<78<8$B7C$OBG<IDB9<8>8C$9?BA<?9P$OBG<8K$.7$9@:8$9BDH($.$O:DD$I?<8<79$9<?B@<?9P$
:7$O@:A@$8<G<?BD$I?>9?;C:7E$89?;A9;?<8$B?<$MB9B7:BDD$?$9@<($=BQ?:AB9<C$8@>?90I;D8<C$DB8<?8
O@:A@$BDM>89$A>MID<9<DF$8;II?<88<8$?<=D<A9:>78$9@B9$>AA;?$>7$9@<$8;?=BA<K$7$<?9P$?<E:>78($B7C$8@>?D$9@<:?$B

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O:?<D<88$A>MM;7:AB9:>7$9<A@7>D>E:<8K$.7$9@:8$9BDH($.$O:DD$I?<8<79$MB7C<C$9>$?<C;A<$8:E7BD$D>8
N?<87<D$?<=D<A9:>78$9@B9$>AA;?$>7$9@<$8;?=BA<K$@B8$D<78<8$B7C$OBG<IDB9<8$;8<C$9
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B?<$>7<$>=$9@<$B79:?<=D<A9:>7$9<A@7:R;<8$;8<C$9@<$B7$I?<88<D<A9:>78$TUVK$W>O<G<?($D:9@>
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OBG<8K$ $

.7$?<A<79$ F<B?8($;D9?B8@>?90I;D8<C$ DB8<?$ 9<A@7:R;<8$ @BG<$ Q<<7$ 9<A@7:R;<8$ =>?$ I?>
9@?<<0C:M<78:>7BD$ M:A?>89?;A9;?<8$ <7BQD:7E$ @:E@<?$ M<D>7$ I?>A<88:7EK$ X<$ B?<$ C<G<D>I:7E$
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'K! +K$)BHBH;$<9$BDK($\c?>BCQB7C($M:DD:M<9<?0OBG<$B79:0?<=D<A9:G<$89?;A9;?<8$>7$8BII@:?<$BQDB9<C$
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Z!K +K$)BHBH;$ <9$ BDK($ \!$ -B?E<$ d:BM<9<?$,:DD:M<9<?0XBG<$ ->O01B88$ N:D9<?$,BC<$ >=$!D;M:7B$ O:9@$
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A Simple mm-Wave Chipless Pressure Sensor

S. Rodini[1*], S. Genovesi[1], G. Manara[1], and F. Costa[1]

[1]Department of Information Engineering, University of Pisa, Italy

[*]corresponding author: sandra.rodini@phd.unipiit

Abstract 3UHVVXUH LV RIQUH TRXHWQKHO\PRVWDVXUHG SK\VLFDO IXDQWLWLHVQLHWF SUHVVXUH VHQVRUV WKDW DGDSW WR WKH $URHWVVXDHLVHFHQDSZDOEHFDWG FKLSOHVV 5),' WDJ LV SURSRVHGDWKLFFWDDQ LPSFHFDSRFVHVXGSRUDFHUDWRHC FRPELQDWLRQ RI WKH SHULRGLF VXUIDFH ZLWK WKH VXSHUVWUDWH U LV DSSOLHG WR WKH WDJ

Introduction Pressure sensors are required in a large number of applications ranging from biomedical [1], robotics [2], aerospace industries [3]. Pressure sensors can be classified as capacitive, resistive and piezoelectric according to the characteristics of the active layer [4-5]. Many of the pressure sensors released to date are wired, difficult to install, and require active excitation. One way to make fully wireless, battery-free sensors is through RFID technology [6]. In this case it is possible to interface the sensor with the RFID chip in order to have the sensing functionality in the radio frequency system. Another possibility is to create chipless RFID sensors [7]. In chipless RFID technology the tag has no electronic components and requires no power source. In this case the sensor is based solely on the frequency response of a resonator. Here a chipless pressure sensor composed of a resonator working at mm-wave frequencies is proposed. The resonator operates in conjunction with a dielectric superstrate and pressure is applied to the ground of the resonator. The application of pressure causes a frequency shift of the resonance peak.

Pressure sensor design !"#$%#&()$*+$,"#$-.*-*&#%$-.#&&/.#$&#)&*.$'&$&"*0)$')$1/#($23456$"#$&#)&*.$'&$ 74&#%$*)$4$89$4:#$;"'-<#&&$,4(6$"#$,4($'&$*8-*&#%$7=$,".##$%'-*<#&2',"$%'++#.#),$<#)(,$8&#-4.4,#%$ +.*8$4$(.*/)%$-<4)#$7$4$,"')$?*(#.$@AA@$/7&,.4,#$3%B2CD$56$!"#$/)',$#<<$*+$,"#$-#.'*%';$&/.+4;# 31.#E/#);=$F#<#;,':#$F/.+4;#$1F5&"*0)$')$1'(/.#62375"#$-#.'*%';',=$G$*+$,"#$/)',$;#<<$'&$#E/4<$$*$@6D 88 6$H)$*.%#.$,*$7#$47<#$,*$/&#$,"#$,4($4&$4$-.#&&/.#$&#)&*.$4$&/-#.&,.4,#$'&$4--<'#%$$%4#$/4'#$1F$F6 ');.#4&')($-.#&&/.#$'&$4--<'#%$,*$,"#$(.*/)%$-<4)#$76#$'%#4$'&$,*$-<4;#$4$;*),4')#.$*)$,*-$*+$,"#$,4($4)%$+'<<$,"4,$;*),4')#.$0',"$04,#.6$I&$,"#$:*</8#$*+$04,#.$');.#4&#&>$,"#$-.#&&/.#$J#.,#%$*)$,"#$,4($0'<<$');$#4&#6 !"#$4--<'#%$-.#&&/.#$K$4<;/<4,#%$4&$KBL(MI>$0'#.#$($'&$,"$#4.,"$(.4:',=$4;;#<#.4,'*)>$L$&$,"#$8$4&&$*+$,"#$ 04,#.$')$,"#$;*),4')#.$4)%$I$'&$,"#$4.#$4'"#.#$-.#&&/.#$'&$4--<'#%$6#$,4($'&$;*8-*&#%$*+$2A$J$2A$;#<<&$4)%$,"#.#+*.#$,"#$4.#4$0'<<$7#$$G6$2@$6D$88$6$"#$-.*-*&#%$&#)&*.$;4)$7#$'),#..*(4,#%$0',"$,0*$N?CO$ &,4)%4.%$(4"$.)$4),#))4&$*-#.4,')($')$,"#$+.#E/#);=$.4)(#$*+$'),#.#&,6$

Numerical results H)$*.%#.$,*$#:4</4,#$,"#$+#4&'7'<',=$*+$,"#$-.*-*&#%$&#)&*.>$)/8#.';4<$#<#;,.*84()#,';$ &'8/<4,'*)&$4.#$+'.&,$-#.+*.8#%$6$"#$)/8#.';4<$&'8/<4,'*)$"4&$7##)$;4..'#%$*/,$7=$/&')($,"#$PF!$F,/%'*$ F/',#$F*+,04.#6$!"#$&'8/<4,'*)$04&$-#.+*.8#%$/&')($-#.'*%';$7*/)%4.=$;*)%','*)&$H)$*.%#.$,*$#J-<*',$,"#$ 0*.Q')($-.');'-<#$*+$,"#$-.*-*&#%$&#)&*.$&#:#.4<$;4&#&$4.#$;*)&'%#.#%$4&$&"*0)$')$1'(/.#62 3;5$!"#$,4($)<=>$,"#$,4($0',"$,"#$&/-#.&,.4,#$4)%$+')4<<=$,"#$,4($0',"$&/-#.&,.4,#$+'<<'($,"#$&-4;#$7#,0##)$%'-*<#&$

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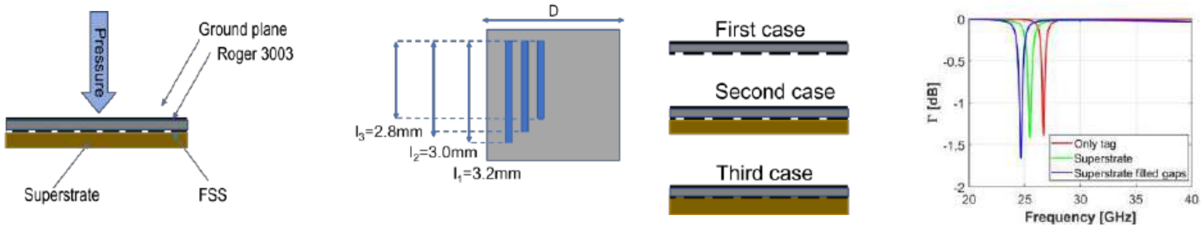
Pressure
Ground plane
Roger 3003
Superstrate
FSS
D
l$_3$=2.8mm
l$_2$=3.0mm
l$_1$=3.2mm
First case
Second case
Third case
0
-0.5
-1
-1.5
-2
Γ [dB]
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40
Frequency [GHz]
Only tag
Superstrate
Superstrate filled gaps

(a) (b) (c) (d)

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&'8/<4,#%$3%5$.#+<#;,'*)$;*#++';'#),$4&$,"#$4--<'#%$-.#&&/.#$:4.'#&6

Conclusions I)$'))*:4,':#$-.#&&/.#$&#)&*.$&$"#.#$-.*-*&#%6$!"#$&#)&*.$;*)&'&,&$4$88 9N4:#$;"'-<#&&$,4($*8-*&#%$*)$,".##$8#,4<<';$%'-*<#&$&-4.4,#%$7=$,"#$(.*/)%$-<4)#$+.*8$4$,"')$?*(#.$&/7&,.4,#6$ ;*87')4,'*)$*+$,"#$&/-#.&,.4,#$0',"$,"#$,4($.#&/<,&$')$4$+.#E/#);=$&"'+,$*+$,"#$.#&*)4);#$-#4Q$-.*-*.,'*)4<$,*$,"#$4--<'#%$-.#&&/.#6

Acknowledgements Work partially supported by the Italian Ministry of Education and Research (MIUR) in the framework of both the FoReLab project and the Crosslab project (Departments of Excellence).

References

1. ?*.'U>$K6>$1.4UV*>W'7#.*>$I6$X6>$F4),*&>$Y6$T6>$Z$F'8[#&>$Y6$I6$3CA7@56$-.#&&/.#$&#)&*.&$ +*.$7'*8#%';4<$4)%$7'*8#;"4)';4<$4--<';4,'*)&$"#$%&'(")(*+",-.+/&'("01+/2$343\5>$A\A]A@\A]A@$
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5. Y4:#%>$b6>$L4)&**.>$L6>$Z$F"4">$H6$I6$3CA2]56$I$.#:'#0$*+$-.');'-<#&$*+$LcLF$-.#&&/.#$&#)&')($0',"$',&$4#.*&
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7. P*&,4>$16>$`#)*:#&'>$F6>$X*.(#&#>$L6>$L';"#<>$I6>$G';4)%'4>$16$I6>$Z$L4)4'40$`6$3CAC256$&*.&>$,"#$)#0$+.*),'#.$*+$'),#.)#,$*+$,"')(&$5-%2"$2633]5>$@2@O6

AES 2023, TORREMOLINOS - SPAIN, 5 ±8 JUNE 2023

Improved Foreign Object Detection Method for Wireless Charging using Balanced and Synchronous Coils

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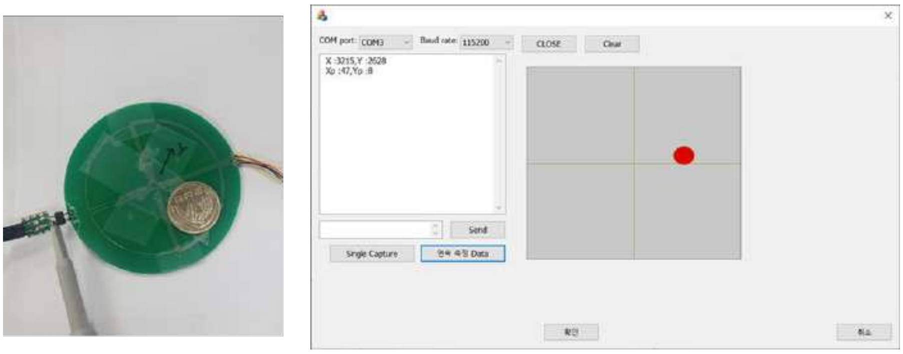
Abstract: In this paper, we propose a new foreign object detection (FOD) structure in which a synchronous coil is added to the balanced coils. The location of the foreign object can be identified by comparing the phase of the added coil with that of the two balanced coils, and using the signal processing method known as the sample and hold method. This paper presents the configuration of the FOD system and the results of the detection method.

The proposed FOD (Foreign Object Detection) method in this paper utilizes a synchronous coil added to the center of the detecting coil to obtain a transmission signal, which allows for the location of a foreign object to be determined using phase detection. The balanced coil method has been used previously, but it has limitations such as low detection rates and an inability to locate foreign objects in certain areas. The proposed method is designed to address these limitations and is applied to mobile phone charging. The location of foreign objects can be identified through simple signal processing.

The FOD structure proposed in this paper is composed of a transmitting coil and a detecting coil. The detecting coil includes two balanced coils and a synchronous coil in the center. The balanced coil generates an electromagnetic field, and when a metal object is placed in the area where the balanced coil is located, the electromagnetic field becomes unbalanced, and current begins to flow. The synchronous coil receives the transmission signal, which is synchronized with the charging signal sent by the transmitting coil, and converts it into a digital signal. This signal is then supplied to the microprocessor, where sample and hold processing is used to create a pulse. The output signal of this method changes its output level and sign depending on the location of the foreign object. The method can determine the presence or absence of a metal object and its location based on the signal change of V^1_{out} and V^2_{out}.

To verify the proposed structure, analog circuits such as filters, amplifiers, and various signal processing functions are required. By using Cypress's PSOC5 microprocessor, it can be configured relatively simply. This processor has built-in high-performance programmable analog blocks that can be configured to perform various signal processing functions. The proposed FOD method can be used to improve the safety and convenience of mobile phone charging by detecting foreign objects and preventing potential hazards.



COM port: COM3
Baud rate: 115200

```
X :3215,Y :2628
Xp :47,Yp :8
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Figure 1. Experimental setup and detection result.

Acknowledgements

This work was supported by ICT R&D program of MSIP/IITP. [2020-0-00259, Development of a Fast Wireless Charging System for Portable Terminals with Improved Heat Dissipation and Shielding Performance]

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Analytical, Computational and numerical techniques

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KGC<<;=LC8J98E$FD>MC<N$E;<F<JOE<F8;>PDGFOQ<

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FJ:F8>FE;$CQ$>M;$=L;G><FA$;A;B;8>$#$B;>MCJUMF>$9>$GCBT98;=$>M;$E;CB;><9G$QA;W9T9A9>R$CQ$
S9>M$M9EM$L<;G9=9C8$CQ$=L;G><FA$B;>MCJ$9J$OA;D=$<F>J$S9>M$E<F>98E=$SMC=;$LF>>;<8=$F<;$8
S9>M$>M;$TCD8JF<9;=$CQ$>M;$;A;B;8>F<R$G;AAO

+;G;8>AR$>FBF>;<9$A=8JB$>F=D<QF$M$F:;$F<CD=;J$9BB;8=;$98>;<;=>$T;GFD=;$>M;R$L<C:9J;$988C:F
=CAD>9C8=$>C$GC8><CA$;A;G><CBFE8;>9G$SF:;=O$X;$GF8$=;;$98$>M;$B$LF<>9GDAF<$L;<9CJ9G$=><DG>
GAF==$CQ$E<F>98E=O$)M;<;QC<;($>M;$8DB;<9GFA$B;>MCJ=$J;:;ACL;J$>C$GFAGDAF>;$>M;$;A;G><CBFE8;>9
98$BF8R$GF=;=$=LC=$TAC$>FBF>;<9$A=8J$>F=D<QFC$HC<$><F8=AF>9C8$98:F<9F8>$=><DG>D<;=($BCJFA
F8J$BCJ;$BF>GM98E$>;GM89YD;=$F<;$:;<R$98>;<;=>98E$9>GF>$Z;:S$J8$M;$F$W9=>98E$
/DB;<9GFA$BCJFA$B;>MCJ=$J9QQ;<$98$>M;$GMC9G;$CQ$;WLF8=9C8$F8J$>;=>$QD8G>9C8=O$*8$GF8
QD8G>9C8=$C<$=DT0JCBF98$QD8G>9C8=$FGGC<J98E$>C$SM;>M;<$>M;R$F<;$J;Q98;J$C8$>M;$SMCA;$JCB
9>O$HC<$L;<9CJ9G$L<CTA;B=($>M;$BC=>$LCLDAF<$B;>MCJ$9=$G;<>F98AR$>M;$S;AA0[8CS8$98D<9;<$,CJ
SM9GM$;WLF8=9C8$F8J$>;=>$QD8G>9C8=$F<;$L=;DJC$L;<9CJ9G$QD8G>9C8=O$*8$>M;$GC8><F<R($D=9
S9>M98$;FGM$JCBF98$>MF>$GC8=>9>D>;$>M;$=><DG>D<;$FAACS=$>C$;WL<;==$<9EC<CD=AR$>M;$J9Q
J;>;<B98;$>M;$;9E;8:FAD;$L<CTA;B$F8J$>MD=$A;FJ=$>C$;WLC8;8>9FA$GC8:;<E;8G;$QC<$>M;$;9E;8:FAD;=S
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C>M;<$8DB;<9GFA$BCJFA$B;>MCJ=$QC<$J9;A;G><9G$B;>FAA9G$=><DG>D<;=O$)M;$F9B$CQ$>M;$L<;=;8>$
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18##$+&98)%.<$+98%<'.8%.&)%8&+5.,):%98%<-6.=/.>?9/.@)&/.A,/.A-.B)5/.FF-.ESCI;ESGS-.DQES/

Exploring the Thermally Activated Delayed Fluorescence Performance for a Phenothiazine Derivative via TD-DFT

L. Cascino[1,2*], A. Maggiore[2*], I. Rivalta[3,4], G. P. Suranna[5], R. Grisorio[5], D. Conelli[5],
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[2]Institute of Nanotechnology, National Research Council (CNR-NANOTEC), Lecce 73100
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[4]ENSL, CNRS, Laboratoire de Chimie UMR 5182, 69364 Lyon France
[5]DICATECh, Politecnico di Bari, Bari, Italy
[6]Center for Biomolecular Nanotechnologies, Istituto Italiano di Tecnologia, Arnesano (LE) 73010
[*]corresponding author: lucia.cascino@unisalento.it

Abstract: To design new materials for Thermally Activated Delayed Fluorescence (TADF) [illegible] achieve a detailed [illegible] sensitive to environment [illegible] quantum mechanical calculations [illegible] We report a computational analysis based on Time Dependent Density Functional Theory (TD-DFT) to investigate a phenothiazine derivative [illegible] TADF only upon aggregation

In classical fluorescent systems, especially at room temperature, the triplet electronic states can decay only through non-radiative pathways by vibration or phonon interactions, while radiative decay is forbidden. On the other hand, in phosphorescence metal organic complex featuring heavy metals, the strong spin-orbit coupling enables a radiative emission from triplet excited states. In order to overcome the drawbacks of the latter (toxicity and high costs), new full organic systems that recovering triplet excitation through a delayed fluorescence mechanism have been largely investigated. Such process, namely the TADF, [1] occurs because of fast reverse intersystem crossing (rISC), which up convert triplet to singlet by thermal energy. Therefore, in order to achieve good TADF performances, besides a large transition dipole moment between excited and the ground singlet states, it is of vital importance to ensure a small enough singlet-triplet energy gap (~ 0.1 eV) [2]. In order to reduce this gap, the exchange energy (J), which is inversely proportional to the spatial separation between the highest occupied molecular orbital (HOMO) and the lowest unoccupied molecular orbital (LUMO), has to be minimized ($2J \approx \Delta E$). It has been demonstrated that Donor-Acceptor (D-A) molecules presenting strong charge transfer states (CT) are among the most efficient systems to reduce the exchange coupling J.

In this work, we investigated the TADF performance of a phenothiazine derivative consisting of a strong donor (phenothiazine) and acceptor (fluorenone) component, adopting a quasi-equatorial D-A conformation [3] and we analyse the possibility for this molecule to activate TADF by forming aggregated electronic states (Fig. 1a). All simulations were performed by using the ORCA 5.0 package. The geometry of the ground state was optimized in the gas phase by employing the B3LYP functionals and a TZVP basis set, with the def2/J auxiliary basis set for the RIJCOSX approximation to the Coulomb integrals [4]. Electronic and optical properties were analysed for the monomer in the quasi-equatorial conformation and in the non-polar cyclohexane solvent. After characterization of the monomer properties in terms of relative position of the first singlet (S_1) and triplet (T_3) charge transfer states, we considered three different dimer geometries, analysing their structural and electronic properties as a function of the inter-monomer separation distance (see Fig. 1).

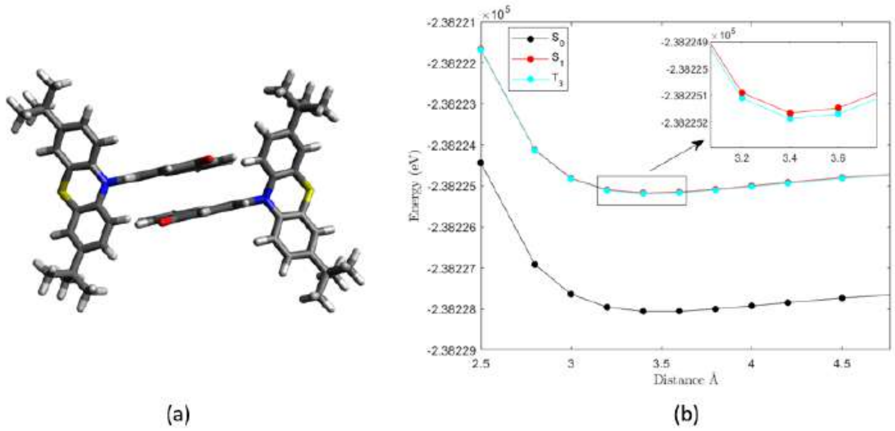


Fig. 1 (a) Sketch of a dimer of phenothiazine GHULYDWLYHVLQ WKH HTXDWRULDO FRQIRUPDWLRQ (b) [HG Energies of S_0, S_1 and T_3 states vs separation distance between molecules (system sketched in panel a) for the monomers relaxed to their ground state geometry.

An important reconstruction in both S_1 and T_3 states was observed, resembling the typical one of dimer electronic state with one monomer in the ground state (S_0) geometry and the other one in the excited state geometry, i.e. S_1 and T_3 geometries, respectively. Moreover, fingerprints of aggregate formation were also tracked down in the nature of Natural Transition Orbitals of S_1. With respect to monomer, we registered a promising change in the relative position of the electronic states of interest for TADF. Moreover, coherently with experimental PL spectrum, we observed a red-shift of the emission peak. In addition, to what is well known about the effect of environment conditions (e.g. polarity of solvent affecting the TADF performances), this study attests a new path to activate TADF trough the formation of a new aggregate electronic state. This open new perspective toward an on-demand control of the TADF response in molecules of interest for optoelectronics and nanomedicine.

7KLV ZRUN ZDV SDUWLDOO\ ILQDQFHG ³$5(6´ E\ WKH 5HJLRQH (& SURMHF Sustainable and intelligent fibers and fabrics for TEChnic clothing (CUP % & ´

References

1. 8R\DPD + . *RXVKL . 6KL]X + 1RPXUD DQG & $GDFKL ³+LJKO\ HIILFLHQW emitting diodes from GHOD\HG IOXRUHVFHQFH´ 1DWXUH, 2012. 9RO 1R
2. Lv, L., K. Yuan, T. Zhao, and * 'DL ³,QWULQVLF $QDO\VLV RI 7KHUPDOO\ $FWLYDWH (I) Complex Based on the Path Integral Approach: Origin of the Effective Spin-Flipping Channel and Vibrational Spin-2UELW &RXSOLQJ (IIHFW´ - 3K\V &KHP $, 2022. 9RO 1R
3. =KDQJ - 0 =KX < /X ; =KDQJ 6 ;LDR + /LQ ³6WLPXOL-Responsive Phenothiazine Derivatives with Triplet-Related Dual Emission and High &RQWUDVW 0HFKDQRFKURPLVP *XLGHG E\ 3RO Chem, Vol. 28, No. 29, 2022.
4. 1HHVH) ³7KH 25&$ SURJUDP V\VWHP´ Wiley Interdiscip. Rev. Comput. Mol. Sci., Vol. 2, Issue 1, 73, 2012.

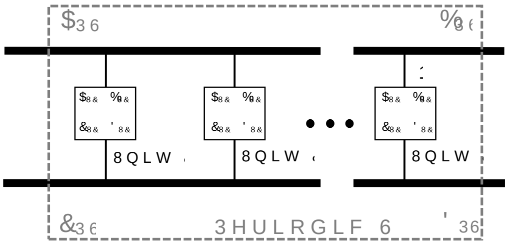
0RGHO 7HFKQLTXH IRU)LQLWH /HQJWK 8QLW &HOO 0LFURVWULS
IRU 00:)LOWHUV

$ 'LYVDO 'D0LUDQ? KGHNDU 6\DKNDO
5) 0LFURZDYH 5HVHDUFK /DE 6FKRRO RI &RPSXWHU 6FLHQFH
8QLYHUVLW\ RI (VVH[8QLWHG .LQJGRP
FRUUHVSRQGLQJ DXWKRU DGLYVD#HVVH[DF XN

Abstract: A technique to analyze MMW microstrip tunable filters with finite number of unit cells is developed It uses eigen decomposition for factorization of the unit cell transmission matrix to obtain constituent parts and then canonicalize the periodic structure with N unit cells. Based on this concept MATLAB scripts have been developed to determine the dimensions of finite length MMW microstrip periodic structure filter. The results from ADS simulations uphold the validity of the technique.

With the global demands for high data rate/wider bandwidth networks, most telecommunication service providers are considering wireless MMW technology for mission-critical capabilities including superior speeds and low latencies. Due to their small sizes, development of MMW filters essential for the network transceivers are cumbersome and one promising approach is to use microstrip line periodic structures with finite number of unit cells. As such, the usual theory of periodic structures assuming infinite number of repeated cells is not accurate. In this paper an alternative approach for fast analysis of these structures is proposed.

Periodic structures are modeled based on their unit cells as shown in Fig. 1. In this technique, the reciprocal



)LJ 7UDQVPLVVLRQ

transmission matrix of a unit cell is factorized into its constituent parts (i.e. canonical and eigenvectors matrix)

B%# $&C ^Î¼ L B%# $&C ^Î¼áÖ Ô á â á Ü Ö Ô ß B%# $&C ^¾ Ï :B%# $&C ^Î¼áÖ Ô á â á Ü Ö Ô ß ;?5 (1)

Therefore, the transmission matrix of the unit cell can be expressed as a diagonal matrix. This guarantees a simpler and faster determination of the overall transmission matrix of a periodic structure with finite number of cells. The set of eigenvalue (EV) solutions (i.H the spectrum of the reciprocal transmission matrix is calculated from characteristic eigenvalue equation:

,d #Î¼ $Î¼ %Î¼ &Î¼ hF ã ;L r (2)

Therefore, the EV and Canonical matrices can be obtained

B%# $&C ^¾ Ï L d ã5 r r ã6 hL H #Î¼ E ¥#6Î¼ F s r #Î¼ F ¥#6Î¼ F s I (3)

B%# $&C ^Î¼áÖ Ô á â á Ü Ö Ô ß L H F$Î¼ F¥#6Î¼ F s F$Î¼ ¥#6Î¼ F s I (4)

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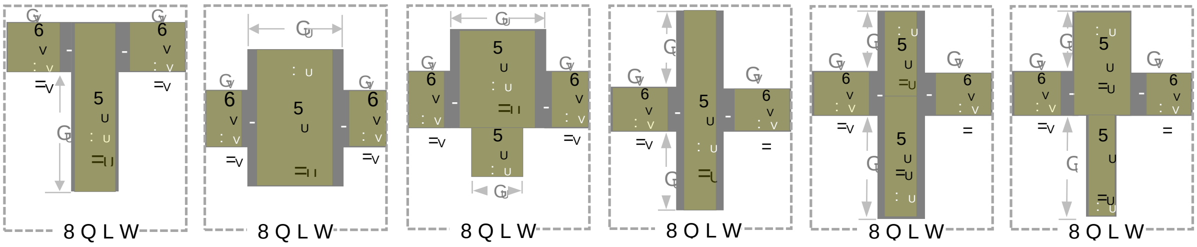

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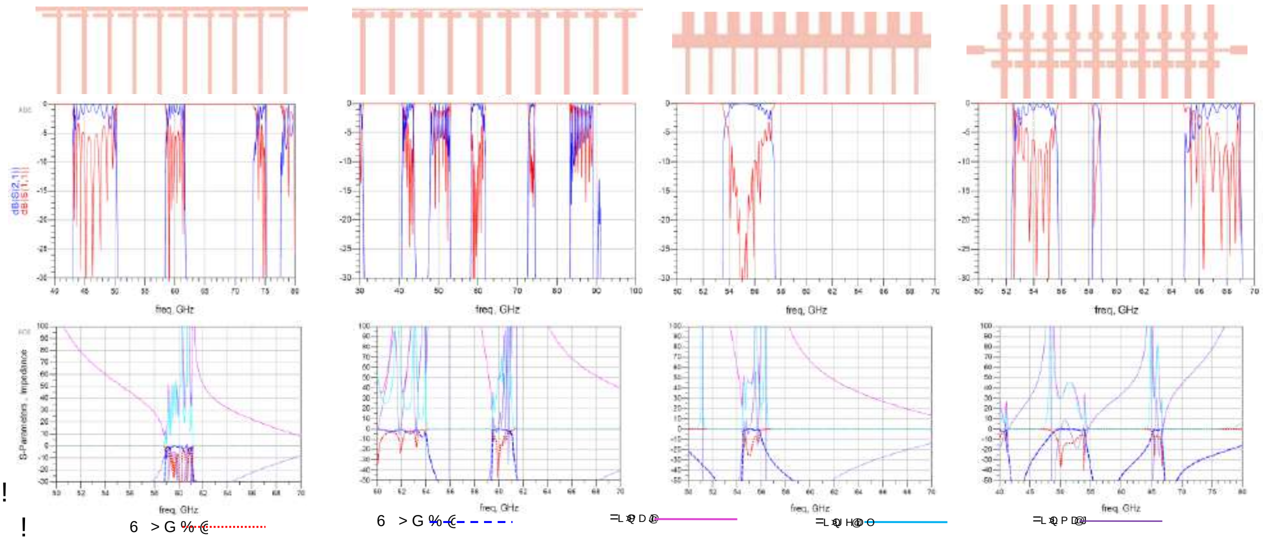
Hence, for N unit cells connected in cascade, the overall transmission matrix (where PS represents the overall transmission matrix) will be obtained as follows

B#% $& C ÉÌ L B#% $& C Î¼ÃÖ Ôáââ ÜÖÔß :B#% $& C ¾Ï ;Ç :B#% $& C Î¼ÃÖ Ôáââ ÜÖÔß ;?5 (5)

Based on the method presented, different unit cells made of microstrip structures for periodic filters are analyzed. MATLAB scripts are written to design a filter based on optimization of the periodic structure transmission matrix. The program receives basic inputs such as desired frequency, bandwidth, input impedance, number of unit cells and the microstrip lines parameters (i.e. VXEVWUDWH SHUPLWWLYLW\ WKLFNQH then by running different loops it determines the physical dimensions of the microstrip unit cell. Several filters are designed using the MATLAB script. Designed filters are also simulated by ADS which verifies the validity and accuracy of the design method presented here



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A hybrid wavelet-based method to model the electromagnetic propagation above a polluted sea surface

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Abstract

Electromagnetic propagation above a rough polluted sea surface differs from one above a clean sea. Indeed, a damp effect on the waves appears. This can be used to detect a pollutant leakage. In this article, we model the propagation of electromagnetic waves above a polluted sea using a fast wavelet-based method and a two-scale model. Numerical simulations in S-band are provided.

1. Introduction

In this paper, we are interested in the tropospheric long-range propagation in the maritime environment. In this context, local phenomena such as sea waves, or the presence of a pollutant on the sea have an impact on the measured field. Indeed, waves introduce diffraction for example, while the presence of oil introduces a damping effect [1]. This latter can be used to detect pollutant leakage on the sea [2, 3].

In this framework, a large part of the literature has focused on computing the radar cross section (RCS) of the sea with and without pollutant [4, 5, 6, 7, 3]. Indeed, these methods are appropriate here, since the sea spectrum (and its modified version for an oily sea [1, 6]) can be conveniently introduced in the integral equation [4, 3]. Results have been obtained showing the difference between the RCS of a clean sea and a polluted sea, even leading to the detection of oil leakage from SAR images [2, 3].

Less work [8, 9] has focused on modeling the long-range propagation above a polluted sea surface. In particular, the sea geometry has been assumed to be flat (with the roughness accounted through Ament coefficient [10]), and the oil to cover the whole domain. Nevertheless, the obtained results have highlighted the effect of the oil on the propagated waves and show that detection is feasible.

In this paper, we develop a fast hybrid approach for computing the propagation over a polluted sea surface. The approach is based on the one developed in [11, 12] for propagation above a clean sea, where the sea spectrum [13] is used to generate random surfaces and a roughness coefficient. Besides, the use of the parabolic wave equation model allows taking into account the refraction [14] (due to tropospheric ducts for example), differing from the other proposed works [8, 2, 3]. Furthermore, we show using a Principal Component Analysis (PCA) that a polluted sea can be detected from a clean one using measurements at a given vertical.

The remainder of this paper is organized as follows. Section 2 focuses on the modelization strategy. First, the parabolic wave equation is recalled. After that, both the clean and polluted sea spectra are introduced. Section 3 introduces the computational method. This latter is based on a hybrid approach to introduce the effect of the maritime environment on propagation. Section 4 shows numerical tests performed in the S-band. Besides, a PCA analysis is provided. Finally, Section 5 concludes the paper and gives some perspectives for future works.

2. The model

In the following work, a $\exp(j\omega t)$ time dependence is assumed, where j is the imaginary unit and $\omega = 2\pi f$ is the angular frequency. We also denote by n the refractive index, and this latter is assumed to be slowly varying in the propagation direction. Furthermore, from now on the Cartesian (x, y) coordinate system is used.

2.1. The parabolic wave equation

As a reminder, we want to compute the long-range propagation above a clean or polluted sea surface. A suitable model in this context is the parabolic wave equation [14] (PWE). Indeed, by only accounting for forward propagation, it allows wide steps in the propagation direction, leading to more computationally efficient methods. Besides, the effect of the refraction, the relief, and the terrain can be incorporated. Note that the PWE is only valid in a paraxial cone. Thus for better accuracy, we use its wide-angle PWE version here. This latter is given by

$$\frac{\partial u}{\partial x} = -jk_0\left(\sqrt{\frac{1}{k_0^2}\frac{\partial^2}{\partial z^2}+1}-1\right)u - jk_0(n-1)u, \quad (1)$$

with u the reduced field [14], x the propagation direction, and k_0 the wave number. If the backward propagation is of interest, one can use the two-way PWE [15, 12].

2.2. Modeling the waves: the sea spectrum

To model the sea surface along the propagation, a common way is to use a sea spectrum, such as the Elfouhaily one [13], which is used from here on. This latter gives a statistical representation of the sea geometry with respect to the wind speed. The spectrum S is then expressed as

$$S(K) = \frac{1}{K^3}(S_l + S_h), \qquad (2)$$

where S_l and S_h correspond to the long and short wave curvature spectrums, respectively. Note that those parameters mostly depend on the wind speed at 10 m (denoted by U_{10}) above the sea, and the interested reader is referred to [13] for more details. An example of the computed sea spectrums for different wind-speed is given in Figure 1.

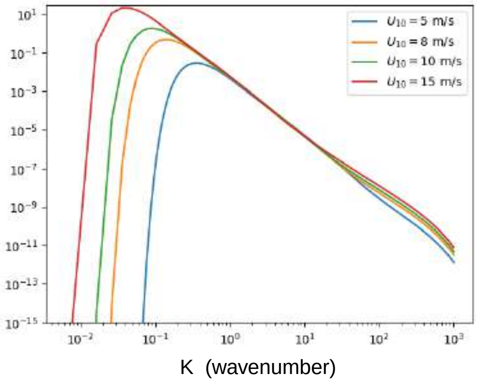

Figure 1: Computed sea spectrums [13] for different wind speeds $U_{10} \in \{5, 8, 10, 15\}$ m/s in a Log/Log scale.

Note that the wind speed has a great influence on the low wavenumber K (i.e. the large scale), thus higher waves are expected.

From this spectrum, one can derive a stochastic process to obtain sea surfaces. Indeed, S describes the statistical properties of the sea surface. The idea is to create a random surface $z_r(x)$, normally distributed with a zero-mean, $\mu = 0$, and centered $\sigma^2 = 1$. To add the correlation with the sea surface, then z_r is convoluted to the inverse Fourier transform of $\sqrt{S}$, such that

$$z(x) = \mathcal{F}^{-1}\left(\sqrt{S}\,\mathcal{F}(z_r(x))\right), \qquad (3)$$

with $\mathcal{F}$ the Fourier transform and z the generated sea surface. Some examples of realizations are given in Figure 2 for different wind speeds.

2.3. Accounting for the pollutant: the dumped spectrum

In this section, we introduce how to model a polluted sea surface. First of all, one can consider, depending on the wind speed U_{10}, whether the oil is soluble or not, meaning that we have an emulsion or not. Here, we focus on the insoluble case, i.e. $U_{10} \leq 8-10$ m/s [8], where the damping model [1] can be used.

This latter is based on the following equation

$$S_{po} = S_{clean}\left(1 - F + \frac{F}{y}\right), \qquad (4)$$

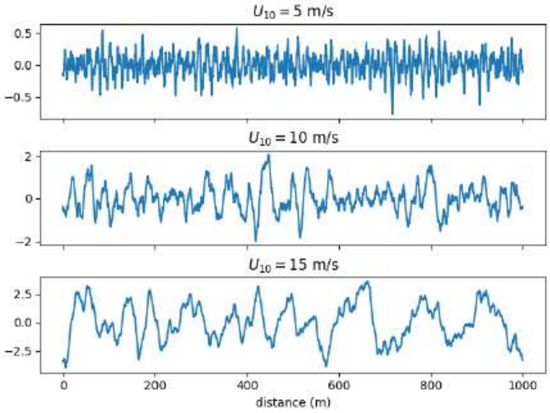

Figure 2: Generated random sea surfaces for different wind speeds $U_{10} \in \{5, 10, 15\}$ m/s using (3).

where S_{clean} corresponds to the clean sea spectrum (see Section 2.2), F to the fraction of oil covered surface, y to a damping ratio and S_{po} to the polluted sea spectrum. Here, we consider only the case where the sea is fully covered, i.e. $F = 1$. In this equation, y introduces the attenuation due to the oil film and depends on the pollutant parameters [4]. In Figure 3, an example of the clean sea spectrum and its polluted counterpart are plotted.

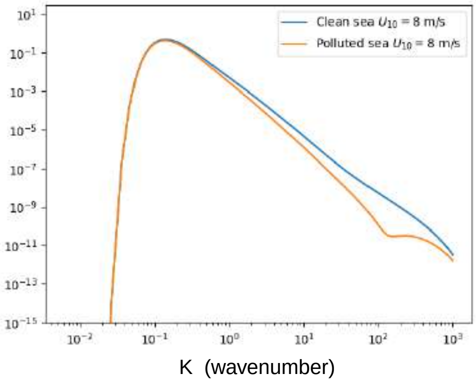

Figure 3: Computed clean and polluted sea spectrum for $U_{10} = 8$ m/s in a Log/Log scale.

One can see that the pollutant affects mainly the capillary waves, even if the maximum is reduced a little.

Using, the polluted sea spectrum S_{po}, we can use the same stochastic method to generate oil-covered sea surfaces. For a wind speed of 8 m/s, an example of the computed clean and polluted sea surface is given in Figure 4.

It should be noted that, as expected [4], the pollutant decreases the waves extremum.

3. The computational method

In this section, we describe the hybrid wavelet-based scheme proposed to solve the PWE (1), while accounting

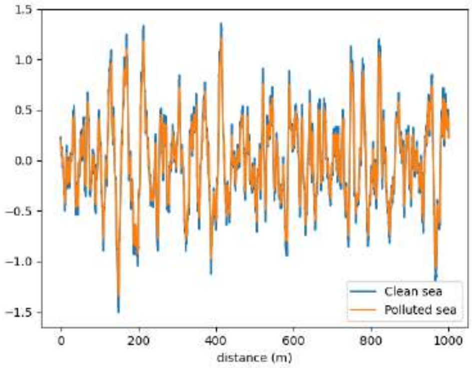

Figure 4: Generated random clean and polluted sea surface for $U_{10} = 8$ m/s.

for refraction, relief (sea surface), and ground composition.

3.1. Discretization

We denote by x_{max} and z_{max} the size of the computational domain ! . The source is placed at $x \$ 0$ and we assume the field at $x = 0$ to be known. Thus, we have $! = [0, x_{max}] \% [0, z_{max}]$, since the propagation above the ground is studied. For numerical reasons ! is discretized along z and x with N_z and N_x the number of discrete points along each direction. The mesh size is thus given by

$$" z = z_{max}/N_z$$
$$" x = x_{max}/N_x$$

Finally, we denote by u_x the reduced field u discretized along z at position x.

3.2. An overview of split-step wavelet

In this article, the PWE is solved using the efficient iterative split-step wavelet method (SSW) [16, 17].

This latter allows computing the field marching in on distances by going back and forth in the wavelet and spatial domain. A step of propagation is thus split into two parts. First, the field is propagated in free space in the wavelet domain. Second, the effect of the refraction, the relief, and the ground composition are taken into account in the spatial domain. A step from x to $x + "x$ can thus be summed up as follows

$$u_{x+!x} = RLW^{!1}PC_{V_s}W u_x, \qquad (5)$$

where W is the wavelet transform, C_{V_s} a compression with hard threshold, P corresponds to the sparse wavelet-to-wavelet propagation [17], and R and L ammount for the relief and phase-screen operators, respectively. The latter allows taking into refraction. For the relief, the staircase model is used [14]. Finally, the ground composition is accounted for through the efficient local image method [16].

To conclude on the computational method for the propagation, SSW is efficient both in terms of memory storage and computation time, with a complexity and a memory footprint lower than the conventional split-step Fourier method [16, 17].

3.3. The hybrid approach

In this section, we describe the hybrid approach [11, 12] to accurately model the effect of the sea (polluted or not) on field propagation.

The idea is that given a spatial discretization of N_x points (or a step " x), not all the levels of the sea spectrum, S_{clean} or S_{po}, can be accounted for. Thus, we can compute the cut-off parameter K_{max}, due to the discretization, between the large-scale and low-scale waves. This latter is given by

$$K_{max} = N_x \frac{2"}{x_{max}}. \qquad (6)$$

Using this cut-off the effect of the sea is introduced with a two-scale model. First, the lowest part of the spectrum, with respect to K_{max}, is used to generate the random sea surfaces, as described in 2.2. Second, the highest part of the spectrum is used to compute a new roughness coefficient [11, 12] to take into account the capillary waves effect. This latter is multiplied by the Fresnel coefficient in the local image method.

Nevertheless, the geometry generation is based on a stochastic process, thus a Monte Carlo method is used to compute the mean of the propagation over N_{MC} cases. Therefore, the efficiency of SSW is very interesting here [12], in particular for large N_{MC}.

4. Numerical experiments

The objective of this section is twofold. First, we test that the method works well in different scenarios. Second, a PCA analysis is performed on the constructed database to obtain insights into the pollutant effect.

All the tests are performed in the S-band, at $f = 3$ GHz, in a domain of size $x_{max} = 5$ km and $z_{max} = 128$ m. The discretization steps are set to $" x = 50$ m and $" z = 0.05$ m. We also consider a surface duct, as it is frequent above the sea. A complex source point (CSP) placed at $x_s = !\ 50$ m and $z_s = 20$ m with a width of 3 m is considered as the source. Finally, we use the following dielectric constant for the sea (resp. the oil): $\%_r = 70$ (resp. $\%_r = 2.2$) and $\$ = 5$ S/m (resp. $\$ = 0.0017$ S/m).

4.1. Field propagation results

In this first part, we consider two different pollutants, one with an elasticity $E_0 = 9$ mN/m and a characteristic pulsation $!_D = 6$ rad/s, while the other has an elasticity of 25 mN/m and a characteristic pulsation of 11 rad/s.

First, a test with a wind speed of 5 m/s, where with the given parameters, the ground is considered flat. This allows a comparison with the results of [8]. In Figure 5, we plot the field obtained with SSW, with a zoom between 0 and 56 m in altitude, at the last iteration for a clean sea and when both pollutants are considered.

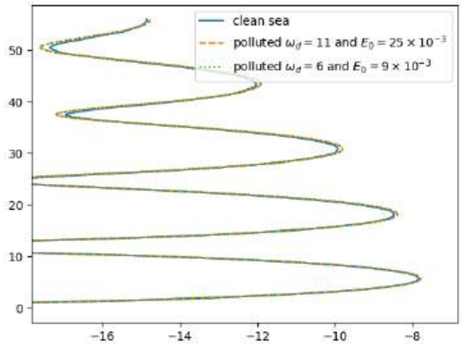

Figure 5: Field at $x = 5$ km computed with SSW for the propagation above a clean and polluted sea.

In Figure 5, one can see the effect of the pollutant on the measured electromagnetic field. Indeed, the extrema are changed when an oil film is considered, as expected since the ground composition is not the same. These results are in line with the one obtained in [8]. In this case, detection seems easy. Nonetheless, it should be recalled that at this wind speed, the sea is considered flat, and one can wonder what happens with a higher U_{10} increasing, and waves appearing.

Therefore, we choose to do the same test, with $U_{10} =$ 7 m/s. In this case, since the sea surface is not flat, the mean over the 20 Monte-Carlo simulation of the field computed with SSW at the last iteration is plotted in Figure 6.

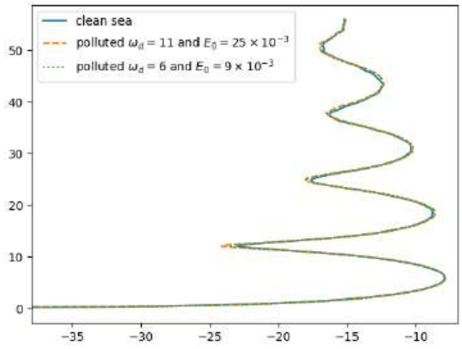

Figure 6: Field at $x = 5$ km computed with SSW for the propagation above a clean and polluted sea when $U_{10} =$ 7 m/s.

In this case, we can still see the effect of the oil film but it is less clear than when $U_{10} = 5$ m/s, even if all the area is covered by the pollutant (i.e. $F = 1$). This difference is due to the surface geometry, which is not flat anymore. Note that in different cases (i.e. other surface generation), the detection can be easier or on the contrary more difficult. This is why we decide using a PCA analysis.

4.2. PCA analysis

Here, the goal of the PCA analysis is to obtain features that can help to detect a polluted sea surface. This method has been used in another context in electromagnetic where stochastic processes are studied, see [18].

Given the task, we still study the three cases (clean and polluted sea, with two different pollutants) for different wind speeds. Therefore, we constructed one database per U_{10} as follows. This latter is composed of 100 features per case, thus we have a total of 300 features. These latter shall represent the field propagation as precisely as possible. Therefore, each feature consists of the mean of the computed field at the last iteration over 20 Monte-Carlo simulations, to take into account the stochastic aspect of the surface. Example of these features are given in Section 4.1 for $U_{10} = 5$ m/s and 7 m/s.

Then, a PCA with a given number of 3 components is performed on each dataset. The goal is to find one (or multiple) directions that describe the effect of the pollutant on propagation.

In Figure 7, we plot the transformed features over the first two components of the PCA decomposition. Here, the wind speed is 5 m/s. Note that label 0 is for a clean sea while labels 1 and 2 correspond to the two pollutants with $E_0 = 9$ mN/m and $\omega_D = 6$ rad/s, and $E_0 = 25$ mN/m and $\omega_D = 11$ rad/s, respectively.

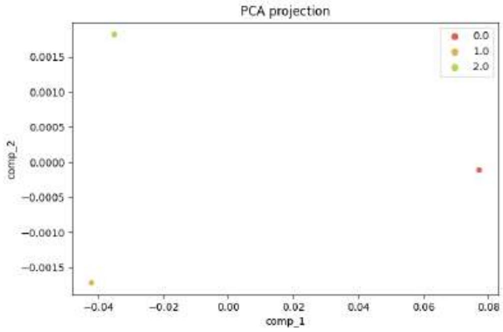

Figure 7: Features transformed onto the PCA components plotted for the first two components when $U_{10} = 5$ m/s.

As expected, the three cases are fully separated, and detection is easy (using for example a logistic regression). Besides, since at this wind speed, the sea surface is flat, all the features for each case are the same. Nevertheless, we can see that the first axis here seems to relate to how close to a clean sea we are.

Therefore, the same analysis is now performed at $U_{10} =$ 7 m/s. As before, we plot the transformed features over the two first components of the PCA analysis in Figure 8. The labels remain the same.

In this case, since the surface is not flat anymore, many points are plotted for each label depicting the features in the first two components' axis. Nonetheless, one can see that the three cases are still separated leading to an easy

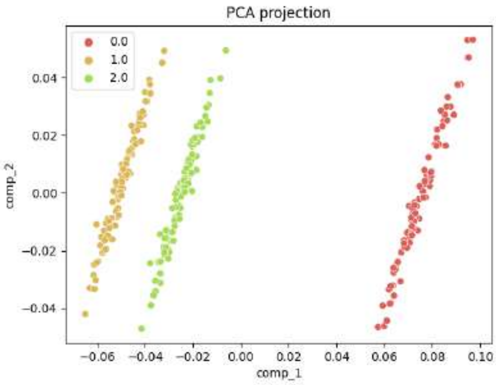

Figure 8: Features transformed onto the PCA components plotted for the first two components when $U_{10} = 7$ m/s.

detection here. Besides, as before, the first axis seems to refer to how close to a clean sea we are.

Other tests have been performed for wind speed upper than $U_{10} = 8$ m/s, upper than the limit for insoluble oil film, and at these speeds, no separation was achieved. This is due to the dominant influence of the sea geometry on the electromagnetic field at these U_{10}.

5. Conclusion

In this article, we studied the tropospheric propagation of the electromagnetic field above a polluted sea.

The propagation model is based on a hybrid approach where the sea spectrum or its damped version to take into account the pollutant, is used to generate random surfaces and to compute a roughness factor.

A wavelet-based computational scheme is used since its efficiency allows fast Monte Carlo simulations. Besides, we constructed a database for different wind speeds to obtain features that help to detect an oil leakage based on electromagnetic measurements.

A PCA analysis, with 3 components, has been performed on these databases, showing that the polluted and clean sea can be detected when the wind speed is below a limit of 8 m/s. Besides, we saw that the first axis of the PCA decomposition could refer to how close we are to a clean see.

Thus, we are currently working on the case where the sea is not fully covered by the pollutant, i.e. $F < 1$. In this case, a new model shall introduce the position of the oil leakage. The same analysis could then be performed to assess the limit of detection. Finally, we are also working on the case where we have an emulsion of oil and water, and when a film and an emulsion are considered.

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Higher-order Modes by Misalignment in Transition from Hollow Metallic Waveguides to Dielectric Waveguides

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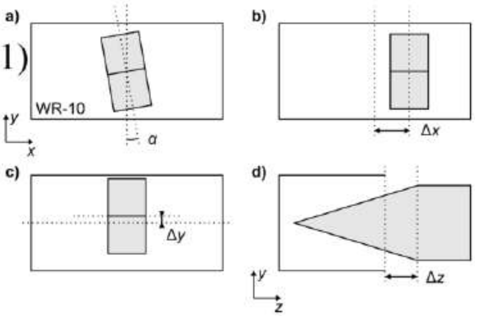
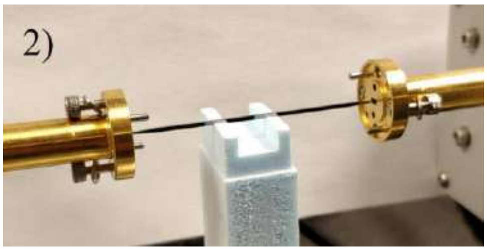
Abstract: In this work, we report the effects of misalignment between a dielectric waveguide and a hollow metallic waveguide in the WR-10 band. The results indicate the excitation of unwanted higher-order modes in the dielectric waveguide that are expected to degrade the performance, especially at higher frequencies.

Dielectric waveguides are a promising guiding structure for THz and sub-THz systems, owing to their low losses and fabrication simplicity. Several platforms to ease integration with standard measurement equipment have been developed, such as effective medium cladded waveguides[1] and unclad dielectric waveguides[2]. However, most dielectric waveguides are excited by a tapered transition structure inserted into a hollow metallic waveguide[3-5]. The manual insertion of the dielectric waveguide into the hollow waveguide can be a source of losses in case of misaligments. If the taper of the dielectric waveguide is not centered in the hollow waveguide, undesired higher order modes will be excited, an effect especially pronounced at higher frequencies. Fig. 1 shows different kinds of misaligments between a tapered dielectric rod waveguide (DRW) and a hollow metallic waveguide.



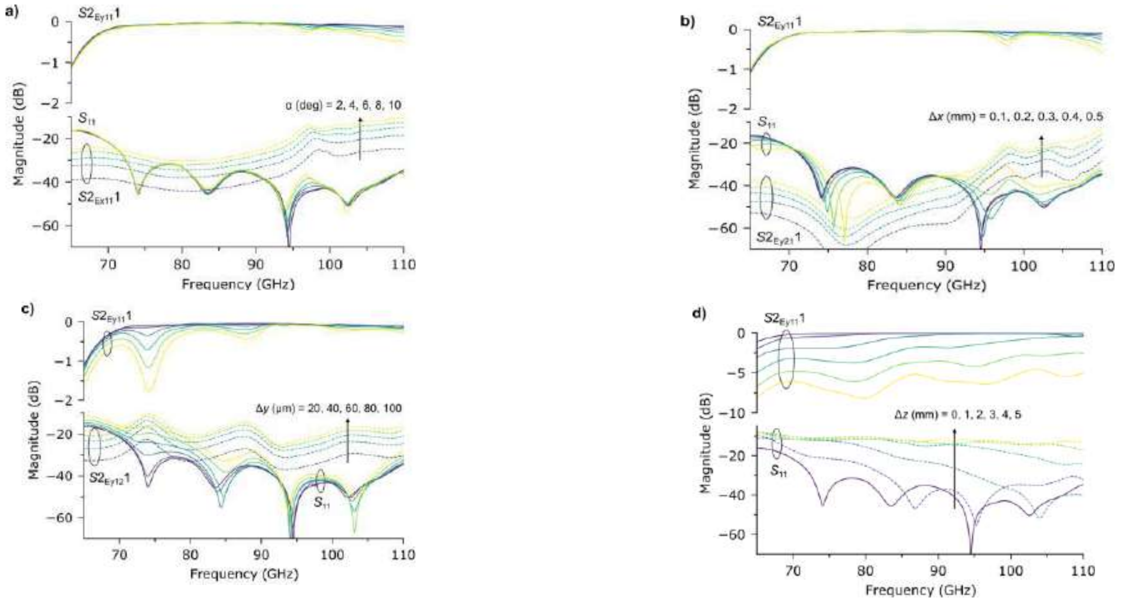


)LJXUH 6FKHPDWLF RI PLVDOLJQPHQW ... RXWOLQQDH URWDWLRQ and DLVSODFHPHQW Δx, Δy, Δz respectively.)LJXUH 0HDVXUHPHQW VHWX

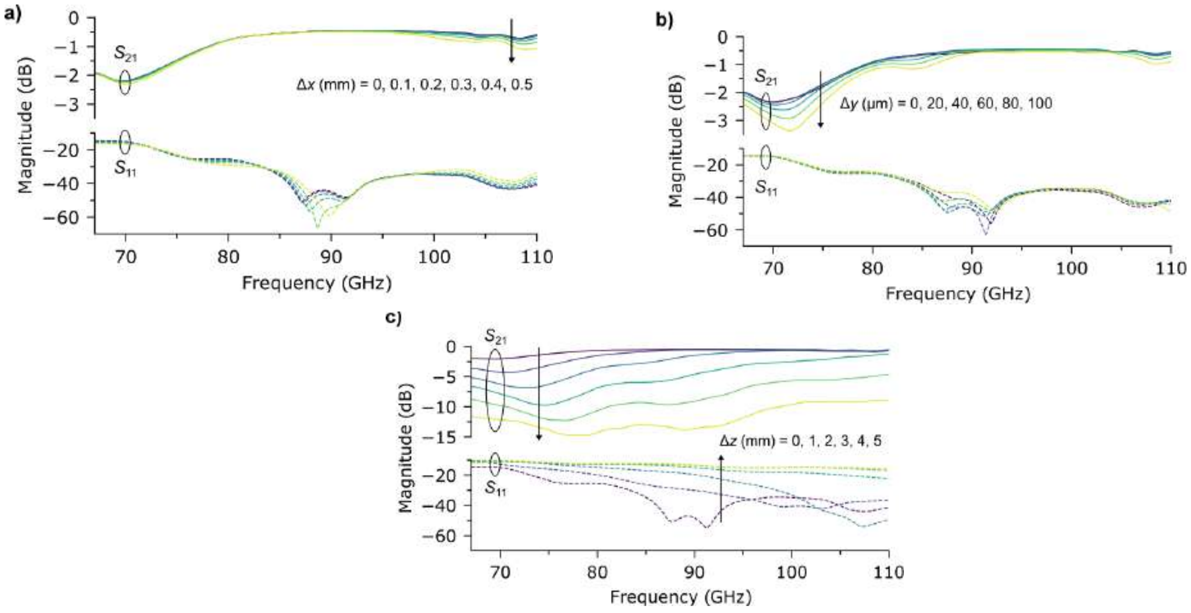
A PP silicon DRW with cross section of 1 PP by 0.5 PP ... WDSHUSLQD ... LQ &67 0LFURZDYH 6WXGLR ... UHVLVWLYLW\ by deep reactive ... etching A WR ... *+]KROORZ PHWDO ... '5: ZKLFK LGHDOO\ RSHUDWHV ... low loss, low permittivity foam was used as a support structure. A 3 D[LV SRVLWLRQH ZDV XVHG WR FRQWURO ... VHWXS LV VKRZQ LQ

)LJ VKRZV WKH VLPXODWHG ... PLVDOLJQPHQW H[FLWDWLRQ ... WKH 65 DQG 56 PRGHV UHVSHFWLYHO\ ... DSSURDFKLQJ WKH HQG RI WKH PHWDOOLF ZDYHJXLGH

Fig. shows the measured results, after TRL calibration at the metallic waveguide flanges and time gating. ,QVRQWLRVV LQWFRUHGD%VHDWWXS *T+]DQGU WR G% DWUä/LV++]JORULPSDFW UHIOHFWLRQ ORVV LV REVHUYHG HVLQFHYVWHDUVHPLOVHDFWLJRQPLHQRVWHVURWLRQ ORPVXSWR G%VL DWPP



)LJXUH6LPXODWHG PHDVXUHPHQW UHVXOWV WR PLVDOLJQPHQWV DQG LPSHUIHFWLRQV UHVSHFWLYHO



)LJXUH0HDVXUHG 6SDUDPHWHUV 5'5: ±:5 WUDQVLWLRQ PLVDOLJQPHQWV UHVSHFWLYHO\

We acknowledge Myfab for provisioning of facilities and experimental support. Myfab is funded by the Swedish Research Council as a national research infrastructure. The work was supported by the European Union's Horizon 2020 FET Open project TERAmeasure (grant agreement No 862788).