Guest Editorial for the Special Issue on Radio Wave Propagation - Part II

Guest Editors: Tapan K. Sarkar, *Life Fellow, IEEE*, Guido Lombardi, *Senior Member, IEEE*, Vikass Monebhurrun, *Senior Member, IEEE* and Monai Krairiksh, *Senior Member, IEEE*

THE objective of this special issue is to publish papers related to the basic physics of Electromagnetism in the context of radio wave propagation, see Editorial of Part I [1].

A total of **70** papers from **28** different countries were initially submitted to the special issue. The number of initial and revised papers then total up to **168**. In general, the submitted papers were of good quality. Because of the production deadline, the special issue has been split into two parts.

The first part of the special issue was published in December 2018 issue of the IEEE AP-S transactions. This constitutes the second part. Papers which took a long time to get reviewed after the revised submission are presented in this second part.

In the first part **22** papers have been presented. In the second part **15** papers are described. Some good papers could not be accepted for this special issue because they were not dealing with the basic physics of propagation phenomena and therefore, they were considered out of scope. Nonetheless, these papers have been transferred to regular issues.

The title along with a brief description of what the paper is about is described. No attempt has been made to further subdivide the category of each paper as the descriptions state what the paper is about.

List of Papers in Part II

- *Horse (Electromagnetics) Is More Important than Horseman (Information) for Wireless Transmission - Marco Donald Migliore*

This paper addresses the question of how much information can be transmitted reliably over a wireless channel. It is shown that the limit of this mode of transmission is dictated by the amount of information that an electromagnetic field is capable of carrying. The methodology for analysis of this problem is along the theory developed by Kolmogorov. This allows one to quantify the amount of information that can be transmitted by a wireless communication system taking into account the physical limitations governed by the laws of electromagnetism. Starting from the results related to the amount of information carried by an electromagnetic field, a novel antenna synthesis technique that simultaneously takes into account the requirements of information and antenna theory is introduced and applied to the synthesis of multi antenna systems.

- *Measurement of Radiated Field from Transmitting Antennas Located in Various Environments - Monai Krairiksh, Chainarong Kittiyanpunya, Thunyawat Limpiti, Tanawut Tantisopharak, Prapan Leekul, Paiboon Yoiyod, Bancha Luadang, Arnon Sakonkanapong, and Chuwong Phongcharoenpanich*

In micro-cellular communications, the transmitting antennas can be installed at low heights above the ground. However, even for low elevation towers, installation cost is still high. One of the possible ways for the deployment of base station antennas is to install them near the ground in order to do away with the tower. The main purpose of this paper is to suggest installation of the radiating antennas near the ground and tilting their orientation towards the sky - a totally non-intuitive solution. It will be shown that such deployments have the potential of reducing slow fading and can further enhance the signal strength close to the radiating antenna. This paper provides measured data for the received fields to validate the theoretical conjecture of such a deployment in various environments. The measured results are presented for 245 MHz, 800 MHz, 1000 MHz and 2400 MHz. It is illustrated that such an unorthodox deployment can result in a low cost for the installation of base station antenna as the towers are not necessary. This can be useful in restoring communications in emergency situations where minimum infrastructure exists.

- *Range and Height Measurement of X-band EM Propagation in the Marine Atmospheric Boundary Layer- Qi Wang, R. J. Burkholder, C. Yardim, L. Xu, J. Pozderac, A. Christman, H. J. S. Fernando, D. P. Alappattu and Qing Wang*

An X-band vertical array system is developed for measuring and characterizing electromagnetic (EM) propagation in the marine atmospheric boundary layer. In particular, the evaporation duct that commonly forms over water is investigated as part of the CASPER (Coupled Air-Sea Processes and Electromagnetic ducting Research) at-sea experimental campaign conducted off the coast of Duck, NC, during October-November of 2015. Monte Carlo simulations are first used to develop an optimal array of four vertically spaced receiving antennas. In the experiment, the antennas are mounted on the stern A-frame of a research vessel and measure EM signals transmitted from beacons mounted on another research vessel and on the pier at the Army Field Research Facility. While the propagation loss vs. range provides a dataset similar to previous work, the vertical array can provide sampling of modes in the leaky waveguide formed in the duct. Combining both range and height sampling results in a robust inversion method for evaporation duct estimation. In this paper the efficacy of the 4-element array is demonstrated by estimation of the evaporation duct height through comparison with a library of precomputed propagation curves generated using the parabolic wave equation. Low model error gives confidence in the estimates, which are consistent with concurrent environmental measurements performed by the CASPER team. It is found that the evaporation duct can vary significantly with range and time over the duration of a data collection run.

- *Realization of Split Beam Antenna using Transmission-Type Coding Metasurface and Planar Lens - Kranti Kumar Katare, Sandhya Chandravanshi, Animesh Biswas, and M. Jaleel Akhtar*

In this paper, a novel compact split beam configuration of the transmission-type coding metasurface in combination with the planar lens and the patch antenna is presented. In the first stage, the spherical electromagnetic (EM) waves originating from the patch antenna are converted to the plane waves by placing the planar metasurface lens above the antenna aperture. This lens enhances the radiation along the broadside direction resulting into high gain operation. Further, a concept of digital metamaterial is adopted by realizing transmission-type coding metasurfaces, capable of splitting the aforementioned high gain beam pattern. The proper spatial mixture of these lattices with different sequences facilitates different elemental metamaterial-pattern resulting into multiple-lobe radiation patterns, which are angularly oriented and symmetrical to the antenna axis. The aforementioned beam-splitting using the proposed configuration is also validated both quantitatively (mathematically) and qualitatively (through the simulation & the measurement) for different types of digital metasurfaces.

- *Analysis and Experiments on Reflection and Refraction of Orbital Angular Momentum Waves - Yu Yao, Xianling Liang, Maohua Zhu, Weiren Zhu, Junping Geng, and Ronghong Jin*

In this paper, theoretical analysis of orbital angular momentum (OAM) waves propagation properties in terms of reflection and refraction is introduced by decomposing OAM waves into infinite plane waves in the spectral domain with different elevation and azimuth angles. Transformations of phases and amplitudes at the interface of two media for different incident angles and elevation angles are numerically analyzed. Similarly, based on the idea of decomposing OAM waves, reflection and refraction properties of OAM waves propagating through slabs are also analyzed and simulated. Finally, experiments of OAM waves with mode numbers 1 and 2 are both conducted to demonstrate reflection and refraction properties of OAM waves.

- *Propagation of Electromagnetic Waves through an Invisible Gradient-Index Lens with Negative Refractive Index - Sergei P. Skobelev*

A radially inhomogeneous (gradient-index) lens made of material with a negative refractive index, invisible from the viewpoint of geometrical optics, is proposed and designed. The design includes derivation and solution of an equation for determining the refractive index profile, as well as derivation of an expression allowing calculation of the ray trajectories in the lens. Propagation of a plane wave through a cylindrical modification of the proposed lens both for the case of E-polarization and for the case of H-polarization is analyzed numerically using the hybrid projection method. The results obtained for the RCS of the lens are compared to the similar performance of a positive-index invisible cylindrical lens described in the previous publications.

- *Modal Expansion Approach for Electromagnetic Propagation in Street Canyons - Alessio Di Simone, and Antonio Iodice*

We present a simple and efficient model to compute electromagnetic propagation in urban street canyons, when transmitting and receiving antennas are located below the rooftop level. A parallel-plate dielectric hollow waveguide model of the street canyon is proposed, and propagation is analysed by using the modal expansion approach. Obtained results for the case of line-of-sight propagation are substantially equivalent to those obtained with the ray-optics method, but, with respect to the latter, our method presents important advantages: it is more efficient from a computational viewpoint, it allows to derive a very simple and reasonably accurate formulation of the average received signal strength, and it provides a fairly simple way to compute coupling at cross junctions, exploited to obtain an analogous formulation for the non-line-of-sight case. Obtained results are compared with simulations of a raytracing-based electromagnetic solver and with experimental measurements available in literature.

- *A New Permittivity Measurement Method for Walls in Indoor Scenes - Dan Shi, Chu Wang, and Yougang Gao*

A new double-reflection free-space method (DRFSM) is presented in this study for measuring the actual wall material permittivity in indoor scenes, especially for the narrow wall corners which cannot accommodate test settings used in traditional free-space method. The method is nondestructive, accurate, and easy to implement. In addition, it does not require a priori knowledge of the thickness of the walls under test. Two experimental setups, namely double-polarization and double parameter free-space measurements, were conducted according to the proposed method. The presented technique acquires the accurate material permittivity on site, which is the key parameter in the modeling and simulation of the radio wave propagation (RWP) prediction. The permittivity of the walls in the buildings measured by the proposed method, which considers the influences from the ageing, machining and practical usage of the wall materials, is more accurate than that by sample test in laboratory. The method was examined by measuring the permittivity of the designed wall corner with two perpendicular plates and validated by the waveguide measurement of the sample chosen from the tested plates. Finally, the explicit uncertainty and error analyses were derived. The proposed method is applicable for accurate modeling of RWP prediction in practice.

- *On the Influence of Diffuse Scattering on Multiple-Plateau Diffraction Analysis at mm-Wave Frequencies - Maria-Teresa Martinez-Ingles, Jos-Vctor Rodrguez, Juan Pascual-Garcia, Jose-Maria Molina-Garcia-Pardo, and Leandro Juan-Llacer*

A study of the impact of the diffuse scattering phenomenon when calculating radiowave multiple-plateau diffraction losses at mm-wave frequencies is hereby presented. In this sense, measurements of the total attenuation caused by a series of either rough or polished brick blocks are properly compared with the theoretical multiple-diffraction losses of an array of ideally-smooth brick blocks predicted by a hybrid uniform theory of diffraction-physical optics (UTD-PO) formulation. The results show the influence of diffuse scattering phenomena when it comes to calculating radiowave multiple-plateau diffraction attenuation, and can be applied to the obtaining of more realistic mm-wave propagation models when multiple-diffraction over rectangular obstacles with irregular (rough) surfaces has to be considered.

- *Physics-based Prediction of Atmospheric Transfer Characteristics at THz Frequencies - Xiaoyu He and Xiaojian Xu*

The amplitude and phase distortion of radar echo signal will cause the emergence of undesirable ghost scattering points, which degrade the quality of Terahertz (THz) radar images. In this paper, a physics-based procedure is presented to predict the atmospheric attenuation and dispersion characteristics at THz frequencies, which is mainly based on the line-by-line calculation method with specific modification in phase shift prediction. The line-by-line parameters provided by the HITRAN spectroscopic database and atmospheric condition parameters obtained from the AFGL reference atmospheric constituent profiles are adopted to predict the atmospheric transmittance and the phase shift for specific transfer paths. The results are compared with measured data to demonstrate the accuracy, while the proposed procedure is used to analyze the impacts of atmospheric transfer characteristics on radar imaging via high resolution range profile simulation. The signal distortion is interpreted in terms of paired echoes to illustrate the importance of frequency band selection for high resolution imagery at THz frequencies.

- *Numerical and Experimental Characterization of RF Waves Propagation in Ion Sources Magnetoplasmas - G. Torrisi, D. Mascali, G. Sorbello, G. Castro, L. Celona, and S. Gammino*

This paper describes three-dimensional numerical simulations and Radio Frequency (RF) measurements of wave propagation in microwave-heated magnetized plasmas of ion sources. Full-wave solution of Maxwell's equations has been addressed through the Finite Element Method (FEM) commercial software COMSOL. Our numerical model takes into account the strongly inhomogeneous and anisotropic magnetized "cold" plasma medium. The simulations reproduce the main features of the wave-plasma interaction of the Flexible Plasma Trap (FPT) that recently came into operations at INFN-LNS. A two-pins RF probe has been ad-hoc developed and used as a plasma immersed antenna for measuring local wave electric fields in the FPT device. The measurements of plasma electron density and RF electric field, performed for different external magnetic field configuration, allowed a direct comparison with the assumed simulation model.

- *Lessons Learnt through using a Physics Based Macro Model for Analysis of Radio Wave Propagation in Wireless Transmission - Tapan K. Sarkar, Heng Chen, Magdalena Salazar Palma and Mingda Zhu*

This paper summarizes the lessons learnt in using a physics based macro model in studying electromagnetic wave propagation over an imperfectly conducting ground in cellular wireless communication. Firstly, it has been observed that the path loss exponent is independent of the nature of the ground parameters inside the cell of interest. Secondly, the electrical parameters of the environment have little effect on the path loss exponent in the cellular band. Thirdly, it is observed that lowering the base station antenna towards the ground provides a larger signal in the near field within the cell of interest. Furthermore, tilting the transmitting antenna towards the sky enhances the signal strength. Tilting the antenna towards the ground increases the signal strength but in addition enhances the interference pattern and hence is not a good solution. A typical path loss inside the cell is 30 dB per decade of distance and outside the cell it increases to 40 dB per decade. By bringing the antenna closer to the ground and then tilting it towards the sky provides a good non intuitive solution. In such scenarios, a path loss of 20 dB per decade for some components of the field, the lowest possible, can be achieved for certain orientation and deployment of the base station antenna. In addition, it is shown that operating an antenna inside a metallic box eliminates its radiation capabilities and hence has no physical meaning even though it is claimed in the contemporary literature that it simulates a rich multipath environment. Lastly, a note on the proper interpretation of the term channel capacity and its implications are delineated.

- *Simulation and Experimental Verification for a 52 GHz Wideband Trapped Surface Wave Propagation System - Jixiang Wan, Kin Fai Tong, Chi Hou Chan*

Trapped Surface wave (TSW) provides a flexible two-dimensional wireless solution when compared to existing wired and free space communications systems. This work aims to provide the theoretical guidance, supported by simulation techniques and experimental verifications, for i) designing the wideband and highly efficient rectangular aperture TSW transducers, and ii) selecting the best reactive surface impedance for high efficiency. Firstly, a method for computing the TSW excitation efficiency is proposed for the first time and it can be applied to different kinds of reactive surface geometries and transducer apertures. Then the relation between the TSW excitation efficiency, surface reactance and aperture height is derived. Then the maximum excitation efficiency, the corresponding optimal surface reactance and aperture height are presented. Further, the relation between the TSW angular coverage and aperture width is determined. These studies show that the aperture height determines mainly the TSW excitation efficiencies while the aperture width controls the TSW angular coverage, hence the two aperture parameters of a transducer can be determined independently. Finally, an experiment setup, based on the provided guidelines, has been built to demonstrate a 52 GHz wide 3dB-transmission-bandwidth for high performance communications systems.

- *Analysis of Propagation of Electromagnetic Waves in Difficult Conditions by the Parabolic Equation Method - V. A. Permyakov, M. S. Mikhailov and E. S. Malevich*

Studies devoted to the application of numerical solution of the parabolic equation to prediction of propagation conditions of radio waves traveling above the ground surface are briefly reviewed. The emphasis is placed on the analysis of physical irregularities of propagation of radio waves in difficult conditions (above the sea surface, including formation of evaporation ducts; in forests, including the influence of forest and terrain profile on the radiation field of phased array antennas).

- *A Bloom Filter for Double Counting Avoidance in Radio Frequency Ray Tracing - Roman Novak*

Brute force radio frequency ray tracing scales well on multicore computing architectures as each ray can be traced independently. The discrete nature of rays with no thickness shows a weakness in the aggregation step where nearby rays to the observation point need to be detected and differentiated. The fact that angular defect cannot be distributed evenly for more than twelve rays in space leads to a double counting phenomenon, i.e., the radius of a reception sphere cannot exclude all but one ray per wavefront. This either leads to significant signal errors or requires the use of space and time consuming wavefront differentiation. Bloom filters configured with marginal false positive rate are proposed here as a replacement of the exact wavefront differentiation, effectively eliminating double counting errors. Substantial space gains while computing channel impulse responses are reported. Further, due to the importance of ray launching template grids for the double counting avoidance, the analytical angular bounds for the two common icosahedral grids are presented. The frequently referenced approximate double counting probability of 20.9% is shown to be highly underestimated when affected by the refraction- and diffraction induced changes in ray spacing.

REFERENCES

[1] T. K. Sarkar, G. Lombardi, V. Monebhurrun and M. Krairiksh, "Guest Editorial for the Special Issue on Radio Wave Propagation," *IEEE Transactions on Antennas and Propagation,* vol. 66, no. 12, pp. 6470-6475, Dec. 2018. doi: 10.1109/TAP.2018.2881496