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Editorial

Applications of Electromagnetic Waves: Present and Future

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1. Introduction

Electromagnetic (EM) waves carry energy through propagation in space. This radiation associates with entangled electric and magnetic fields which must exist simultaneously. Although all EM waves travel at the speed of light in vacuum, i.e., 3×10^8 m/s, they cover a wide range of frequencies called the EM spectrum. The various portions of the EM spectrum are referred to by various names based on their different attributes in the emission, transmission, and absorption of the corresponding waves, and also based on their different practical applications. There are no certain boundaries separating these various portions and the ranges tend to overlap. Overall, the EM spectrum, from the lowest to the highest frequency (longest to shortest wavelength) contains the following waves: radio frequency (RF), microwaves, millimeter waves, terahertz, infrared, visible light, ultraviolet, X-rays, and gamma rays.

In general, the applications of EM waves significantly depend on their corresponding frequency (wavelength). Harnessing the capabilities of EM waves has led to great impacts on various fields such as wireless communication (e.g., see [1]), industrial sensing/imaging (e.g., see [2,3]), biomedical sensing/imaging (e.g., see [4,5]) and treatment (e.g., see [6]), remote sensing (e.g., see [7]), radar (e.g., see [8]), security screening (e.g., see [9]), wireless power transfer (e.g., see [10]), and so on.

2. The Present Issue

This Special Issue consists of sixteen papers covering a broad range of topics related to the applications of EM waves, from the design of filters and antennas for wireless communications to biomedical imaging and sensing and beyond. The contents of these papers are briefly introduced here.

Regarding imaging efforts with EM waves, in [11] a compact and cost-effective three-dimensional (3D) microwave imaging system is proposed based on a fast and robust holographic technique. Unlike the previous 3D holographic imaging techniques which are based on wideband data collection, here, narrow-band microwave data are employed along with an array of receiver antennas. To achieve a low cost and compact size, off-the-shelf components have been employed to build a data acquisition system replacing the costly and bulky vector network analyzers (VNAs). In [12], the feasibility study of a microwave imaging technique is studied based on the Huygens principle for bone lesion detection. An artificial multilayered bone phantom comprised of cortical bone and bone marrow layers has been constructed and the imaging has been implemented based on the measurements in the frequency range of 1–3 GHz. In [13], a non-invasive and repeatable blood glucose monitoring technique is proposed at microwave frequencies by eliminating the leaky modes through the use of surface EM waves from a curved Goubau line. In [14], reverse time migration (RTM) technique is employed to process the permafrost ground penetration radar (GPR) data of the Tibetan highway. The RTM profiles clearly reflect the internal fine structure of permafrost and the thawing state.

Regarding high frequency component design, in [15] the design of a fifth order bandpass waveguide filter with Chebyshev response is proposed, which operates in the X-band at a center frequency of 10 GHz. The structure is based on complementary split ring resonators (CSRRs) and reduces the overall physical length by 31% while enhancing the bandwidth up to 37.5% compared to the conventional designs. In [16], an ultra-wideband bandpass filter (UWB-BPF) with a notch band and a wide upper stopband is proposed. Two pairs of half-wavelength high-impedance line resonators tightly and strongly coupled to the input/output lines are used to provide the wideband responses. In [17], an ultra-broadband terahertz bilayer graphene-based absorption structure is proposed which has high absorption and independence of polarization property. It has two stacking graphene layers sandwiched by an Au cylinders array, backed by a metallic ground plane. The structure shows a bandwidth of 7.1 THz with the absorption exceeding 80%. In [18], a technique is proposed to enhance the bandwidth and gain of an endfire radiating open-ended waveguide using a thin slow-wave surface plasmon structure. Mounted on the E-plane of the stated waveguide, a thin corrugated slow-wave structure has been used in conjunction with a waveguide transition to generate an endfire electromagnetic beam. For the proposed structure, an impedance bandwidth from 8 to 18 GHz has been achieved along with a gain enhancement from 7 to 14.8 dBi. In [19], single-ended and balanced bandpass filters are proposed for multi-channel applications. The proposed U-shaped stepped impedance resonator (USIR) can achieve size miniaturization. Moreover, by using the source–load coupling scheme, two transmission zeros (TZs) are respectively generated at the lower and upper sides of the passbands, which is useful for improvement of the selectivity performance. In addition, spurlines are introduced at the input and output ports to produce another TZ to further enhance the stopband performance. In [20], first applications of metamaterials to microwave antennas are reviewed over the past decade. Then, the manufacturing of microwave antennas using graphene-containing carbon composite materials has been developed and prototypes of dipole and horn antennas made from such materials have been created and studied.

Among another set of diverse applications, in [21] a novel methodology is proposed for material identification based on the use of a microwave sensor array with the elements of the array resonating at various frequencies within a wide range and applying machine learning algorithms on the collected data. The performance of the proposed methodology is tested via the use of easily available materials such as woods, cardboards, and plastics. In [22], the Fourier series expansion method (FSEM) is employed to calculate the complex propagation constants of plasma structures consisting of infinitely long, silver nanorod arrays in the range of 180–1900 nm, and the characteristics of the complex propagation constant are analyzed in depth. In [23], a technical analysis of LED arrays used in monochrome computer printers is presented along with their contribution to unintentional EM emanations. Analyses are based on realistic type sizes and distribution of glyphs. Usable pictures are reconstructed from intercepted RF emanations. In [24], the analysis of levels of EM disturbances from different types of electronic devices is studied. Obtained results are connected with possibilities of existence of sensitive emissions correlating with processed data. The devices of a given type are measured in similar conditions. In [25], an energy verification method for the nozzle of the SC200 proton therapy facility is proposed to ensure safe redundancy of treatment. In [26], electrical characteristic analysis and corresponding experimental tests on gold bonding wire are presented. Firstly, according to EIA (Electronic Industries Association)/JEDEC97 standards, this paper establishes the electromagnetic structure model of gold bonding wire. The parameters, including flat length ratio, diameter, span, and bonding height, are analyzed. In addition, the influence of three kinds of loops of bonding wire is discussed in relation to the S parameters.

3. Future

While some applications of EM waves, such as communication systems and radar, can be considered more traditional, others, such as biomedical imaging and treatment, wireless power transfer, and security screening, are more recent and rapidly growing. This is in part due to the introduction of new concepts such as metamaterials (e.g., see [27]), holographic processing (e.g., see [28]), wireless power transfer methods, radio-frequency identification (RFID) (e.g., see [29]), and so on, which has resonated well with the rapid and significant progress in the field of RF electronics, leading to new commercial products. For instance, for biomedical imaging, microwave imaging systems have been developed and have recently been commercialized (e.g., see [30,31]). As the implementation cost of the EM systems reduces due to the emergence of cost-effective hardware components, it is expected that such systems will grow significantly in the near future and their applications will be expanded in various unexplored directions.

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References

1. Tse, D.; Viswanath, P. *Fundamentals of Wireless Communication*; Cambridge University Press: Cambridge, UK, 2005.
2. Zoughi, R. *Microwave Non-Destructive Testing and Evaluation*; Kluwer Academic Publishers: Norwell, MA, USA, 2000.
3. Amineh, R.K.; Martin, L.E.S.; Donderici, B. Holographic Techniques for Corrosion Evaluation of Wellbore Pipes. US Patent No. 9488749, 8 November 2016.
4. Nikolova, N.K. Microwave Imaging for Breast Cancer. *IEEE Microw. Mag.* **2011**, *12*, 78–94. [CrossRef]
5. Sun, Q.; He, Y.; Liu, K.; Fan, S.; Parrott, E.P.G.; Pickwell-MacPherson, E. Recent Advances in Terahertz Technology for Biomedical Applications. *Quant. Imaging Med. Surg.* **2017**, *7*, 345–355. [CrossRef] [PubMed]
6. Yerushalmi, A. Localized, non-invasive deep microwave hyperthermia for the treatment of prostatic tumors: The first 5 years. In *Application of Hyperthermia in the Treatment of Cancer*; Recent Results in Cancer Research; Issels, R.D., Wilmanns, W., Eds.; Springer: Amsterdam, The Netherlands, 1988; p. 107.
7. Campbell, J.B.; Wynne, R.H. *Introduction to Remote Sensing*, 5th ed.; The Guilford Press: New York, NY, USA, 2011.
8. Maio, A.D.; Greco, M.S. *Modern Radar Detection Theory*; SciTech Publishing: Raleigh, NC, USA, 2016.
9. Sheen, D.M.; McMakin, D.L.; Hall, T.E. Three-Dimensional Millimeter-Wave Imaging for Concealed Weapon Detection. *IEEE Trans. Microw. Theory Tech.* **2001**, *49*, 1581–1592. [CrossRef]
10. Artan, N.S.; Amineh, R.K. Wireless Power Transfer to Medical Implants with Multi-Layer Planar Coils. Chapter 9; In *Emerging Capabilities and Applications of Wireless Power Transfer*; IGI Global: Hershey, PA, USA, 2018.
11. Wu, H.; Amineh, R.K. A Low-Cost and Compact Three-Dimensional Microwave Holographic Imaging System. *Electronics* **2019**, *8*, 1036. [CrossRef]
12. Khalesi, B.; Sohani, B.; Ghavami, N.; Ghavami, M.; Dudley, S.; Tiberi, G. A Phantom Investigation to Quantify Huygens Principle Based Microwave Imaging for Bone Lesion Detection. *Electronics* **2019**, *8*, 1505. [CrossRef]
13. Liu, L.W.; Kandwal, A.; Cheng, Q.; Shi, H.; Tobore, I.; Nie, Z. Non-Invasive Blood Glucose Monitoring Using a Curved Goubau Line. *Electronics* **2019**, *8*, 662. [CrossRef]
14. Wang, Y.; Fu, Z.; Lu, X.; Qin, S.; Wang, H.; Wang, X. Imaging of the Internal Structure of Permafrost in the Tibetan Plateau Using Ground Penetrating Radar. *Electronics* **2020**, *9*, 56. [CrossRef]
15. AbuHussain, M.; Hasar, U.C. Design of X-Bandpass Waveguide Chebyshev Filter Based on CSRR Metamaterial for Telecommunication Systems. *Electronics* **2020**, *9*, 101. [CrossRef]
16. Weng, M.-H.; Hsu, C.-W.; Lan, S.-W.; Yang, R.-Y. An Ultra-Wideband Bandpass Filter with a Notch Band and Wide Upper Bandstop Performances. *Electronics* **2019**, *8*, 1316. [CrossRef]
17. Liu, S.; Deng, L.; Qu, M.; Li, S. Polarization-Independent Tunable Ultra-Wideband Meta-Absorber in Terahertz Regime. *Electronics* **2019**, *8*, 831. [CrossRef]
18. Kandwal, A.; Nie, Z.; Li, J.; Liu, Y.; WY Liu, L.; Das, R. Bandwidth and Gain Enhancement of Endfire Radiating Open-Ended Waveguide Using Thin Surface Plasmon Structure. *Electronics* **2019**, *8*, 504. [CrossRef]

19. Yan, F.; Huang, Y.M.; Huang, T.; Ding, S.; Wang, K.; Bozzi, M. Transversely Compact Single-Ended and Balanced Bandpass Filters with Source–Load-Coupled Spurlines. *Electronics* **2019**, *8*, 416. [CrossRef]
20. Dugin, N.A.; Zaboronkova, T.M.; Krafft, C.; Belyaev, G.R. Carbon-Based Composite Microwave Antennas. *Electronics* **2020**, *9*, 590. [CrossRef]
21. Harrison, L.; Ravan, M.; Tandel, D.; Zhang, K.; Patel, T.; K Amineh, R. Material Identification Using a Microwave Sensor Array and Machine Learning. *Electronics* **2020**, *9*, 288. [CrossRef]
22. Zong, C.; Zhang, D. Analysis of Propagation Characteristics along an Array of Silver Nanorods Using Dielectric Constants from Experimental Data and the Drude-Lorentz Model. *Electronics* **2019**, *8*, 1280. [CrossRef]
23. Kubiak, I.; Loughry, J. LED Arrays of Laser Printers as Valuable Sources of Electromagnetic Waves for Acquisition of Graphic Data. *Electronics* **2019**, *8*, 1078. [CrossRef]
24. Kubiak, I. Impact of IT Devices Production Quality on the Level of Protection of Processed Information against the Electromagnetic Infiltration Process. *Electronics* **2019**, *8*, 1054. [CrossRef]
25. Wang, P.; Zheng, J.; Song, Y.; Zhang, W.; Wang, M. Analysis and Design of an Energy Verification System for SC200 Proton Therapy Facility. *Electronics* **2019**, *8*, 541. [CrossRef]
26. Tian, W.; Cui, H.; Yu, W. Analysis and Experimental Test of Electrical Characteristics on Bonding Wire. *Electronics* **2019**, *8*, 365. [CrossRef]
27. Eleftheriades, G.V.; Balmain, K.G. *Negative-Refraction Metamaterials: Fundamental Principles and Applications*; Wiley: Hoboken, NJ, USA; IEEE Press: Piscataway, NJ, USA, 2005.
28. Amineh, R.K.; Nikolova, N.K.; Ravan, M. *Real-Time Three-Dimensional Imaging of Dielectric Bodies Using Microwave/Millimeter Wave Holography*; Wiley: Hoboken, NJ, USA; IEEE Press: Piscataway, NJ, USA, 2019.
29. Hunt, V.D.; Puglia, A.; Puglia, M. *RFID: A Guide to Radio Frequency Identification*; Wiley: Hoboken, NJ, USA, 2007.
30. Micrima Limited. Available online: https://micrima.com/ (accessed on 31 May 2002).
31. EMTensor GmbH. Available online: https://www.emtensor.com/ (accessed on 13 May 2002).