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S-Shaped Metamaterial Ultra-Wideband Directive Patch Antenna

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Abstract—Antenna parameter optimization using S-shaped metamaterial embedded in antenna substrate is elucidated in this paper. Upon incorporation of proposed metamaterial array inside the antenna substrate, the bandwidth of antenna increases by 74% and directivity by about 11%. Results obtained are in good coherence when using the FEM based Ansoft HFSS simulation and MATLAB programming based on CAD formulas using the equivalent circuit analysis of patch antenna. The evolution of 'S-shape' has been explained beginning from the primitive Single Split Ring Resonator's shape. The proposed structure was fabricated and nearly 6% deviation was obtained in comparison with the simulation results. This metamaterial antenna overcomes the low bandwidth limitation of patch antenna and helps in maintaining a low profile by obtaining 81% miniaturization.

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1. INTRODUCTION

"Metamaterials" (MTMs) are engineered to modify the bulk permeability and/or permittivity of the medium [1]. They are realized by placing periodically structures that alter the material parameters, with elements of size less than the wavelength of the incoming electromagnetic wave. This results in "meta" i.e. "altered" behavior or behavior unattainable by natural materials [2]. Particle shape has effect on the value of negative permittivity corresponding to the Frohlich resonance. The geometry of negative permittivity particle has a strong effect on its surface plasmonic properties.

The software tool HFSS is used because it is a high performance full wave electromagnetic (EM) field simulator for arbitrary 3D volumetric passive device modeling [3].

This paper abridges the design of RMPA with resonant frequency 4.3 GHz and the operating frequency range 3.8–4.8 GHz having FR4 ($\varepsilon_r = 4.4$) as a substrate material (Section 2) by using the Finite Element Method (FEM) based Ansoft HFSS software and the parametric study using the equivalent circuit analysis in MATLAB. Section 3 describes DNG MTM (S-shaped) having negative refraction in the same frequency range and explains its evolution from the primitive Single Split Resonator structure. Section 4 mathematically demonstrates the resonant frequency of S-shaped MTM using internal inductances and capacitances from circuit diagram. Section 5 deals with MTM application in antenna parameter optimization by embedding it in substrate. Section 6 describes the trade-offs in achieving the bandwidth enhancement in RMPA with DNG material in substrate.

2. RMPA DESIGN

2.1. Design

Rectangular Microstrip Patch Antenna (RMPA) as its name implies consists of a rectangular patch over a microstrip substrate. Its major disadvantage is a relatively low impedance bandwidth, which limits the field of application of these antennas. Metamaterials are embedded in the middle of its substrate to increase the bandwidth of antenna without altering its parameters and without much effecting antenna's radiation properties. Henceforth, metamaterial based antennas are introduced.

REFERENCES

1. H. Schantz, *The Art and Science of Ultra-Wideband Antennas* (Artech House, 2005).
2. C. A. Balanis, *Antenna Theory*, 4th ed. (John Wiley & Sons, Inc., 2016).
3. D. M. Pozar, "Microstrip antennas," *Proc. IEEE* **80**, No. 1, 79 (1992). DOI: 10.1109/5.119568.
4. J. Volakis, *Antenna Engineering Handbook*, 4th ed. (McGraw Hill, 2007).

5. S. Wang. A. P. Feresidis, G. Goussetis, J. C. Vardaxoglou, "Low-profile resonant cavity antenna with artificial magnetic conductor ground plane," *Electronics Lett.* **40**, No. 7, 405 (2004). DOI: 10.1049/el:20040306.
6. M. R. Ahsan, M. T. Islam, M. H. Ullah, N. Misran, "Bandwidth enhancement of a dual band planar monopole antenna using meandered microstrip feeding," *The Scientific World J.* **2014**, ID 856504 (2014). DOI: 10.1155/2014/856504.
7. K. F. Lee, K. M. Luk, K. M. Mak, S. L. S. Yang, "On the use of U-slots in the design of dual-and triple-band patch antennas," *IEEE Antennas Propag. Mag.* **53**, No. 3, 60 (2011). DOI: 10.1109/MAP.2011.6028422.
8. K.-L. Wong, *Compact and Broadband Microstrip Antennas* (Wiley-Interscience, Hoboken, NJ, 2004).
9. Parul Dawar, N. S. Raghava, Asok De, "Ultra wide band, multi-resonance antenna using swastika metamaterial," *Int. J. Microwave Optical Technology* **11**, No. 6, 423 (2016).
10. M. R. Ahsan, M. T. Islam, M. H. Ullah, M. J. Singh, M. T. Ali, "Metasurface reflector (MSR) loading for high performance small microstrip antenna design," *PLOS One*, May (2015). DOI: 10.1371/journal.pone.0127185.
11. S. Linden, C. Enkrich, G. Dolling, M. W. Klein, J. Zhou, T. Koschny, C. M. Soukoulis, S. Burger, F. Schmidt, M. Wegener, "Photonic metamaterials: Magnetism at optical frequencies," *IEEE J. Selected Topics Quantum Electronics* **12**, No. 6, 1097 (2006). DOI: 10.1109/JSTQE.2006.880600.
12. Han Xiong, Jing-Song Hong, Ming-Tao Tan, Bing Li, "Compact microstrip antenna with metamaterial for wideband applications," *Turk. J. Electrical Eng. Comp. Sci.* **21**, 2233 (2013). DOI: 10.3906/elk-1204-6.
13. P. Kaur, S. K. Aggarwal, A. De, "Performance enhancement of rectangular microstrip patch antenna using double H shaped metamaterial," *Radioelectron. Commun. Syst.* **59**, No. 11, 496 (2016). DOI: 10.3103/S0735272716110030.