Mutual Coupling Reduction of Dual-band Printed Monopoles Using MNG Metamaterial

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***Abstract*—In this paper, a μ-Negative metamaterial (MNG) is utilized for mutual coupling reduction between dual-band printed monopole antennas used in Multiple Input Multiple Output (MIMO). A dual-band MNG metamaterial is designed to specifically possess negative effective permeability at the two resonant frequencies where the antennas are operating. MNG is inserted between the two printed monopoles (back to back) to decrease the correlation between them. The printed monopole antennas were designed to operate in the Wireless Local Area Network (WLAN) bands 2.45 GHz and 5.2 GHz. Antenna characteristics such as, scattering parameters far-field radiation patterns with and without the presence of MNG are provided. The design of the MNG unit cell and its effective constitutive parameters are also provided. Design and simulations are conducted using Ansoft's HFSS software which is based on the Finite Element Method (FEM). The proposed technique achieved a 14 dB reduction in mutual coupling at 2.45 GHz and 13 dB at 5.2 GHz. A gain of 2 dB higher than the normal case at the second band is observed while it is maintained the same on the first band. Furthermore, the MNG based antenna system maintains a relatively low profile (16 mm) which is convenient for compact systems and hand-held devices.**

Keywords- MIMO, MNG, Metamaterial, Mutual coupling, Printed monopole antenna .

I. Introduction

The reduction of mutual coupling between closely spaced antennas is necessary to the performance of Multiple Input Multiple Output (MIMO) systems since mutual coupling affects the current distribution, phase, input impedance and radiation pattern in each antenna element which in turn significantly reduces the capacity of MIMO systems [1], [2]. Generally, antenna elements must be spaced by λ/2 in order to achieve low correlation and hence higher isolation between the elements, where λ is the free space wavelength [3]. However, degradation occurs when antenna elements are in close proximity, due to near-field effects, surface waves and reactive mutual coupling between the elements [3], [4]. Several techniques have been recently reported to reduce mutual coupling between radiating elements in MIMO systems. Some of these techniques are based on the use of Electromagnetic Band Gap (EBG) structures [5], defected ground plane [6], and the use of μ-negative metamaterial (MNG) structures [7]. The use of 180° hybrid couplers proposed in [8] is an alternative technique to de-correlate highly-coupled monopole antennas. In [7], MNG structures have been used to reduce the mutual coupling between two high profile monopoles. The achieved reduction in mutual coupling was 20 dB. In this paper, we utilize MNG to reduce the mutual coupling between two closely separated low profile printed monopoles intended for applications that require compact space, i.e., handheld devices and miniaturized sensor nodes. Printed monopoles were chosen due to the demand for small size, ease of fabrication and low cost in the development of low-power communication devices. Moreover, printed quarter wavelength monopole antennas are easy to design; they have a relatively wide bandwidth and can be flexibly tuned by slight changes in their lengths/widths.

In this work, a dual band μ-negative (MNG) metamaterial is developed in order to efficiently suppress the electromagnetic coupling between the proposed antennas. The dual-band MNG metamaterial is designed to specifically have negative permeability at two frequencies where the antennas are operated. The MNG is inserted between the two antennas (back to back) to decrease the correlation between them as will be shown in a later section.

One efficient way of realizing MNG metamaterials is to use Split Ring Resonators (SRRs) which provide negative permeability when excited with a specific polarization [9], [10].

The design of the proposed antenna and MNG is introduced in Section II, where both geometries and characteristics of the antenna-metamaterial system are illustrated. The performance results of the antenna system with and without MNG metamaterial are compared in Section III. Finally, we conclude the paper in Section IV.

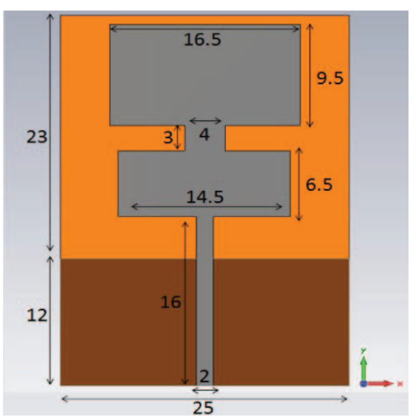
II. DESIGN

A. Antenna Element

The proposed antenna is a modification of the design presented in [11]. However, we have achieved more than 50% reduction in size in addition to an increase in gain and efficiency while maintaining almost the same bandwidth. As can be seen in Fig. 1, the proposed antenna comprises two monopole branches, both operated as quarter wavelength structures. They are fed by a 2 mm wide, 50 Ω microstrip line. Both of the two branches and the microstrip line are printed on the same side of a 35 mm x 25 mm flexible Kapton substrate, 45 μm in thickness and a dielectric constant of 3.5 and a loss tangent of 0.003. On the other side of the substrate, a 12 mm x 25 mm flexible copper ground plane is adhered below the microstrip line (the shaded area in Fig. 1). The upper branch of the monopole controls the first (dominant) mode (2.45 GHz) of the antenna while the lower branch controls the second band (5.2 GHz). Ansoft High-frequency structure simulator (HFSS) [12] was used to optimize the necessary parameters to achieve a dual resonance at 2.45 GHz and 5.2 GHz for the intended WLAN applications. It should also be noted that the dimensions of the ground plane can affect bandwidths of the two modes [11].

Two identical antennas were designed and separated (back to back) by 15 mm (λ/9 and λ/4 at 2.45 GHz and 5.2 GHz respectively, where λ is the free space wavelength) to study the effect of mutual coupling between them. The *S*-parameters results along with the farfield radiation patterns will be discussed in the following section.

Fig. 1 shows the fabricated antenna and the dimensions of the design.



(b)

Figure 1. (a) Geometry of the antenna showing its dimensions (all dimensions are in millimeter).

B. μ-Negative Metamaterial

As we mentioned earlier, the correlation between any two antennas within a MIMO system should be kept as low as possible in order to improve the performance and capacity of MIMO systems. In this research, we utilize MNG metamaterial to decrease the mutual coupling between the radiating elements. One efficient way of realizing MNG metamaterials is to use SRRs. When SRR structures are with a magnetic field **H** polarized parallel to their axes, they provide negative permeability over a certain frequency range which would prevent the existence of real propagating modes within the medium [9]. This behavior would be utilized to reduce the mutual radiation coupling between the radiating elements of the proposed antenna.

Here, we propose a dual band MNG unit cell consists of a concentric combination of Edge-Coupled Split Ring Resonator (EC-SRR) and a Broadside-Coupled Square Ring Resonator (BC-SRR) with dimensions chosen to provide an effective negative permeability at the desired two bands. Fig. 2 shows the geometry and dimensions of the proposed MNG unit cell. The retrieved values of the permeability were -9 at 2.45 GHz and -4 at 5.2 GHz. The permeability retrieval method is based on a procedure reported in [13].

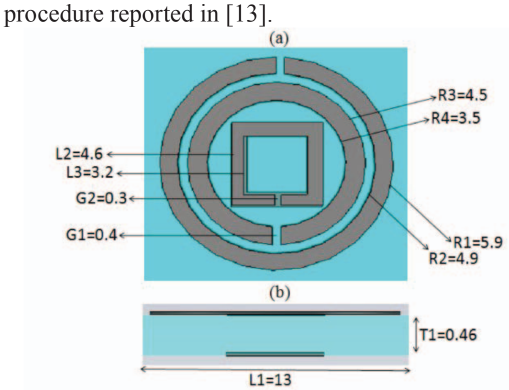


Figure 2. Dimensions (in millimeter) of the proposed MNG (a) Front view (b) Side view.

A group of 8 sets of MNG slabs were inserted between the antennas. Each set consists of 3 unit cells. The optimized separation distance between the MNG slabs is 2.5 mm. The slabs were oriented vertically as shown in Fig. 3 to provide the required polarization for the MNG.

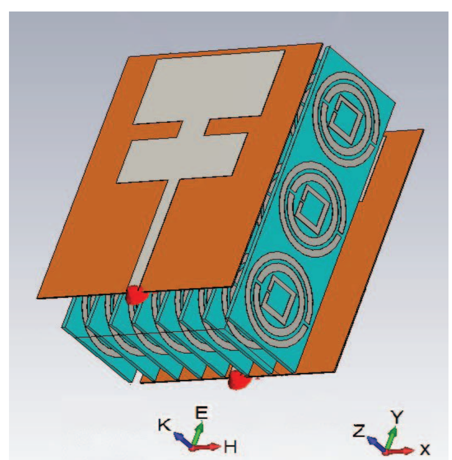


Figure 3. Perspective view of the printed monopole antennas with MNG inserted between them to reduce the mutual coupling. The polarization of the E and H fields are also shown to elaborate the MNG excitation.

III. Performance and Results

A. S-Parameters

The simulated S-parameters for the proposed antenna system with and without MNG are shown in Fig. 4. The antennas (without MNG) resonate at 2.5 GHz and 5.2 GHz with a return loss of -20 dB and -44 dB respectively. From the transmission coefficient S_{12}, we observe a large reduction in mutual coupling when the MNG metamaterial is inserted between the radiating elements. The mutual coupling measured in terms of S_{12}, is -6 dB and -12 dB at 2.5 GHz and 5.2 GHz respectively compared to -20 dB and -25 dB at 2.5 GHz and 5.2 GHz for the design with MNG structures. We also notice a shift in the second resonance frequency for the MNG case (around 120 MHz) which can be compensated for by slightly adjusting the lower monopole branch width in order to keep the patch resonance frequency identical in both cases. This shift is caused by the capacitive coupling with the BC-SRR. Due to the lossy nature of the SRR, the return loss increased for the MNG case from -20 dB to -12 dB and from -44 dB to -32 dB for the first and the second band respectively.

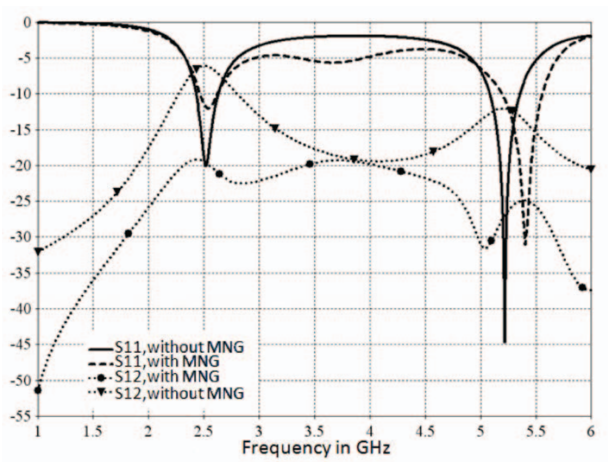
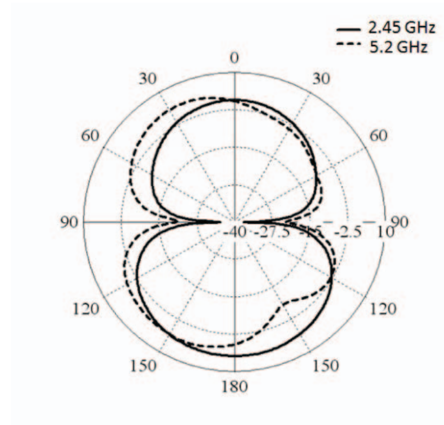


Figure 4. S-Parameters for the antenna system with and without MNG.

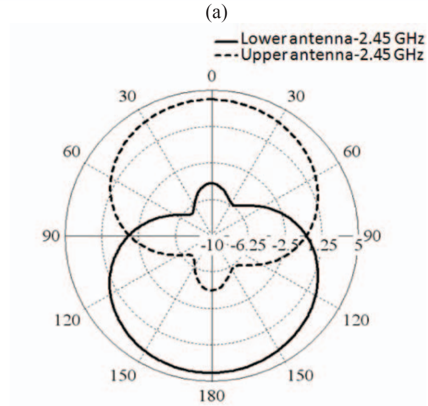
It is also worth mentioning that the -10 dB bandwidths remained the same in both cases (180 MHz and 340 MHz at 2.5 GHz and 5.2 GHz respectively) which cover the assigned WLAN bands.

B. Farfield Radiation Patterns

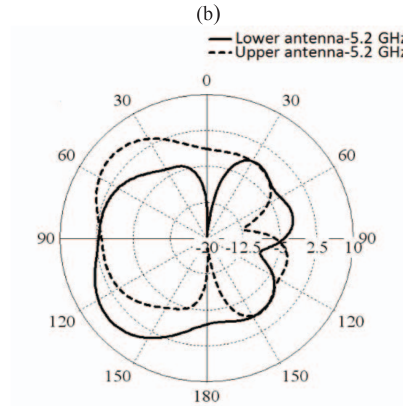
Far-field radiation patterns for the printed monopole antennas with and without MNG metamaterial are presented in Fig. 5. When the combined radiation pattern is simulated, one element is connected to a 50 Ω feed while the other is terminated with a 50 Ω load. It is shown that the antennas without MNG have a typical omni-directional radiation pattern of a monopole/dipole antenna. On the other hand, we notice that the effect of MNG which partially prevents propagating modes converts the radiation pattern to a hemi-spherical type; this effect is clearer in the first resonance rather than the second. This effect is due to the fact the effective negative permeability is more "dominant" in the first band than the second (-9 versus -4 at 2.45 GHz and 5.2 GHz respectively).



(a)



(b)



(c)

Figure 5. E-plane farfield radiation pattern (a) antenna without MNG (b) Lower and upper antennas at 2.45 GHz with MNG (c) Lower and upper antennas at 5.2 GHz with MNG.

IV. CONCLUSION

In this paper, mutual coupling between closely-spaced ultra thin printed monopole antennas is investigated particularly for MIMO systems performance. Specially designed dual band MNG metamaterial were utilized to significantly reduce the mutual coupling between the radiating elements of the proposed dual band printed monopoles. According to the *S*-parameters and farfield radiation patterns, the design with the proposed MNG metamaterial provides significant isolation between the antennas compared to the design without MNG with the same elements spacing. A reduction in mutual coupling of 14 dB and 13 dB at 2.45 GHz and 5.2 GHz respectively was achieved for the antenna system with MNG while the -10 dB bandwidth was maintained the same.

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REFERENCES

[1] G. J. Foschini and M. J. Gans, "On limits of wireless communication in a fading environment when using multiple antennas," Wireless Personal Commun., vol. 6, no. 3, pp. 311–335, 1998.

[2] S. Lu, H.T, Hui, and M. Bialkowski, " Performance analysis of multiple-input multiple-output orthogonal frequency division multiplexing systems under the influence of antenna mutual coupling effect", *IET Microwaves, Antennas & Propagation* (2009),3(2):288.

[3] H. Shin and J. H. Lee, "Capacity of multiple-antenna fading channels: spatial fading correlation, double scattering, and keyhole," IEEE Transactions on Information Theory, vol. 49, no. 10, pp. 2636–2647, 2003.

[4] D. shan Shiu, G. J. Foschini, M. J. Gans, and J. M. Kahn, "Fading correlation and its effect on the capacity of multielement antenna systems," IEEE Trans. Commun, vol. 48, pp. 502–513, 2000.

[5] L. Li, B. Li, H. X. Liu, and C. H. Liang, "Locally resonant cavity cell model for electromagnetic band gap structures," *IEEE Trans. Antennas Propag.*, vol. 54, no. 1, pp. 90–100, Jan., 2006

[6] C. Caloz, H. Okabe, T. Iwai, and T. Itoh, "A simple and accurate model for microstrip structures with slotted ground plane," *IEEE Microwave Wireless Comp. Lett.,* vol. 14, no. 4, pp. 133–135, Apr., 2004.

[7] M. M. Bait-Suwailam, M. S. Boybay, and O. M. Ramahi, "Electromagnetic Coupling Reduction in High-Profile Monopole Antennas Using Single-Negative Magnetic Metamaterials for MIMO Applications," *IEEE Trans. Antennas Propag*.,vol. 58, no. 9, pp. 2894–2902, Sep., 2010.

[8] S. Dossche, S. Blanch, and J. Romeu, "Three different ways to decorrelate two closely spaced monopoles for MIMO applications," in *2005 IEEE/ACES International Conference on Wireless Communications and Applied Computational Electromagnetics*, April 2005, pp. 849–852.

[9] J. Pendry, A. Holden, D. Robbins, and W. Stewart, "Magnetism from conductors and enhanced nonlinear phenomena," *IEEE Trans. Microw. Theory Tech.*, vol. 47, no. 11, pp. 2075–2084, Nov 1999.

[10] R. Marques, F. Medina, and R. Rafii-El-Idrissi, "Role of bianisotropy in negative permeability and left-handed metamaterials," *Phys. Rev. B*, vol. 65, pp. 144 440–6, 2002.

[11] Yen-Liang Kuo and Kin-Lu Wong, "Printed Double-T Monopole Antenna for 2.4/5.2 GHz Dual-Band WLAN Operations", IEEE Trans.Antenna and propag., vol. 51,no. 9, pp. 2187- 2192.Sep 2003.

[12] Ansoft HFSS, http://www.ansoft.com.

[13] X. Chen, T. M. Grzegorczyk, B.-I. Wu, J. Pacheco, and J. A. Kong, "Robust method to retrieve the constitutive effective parameters of metamaterials," *Phys. Rev. E*, vol. 70, no. 1, pp. 016 608.1–016 608.7, Jul. 2004.

[14] W. Wasylkiwskyj and W. Kahn, "Theory of mutual coupling among minimum-scattering antennas," *IEEE Trans. Antennas Propag.*, vol. 18, no. 2, pp. 204–216, Mar 1970.

[15] D. R. Smith, W. J. Padilla, D. C. Vier, S. C. Nemat-Nasser, and S. Schultz, "A composite medium with simultaneously negative permeability and permittivity," *Phys. Rev. Lett.*, vol. 84, pp. 4184–4187, May 2000.

[16] S. Maslovski, P. Ikonen,I. Kolmakov,S. Tretyakov, and M. Kaunisto, "Artificial magnetic materials based on the new magnetic particle: Metasolenoid," *Progress in Electromagnetic Research*, vol. 54, pp. 61– 81, 2005.

[17] A. Erentok, P. Luljak, and R. Ziolkowski, "Characterization of a volumetric metamaterial realization of an artificial magnetic conductor for antenna applications," *IEEE Trans. Antennas Propag.*, vol. 53, no. 1, pp. 160–172, Jan. 2005.