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Compact magneto-dielectric resonator MIMO antenna for angle diversity

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Abstract: This paper presents a two-element MIMO antenna configuration designed using magneto-dielectric (MD) material. The MD material has been designed such that its temperature coefficient value approaches zero. The microwave dielectric constant and permeability of the material is calculated by Nicholson-Ross-Weir conversion technique and found to be 8.02 and 1.64, respectively. Each element is designed so that it can operate at 5.71 GHz. The two elements of the MIMO configuration are separated by quarter wavelength and half wavelength and are compared. The designed antenna can give a quad-directional radiation property, which can be utilized for the diversity scheme.

Key words: Angle diversity, WLAN, magneto-dielectric material

1. Introduction

Magneto-dielectric resonator antennas (MDRAs) have been widely used in the last few years. Due to some properties such as compact size, broad bandwidth, and high radiation efficiency [1,2], they have attracted much attention. Dielectric materials are used for size miniaturization [3]; however, as the permittivity increases, the frequency bandwidth of the antenna is reduced [4], leading to limitations in size reduction and trade-off in performance. It has been shown that the use of magneto-dielectric materials allows antenna miniaturization without compromising the frequency bandwidth [1,2]. Magneto-dielectric material is one kind of dielectric material whose value of permeability can be varied on a large scale. In this manner, magneto-dielectric material offers a larger number of parameters of dielectrics to improve the performance and some characteristics of antennas as per the requirements for numerous applications [5]. By using such types of materials the matching and radiation efficiency is improved and it also provides low mutual coupling and a higher rejection level [6–11].

Current mobile communications need diverse antennas to mitigate the fading effects of a multipath environment [12]. The antennas should have low correlation to achieve a good diversity performance. Conventionally, low correlation can be achieved by spacing the antennas an appropriate distance apart, which is known as spatial diversity. However, other diversity techniques reported in the literature include frequency, pattern, and angle diversity [12].

In the present work, we present two-element antenna configurations. This element of the antenna has magneto-dielectric properties and was specifically designed for the proposed antenna. The proposed configuration can radiate in more than one direction at the same time at resonant frequency. This property of

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the antenna array can be used for the angle diversity technique. This antenna configuration is very simple to design and easy to fabricate.

2. Material synthesis and antenna design

Highly pure (99.99%, Merck India Chemicals) analytical grade reagents with appropriate stoichiometric amounts were used for the synthesis of all nanoparticles. Materials were mixed such as $Ni_{0.2}Co_{0.8}Fe_2O_4$ [13] and $SrTi_{0.1}Zr_{0.9}O_3$ [4] in a proportion such that the new material attained approximately zero temperature coefficient value, using the following formula:

$$\tau_f = (1 - x)\,\tau_{f1} + x\tau_{f2}$$

where τ_{f1} is the temperature coefficient of $SrTi_{0.1}Zr_{0.9}O_3$ and τ_{f2} is temperature coefficient of $Ni_{0.2}Co_{0.8}Fe_2O_4$.

The Nicholson–Ross–Weir conversion technique is used to calculate the microwave permittivity, permeability, and losses (dielectric as well as magnetic) by measuring S-parameters with the help of the Vector Network Analyzer for the TM_{010} resonance mode [14–16].

The temperature coefficient (τ_f) of the sample is measured by keeping the cavity in a temperature-controlled chamber using the following equation [17,18]:

$$\tau_f = \left(\frac{1}{f}\right)\left(\frac{\Delta f}{\Delta T}\right)$$

where f is the resonance frequency and $\frac{\Delta f}{\Delta T}$ is the change in the frequency w.r.t change in temperature.

The microwave dielectric properties of the material are summarized in Table 1.

Table 1. The microwave dielectric properties (permittivity, permeability, dielectric loss, magnetic loss, and temperature coefficient) of the material.

ε_r	Tanδ	μ_r	tanδ_m	τ_f (ppm/°C)
8.02	0.00031	1.64	0.058	–1.02

The sintered ceramic is used for fabricating the cuboid shaped magneto-dielectric resonator antenna since it offers multiple degrees of freedom and is easy to fabricate [19]. The schematic diagram of the antenna configuration and its image are given in Figures 1 and 2, respectively. The configuration consists of two antenna elements, made up of the same material and mounted over a FR4 substrate. The dimensions of the FR 4 substrate are 100 mm × 100 mm × 1.6 mm. The dimensions of both the elements under consideration are length (a) = 15 mm, width (b) = 10 mm, and height (h) = 7 mm. Each element is excited by a CPW transmission line with strip width (w_1) = 3 mm and gap (g) = 0.3 mm. The length of the CPW transmission line is l_1 = 45.5 mm. Two different cases with the separation $\lambda/2$ and $\lambda/4$ are considered and compared. λ is calculated at a resonant frequency of 5.79 GHz.

3. Results and discussion

The proposed antenna configuration is analyzed using the simulation software HFSS [20]. First the single antenna element is analyzed and the simulated results are given in Table 2.

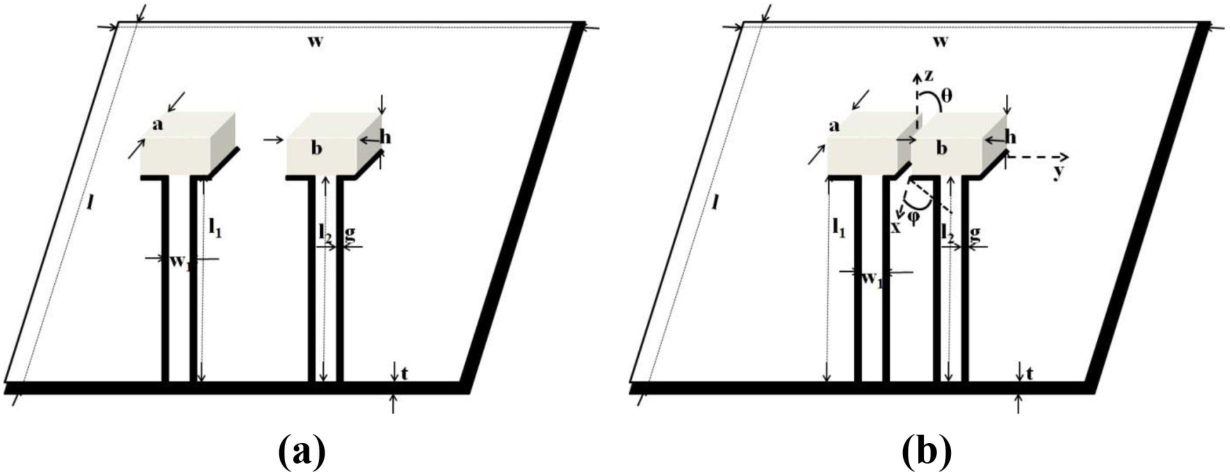


Figure 1. The schematic representation of antenna configuration at distance of (a) $\lambda/2$, (b) $\lambda/4$.

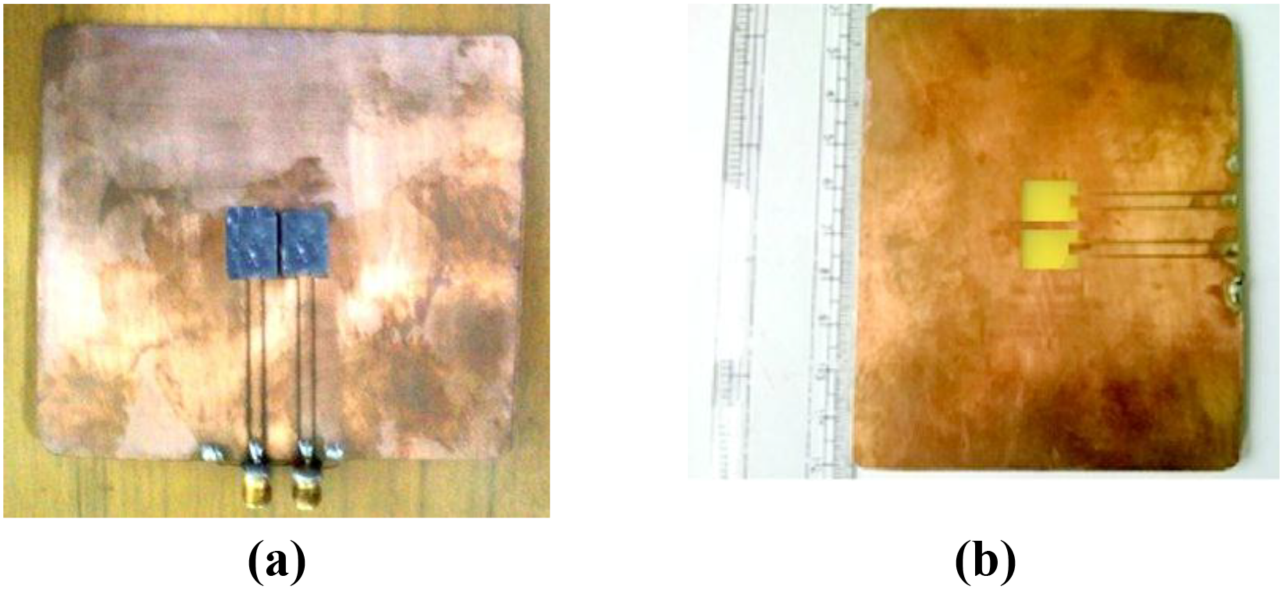


Figure 2. (a) Top view of fabricated antenna; (b) top view of fabricated antenna without MD material to show the feeding technique at distance $\lambda/4$.

Table 2. Simulated antenna characteristics for the single element.

Parameters	
Resonance frequency (GHz)	5.71
Reflection coefficient (dB)	–15.47
Bandwidth (MHz)	5.32–6.06
Max. gain (dB)	4.62 dB at 318°

Case I: Antenna elements separated by $\lambda/2$

Next the two elements of the antenna configuration are separated by 24.6 mm, half the wavelength of resonant frequency. The simulated and measured S-parameters are shown in Figures 3 and 4. It can be observed from

Figure 5 that the radiation pattern of this antenna configuration provides a multiangle radiation pattern with sufficiently high gain. This frequency range covers the operating ranges of the WLAN band [16,21].

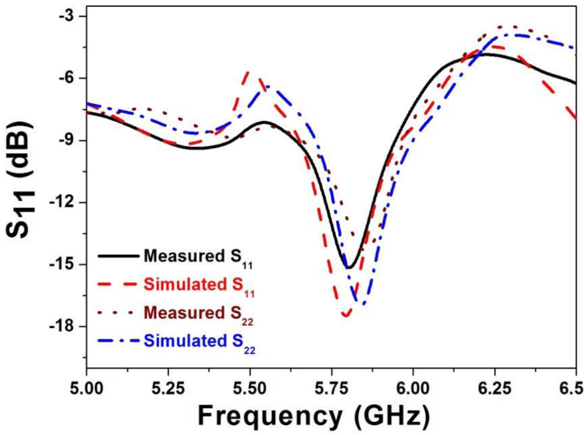


Figure 3. Comparison between simulated and measured return loss (S_{11}) and (S_{22}) at $\lambda/2$ interelement spacing.

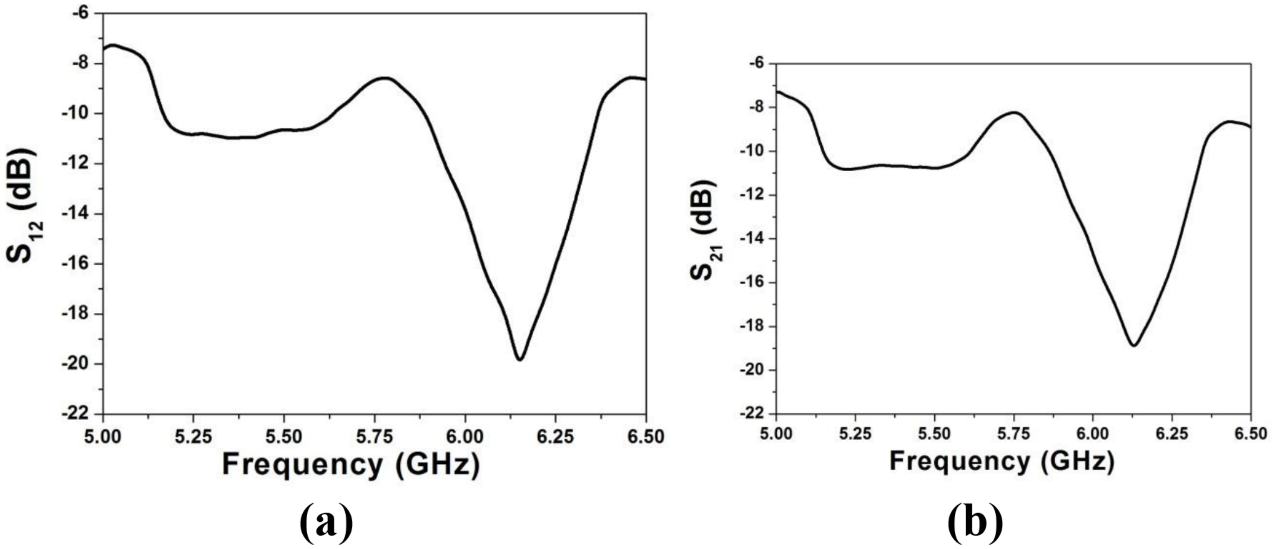


Figure 4. Simulated (a) S_{12} and (b) S_{21} at $\lambda/2$ interelement spacing.

The two-element antenna configuration is identical; hence, the S_{11} and S_{22} characteristics are also identical. It is also evident from Figure 4 that the mutual coupling between the two elements is less than 8 dB. The envelope correlation coefficient between the two antenna elements is calculated as 0.0029 by using the following formula [16,22]:

Correlation coefficient, $\rho_e = -(S_{11}^{*}S_{12} + S_{21}^{*}S_{22})^2/[1-(|S_{11}|^2 + |S_{21}|^2)][1-(|S_{22}|^2 + |S_{12}|^2)]$

It can be observed from Figure 5 that the antenna radiates in three different directions at 5.81 GHz. At the resonant frequency the E-plane and H-plane of the designed antenna radiate at 0°, 91°, and 184°. The bandwidth of this configuration is 220 MHz, which covers the range of 5.69 GHz to 5.91 GHz. At the same time the gain in the given range is more than 3.5 dB. Results are shown in Table 3.

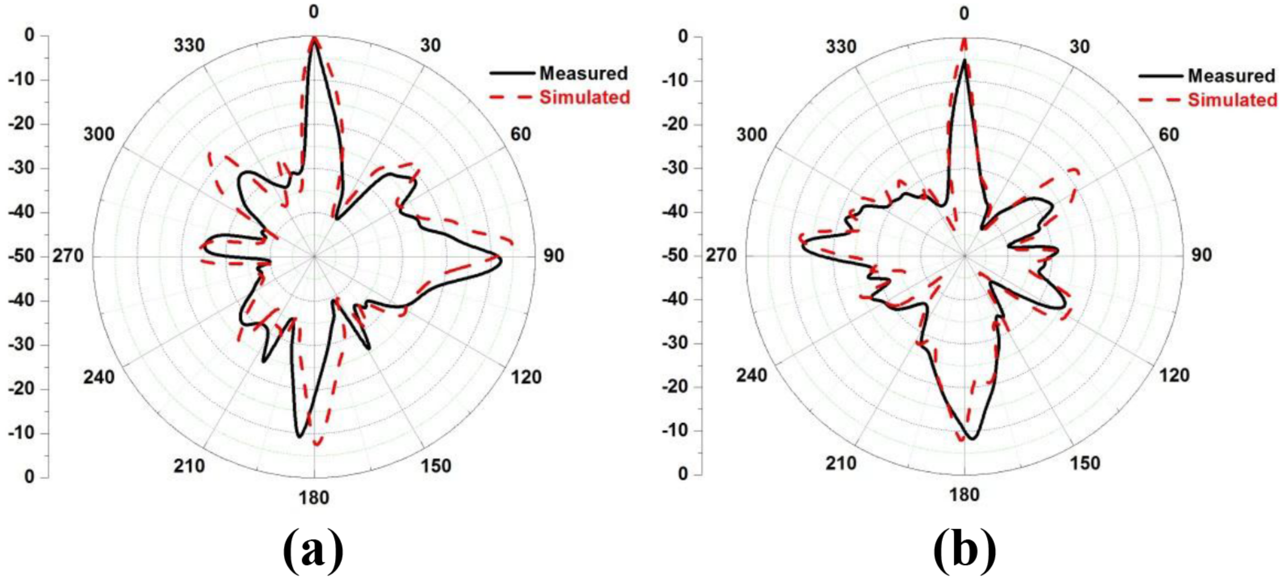


Figure 5. Comparison between measured and simulated far field radiation pattern at 5.81 GHz: (a) $\varphi = 0°$, (b) $\varphi = 90°$.

Table 3. Simulated and measured antenna characteristics with $\lambda/2$ separation between two elements.

Parameters	Simulated	Measured
Resonance frequency (GHz)	5.79	5.81
Reflection coefficient (dB)	–17.4	–15.2
Bandwidth (MHz)	240	220
Gain (dB) at 0°	10.04	8.2
Gain (dB) at 91°	5.92	3.51
Gain (dB) at 184°	5.97	3.59

Case II: Antenna elements separated by $\lambda/4$

Next a two-element antenna separated by 12.3 mm, quarter wavelength of resonant frequency (5.79 GHz), is developed. The simulated and measured S-parameters are shown in Figures 6 and 7. The resonant frequency is 5.77 GHz with 5.67 GHz to 5.905 GHz operating range, which covers the operating range of the WLAN band [16,21]. The mutual coupling in this case is less than 6 dB. The envelope correlation coefficient between the two antenna elements is 0.0054.

The E-plane and H-plane radiation characteristics of the antenna are shown in Figure 8. It is evident from the figure that the antenna radiates in four different directions. Bandwidth and gain are measured and compared with the simulated results in Table 4. The signal can transmit/receive with different directions (angles), which can be used to mitigate the fading effects of signals.

The E-plane and H-plane radiation properties at resonant frequency are given in Figure 8. At resonant frequency the E-plane radiation pattern is quaddirectional at 0°, 89°, 122°, and 182°.

The main features of this antenna configuration are given in Table 4.

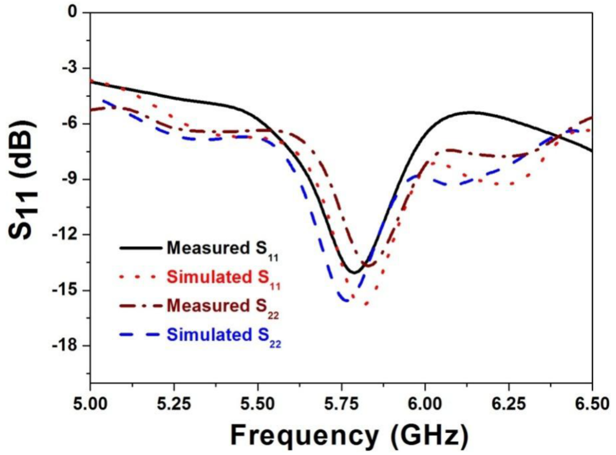
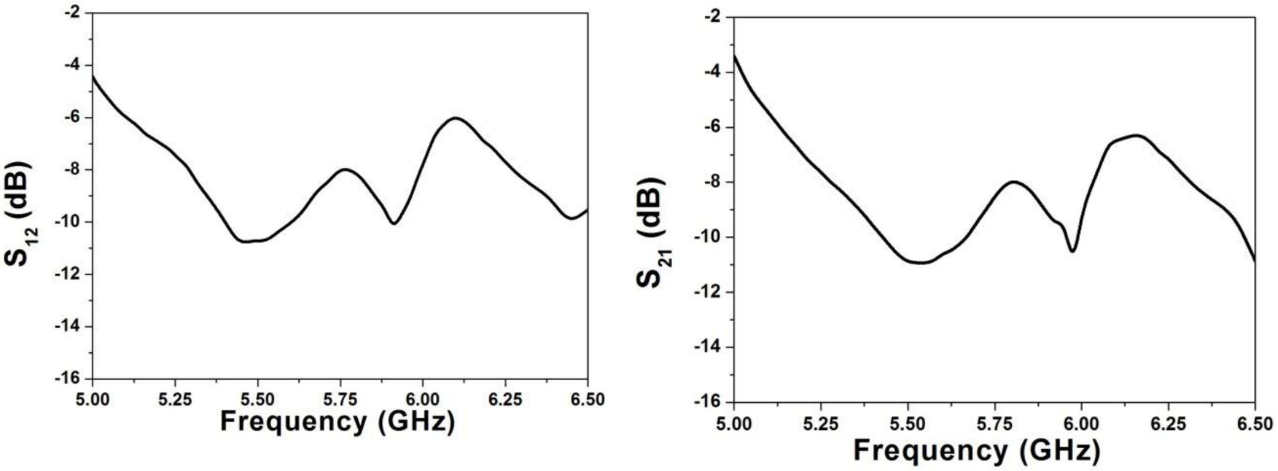


Figure 6. Comparison between measured and simulated return loss (S_{11}) and (S_{22}) at $\lambda/4$ interelement spacing.



(a) **(b)**

Figure 7. Simulated (a) S_{12} and (b) S_{21} at $\lambda/4$ interelement spacing.

Table 4. Simulated and measured antenna characteristics with $\lambda/4$ separation between two elements.

Parameters	Simulated	Measured
Resonance frequency (GHz)	5.82	5.77
Reflection coefficient (dB)	–16	–14.1
Bandwidth (MHz)	265	235
Gain (dB) at 0°	9.62	7.41
Gain (dB) at 89°	5.71	3.82
Gain (dB) at 122°	3.07	1.94
Gain (dB) at 182°	5.78	3.87

4. Conclusion

A magneto-dielectric material with nearly zero temperature coefficient and 8.02 and 1.64 values of permittivity and permeability respectively has been developed and used to design a two-element MIMO (multiple-input, multiple-output) antenna. This antenna configuration can operate at different angles. When the interelement distance is $\lambda/4$ then the designed antenna radiates in four different directions simultaneously at resonant frequency. It has also been observed that the mutual coupling between the two elements is less than 6 dB, whereas for the separation of $\lambda/2$ it is 8 dB. The separation distance affects the mutual coupling only by 2 dB. Thus, MD resonators are good candidates for the design of MIMO antennas, where size and space of the antenna is one of the major concerns.

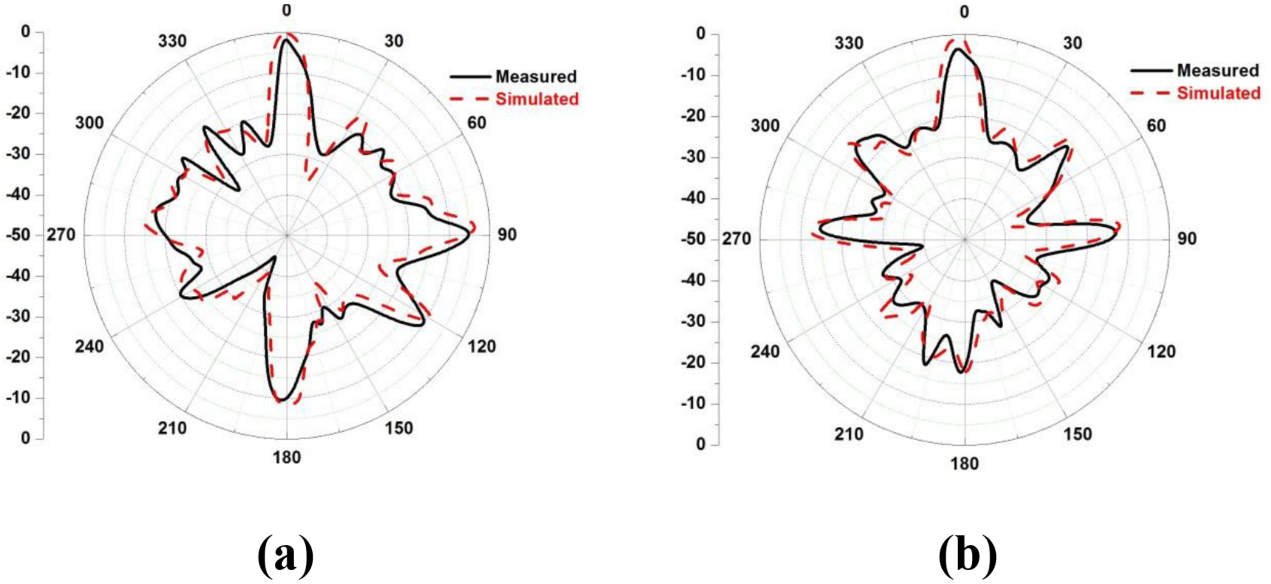


Figure 8. Comparison between measured and simulated far field radiation pattern at 5.77 GHz: (a) $\varphi = 0^\circ$, (b) $\varphi = 90^\circ$.

References

[1] Louzir A, Minard P, Pintos JF. Parametric study on the use of magneto-dielectric materials for antenna miniaturization. In: IEEE 2010 International Symposium of Antennas and Propagation Society; 11–17 July 2010; Toronto, Canada. New York, NY, USA: IEEE. pp. 1-4.

[2] Hansen RC, Burke M. Antennas with magneto-dielectrics. Microw Opt Techn Let 2000; 26: 75-78.

[3] Saed M, Yadla R. Microstrip-fed low profile and compact dielectric resonator antenna. Prog Electromagn Res 2006; 56: 151-162.

[4] Parida S, Rout SK, Subramanian V, Barhai PK, Gupta N, Gupta VR. Structural, microwave dielectric properties and dielectric resonator antenna studies of Sr(Zr$_x$Ti$_{1-x}$)O$_3$ ceramics. J Alloys Compd 2012; 528: 126-134.

[5] Albuquerque AS, Ardisson JD, Macedo WAA, Alves MCM. Nanosized powders of NiZn ferrite: synthesis, structure, and magnetism. J Appl Phys 2000; 87: 4352-4357.

[6] Psychoudakis D, Koulouridis S, Volakis JL. Magneto-dielectric antenna designs using material and metallic genetic algorithm optimization. In: IEEE 2006 Antennas and Propagation Society International Symposium; 9–14 July2006; Albuquerque, NM, USA. New York, NY, USA: IEEE. pp. 4505-4508.

[7] Foroozesh A, Shafai L. Size reduction of a microstrip antenna with dielectric superstrate using meta-materials: artificial magnetic conductors versus magneto-dielectrics. In: IEEE 2006 Antennas and Propagation Society International Symposium; 9–14 July 2006; Albuquerque, NM, USA. New York, NY, USA: IEEE. pp. 11-14.

[8] Pintos JF, Louzir A, Minard P, Perraudeau J, Mattei JL, Souriou D, Queffelec P. Ultra-miniature UHF antenna using magneto-dielectric material. In: 14th IEEE 2010 International Symposium on Antenna Technology and Applied Electromagnetics & the American Electromagnetics Conference; 5–8 July 2010; Ottawa, Canada. New York, NY, USA: IEEE. pp. 1-4.

[9] McLean JS, Foltz H, Sutton R. Electrically-small TE01 mode spherical wire antennas employing lossy magneto-dielectric materials. In: IEEE 2010 International Workshop on Antenna Technology; 1–3 March 2010; Lisbon, Portugal. New York, NY, USA: IEEE. pp. 1-4.

[10] Shin YS, Park SO. A monopole antenna with a magneto-dielectric material and its MIMO application for 700 MHz-LTE-band. Microw Opt Techn Let 2010; 52: 2364-2367.

[11] Mosallaei H, Sarabandi K. Magneto-dielectrics in electromagnetics: concept and applications. IEEE T Antenn Propag 2004; 52: 1558-1567.

[12] Mattheijssen P, Herben MHAJ, Dolmans G. Diversity: a fading mitigation technique. IEEE T Veh Technol 2004; 53: 1035-1042.

[13] Mohit K, Gupta VR, Gupta N, Rout SK. Structural and microwave characterization of $Ni_{0.2}Co_xZn_{0.8-x}Fe_2O_4$ for antenna applications. Ceram Int 2014; 40: 1575-1586.

[14] De Paula AL, Rezende MC, Barroso JJ. Experimental measurements and numerical simulation of permittivity and permeability of Teflon in X band. Journal of Aerospace Technology and Management 2011; 3: 59-64.

[15] Mohit K, Gupta VR, Rout SK. A CPW-fed quad-directional stacked magneto-dielectric resonator antenna for angle diversity application. Microw Opt Techn Let 2016; 58: 61-64.

[16] Mohit K, Gupta VR, Rout SK. Two element magneto-dielectric resonator antenna for angle diversity. Frequenz 2016; 70: 203-210.

[17] Rajput SS, Keshri S. Structural and microwave properties of $(Mg,Zn/Co)TiO_3$ dielectric ceramics. J Mater Eng Perform 2014; 23: 2103-2109.

[18] Keshri S, Rajput SS. Investigation on low loss (1–x) $Mg_{0.95}Co_{0.05}TiO_3$–(x) $Ca_{0.6}La_{0.8/3}TiO_3$ composite series for achieving a nearly zero temperature coefficient of resonant frequency. Ceram Int 2014; 40: 4257-4266.

[19] Luk KM, Leung KW. Dielectric Resonator Antennas. Baldock, UK: Research Studies Press Limited, 2002.

[20] Rezaei P, Hakkak M, Forooraghi K. Design of wide-band dielectric resonator antenna with a two-segment structure. Prog Electromagn Res 2006; 66: 111-124.

[21] Mazumdar B. A compact printed antenna for Wimax, WLAN & C band applications. International Journal of Computational Engineering Research 2012; 2: 1035-1037.

[22] Wang X, Nguyen HD, Hui HT. Correlation coefficient expression by S-parameters for two omni-directional MIMO antennas. In: IEEE 2011 International Symposium on Antennas and Propagation; 3–8 July 2011; Spokane, WA, USA. New York, NY, USA: IEEE. pp. 301-304.