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ULTRA-WIDEBAND AND MINIATURIZATION OF THE MICROSTRIP MONOPOLE PATCH ANTENNA (MMPA) WITH MODIFIED GROUND PLANE FOR WIRELESS APPLICATIONS

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Abstract—In this paper, ultra-wideband and miniaturization, technique for the microstrip monopole patch antenna (MMPA) in wireless applications is presented. Ultra-wideband was achieved by using printed modified ground plane on a dielectric substrate with $50\,\Omega$ microstrip feed line. This technique allows the bandwidth of the MMPA to be ultra-wideband with satisfactory radiation properties and reduces the antenna size. The proposed antenna with modified ground plane provides an impedance bandwidth ($S_{11} < -10\,\mathrm{dB}$) more than 5.5 GHz corresponding to 116% of fundamental resonant frequency with reduction in antenna size by 20% from original size. For further improvement in antenna characteristics, electromagnetic

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band-gap (EBG) structure is used. The surface wave was suppressed so the antenna bandwidth was increased to be 3–11 GHz corresponding to 170%, and the antenna size was reduced 43% of its original size. Two types of EBG are used. Holes are drilled around the patch, and embedded circular patches of the electromagnetic band-gap structure with suitable dimension are used. Details of the proposed antenna design have been describe, and the typical experimental results are presented and discussed. Commercial software high frequency structure simulator (HFSS®) version 11 was used for the antenna design.

1. INTRODUCTION

Recently, UWB has become a very promising wireless technology for many applications because of the attractive benefits it provides such as its resistance against jamming and multipath fading, low complexity and cost, power requirements and finally penetrating capability. According to the FCC the spectral mask of UWB for commercial applications is of frequency band 3.1 to 10.6 GHz [1]. The design of UWB antennas has received much attention in the research community in recent years. Most of these designs use canonical elements such as circles [2] or ellipses [3] for the radiating element. Combinations of these elements have also been used [4]. Printed monopole antennas are good candidates for such systems because of its numerous advantages such as small size, lightweight, low profile, low cast, and ease of integration with other microwave components. It is being used in large variety of applications such as radar, missiles, aircraft, satellite communications, mobile communication base stations, handsets, as well as in biomedical telemetry services [1]. However, these applications require wide bandwidth. There are numerous and well-known methods to increase the bandwidth of the antennas including the use of substrate thickness, low dielectric substrate, various impedance matching and feeding techniques [3], multiple resonators [4–6], and slot antenna geometry [7–9]. There has been extensive research on the antenna broadband and size reduction of microstrip monopole antennas [9, 10]. However, conventional UWB antennas in the geometry of either log periodic or spiral tend to be dispersive. They usually radiate different frequency components from different parts of the antenna, which distorts and stretches out the radiated waveform [3]. In wireless applications, the ground plane is an integral part of the antenna structure. In convention, MMPA shrinkage of the extended ground plate is an essential step for overall size reduction of antenna.

In this paper, a modified ground plane (MGP) is used to produce UWB antenna. The effects of the modified ground plane geometries on the antenna characteristics in terms of frequency domain and bandwidth are studied. Then, they are analyzed both numerically and experimentally in order to understand the operation of the antenna. It has been demonstrated that the optimal design of this type of antenna can achieve an ultra wide bandwidth with satisfactory radiation properties.

The second part of this paper uses electromagnetic band-gap structure (EBG) for further improvement of antenna characteristics such as impedance matching and surface wave suppression. The antenna bandwidth is increased. And by adding, inductive and capacitive load, the electrical antenna size is reduced. EBG structure has also been suggested under a broad terminology [12]. Several types of EBG structures have been proposed to improve the MMPA performance as drilling holes surrounded the antenna structure [13] and embedded EBG structure as shown in the following sections.

2. PROPOSED ANTENNA GEOMETRY

2.1. Microstrip Monopole Patch Antenna with Modified Ground Plane

First part of this paper uses conventional microstrip monopole patch antenna (MMPA) with modified ground plane (MGP) to obtain UWB antenna and reduce the antenna size. The antenna design is started with printed conventional square ground plane on substrate RT/D 6010 with dielectric constant 10.2 and dimension $20\,\text{mm} \times 20\,\text{mm}$. The substrate height is $2.5\,\text{mm}$ ($0.08\lambda_g$) guided wavelength at fundamental frequency 5.2 GHz, and the ground plane side length is 20 mm. The dimensions of rectangular radiator patch are $W_p \times L_p$ equal to $8 \times 6.5\,\text{mm}^2$ as shown in Figure 1(a), and the feed line is designed to provide $50\,\Omega$ feed width W_f at fundamental resonance frequency 5.2 GHz. Moreover, the feed length L_f was optimized to obtain the possible bandwidth. Then the effects of the ground plane length on both antenna resonant frequency and bandwidth are studied. The length L_g of the antenna ground plane is optimized to obtain maximum bandwidth at L_g equal to $0.32\lambda_g$ as shown in Figure 2(b).

Second step is modifying the shape of the ground plane as shown in Figure 1(c) to improve and decrease the bandwidth discontinuity as well as reduce the antenna resonant frequency. The MGP has many parameters as curved radius r_g, L_{gs} and L_s. For MMPA, the ground plane serves as an impedance matching circuit. Consequently, it tunes

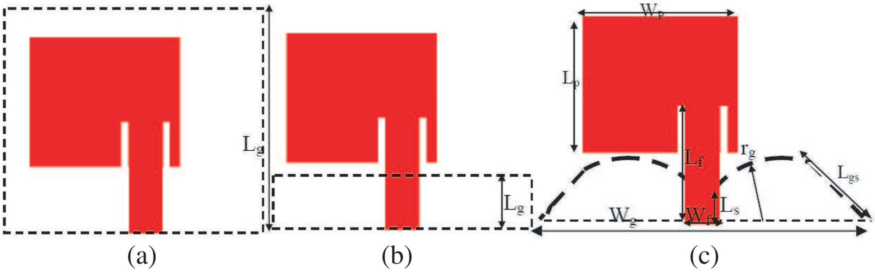

Figure 1. (a) MMPA with conventional ground plane with variable length, (b) MMPA with reduced ground length and (c) MMPA with modified ground plane.

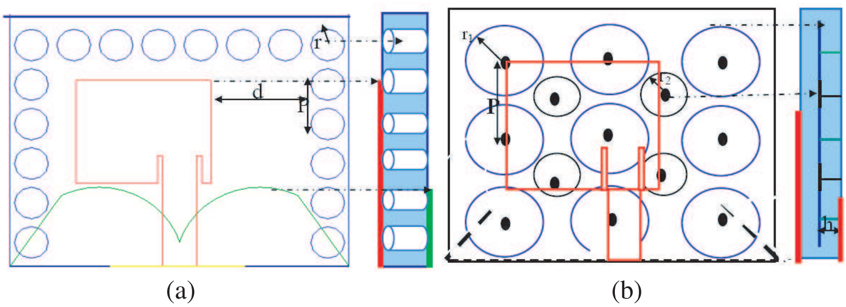

Figure 2. The proposed antenna elevation and side view (a) with surrounded cylindrical holes, (b) with embedded EBG.

the input impedance and hence the 10 dB return loss bandwidth by changing the feed length L_f. Another two important design parameters that affect the antenna performance are the parameters of the ground plane as r_g, L_{gs} and L_s and the dimensions of radiator patch $W_p \times L_p$.

2.2. Microstrip Monopole Patch Antenna with EBG Structure

Second part of this paper uses electromagnetic band gap (EBG) structure to improve the antenna performance. Three principal categories of such metamaterial have arisen and established. They are the photonic bandgap (PBG), the electromagnetic band-gap (EBG) structures [9], and the double-negative materials. This paper is focused on the second category mentioned above, namely the EBG structures. Cylindrical holes are drilled in the substrate surrounded the antenna radiator as shown in Figure 2(a) to prevent the surface wave to propagate then improve the antenna bandwidth [14]. The radius of the drilling holes, r, was selected to improve the antenna performance in the frequency region where high reflections were observed. This so called "discontinuity region" occurs in the frequency range around 10 GHz as shown in Equation (1). Guided wavelength in the dielectric material at 10 GHz is 9.3 mm, and this approximately equals the periodicity $P = 8$ mm of the whole. This diameter $d = 2r$, however, is sufficiently small to affect the antenna performance at lower frequencies particularly at the fundamental frequency of 5.2 GHz, and the distance between the drilling holes and the radiation patch are also optimized.

$$2d = \lambda_g \tag{1}$$

where d, λ_g are the diameter of the drilling holes and the guided wavelength, respectively.

Secondly embedded circular patches EBG structure are used to create band-gap that prevents electromagnetic wave to propagate in the substrate and add additional inductive and capacitive load to improve the matching impedance of MMPA. Different radiuses of the circular embedded patches are used to create dual band-gap. This has been the first attempt to exploit the properties of the EBG surface for antenna design and optimization. In this design, two different radii patches are used with same periodicity P to achieve dual band-gap. This parameter is calculated from Equation (2) to obtain optimum performance with inner via radius 0.25 mm; the embedded EBG structure is far from antenna radiator by 1.25 mm as shown in Figure 2(b) [9].

$$2r/P = 0.9 \sim 0.75 \tag{2}$$

where r may be r_1 or r_2, and P is periodicity.

Another interested property of EBG surfaces relates closely to the reflection phase, i.e., the phase of the reflected electric-field intensity at the reflecting surface, normalized by the phase of the incident electric-field intensity. It is well-known that a perfect electric conductor (PEC) presents reflection phase equal to 180° when a plane wave is normally incident on it. In contrast to that phenomenon, the reflection phase of a perfect magnetic conductor (PMC), which does not exist in nature, is equal to 0°. EBG structures have been known to function in a way that reminds of a PMC. Actually, the reflection phase of an EBG structure may vary with frequency continuously, and because of that property, EBG surfaces can exhibit both PEC and PMC-like behaviors, albeit at different frequencies. Furthermore, the anisotropic characteristics of EBG structures have been studied [14] and applied to the design of microstrip patch antenna as shown in Figure 2(b). The EBG used in this antenna structure is two different sizes of circular patches to create staggered electromagnetic band-gap bands.

3. EXPERIMENTAL RESULTS DISCUSSION

The antenna performance was investigated by using both simulations and measurements. Simulations were done by commercially available finite element program, HFSS, version 11. Fabrication was done by using photolithographic technique, then the measurements were done by using vector network analyzer. In order to provide the design criteria for the proposed antenna, the effects of each parameter of geometrical shape are analyzed.

First part in this paper reshapes the monopole antenna ground plane, started from conventional length equal to substrate length and then optimized L_g as shown in Figure 1(b). The reflection coefficient of the antenna at different ground plane lengths L_g is shown in Figure 3. There is optimum value of L_g that obtains larger bandwidth and reduces the antenna size at $L_g = 5\,\mathrm{mm}$.

Second, an optimization in reshaping the MGP with length and width that selected from previous step $5 \times 20\,\mathrm{mm}^2$ is used. Then the effects of each parameter of MGP are studied as the radius r_g and length L_{gs} are modified and optimized to obtain the ultra-wide bandwidth. Figure 4 shows that the effect of changed r_g on the antenna bandwidth. It shows that there is optimum value of r_g equal to 5 mm when the radius is smaller than the antenna resonate at multi frequencies with small bandwidth and on the other side when the radius increase compared to this value. The antenna reflection coefficient

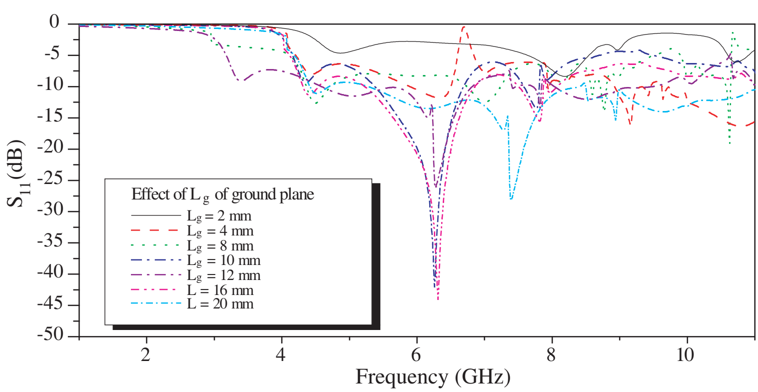

Figure 3. Effect of the antenna ground plane length L_g.

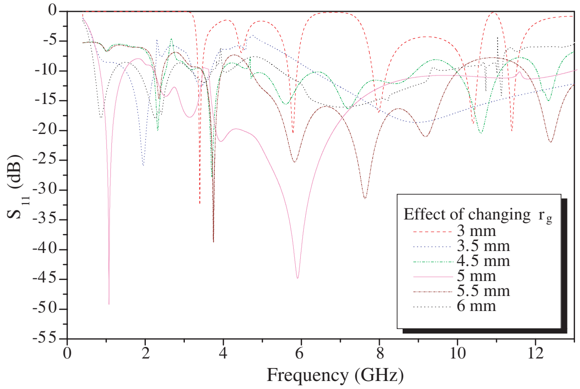

Figure 4. Effect of the radius r_g of the MGP.

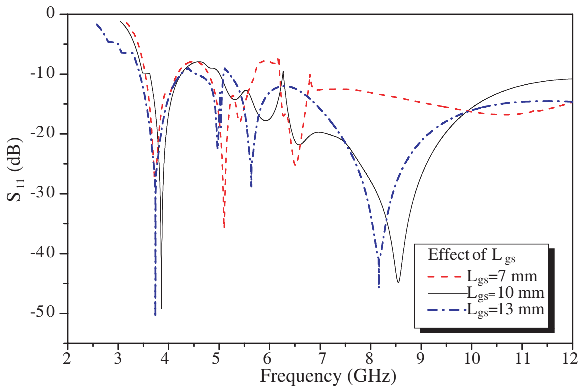

Figure 5. Effect of the L_{gs} of the MGP.

decreases all over the band. Moreover, the concept of using curvature ground plane is to make staggered resonant and smoothing in antenna bandwidth. Then the effect of L_{gs} is studied as shown in Figure 5. There is optimum value of L_{gs} equal to 10 mm and $L_s = 2$ mm, which gives ultra-wide bandwidth extended from 4.2 GHz to 10 GHz and 20% reduction in antenna size. The comparison between measured and simulated results of the reflection coefficient for MMPA with MGP is shown in Figure 6.

From Figure 6, there are many dips in the figure due to discreet solution in HFSS simulation. Figure 6 shows about 0.25 GHz difference between measured and simulated results, due to some error in fabrication as soldering size problem and associated discontinuity

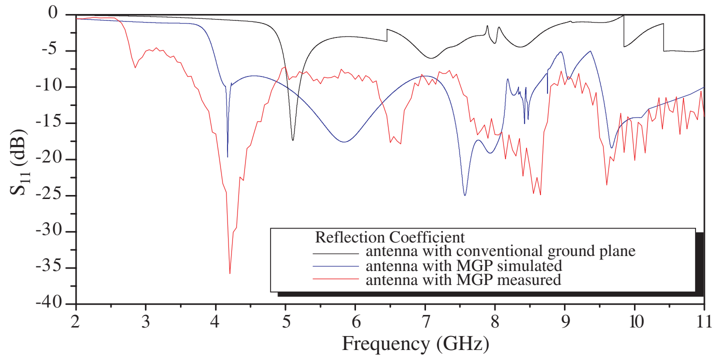

Figure 6. The comparison between simulated and measured of the reflection coefficient of the proposed antenna.

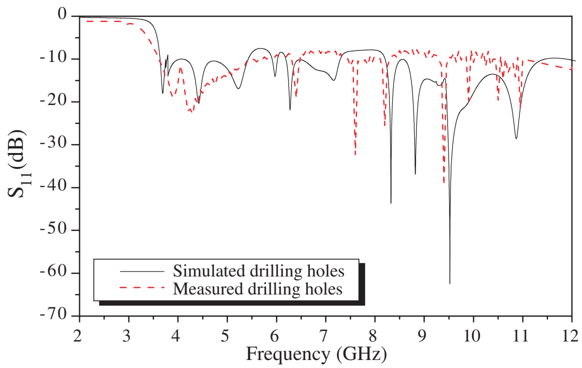

Figure 7. The comparison between simulated and measured of the reflection coefficient for drilling holes EBG.

effect. However, the modified ground plane reduces the antenna gain from 2.75 dBi to less than 1.5 dBi. Therefore, to obtain UWB antenna with acceptable gain, the electromagnetic band-gap structure is used.

Electromagnetic band gap structures are used to add further improvement in antenna bandwidth, increase gain, and reduce the electrical size of MMPA. Started with used photonic band gap as drilling cylindrical holes that surround the antenna radiator, the layout dimensions have been recomputed in a conventional way as Equation (1). Substrate with PBG does not interfere with the near field of the antenna, and it suppresses the surface waves, which are not included in the patch antenna design with condition [12–14]. The reflection coefficient comparison between measured and simulated results is shown in Figure 7. Figure 7 shows that an improvement in antenna bandwidth from 2.5 GHz to 11 GHz with lower discontinuity in antenna operating band as well as the surface wave is suppressed, thus the antenna gain is improved.

Further improvement is achieved by using electromagnetic band gap structure as embedded circular patches of EBG at height 1.25 mm from the ground plane. In these designs, two different radius patches are used with radii 1.75 mm and 1 mm and with the same periodicity 4 mm to achieve two-staggered band-gaps as shown in the transmission response in Figure 8. This parameter is calculated from Equation (2) to obtain optimum performance with inner via radius 0.25 mm. The embedded EBG structure far from radiator by 1.25 mm is shown in Figure 2(b) [9].

This embedded EBG structure produces capacitive load so that it improves the impedance matching and reduces the electrical antenna size. The antenna bandwidth extends from 2.75 GHz to 12 with 52% reduction in antenna size which is shown as a green line in Figure 7. From Figure 7, there is a difference between the measured and the simulated data. They may be explained in two main reasons; the first is related to inaccuracies in the fabrication process. This includes relatively large size soldering and the associated discontinuity with air gap between two layers used. The second reason may be due to the use of hand drilling machine that increases the tolerance. The simulated antenna gain with and without embedded EBG is shown in Figure 9. This figure shows that the antenna with embedded EBG produces

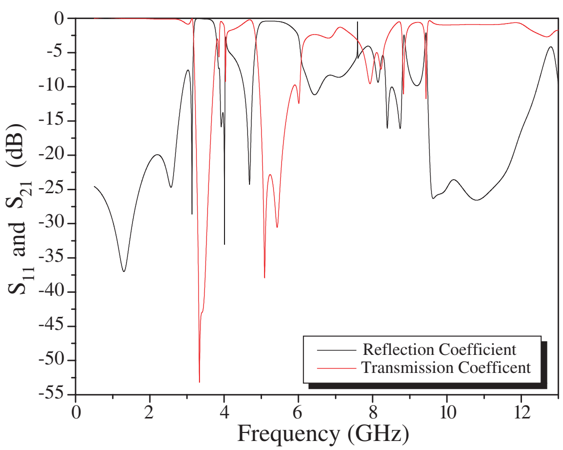

Figure 8. Transmission and reflection coefficient of the embedded circular patches.

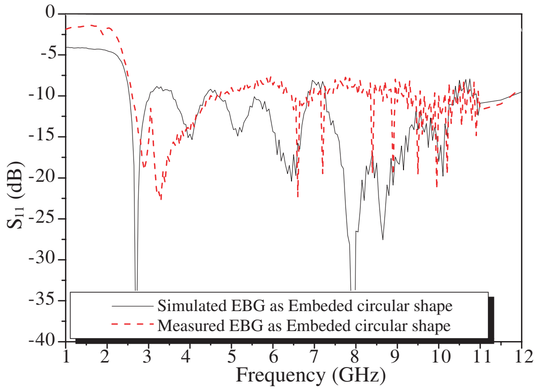

Figure 9. The comparison between simulated and measured of the reflection coefficient for embedded EBG.

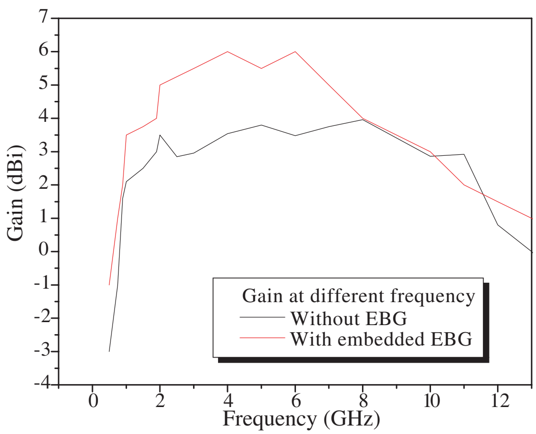

Figure 10. The MMPA gain without and with EBG structures.

better gain than without embedded EBG all over the operating band by 2 dBi in average. The higher gain obtained at frequencies 3 and 6 GHz is equal to 5.8 dBi. One may explain that this band is the resonant frequency band of the embedded circular patches as shown in Figure 8. The phase reflection comparisons among the three structures are shown in Figure 10. Figure 10 indicates that both EBG structures give better phase reflection response than without EBG, and the embedded circular patches give better response than drilling surrounded holes. As shown in Table 1, all the antenna parameters are summarized for different configurations. The photos of the fabricated antennas without and with EBG are shown in Figure 11.

Table 1. The full proposed antenna design procedures.

Parameterizes	Average gain (dBi)	Radiation Efficiency	Bandwidth
Full Ground	2.75	0.97%	3%
Partial Ground	1.5	0.75%	78%
Surrounded Holes	2.5	0.8%	117%
Embedded EBG	4.75	0.90%	200%

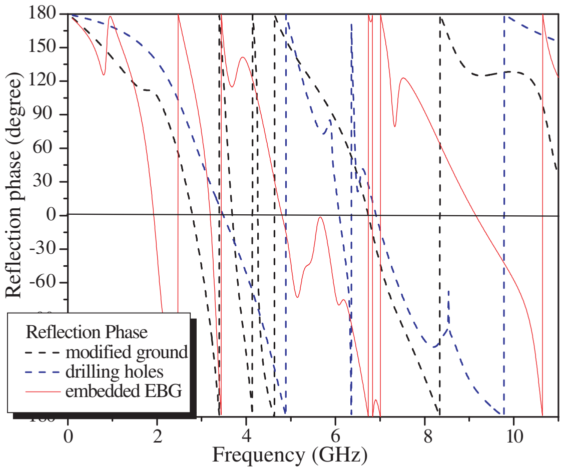

Figure 11. Reflection phase for MMPA without and with EBG structures.

Figure 12. The fabricated of the proposed antennas without and with EBG structures.

The different configurations of the proposed antennas are measured in both E- and H-planes, and this is shown in Figures 12 and 13 for the lower and higher frequencies 2.5 and 12 GHz, respectively. Figure 12 shows the measured radiation pattern in E- and H-planes at lower frequency 2.5 GHz for conventional ground plane and the modified ground plane without and with EBG structures. The

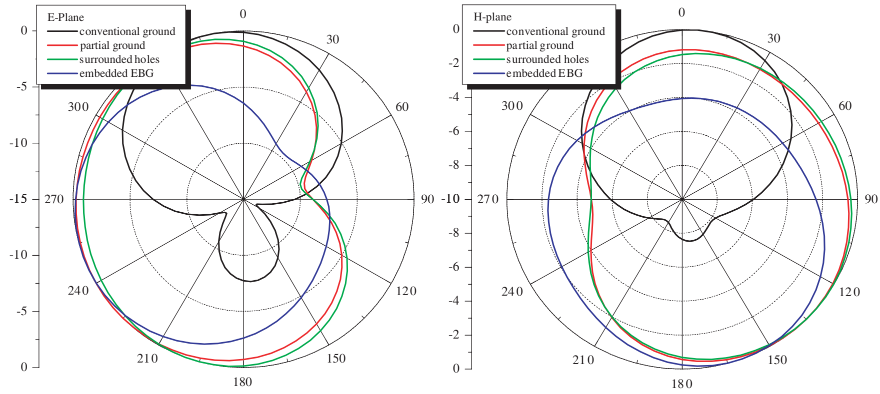

Figure 13. The measured E-plane and H-plane radiation pattern for MMPA at lower frequency (2.5 GHz).

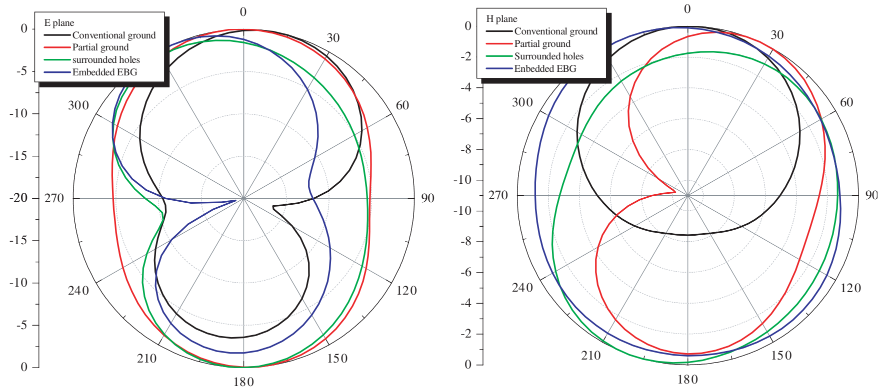

Figure 14. The measured E-plane and H-plane radiation pattern for MMPA at higher frequency (12 GHz).

radiation pattern looks acceptable for the lower and higher frequencies, and it looks unidirectional for antenna with embedded EBG.

4. CONCLUSION

In this paper, a novel shape of modified ground plane with conventional inset feed microstrip monopole patch antenna is present. The bandwidth is extended from 4 to 10 GHz, and a reduction in the antenna size by 20% is achieved by modifying the ground plane. This improves the impedance matching. For further improvement in the antenna parameters such as bandwidth, antenna size and gain, electromagnetic band-gap structure is used by drilling holes and embedding circular patches with different radii. The final proposed antenna is MMPA with embedded circular patches. It uses different radii to add additional capacitor that improves the impedance matching, obtains bandwidth extended from 2.5 GHz to 12 GHz with acceptable antenna gain 4.75 dBi, and reduces the electrical antenna size by 43% from the original one. The antenna phase reflection and radiation pattern in E- and H-planes are also presented.

REFERENCES

1. Ray, K. P., Y. Ranga, and P. Gabhale, "Printed square monopole antenna with semicircular base for ultra-wide bandwidth," *Electronics Letters*, Vol. 43, 13–14, 2007.
2. John, M. and M. J. Ammann, "Spline-based geometry for printed monopole antennas," *Electronics Letters*, Vol. 43, 7–8, 2007.
3. Liang, J., C. C. Chiau, X. Chen, and C. G. Parini, "Study of a printed circular disc monopole antenna for UWB systems," *IEEE Trans. on Antennas and Propag.*, Vol. 53, 3500–3504, 2005.
4. Wu, Q., R. Jin, J. Geng, and J. Lao, "Ultra-wideband rectangular disk monopole antenna with notched ground," *Electronics Letters*, Vol. 43, 605–606, 2007.
5. Liu, Z. D., P. S. Hall, and D. Wake, "Dual-frequency planar invert-F antenna," *IEEE Trans. on Antennas and Propag.*, Vol. 45, 1451–1457, 1997.
6. Kan, H. R. and R. B. Waterhouse, "Size reduction techniques for shorted patches," *Electronics Letters*, Vol. 35, 948–949, 1999.
7. Nashaat, D., H. Elsadek, and H. Ghali, "Broad band U-shaped PlFA with dual band capability for bluetooth and WLAN applications," *Proceedings of IEEE International Symposium on Antenna and Propagation*, Vol. 4, No. 1, January 2005.
8. Elsadek, H., and D. M. Nashaat, "Multiband and UWB V-shaped antenna configuration for wireless communications applications," *IEEE Antenna and Wireless Propagation Letters*, Vol. 7, 2008.
9. Brown, E. R., C. D. Parker, and E. Yablonovitch, "Radiation properties of a planar antenna on a photonic-crystal substrate," *Opt. Soc. Amer. B*, Vol. 10, No. 2, 404–407, February 1993.
10. Matthew, M. B., B. B. John, O. E. Henry, et al., "Two dimensional photonic crystals fabry-perror resonators with loss dielectrics," *IEEE Trans. Microwave Theory Tech.*, Vol. 49, No. 11, 2085–2090, November 1999.

11. Gonzalo, R., P. Maaget, and M. Sorolla, "Enhanced patch antenna performance by suppressing surface waves using photonic band-gap substrates," *IEEE Transaction on Microwave Theory and Techniques*, Vol. 47, No. 11, 2131–2138, November 1999.
12. Mosallei, H. and K. Sarabandi, "Antenna miniaturization and bandwidth enhancement using a reactive impedance substrate," *IEEE Trans. on Antennas and Propag.*, Vol. 52, No. 9, September 2004.
13. Hao, Y. and C. G. Paini, "Isolation enhancement of anisotropic UC-PBG microstrip diplexer patch antenna," *IEEE Antennas and Wireless Propagation Letters*, Vol. 1, 135–137, 2002.
14. Nashaat, D., H. A. Elsadek, E. Abdallah, H. Elhenawy, and M. F. Iskander, "Enhancement of ultra-wide bandwidth of microstrip monopole antenna by using metamaterial structures," *IEEE Antenna and Wireless Propagation Letters*, submitted, 2009.