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Implementation of An Ultra-Wideband MPA with Two Perpendicular Rectangular Slots for Wireless Mobile Sensor Applications

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ABSTRACT

A new ultra-wideband probe-fed microstrip patch antenna has been designed and fabricated. Two perpendicular rectangular slots were incorporated to perturb the surface current, introducing capacitive reactance which counteracts the inductive reactance of the probe that is responsible for the excitation of additional resonant modes. A comprehensive parametric study has been carried out to understand the effects of various dimensional parameters and to optimize the performance of the antenna. A 3.8-8.6 GHz impedance bandwidth has been achieved for VSWR ≤ 2. The radiation pattern is nearly stable as the frequency changes along the bandwidth with maximum radiation in the broadside direction. The final antenna peak gain is changed from 4 dB up to 7.5 dB and the radiation efficiency varies from 62% to 80 % through the operating impedance bandwidth. The proposed antenna has been examined using two simulation techniques, HFSS and FDTD home-made MATLAB program. A prototype of the proposed antenna has been fabricated and experimentally measured. The measurement results are in very good agreement with the simulated ones. Using such an antenna, many applications, including WiMAX, Wi-Fi, UWB applications, as well as wireless sensor mobile applications would be available.

Keywords: Ultra-Wideband, MPA, return loss, impedance bandwidth, UWB, HFSS, FDTD, wireless sensors

1 INTRODUCTION

The demand for mobile communication systems has increased significantly during the past ten years and is still growing. Wireless sensors, GPS, WLAN, Wi-MAX, as well as UWB are significant standards in mobile communication. Effective small-size antennas are needed for these wireless applications. Along with cellular and mobile technologies, portable antenna technology has developed [1-4].

Due to their inherent advantages, such as their low profile, compact size, lightweight, and inexpensive production, MPAs are frequently utilized in modern communications [1]. The MPA's constrained impedance bandwidth is one of its greatest flaws. This problem can be solved in a variety of ways [5–16]. For instance, the U-slots approach, a common patch-etching method for multiband operation, was largely used to increase bandwidth [7]. The E, H, and U-slotted patch MPAs are quite prevalent and have certain unique characteristics [11–14]. A report on the design of MPAs with many layers may be found in [11]. Khunead et al. [15] examined the performance of rectangular patch antennas of similar size with and without the inclusion of two L-shaped strips.

The objective of this paper is to design and practically realize an ultra-wideband probe fed MPA. The proposed technique to widen the operating frequency band is a mixture of using slots, selecting of dielectric material type, and controlling the thickness of the dielectric wafer. A band from 3.8 GHz up to 8.6 GHz has been achieved. The antenna peak gain changes from 4 dB up to 7.5 dB. The radiation efficiency varies from 62% to 80 % over the operating frequency range. Ansys HFSS [17] and FDTD homemade MATLAB program [18-20] have been used to investigate the radiation characteristics of the proposed antenna. To assess the validity of the used simulation techniques, the proposed antenna has been fabricated and tested. Measured results are in very good agreement with the simulated results.

2 ANTENNA DESIGN

The design of the proposed antenna is shown in Fig. 1. The antenna structure consists of a rectangular patch with 30×40 mm. Two perpendicular slots are incorporated. This would perturb the surface current path that would introduce local inductive effects responsible for the excitation of additional resonant modes. The slots' dimensions are $L_1 \times W_1$, and $L_2 \times W_2$ respectively. A 50 Ω coaxial probe with a 0.75 mm inner radius is used to excite the proposed antenna and centered at (X_o, Y_o). The ground plane dimensions are 100×100 mm^2.

3 PARAMETRIC STUDY

A prototype antenna with initial dimensions as given in table 1 is considered. A comprehensive parametric study has been carried out to understand the effects of varying dielectric material types, wafer thickness, and slots' dimensions on the performance of antenna return loss.

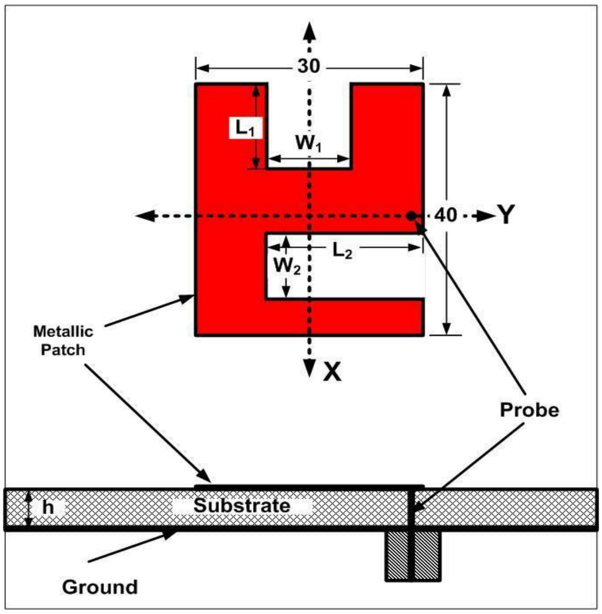

Figure 1. Proposed ultra wideband MPA

Table 1. The detailed parameters for the proposed MPA antenna.

Symbol	Value (mm)
L_1	16
W_1	12
L_2	21
W_2	13
ε_r	variable
h	variable
X_o	0
Y_o	13

Figures 2-5 show the return loss S_{11} in dB versus frequency for different dielectric materials with different heights, good results are only shown. From the results, one can notice that increasing the dielectric constant of the dielectric material improves the operating impedance bandwidth in the upper-frequency range. While increasing the height of the dielectric material improves the operating impedance bandwidth in the lower frequency range.

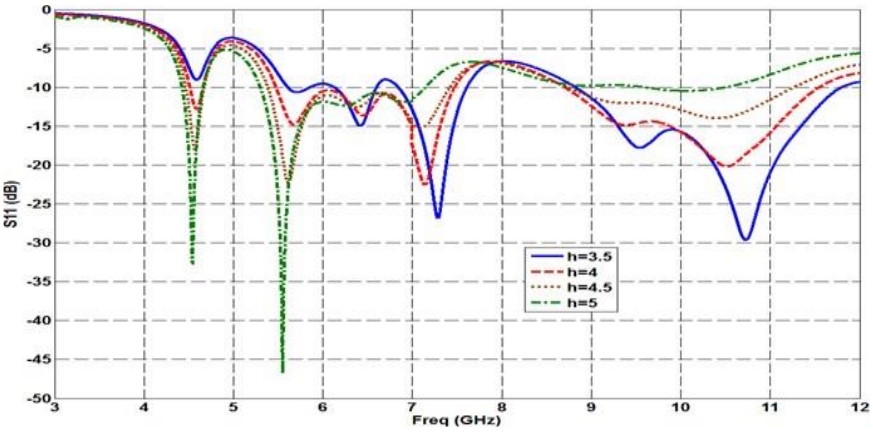

Figure 2. The effect of varying the dielectric height (h in mm) for Rogers RT/duroid 5880 (tm) With dielectric constant = 2.2 and dielectric loss tangent=0.0009.

Results show that the best suitable dielectric material is FR4 epoxy with a height equal to 5mm and that results in a frequency bandwidth ranging from 3.9 up to 8.4 GHz with a band rejection ranging from 5.5 up to 5.8 GHz. This case has been further optimized to further widen the operating impedance bandwidth by optimizing the slots' dimensions. The values of L_1, L_2, W_1, and W_2 were changed and their effect on the reflection coefficient was investigated.

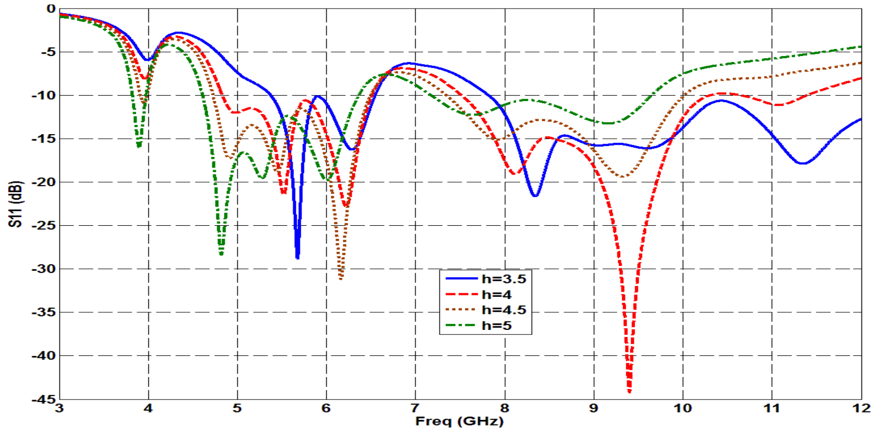

Figure 3. The effect of varying the dielectric height (h in mm) for Rogers RO 3003 (TM) with dielectric constant = 3 and dielectric loss tangent=0.0013.

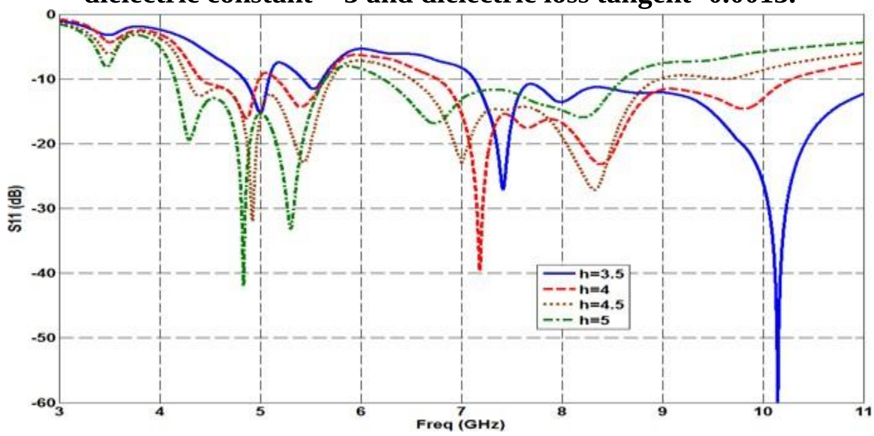

Figure 4. The effect of varying the dielectric height (h in mm) for polymide Quartz With dielectric **constant = 4 and dielectric loss tangent=0.**

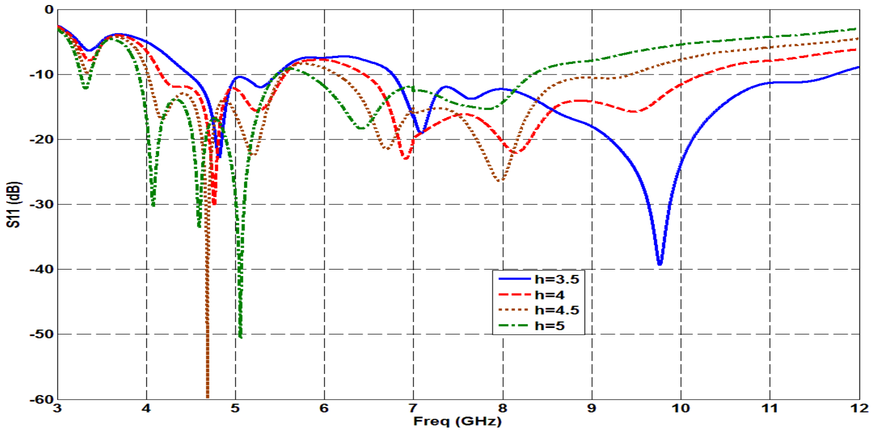

Figure 5. The effect of varying the dielectric height (h in mm) for FR4 epoxy with dielectric constant = 4.4 and dielectric loss tangent=0.02.

Figure 6 shows the effect of changing L_1 on the return loss. At L_1=14 mm the frequency band has been extended from 3.9 up to 8.4 GHz without any exceptions.

Figure 7 shows the effect of varying the width W_1 on the return loss value when L_1 is held constant at 14 mm. Figure 7 shows that at W_1=14 mm a wider impedance bandwidth that extends from 3.8 up to 8.4 GHz is achieved. Figure 8 shows the variation of the reflection coefficient S_{11} with frequency for different values of L_2. At L_2=20 mm the resultant impedance bandwidth extends from 3.8 up to 8.5 GHz. Finally, W_2 has been changed and the return loss has been recorded in Fig. 9. An impedance bandwidth ranging from 3.8 up to 8.6 GHz is obtained at W_2= 8 mm.

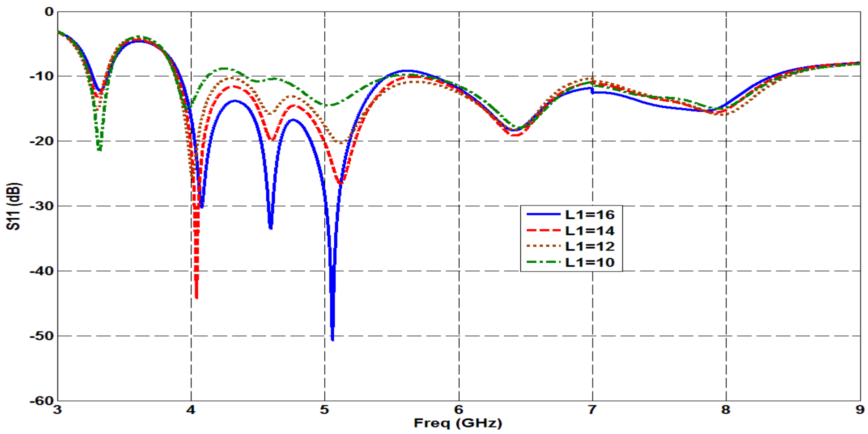

Figure 6. The effect of varying the upper slot length L1 in mm.

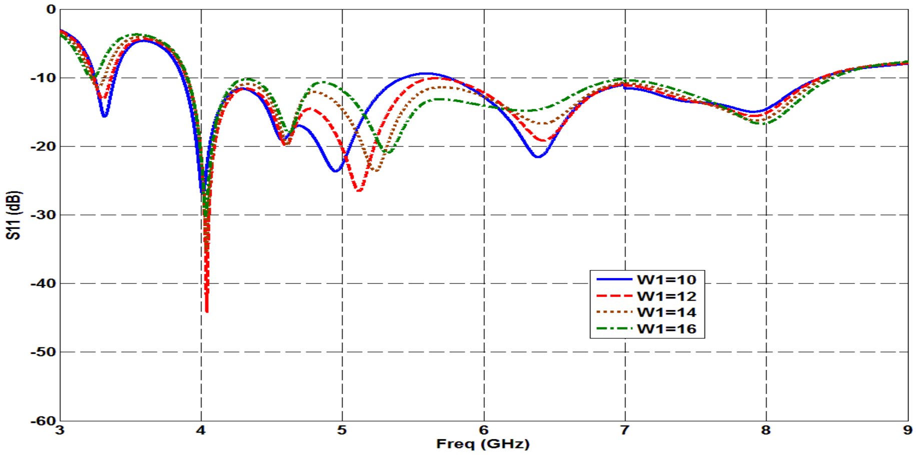

Figure 7. The effect of varying the upper slot Width W1 in mm.

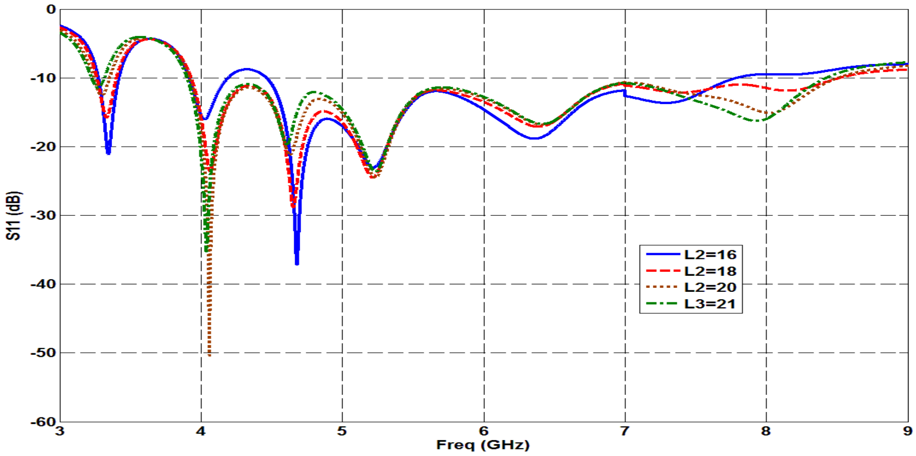

Figure 8. The effect of varying the lower slot length L2 in mm.

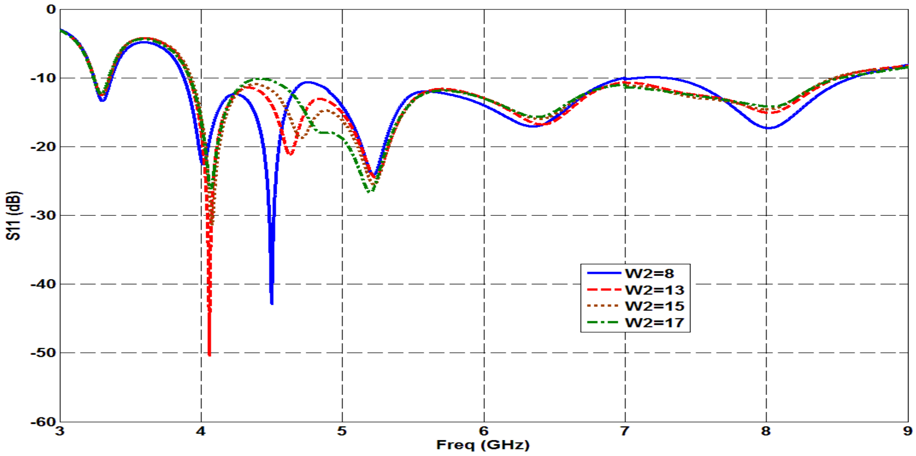

Figure 9. The effect of varying the lower slot width W2 in mm.

According to the parametric study, the design that satisfies the widest impedance bandwidth is characterized by; a dielectric wafer that is made from FR4 epoxy with a height equal to 5mm, and slots of dimensions L_1= 14 mm, L_2= 20 mm, W_1= 14 mm, and W_2= 8 mm. Figure 10 shows a comparison between the results of the proposed design compared to the same antenna but without using slots. The antenna with a solid patch has two resonant frequencies at 3.4 GHz and 5.7 GHz. The results show the effect of the two perpendicular slots on widening the operating frequency bandwidth. This is due to the effect of the slots to perturb the surface current, introducing capacitive reactance which counteracts the inductive reactance of the probe that is responsible for the excitation of additional resonant mode.

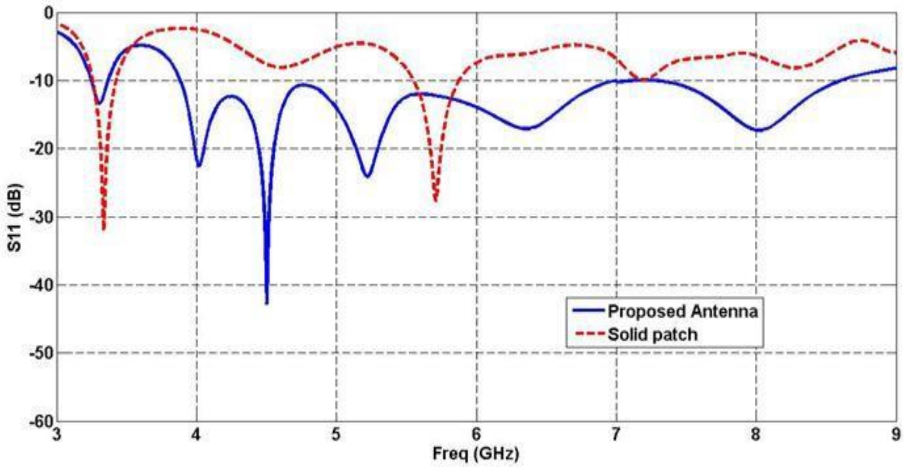

Figure 10. S11 comparison between the final optimized case and the antenna with a solid patch.

4 FDTD IMPLEMENTATION

The Finite Difference Time Domain MATLAB program has been used as a 2nd simulation technique to check the previous results. A cubic cell of length λ/25 is used to discretize the proposed antenna structure. The time step size Δt is calculated to meet the Courant stability condition. Ten Berenger's PML layers with polynomial conductivity profiles are used to terminate the simulation domain. Figure 11, shows the comparison between HFSS and FDTD return loss versus frequency results. A very good agreement has been obtained between both results.

5 ANTENNA FABRICATION and EXPERIMENTAL RESULTS

To ensure the above-simulated results, experimental work is needed. Slabs of dielectric constant 4.5 instead of 4.4, and thickness of 1.5 mm are available at National Research Centre in Egypt. The practical prototype antenna would be made of three dielectric slabs glued together each of thickness 1.5 mm, producing a total dielectric height of 4.5 mm, instead of 5mm. The antenna with the available practical dimensions has been fabricated and tested. The RF cable is connected from the Vector Network Analyzer to the SMA connector to excite the antenna.

Figure 12 shows the photograph of the practical MPA. Figure 13 shows the variation of the measured and simulated return losses of the proposed antenna with frequency. A very good agreement has been obtained between both results. The differences between the simulated and measured results would be due to the effect of RF cable, whereas in the measurements of small antennas, the RF cable usually affects the performance of the antenna under test greatly [1]. Also, the substrate is made from three layers each of 1.5 mm thickness and glued to each other to form the 4.5 mm thickness substrate, which yields the composite dielectric with different materials and hence different performance.

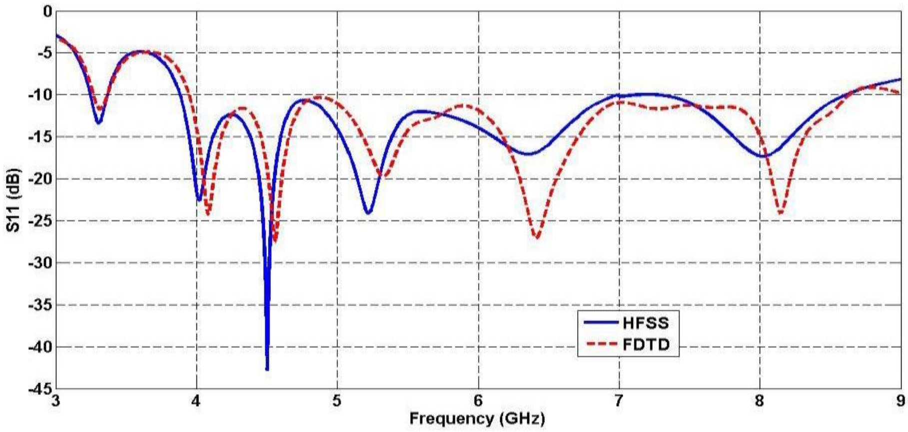

Figure 11. Comparison between FDTD and HFSS S11 results for the final optimized case.

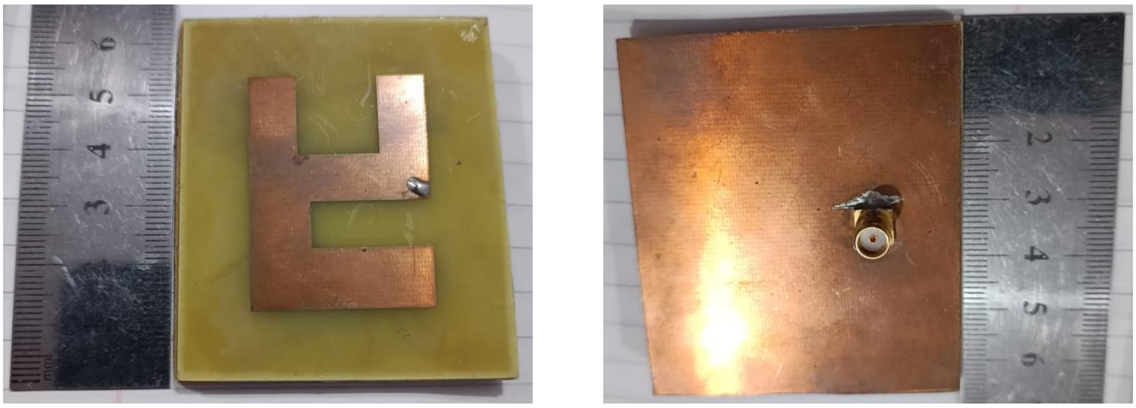

Figure 12. The photograph of the proposed MPA.

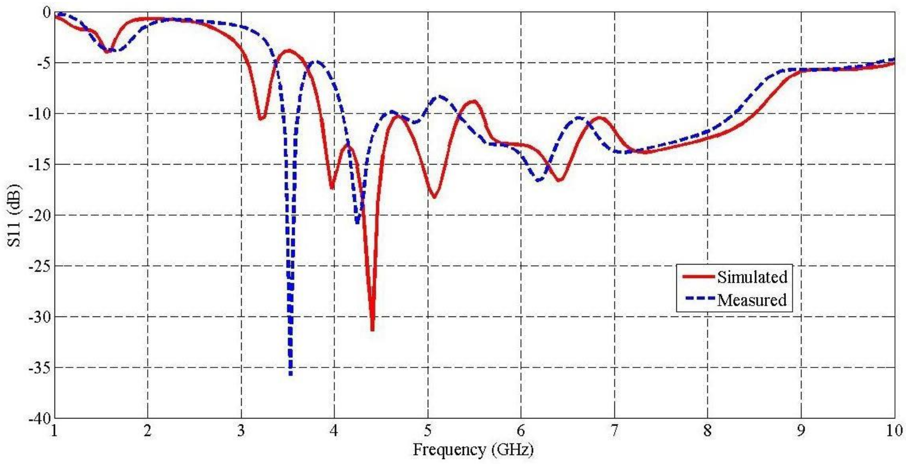

Figure 13. The comparison between simulated and measured return losses.

The simulated radiation patterns at 4.5, 5.2, 6.4, and 8 GHz in XZ, YZ, and XY planes are shown in Fig. 14. From the figure, there are no significant changes in the radiation patterns in most frequencies. Also, the results show that the radiation patterns have their maximum radiation in the broad side direction.

The peak gain and radiation efficiency versus the operating frequency of the proposed antenna are shown in Fig. 15 and 16 respectively. The peak gain varies from 4 dB to 7.5 dB over the operating frequency range. The radiation efficiency varies from 62% to 80 % over the operating frequency range.

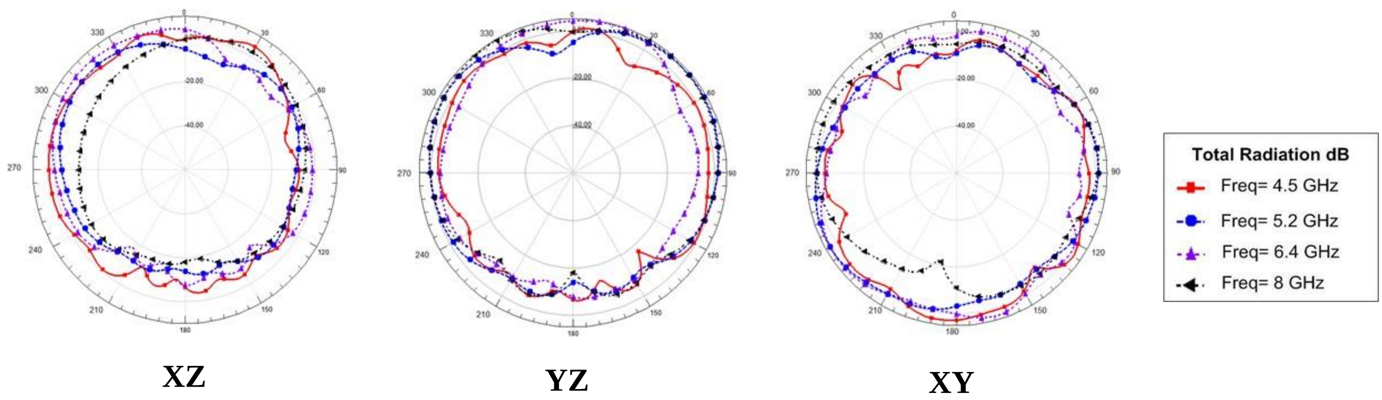

Figure 14. The simulated radiation patterns for the proposed antenna.

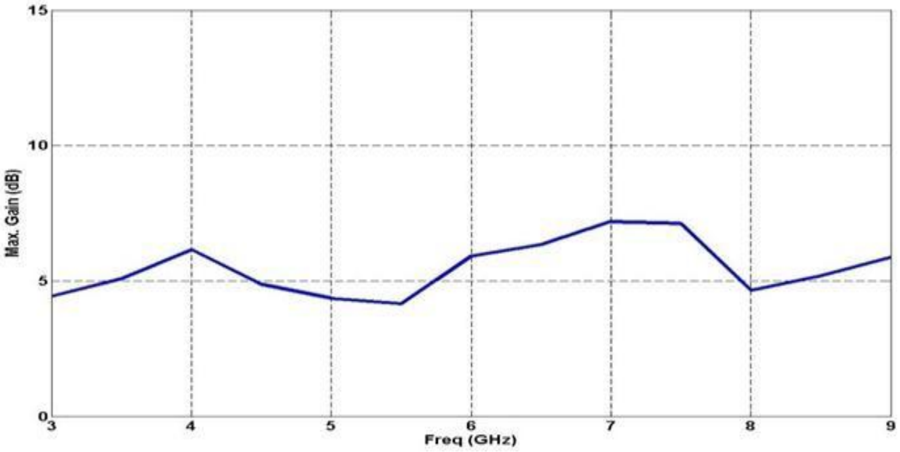

Figure 15. The simulated peak gain for the final case.

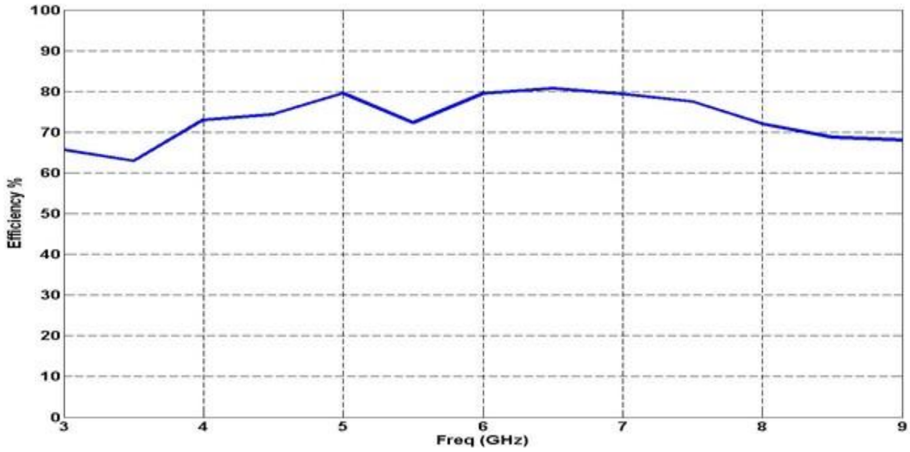

Figure 16 The simulated radiation efficiency for the final case.

6 CONCLUSIONS

In this paper, a new ultra-wideband probe fed MPA with two perpendicular slots has been designed and fabricated. An impedance bandwidth from 3.8 GHz up to 8.6 GHz has been obtained. This is referred to as the effect of introducing the slots that perturb the surface current, generating capacitive reactance which counteracts the inductive reactance of the probe. This is responsible for the excitation of additional resonant mode. Adjusting the slots' dimensions keeps controlling the operating frequency bandwidth. A maximum peak gain of about 7.5 dB has been achieved at 7 GHz. The radiation patterns for the proposed MPA antenna at different frequencies have been given. The results show that the radiation patterns are approximately stable as the frequency changes with broadside directional patterns. The proposed antenna would be used for many applications including WiMAX, Wi-Fi, UWB as well as wireless sensor mobile applications.

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