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Connected U-Slots Patch Antenna for WiMAX Applications

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Abstract

A compact microstrip patch antenna with two U-slots shape is presented. Detailed simulation and experimental investigation are conducted to understand the behaviour of the two U-slots. The designed antenna generates three resonant modes at 2.7, 3.3 and 5.3 GHz and can, therefore, be used in WiMAX compliant communication equipment. It is shown that, each U-slot generates a single band and when combined in one shape, a third resonant mode can be obtained. Two bridge elements have been added to shift the frequencies to lower bands. A comprehensive parametric study has been applied to understand the effect of each U-slot on the antenna's performance. The proposed antenna is verified experimentally and the simulated and measured results are in good agreement.

Index Term— *Double U-Slot, Patch Antenna, Small Antenna, U-Shape Antenna, WiMAX Antenna*

1. Introduction

The IEEE 802.16 working group has established a new standard known as WiMAX (Worldwide Interoperability for Microwave Access) which can reach a theoretical up to 30-mile radius coverage. Moreover, in the case of WiMAX, the highest theoretically achievable transmission rates are possible at 70 Mbps. As currently defined through IEEE Standard 802.16, a wireless MAN provides network access to buildings through exterior antennas communicating with central radio base stations (BSs). One of the potential applications of WiMAX is to provide backhaul support for mobile WiFi hotspots. In order to satisfy the integration of WiFi, WiBro and WiMAX for WMAN applications, multiband compact antennas are the preferred front-end for mobile terminals [1].

The broadband characteristic of a microstrip patch antenna with U-shaped slot has been confirmed by many published results [2-4]. Also, several designs of broadband slots antenna have been reported [5-6]. A multi U-slot Patch antenna has been reported recently for 5 GHz WLAN [7], and a monopole antenna for WiMAX applications was proposed in [8]. A rectangular microstrip antenna with two U-shaped slots on the patch using foam layer has been reported in [9]. Recently, some designs have been reported to achieve multi-band antenna for Wireless LAN application [10-11]. Many researchers have studied the deviation of multiple resonances and low-profile structure by using shorting walls. In [12] a half U-slot antenna with a shorting wall has been reported with a 28 % impedance bandwidth. A bandwidth enhancement for conical radiation using a shorting wall has been studied recently and reported in [13], and a wideband stacked antenna using a shorting wall has been introduced in [14]. In all the above designs, single and multi bands were achieved by either modifying the shape or by inserting a single or double shorting wall to the antenna. The main goals of the previous research work and literature related to the patch antenna are focusing on achieving multi-wide bands, improving the impedance bandwidth performance and stable gain.

In this paper, two slots and two bridge elements have been applied to achieve triple bands to be used in WiMAX application. It has been found that, by connecting the two U-slots, the exact resonant frequencies can be shifted to a lower mode. The total size of the ground plane is 70 mm x 70 mm and the size of the radiated patch is 40 mm x 50 mm., fed by a 50 Ω microstrip line. A comprehensive parametric study on the structure is made in order to understand the effect of various dimensions of the main parameters. The proposed antenna is simulated with commercially available package HFSS software which is based on the finite element method. The antenna has been fabricated; its return loss was measured using Agilent N5230A Network Analyzer. The results of the simulations and measurements were found to be in good agreement.

The paper is divided as follows: Section 2 discusses the antenna dimensions and configuration; Section 3 presents the design procedure in detail; Section 4 shows parametric study on some important parameters; Section 5 explains the fabrication process for the antenna and comparison between the simulated and the measured results; Section 6 concludes the paper.

2. Antenna Design and Configuration

The design specifications for the proposed antenna are:

- The dielectric material selected for the design is FR4.
- Dielectric constant 4.4

- Height of substrate (h) = 1.57 mm.

The antenna is fed by 50 Ω microstrip line, the main advantage of using transmission line feeding is very easy to fabricate and simple to match by controlling the inset position and relatively simple to model. The proposed antenna has two U-slot shaped and two bridges to connect both shapes together as shown in figure 1, the detailed dimensions are given in table I. The proposed antenna generates three bands at 2.7, 3.3 and 5.3 GHz with simulated impedance bandwidth of 4.8 %, 3 % and 2.5 % respectively. Thus the three bands satisfied the required bandwidth for the WiMAX compliant transmitters.

3. Antenna Design Procedure

This section describes the approach of designing a patch antenna using two U-slots techniques to adapt the structure to the desired interest operating frequency. The proposed antenna consists of a ground plane, a printed patch and a microstrip feeding line. The most important parameters that affect the antenna performance, such as impedance bandwidth, gain and efficiency are described in this section.

A rectangular patch antenna fundamentally resonates at half wavelength. In step one, some formulas have been used to design the total size of the patch [1]. The total size obtained is 40 x 50 mm^2; as a first step to generate three bands, the first U-slot was designed which can generate a single resonant frequency at 3.5 GHz. The 3.5 GHz is one of the targeted frequencies as it represents the second band of the WiMAX application as shown in figure 2. In order to generate another frequency band, the current path has to travel longer than its usual path; this can be obtained by looking at the current distribution of the first U-slot - the current will be forced to travel further than the normal way. The second step is to design another U-slot larger than the first one, which generates a single band at 4.5 GHz as shown in figure 3.

The third step is to combine the first and the second U-slots together in one shape as shown in figure 4 (a). As a result of combining both U-slots in one shape, three bands have been generated at 3.2, 4.2 and 5.4 GHz. However, WiMAX has been allocated three frequency bands called the low band (2.5 to 2.8 GHz), the middle band (3.2 to 3.8 GHz) and the high band (5.2 to 5.8 GHz). Therefore, connecting both U-slots together by two bridges will shift the frequencies to lower bands. In addition, the fine tuning of the length, width and the location of the bridges and the feeding line results in the final targeted frequencies as shown in figure 4 (b) and table II. The proposed antenna operates with adequate bandwidths at the specified operating frequencies within the WiMaX bands. An edge feed approach was employed in the design as it will be convenient to integrate the antenna with other microstrip circuits printed on the same board and also to reduce space requirements. The offset feeding arrangement was found to give a better input match at these operating frequencies and hence it was adopted.

4. Parametric Study

Of all the investigated design parameters, two of them have a very noticeable effect in determining the performance of the antenna. The parameters that show the most effect are W and W_2. In order to check the changes of the frequencies shift or bandwidth changes, parametric studies for each parameter have been optimized and obtained from iterative simulation with initial data. Figs. 5 and 6 show the difference in the return losses according to parameter changes. These effects will be explained and summarized in this section.

In figure 5, it shows the return loss based on variation in the width of the second U-slot (W) from 40 mm to 45 mm and to 35 mm. The first and second bands are not affected by the width of the second U-slot. However, there is a noticeable change on the bandwidth and the matching of -10 dB on the third band when decreasing the size of (W) from 40 mm to 35 mm. Not only that, but also the resonant frequency moves to the lower band. This is due to the increase in the width of the total size of the antenna. The good characteristic of the return loss and the bandwidth is obtained when (W) is 40 mm.

Figure 6 describes the return loss based on increasing and decreasing the width (W_2) of the first U-slot. (W_2) affects the resonance frequency of the first band by only 2.7 GHz. Therefore, when (W_2) is 15 mm the first band is at 2.7 GHz. By increasing the value to 17 mm the bandwidth of the first band is decreased and shifted to a lower band whereas by decreasing the value to 13 mm, the band is shifted to a higher mode and also the bandwidth becomes narrower. The good characteristic of the return loss and the bandwidth is obtained when (W_2) is 40 mm. As a result, the antenna can be easily constructed on any other band by choosing the appropriate width for both U-slots.

5. Experimental Results

In order to validate the simulation results from HFSS software, the proposed antenna has been fabricated according to the specifications given in the previous section. Figure 7 (a) shows the prototype of the antenna. The proposed antenna was fabricated, tested, and compared with simulated results. The return loss was measured using Agilent N5230A vector network analyser. In figure 7 (b), the simulated values of the S_{11} in the final design are compared with the measured data. It was found that the simulated and measured results were in good agreement, confirming that the simulated results were obtained with reasonable accuracy. The discrepancy between the simulated and measured results might be attributed to the fabrication process. The radiation patterns at the centre frequencies 2.7, 3.3 and 5.3 GHz of WiMAX application are plotted as shown in figure 8 (a)-(c). From the radiation patterns it can be observed that there is a stable response throughout the WiMAX bands with -8 dB low cross polarization for the first band and below -10 dB for the second and third bands. The antenna gain is 1.7 dBi at 2.7 GHz, 2.3 dBi at 3.3 GHz and 4.1 dBi at 5.2 GHz as shown in figure 9 (a). The three bands have a radiation efficiency of 67 %, 60 % and 80 % respectively as shown in figure 9 (b). The current distributions calculated for the antenna are plotted in figures10 (a)-(c) at 2.7, 3.3 and 5.3 GHz which shows the radiation mechanism of the antenna.

Conclusion

This paper presented the simulation and experimental investigation of a printed patch antenna with two U-slots. By adding two U-slots shape on the patch, the three bands can be generated, and by adding two bridges the exact frequencies band for WiMAX can be achieved. Very broad radiation pattern results have been obtained which seems to be adequate for the envisaged applications. The designed antenna has been fabricated and tested to verify the results from HFSS software. The measured and simulated results showed very good agreement. It has been verified that two bridges can decrease the size of the antenna by shifting the operating frequencies to lower bands without changing the size of the main parameters. The proposed antenna complies with WiMAX specifications.

Acknowledgment

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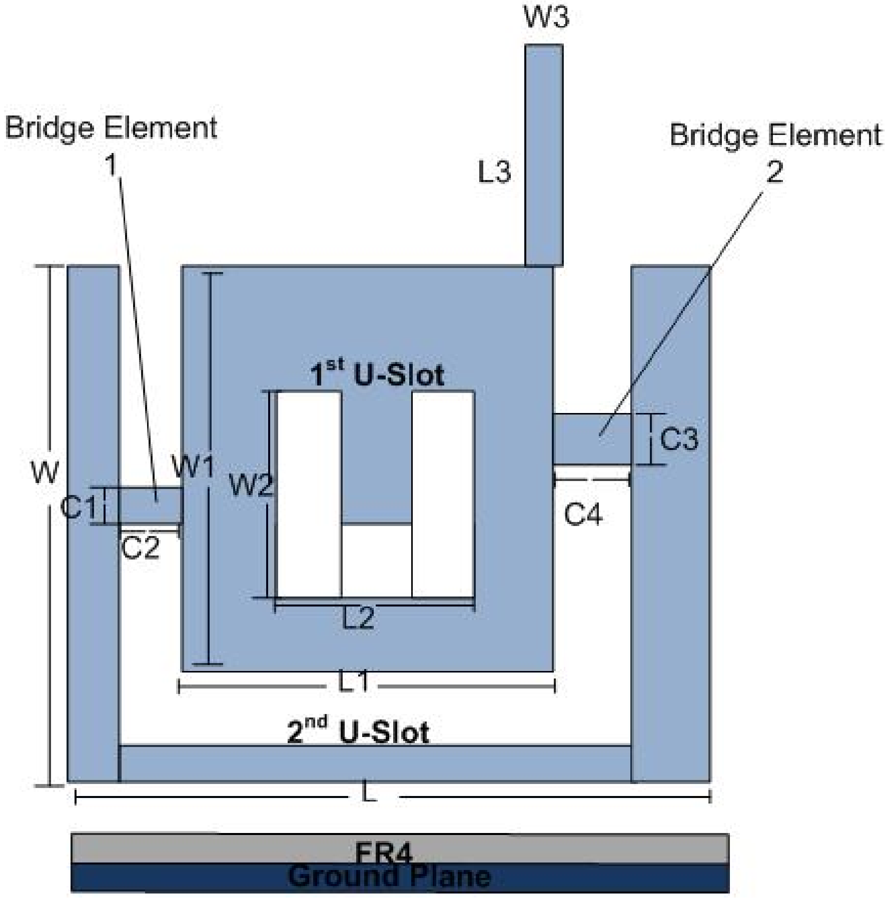


Figure 1 The structure and detailed diminutions of the proposed patch antenna

TABLE I THE DIMINUTIONS FOR THE DOUBLE U-SLOTS ANTENNA (UNIT: MM)

W	**L**	**W_1**	**L_1**	**W_2**	**L_2**
40	50	30	25	15	15
W_3	**L_3**	**C_1**	**C_2**	**C_3**	**C_4**
2.89	20	5	2.5	5	5

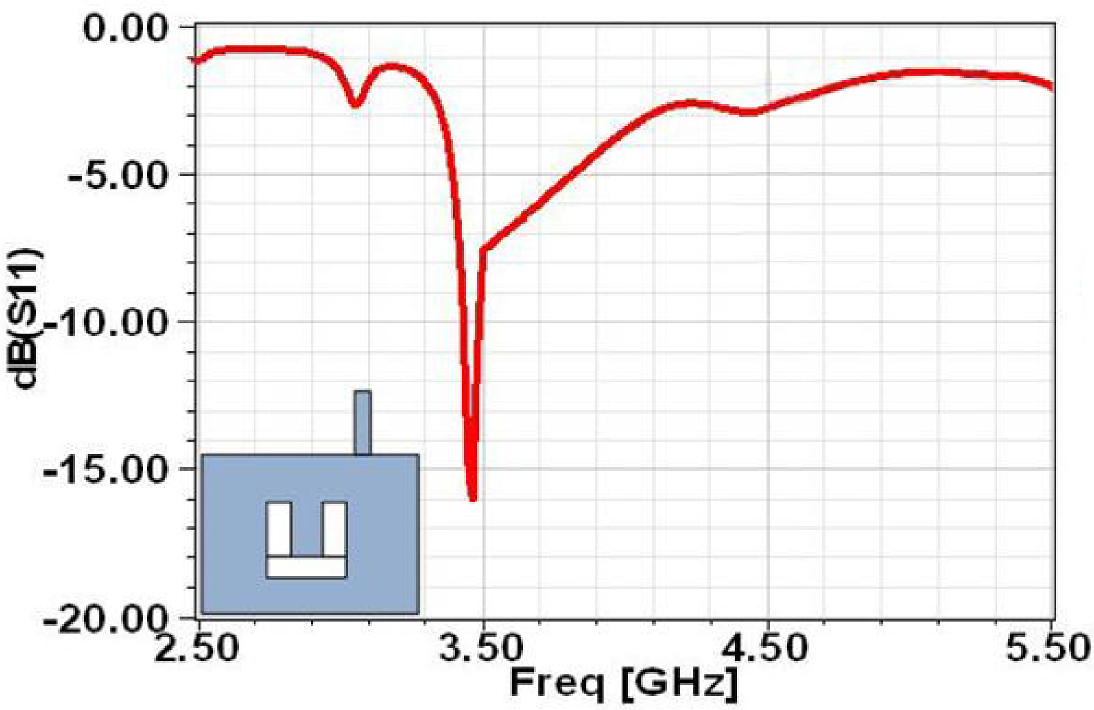


Figure 2 The return loss with the first U-slot

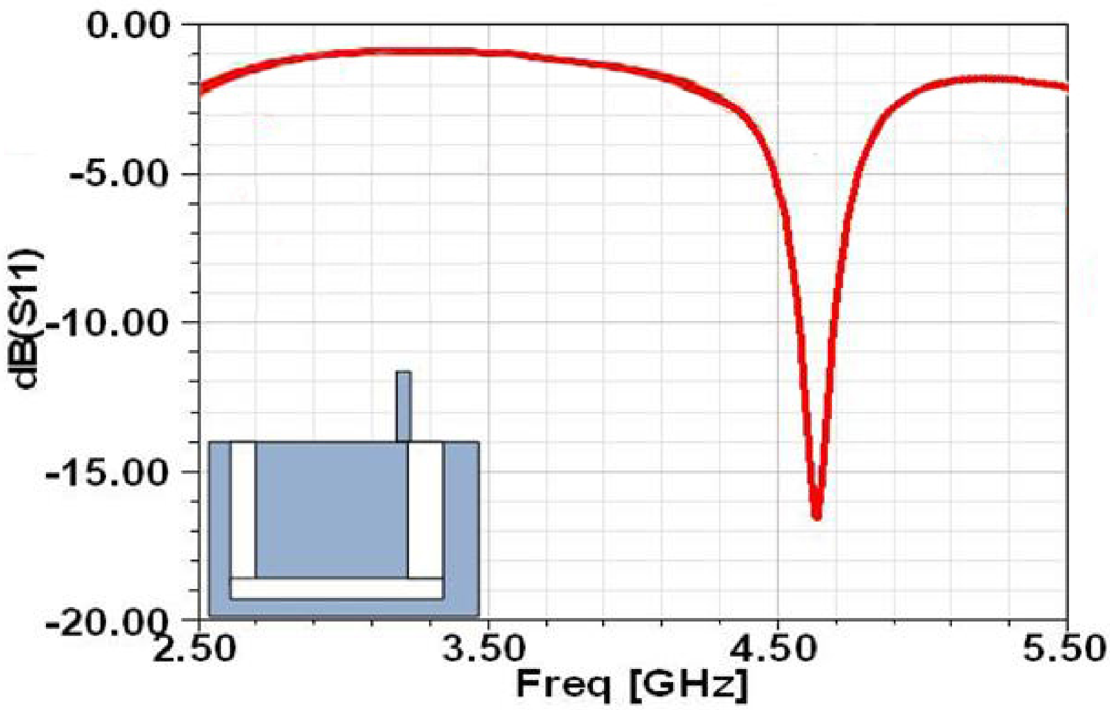
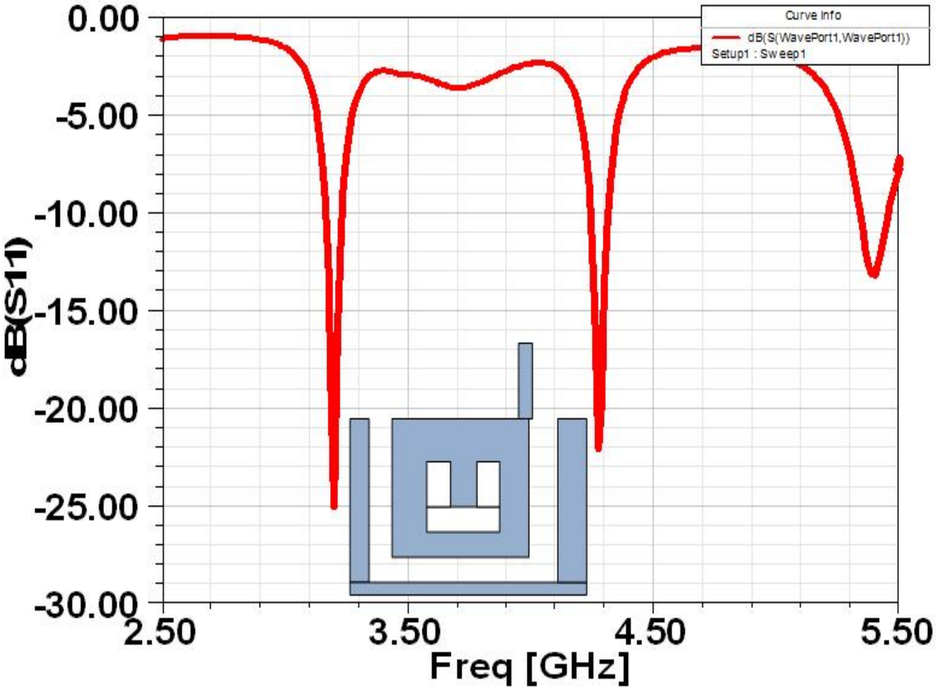
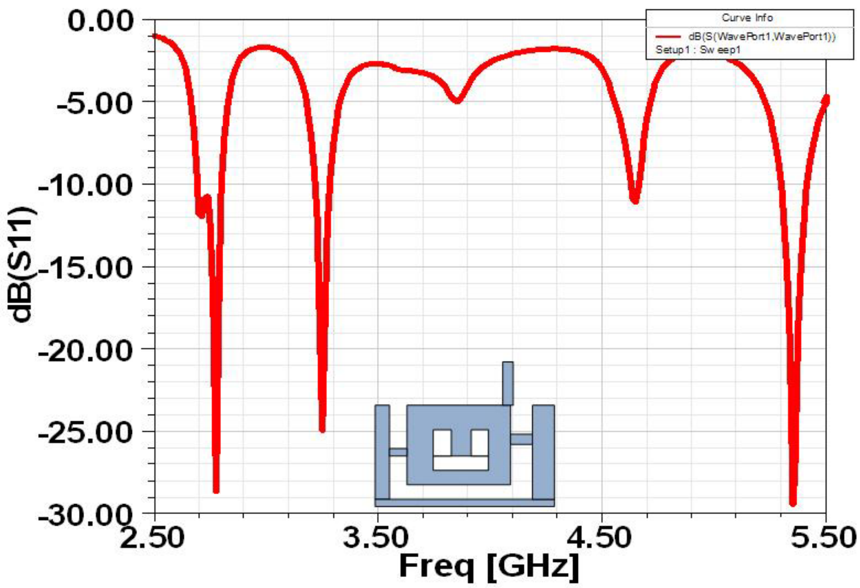


Figure 3 The return loss with the second U-Slot



(a)



(b)

Fig.ure 4 The return loss (a) With Both U-slots (b) After adding two bridges.

TABLE II The affect of the Bridges on the proposed antenna

	Band I	Band II	Band III
Without Bridges	3.2 GHz	4.3 GHz	5.4 GHz
With Bridges	2.7 GHz	3.3 GHz	5.3 GHz

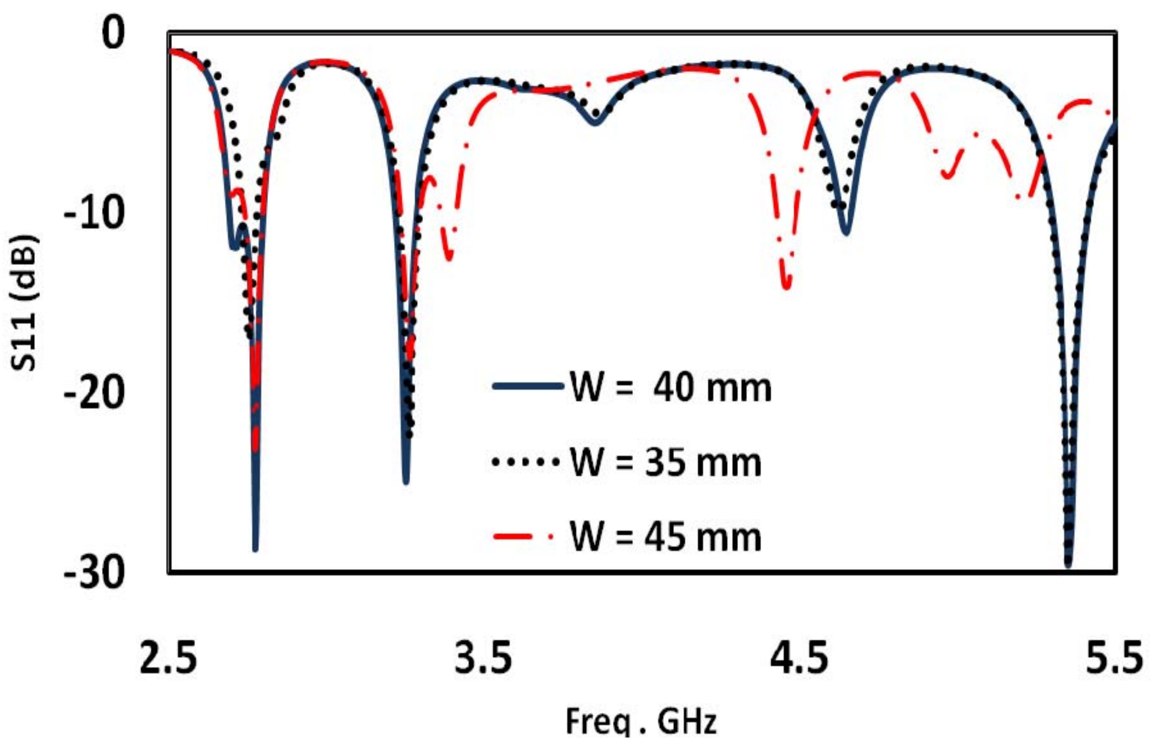


Figure 5 The variation of the (W) parameter on the return loss response

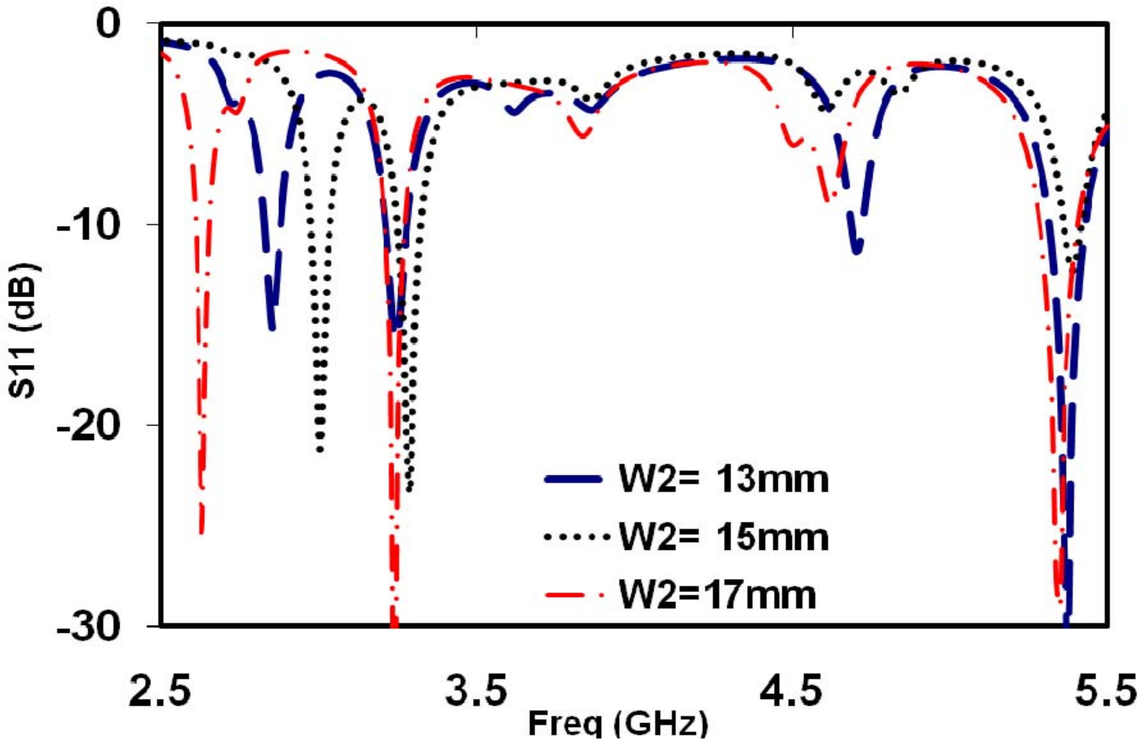
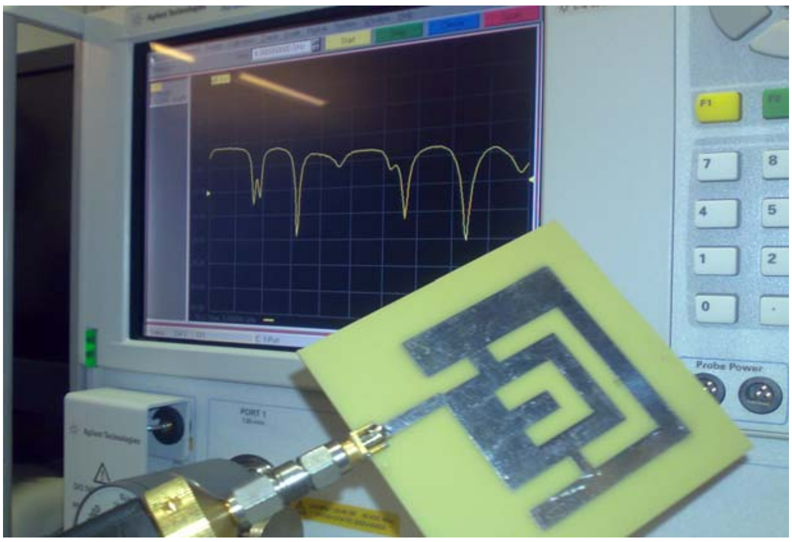
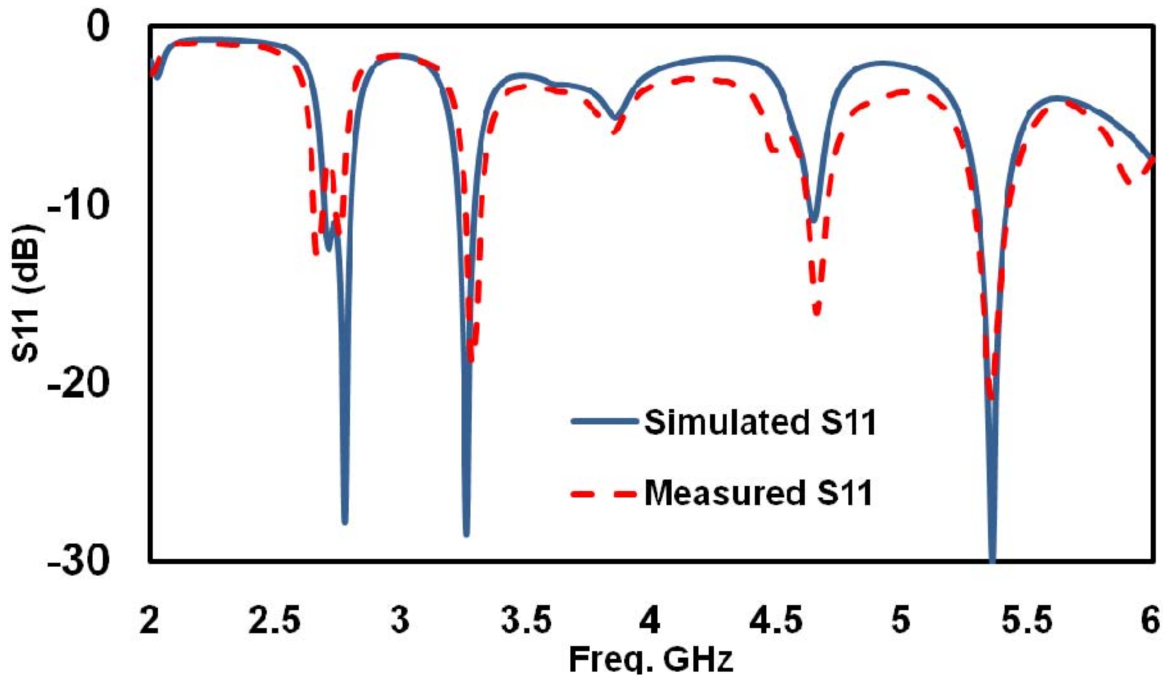


Figure 6 The variation of the (W_2) Parameter on the return loss response

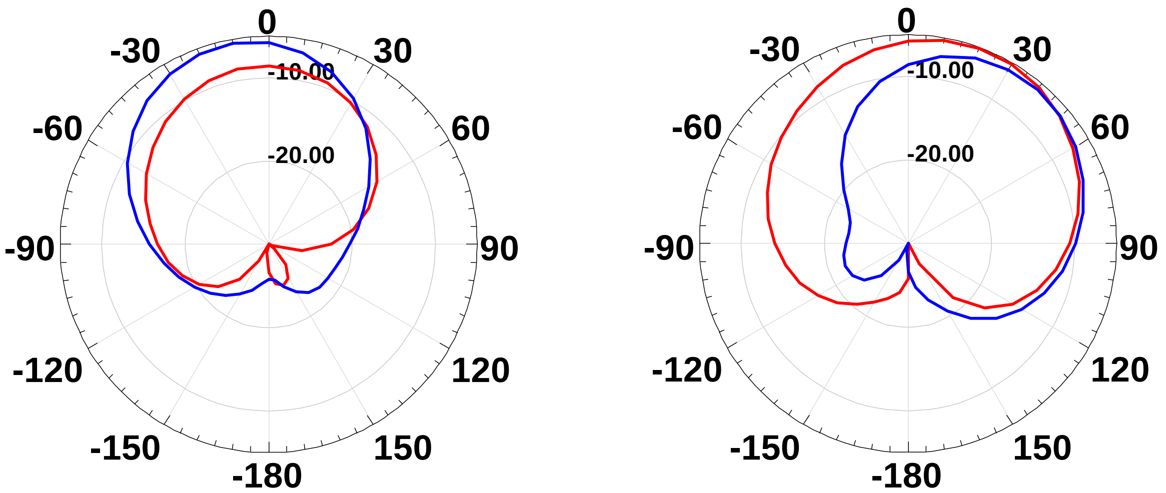


(a)

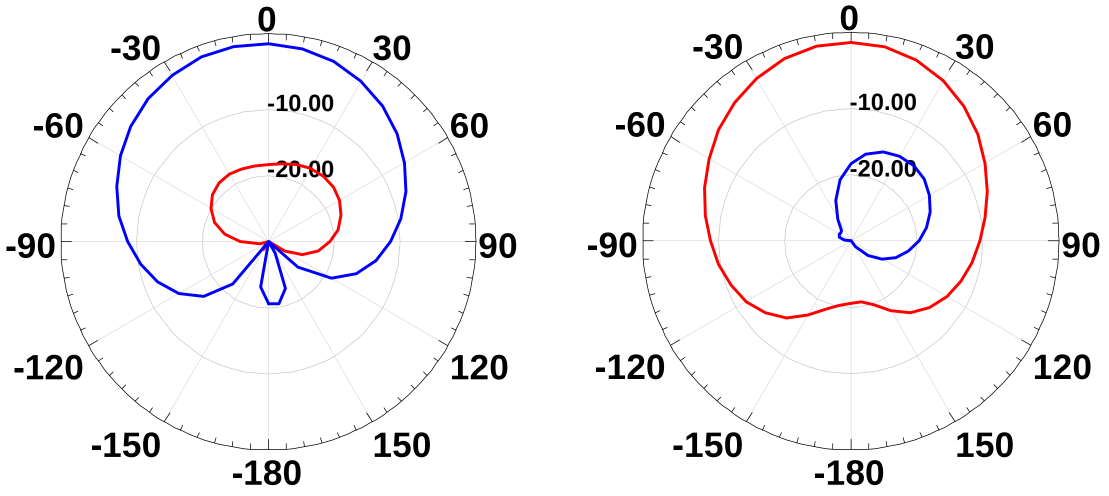


(b)

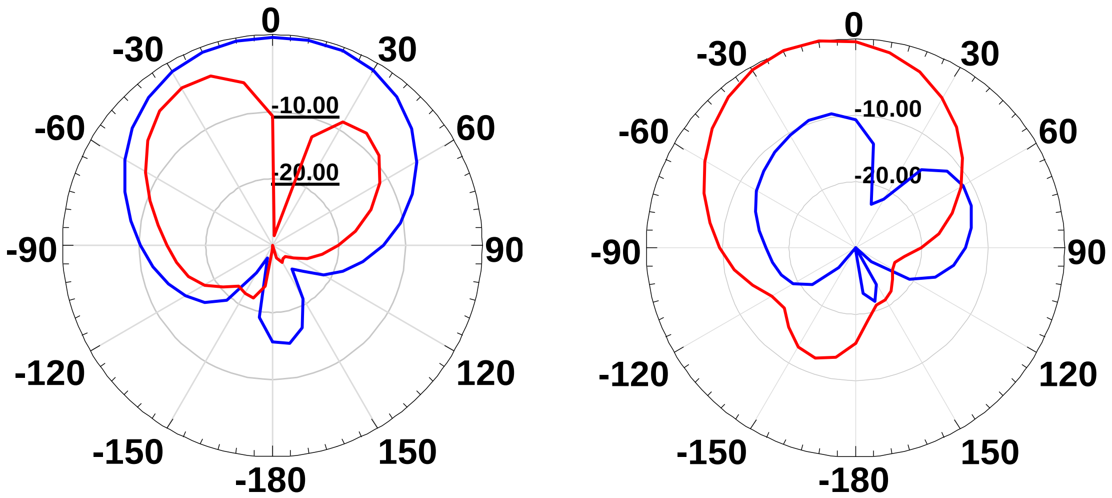
Figure 7 (a) The fabricated prototype. (b) The measured and simulated results for the proposed antenna



(a)

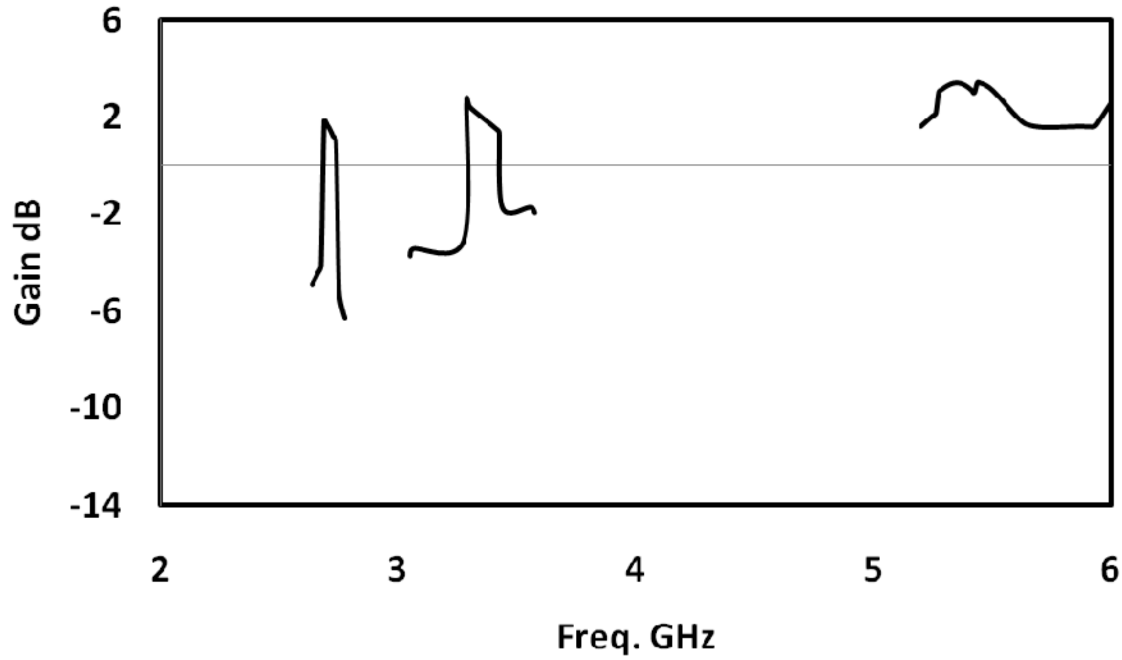


(b)



(c)

Figure 8 (a) Radiation Pattern E and H Plane at 2.7 GHz. (b) Radiation Pattern E and H Plane at 3.3 GHz. (c) Radiation Pattern E and H Plane at 5.3 GHz.



(a)

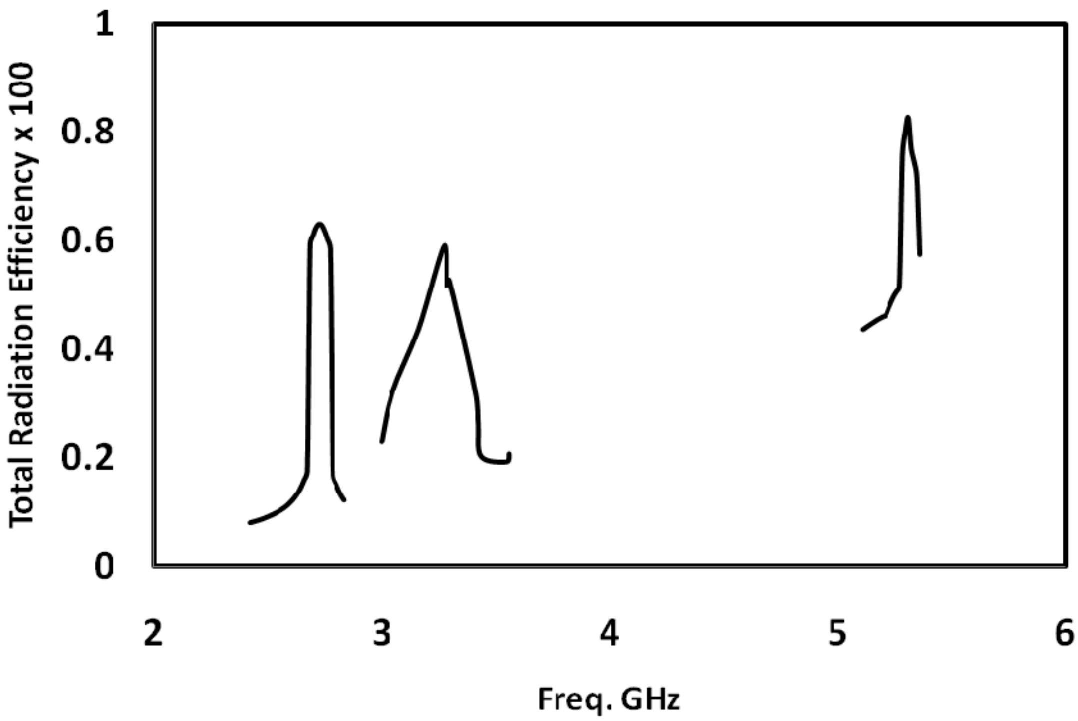
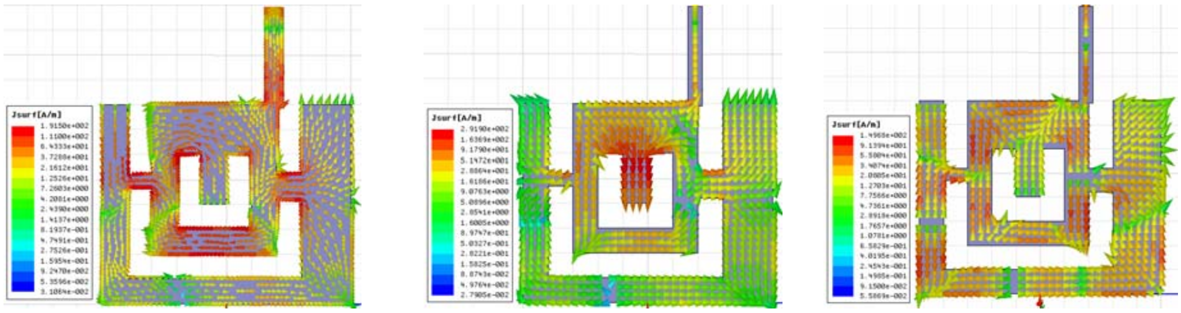


Figure 9 (a) The peak gain for the proposed antenna **(b)** The total radiation efficency for the three bands.



(a) (b) (c)

Figure 10 The current destitution for the proposed antenna at (a) 2.7 GHz, (b) 3.3 GHz and (c) 5.3 GHz