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A PRACTICAL MINIATURIZED U-SLOT PATCH ANTENNA WITH ENHANCED BANDWIDTH

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Abstract—In this paper, an asymmetric U-slot patch antenna with low probe diameter is presented. It will be shown that reduction in probe diameter causes in reduction in bandwidth. One of the characteristics of this antenna is keeping the bandwidth in 30% in spite of reduction in antenna size and use of low probe diameter compared to antenna presented in [1]. The presented antenna in this paper has been fabricated by pcb technique and tested. The far-field results have also been presented based on simulation and measurement. Although the antenna has high cross polarisation level, in the case of using circular polarisation, the use of this antenna can be recommended because of its reduced size, high impedance bandwidth, high total gain in spite of having low size, and ease of fabrication.

1. INTRODUCTION

The major disadvantage of microstrip antennas is their low bandwidth. One of the methods to increase the bandwidth, which has lower increment in antenna volume behind, is the use of a U-slot in the single layer single patch antenna. In 1995 a broad band single layer probe fed patch antenna with a u-shaped slot was presented by Huynh and Lee [2] and [1]. In [1] a symmetric type of this antenna with 30% bandwidth and probe with 1.27 mm diameter and center operating frequency of 4.5 GHz with Foam substrate has been presented. Since probes that are available for us have 1.27 mm diameter, in the case of designing the antenna for this probe and lower frequencies the ratio of probe diameter to wave length will be reduced. According to [3], the reduction in probe diameter results in the increment in the fringe inductive at the feed. Through an example we will show that this phenomenon causes in reduction in the bandwidth.

In [4] a technique for reduction the size of symmetric E-patch antenna has been presented. In this technique the symmetric E-patch antenna has been divided into two equal parts using its symmetry line. One of the parts has been eliminated, and the design procedure has been done only using the topology produced by the other one of the parts. In this paper with inspiration of the technique [4], we present an asymmetric U-slot patch antenna with smaller size compared to [1].

In this design, we assume the left and right sides of symmetric u-slot patch antenna has not enough effective role in antenna structure to increase bandwidth. We eliminate one side, and decrease the antenna width so that the TM10 mode resonant frequency uppers and in regard to antenna asymmetry, this mode can be excited. This change joins the size reduction and increment in band width together, and the presented antenna in spite of using lower probe diameter compared to wavelength of center frequency, and having smaller size, has kept the bandwidth in 30% similar to [1]. Besides, considering fabrication procedure, it is based on pcb technique and has lower profile compared to [1].

2. SYMMETRIC U-SLOT PATCH ANTENNA

2.1. Previous Works

Here, we investigate the antenna mentioned formerly, from [1]. In order to reduce the operating frequency to a center frequency of 2.25 GHz, we scaled its structure two times larger, and plotted in Figure 1. This figure shows the dimensions of patch and U-slot. The U-slot is placed in the center of the patch and altogether lays on a foam substrate with permittivity equal to 1 and thickness of 10 mm, then a finite ground plane with sufficiently large size, approximately two times larger than the patch. The feed probe has a diameter equal to 2.5 mm. This antenna has been simulated using HFSS software, and its return loss plot with a solid line is shown in the Figure 2. It can be found that this plot in Figure 2, matches with the indications in Section 1, and shows approximately 30% bandwidth from 1.97 to 2.7 GHz with VSWR lower than 2 or return loss lower than about −9.5 dB. The probe of this antenna which has 2.5 mm diameter is thicker than the available probes. The simulation result of this antenna only with changing the probe diameter to 1.27 mm and keeping other parameters fixed, is shown in dashed line in the same figure. From Figure 2 altogether, it is presumable that reduction of probe diameter causes in reduction in bandwidth.

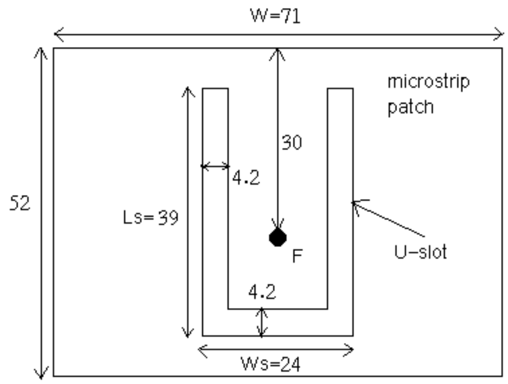

Figure 1. The dimensions of the patch and U-slot for the antenna discussed in Section 2 in millimeters, letter 'F' points to the feed point.

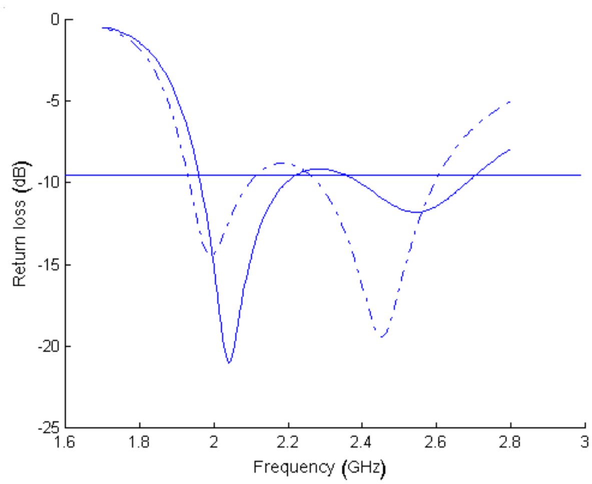

Figure 2. The return loss plot of antenna with the patch and U-slot dimensions presented in Figure 1 and probe diameter equal to 2.5 mm (solid), and 1.27 mm (dashed).

2.2. Symmetric U-slot Patch Antenna with Low Probe Diameter

Here we present a Symmetric U-slot patch antenna with maximum return loss of −10 dB and probe diameter of 1.27 mm in the same frequency as the antenna in Section 2.1. In order to reduce the maximum return loss of the passband, in Figure 1 let $W_s = 23.4$ mm, $L_s = 40$ mm and the probe diameter 1.27 mm, keeping the other

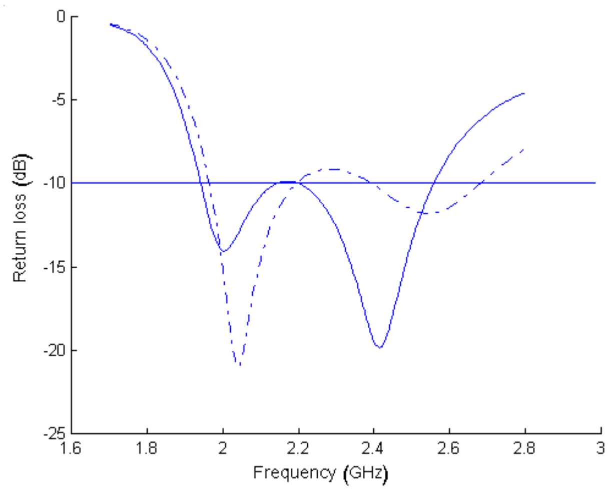

Figure 3. The return loss plot of the antenna discussed in Section 2.2 (solid), and antenna with patch and U-slot dimensions presented in Figure 1 with the probe diameter equal to 2.5 mm (dashed).

parameters in the same values. The simulation result using HFSS is a return loss plot in Figure 3 with solid line. The bandwidth that is resulted in from this plot (solid curve) of Figure 3 is equal to 28.4% from 1.93 to 2.57 GHz. Then there is a decrement in the bandwidth. This change in the bandwidth occurs as the result of two agents, one, reduction in the probe diameter, and the other, reduction in the maximum return loss of the passband. Although this antenna parameters is only one example of low probe diameter U-slot patch antenna, but it can give us an estimation about how much bandwidth decreases in these cases.

3. THE ASYMMETRIC U-SLOT PATCH ANTENNA STRUCTURE

Figure 4 shows the layers of modified U-slot patch antenna with two layer substrate. According to the Figure 4 a ground plane with 1 mm thickness and dimensions of 10×10 cm connects to the connector shield, up to it, there is a 8 mm thick air layer, and then, a Fr4 substrate with permittivity of 4.4 with dimensions 65×65 mm and thickness of 1.6 mm with the patch conductor on it. The patch is also connected to the probe at the feed point. The patch dimensions and the place of the feed point are shown in Figure 5.

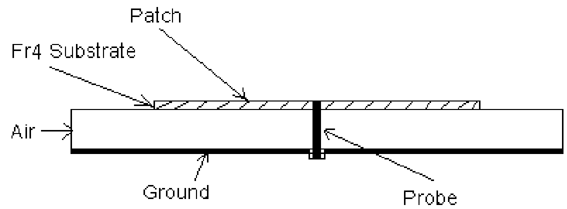

Figure 4. The presented antenna in Section 3 from side view representing the layers of the antenna.

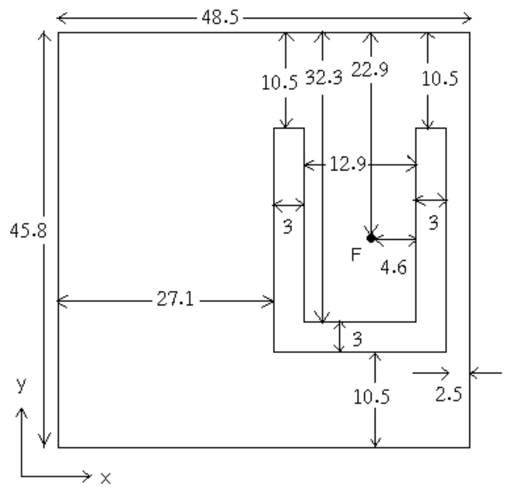

Figure 5. The presented antenna in Section 3 top view representing the dimensions of patch and U-slot in millimeters, letter 'F' points to the feed point.

3.1. The Simulation and Measurement Results

This antenna has been fabricated (Figure 19), and then tested in antenna lab of Khajenasir University. The test results together with simulation results using HFSS has been shown in the Figure 6.

In this figure we see a measurement bandwidth from 1.9 to 2.6 GHz or 31%. This bandwidth is a result of 3 resonant frequencies in passband that indicates a principal difference with symmetric U-slot patch antenna, which has 2 resonant frequencies [1]. The probe used in this antenna is narrower than the corresponding probe in [1] and according to [3] has higher inductance. But although we have used narrower probe contrary to the antenna presented in section 2.2 bandwidth does not decreases. In the case of designing the asymmetric antenna for probe of 2.5 mm diameter, in this frequency (2.2 GHz), with

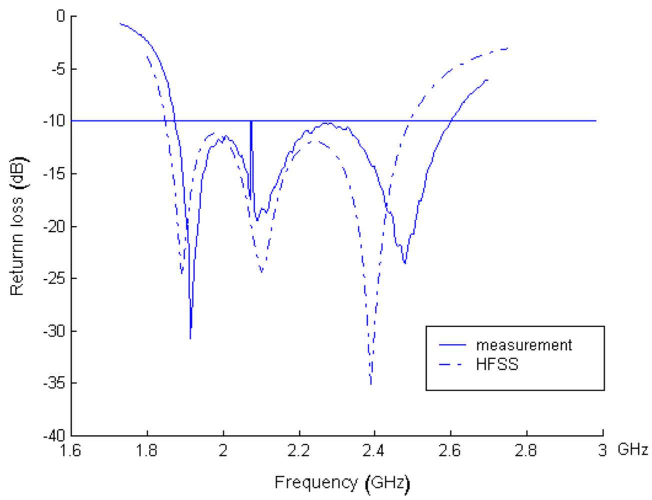

Figure 6. The return loss plot of measurement and HFSS-based simulation for the antenna in Figure 5.

full foam substrate, with height of 11.5 mm, and patch dimensions of Figure 7, we will have more than 36% bandwidth with return loss level under -10 dB and 3 resonant frequencies (Figure 8).

The reason for 3 resonant frequency in the return loss plot of the antenna, is not the use of two layer substrate. In the antenna structure 3 resonators can be recognize. Two of them for patch with current paths of x and y directions, and the other placed among the u-slot, and can effect on the antenna at higher frequencies. This 3 current paths when are excited, gives 3 resonant frequencies.

About measurement results shown in Figure 6, also it can be mention that the unusual jumping in the return loss plot of the measurement in about 2.05 GHz is caused by changing oscillator range in the Network Analyzer used to test the antenna.

3.2. The Antenna Size

The total thickness of this antenna, including Fr4 layer and air layer, is 0.07 of passband center frequency wave length. This is a little lower than the antenna thickness in [1] equal to 0.08 of corresponding wave length. The reduction in the thickness of antenna by decreasing the air layer thickness causes in increment in quality factor of the patch resonator [3]. According to Smith Charts plotted in Figure 9, this change in the air layer thickness, causes an increment in loops size in the smith chart of the antenna. To well investigation of that change,

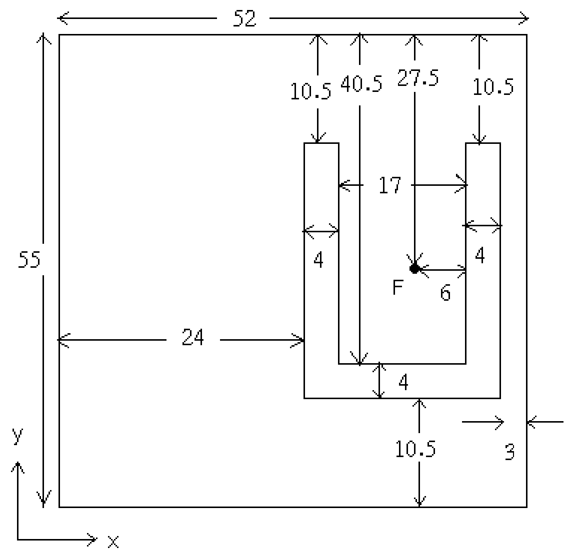

Figure 7. The patch dimensions of asymmetric antenna designed for thicker probe and full foam substrate.

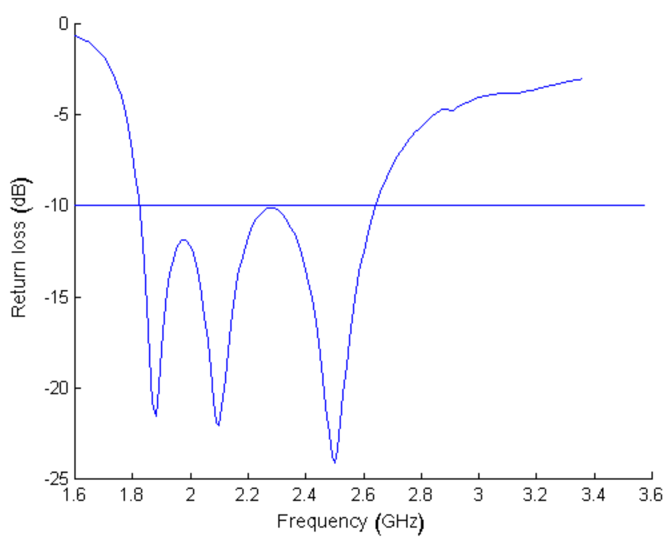

Figure 8. Return loss plot for the asymmetric antenna designed for thicker probe and full foam substrate.

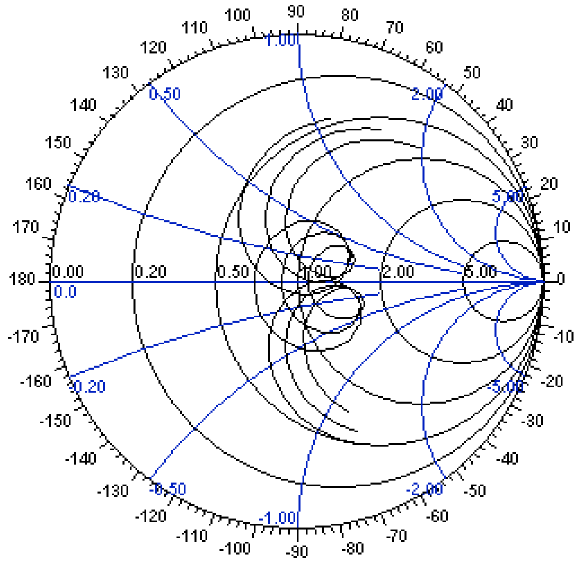

Figure 9. The smith charts of the antenna of Section 3 for total thicknesses 8.6, 9.6 and 10.6 mm, the plot with larger loops is due to decreasing the thickness.

the return loss is shown in Figure 10.

In this figure, it can be seen with reduction of air layer thickness, bandwidth increases. But the maximum return loss in the passband also increases. An optimum case that has been chosen, In this antenna is the thickness of 9.6 mm.

Maximum dimension of the patch is lower than 50×50 mm. Supposing center frequency to be 2.25 GHz, this dimensions would be 0.375×0.375 times of the wavelength of the passband center frequency. Thus a reduction of 33% occurs in the patch area, compared to [1]. This reduction is because of the special topology that's used, and is also because of using Fr4 substrate, with permittivity of 4.4.

The presented asymmetric antenna is well resisting against the fabrication tolerances. Nevertheless the patch sizes can be more exactly observed in fabrication, and in our work a 0.2 mm precision has been observed, but the feed point location and the air layer thickness may have much tolerance. As we saw in Figure 10, a ± 1 mm tolerance in the air layer thickness in order to keep the antenna in broad band condition, is acceptable in a desired way. Also according to the investigation results shown in Figures 11 and 12, a ± 1 mm tolerance in

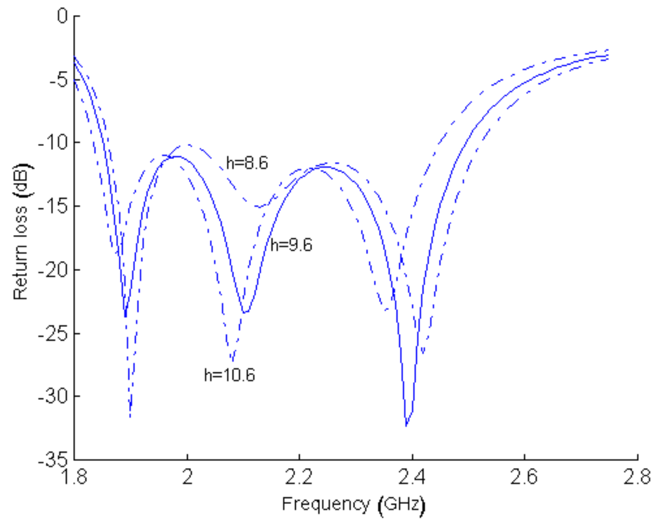

Figure 10. The return loss plot of antenna of Section 3 for various thicknesses.

the feed point location in the x, and y direction does not dismiss the antenna from broad band conditions.

3.3. The Far Field Results

Because of the antenna small size, there is not the TM20 mode on the patch contrary to the symmetric U-slot patch antenna [5]. Besides, because of the antenna asymmetry, the TM10 mode, can be excited. Then, in the antenna radiation pattern of x axis aligned polarisation, (or x polarisation) there is not a null in broadside. This phenomenon shows itself in the antenna gain plot in broadside angle (Figures 13 and 14).

From Figure 13 it can be seen that the antenna gain in broadside, with a proper choice of polarisation in application, does not comes down from 5 dB in the passband. In the second half of the passband, the cross polarisation is the x polarisation, and remains under 0 dB and the co, or y axis aligned (or y polarisation) polarisation is above 5 dB. But the dominant polarisation in the first half is the x polarisation, and its increasing in the first half of passband — compared to the second half — causes in decrement in the y polarisation. Therefore this antenna such as the antenna in [6] has a polarisation switch that should be noticed in the application.

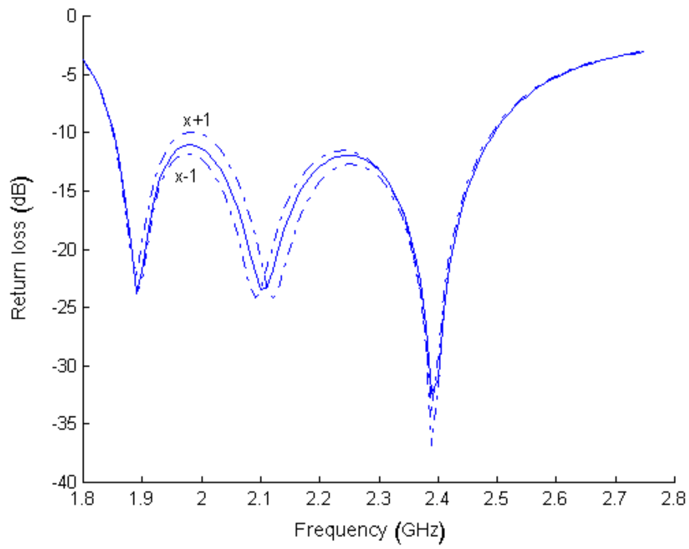

Figure 11. The return loss plot of antenna of Section 3 for moving the feed point 1 mm to the left $(x-1)$ and to the right $(x+1)$.

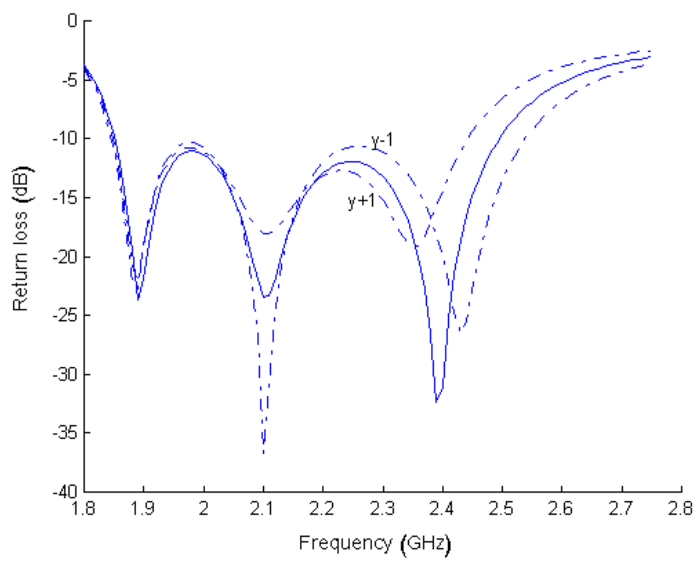

Figure 12. The return loss plot for moving the feed point 1 mm up $(y+1)$ and down $(y-1)$.

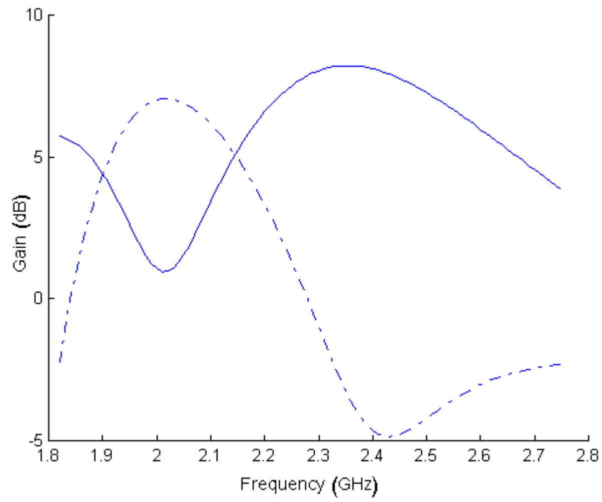

Figure 13. The asymmetric antenna gain plot for x aligned polarisation (dashed) and y aligned polarisation (solid) in broadside angle versus frequency.

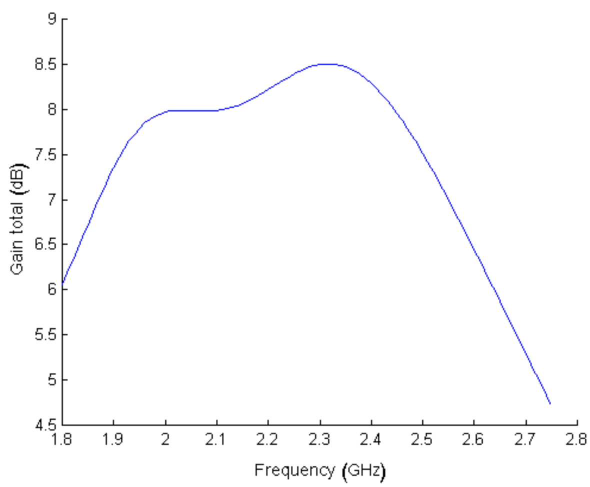

Figure 14. The total gain in the broadside angle versus frequency.

While the average gain of symmetric U-slot patch antenna is about 7 dB [7], the 2 dB decreasing in radiation efficiency occurs with 33% reduction in the size of the antenna which can be useful in array applications to achieve high gain.

In the case of using the antenna with a circular polarisation

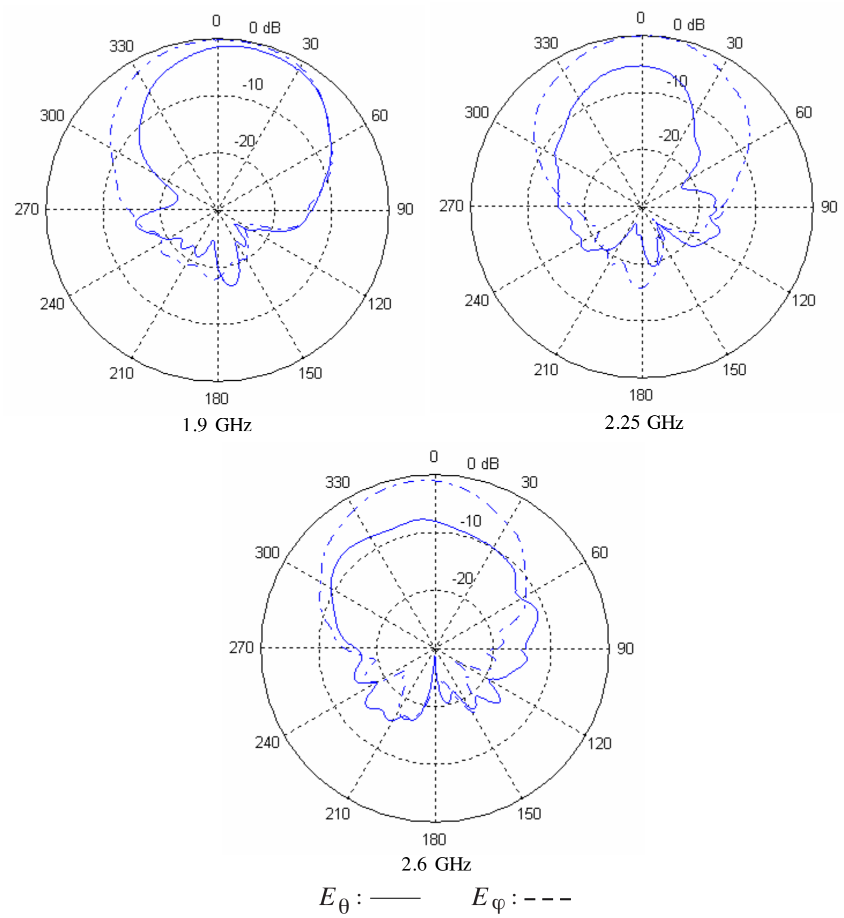

Figure 15. The H-plane measured pattern or pattern in the angle of $\varphi = 0$.

antenna, the gain of the antenna will be evaluated as total gain, and is plotted in the Figure 14 versus frequency. Because there is not a null in x polarisation pattern in broadside, the x polarisation causes to increase the total gain of the antenna in the broadside angle.

The antenna patterns in the H-plane and E-plane in the frequencies of 1.9, 2.25, and 2.6 GHz have been measured and showed in Figures 15 and 16. In each frequency a fixed coefficient has been used to normalize the patterns. The error that is acceptable is about 2 dB. As it is seen the main beam angle is about broadside angle. The differences between co and cross polarisation levels are approximately

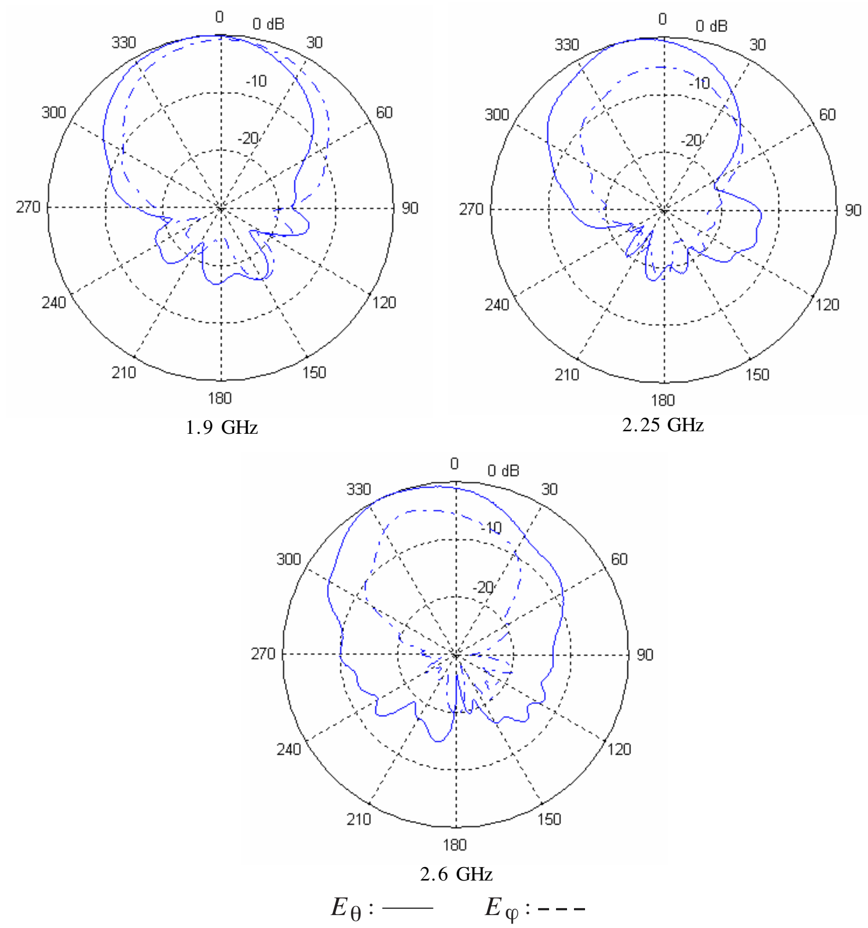

Figure 16. The E-plane measured pattern or pattern in the angle of $\varphi = 90$.

matching, in the measurements and simulations. According to high level cross polarisation of the antenna, the axial ratio may be low. In the Figure 17 the polarisation pattern of the antenna in the frequencies 1.9, 2.25 and 2.6 GHz have been measured and are shown. The axial ratio plot versus frequency in the broadside angle using simulation is also shown in Figure 18. Comparison between these figures shows that the axial ratio in the first two pattern measurement frequencies, is about 10 dB that matches with the simulation well. The decreasing in axial ratio in the first half of the passband, occurs during the increasing the x polarisation level in Figure 13.

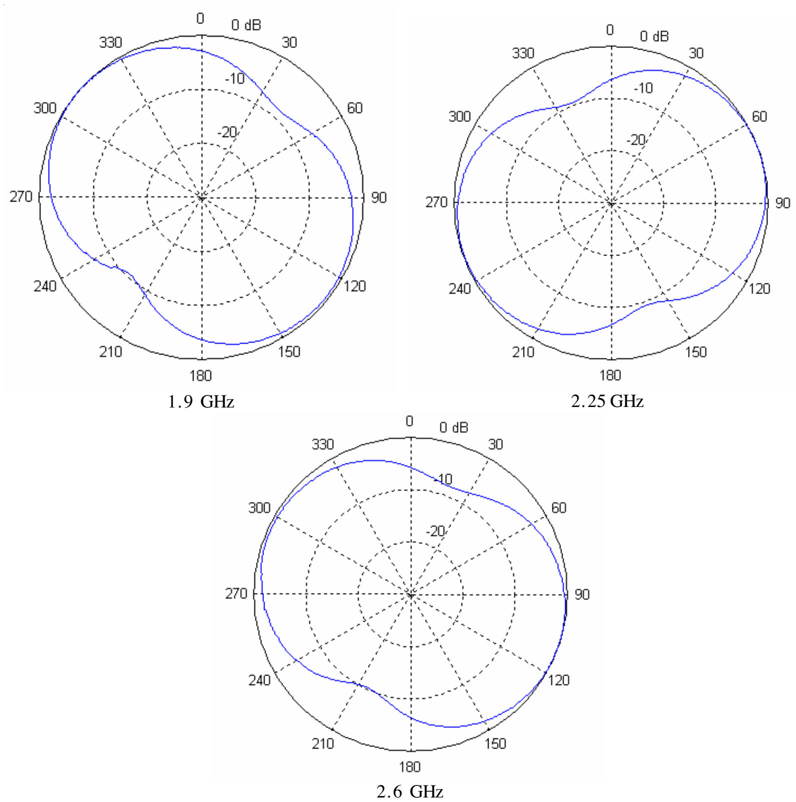

Figure 17. The measured polarisation pattern in the broadside angle, for various φ angles.

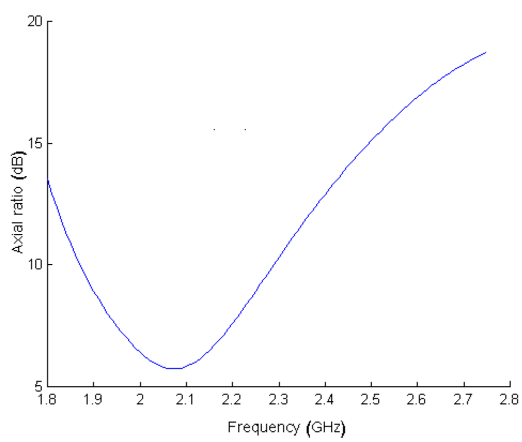

Figure 18. The axial ratio in the broadside angle versus frequency.

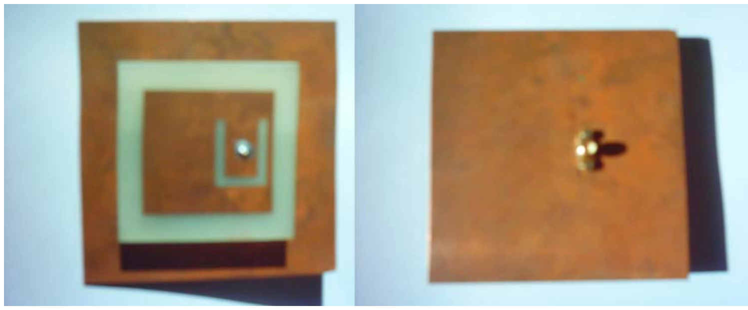

Figure 19. The fabricated antenna front view (left) and back view (right).

4. CONCLUSION

In this paper a broadband asymmetric U-slot patch antenna with narrow probe presented. From this antenna capabilities compared to symmetric U-slot patch antenna, it can be indicated that, it has reduced size, lower probe diameter, without reduction in bandwidth, compared to antenna in [1], and being possible to have more bandwidth than [1] with similar conditions, although it uses a simple structure. Its low size and being possible to fabricate using pcb technique, can be used in array applications. This antenna can be recommended when a circular polarisation is used, but in linear polarisation applications, it has high cross polarisation level, which should be noticed in its application. designer should note that the resonant frequencies should be placed the most far apart each other, but the broad band conditions also should be verified.

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