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Design of Novel Wideband CPW Irregular Pentagonal Patch Antenna

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ABSTRACT
In this paper a printed microstrip patch antenna for bands S, C, X and Parts of L, Ku is proposed. The proposed antenna consists of a beveled CPW irregular pentagonal patch on one side of dielectric substrate and c-shape independent piece in the other side, the dimension of this antenna is (33×30) mm2. Simulated results indicate that the antenna achieved bandwidth (S11≤-10dB) ranges from 1.48-14.2 GHz and give gain varying from 0dBi to 4.3dBi. The proposed antenna exhibits a good characteristics performance. The proposed antenna is fabricated and tested practically and found good agreement between the simulation and measured. This antenna is suitable for the applications that operate in these bands.

General Terms
Microstrip patch antenna

Keywords
Wide-Band Antenna, Return Loss, Voltage Standing Wave Ratio, Radiation Pattern, Group Delay.

1. INTRODUCTION
Microstrip antennas have been studied intensively because of attractive advantages of light weight, low profile, ease of integration with active devices, conformability to mounting hosts, and so on [1]. However, microstrip antennas inherently have a narrow bandwidth, and bandwidth enhancement is usually demanded for practical applications [2]. For extending its bandwidth, many approaches have been used traditionally, such as using thick substrates with low dielectric constant, impedance matching network, or parasitic patches stacked on the top of the main patch or close to the main patch in the same plane [3,4]. In addition, the communication systems in present-day usually require smaller antenna size in order to meet the miniaturization requirements of radio- frequency (RF) units [5]. Many efforts have been made to achieve this purpose, for example, high dielectric constant substrate, adopting short-circuits pin and slots loaded on the patch [6,7]. With development of communication and integration circuit technologies, size reduction and bandwidth enhancement are becoming important design considerations for practical applications of microstrip antennas. However, the previous investigations toward this target emphasize the microstrip antenna with a thick substrate (typically lager than 3%, even over ~12% of working wavelength [8]). Little research has been done to enhance the operation bandwidth and reduce the patch size with a thin substrate less than ~1% of working wavelength [9], whereas developing ultralow-profile microstrip antennas with enhanced bandwidth and reduced size is very challenging in future integrated RF communication systems, for example, RF front-end antenna integration and package in microwave and millimeter-wave bands [10].

2. DESIGN OF THE CPW IRREGULAR PENTAGONAL PATCH ANTENNA
The radiator is in the form of irregular pentagonal patch that excited using a 50 Ω coplanar waveguide (CPW) feed technique. The feed line dimensions are (Wf x Lf) and the gap between the ground plane and the feed line is g. The total size of the antenna including the substrate is (33 x 30) mm2, which has been printed on FR4 substrate of thickness 1.6 mm, and relative permittivity of 4.3. The antenna with the initial parameters is shown in Figure 1.

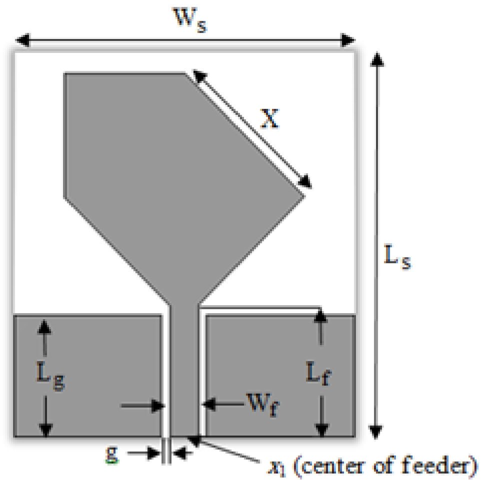

Fig 1: Initial parameters of the CPW irregular pentagonal patch antenna

The antenna with initial parameters not best results gives so that we will resort to varying parameters. In order to study the effect of the various basic parameters on the performance of the antenna, the optimization process is done by changing the value of one parameter and choose the best value that give good results and during the process of variation the other parameters fixed. The return loss (S11) of this antenna is simulation in frequency range from 1-15 GHz for each different parameter. The basic parameters are Lg, Lf, g and x1 is shown below.

2.1 The Effect of varying the ground plane length (Lg)
The first step is to optimize the length of ground plane Lg. Figure 2 shows the simulated return loss versus frequency for different values of Lg, from figure clear that the changing of Lg parameter has a substantial effect on the (S11≤-10dB) bandwidth. The optimal results give at Lg=11.5mm, with the other value parameter is Lf=11.25mm, g=0.75mm and

x1=0mm. That gives 3-bands 3.3-6.8 GHz, 8.9-10.9 GHz and 12.5-13.9 GHz.

2.2 The Effect of varying the feeder length (Lf)

Second step is changing the value of feeder length and show effect on the (S11≤-10dB) bandwidth, so that at increase the value of Lf parameter with fixed the value of the other parameter at Lg=11.5mm, g=0.75mm and x1=0mm that will leads to improve the bandwidth of antenna as shown in Figure 3. At Lf=12.35mm the antenna give dual bands 3.3-6.5 GHz and 9.1-13.6 GHz.

2.3 The Effect of varying the gap (g)

The third step is to optimize the space gap between the feeder and ground plane g. The simulation return loss with a function of frequency can show in Figure 4. The optimal value of g is 0.5mm and the values of other parameters is Lg=11.5mm, Lf=12.35mm and x1=0mm, that give dual bands 2.9-6.6 GHz and 9.1-13.2 GHz.

2.4 The Effect of varying the position of feeder and patch (x1)

The fourth step is to optimize the value of position of feeder and patch x1 around the origin and clarify its influence on the (S11≤-10 dB) bandwidth. Figure 5 show the variation of x1 parameter value with fixed the value of the other parameter at Lg=11.5 mm, Lf=12.35mm and g=0.5mm, it is noticed that the varying x1 parameter value is not affected on the lower resonant frequency but clearly effected on higher resonant frequency. The best results is give at x1=11.5mm make the antenna give dual bands 2.9-6.6 GHz and 8.9-14.2 GHz.

2.5 Effect add C-shape to antenna

The step five shown the effect adding an independent piece has c-shape to the bottom side of dielectric substrate. Figure 6 shows the return loss as a function of frequency, from curve can observed that adding the C-shape lead to increase the bandwidth of antenna, and give the best results at this dimensions CL=30.5mm, CL1=2mm, CL2=11mm, CW=14mm and CW1=11.5mm. The antenna gives 3-bands 1.5-5.1 GHz, 6.6-7.7 GHz and 8.5-15 GHz.

2.6 Effect of adding stairs to the ground plane

The six step appear effect add stairs to the ground plane the stair have 4-steps. Figure 7 shows the size of each step of stair and how to add each of them together on the ground plane.

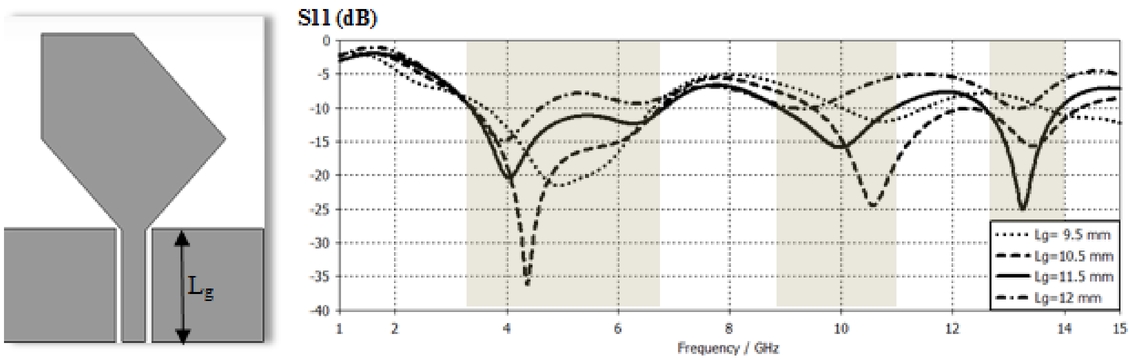

Fig 2: Simulation return loss as a function of frequency of the CPW irregular pentagonal patch antenna for different value of Lg

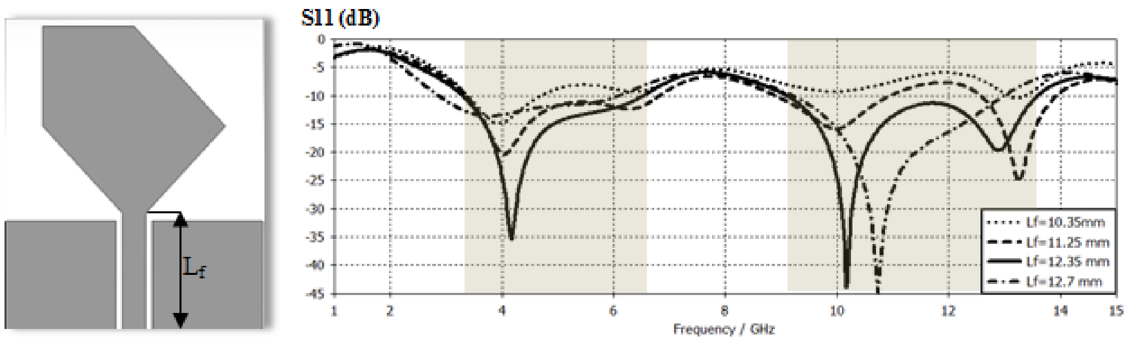

Fig 3: Simulation return loss as a function of frequency of the CPW irregular pentagonal patch antenna for different value of Lf

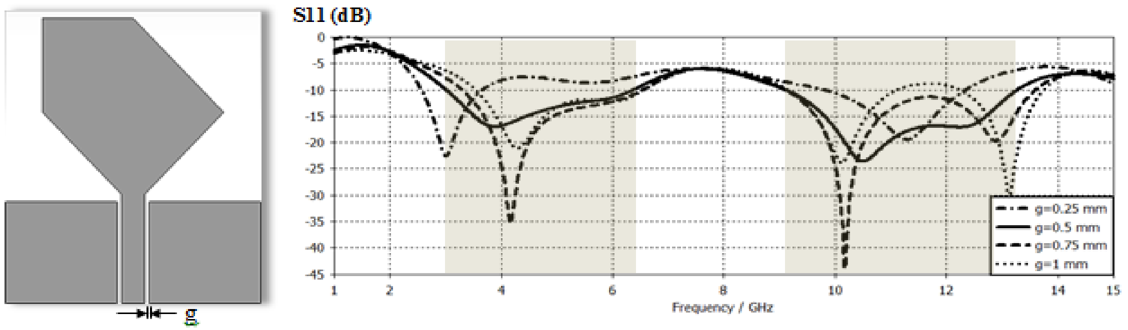

Fig 4: Simulation return loss as a function of frequency of the CPW irregular pentagonal patch antenna for different value of g

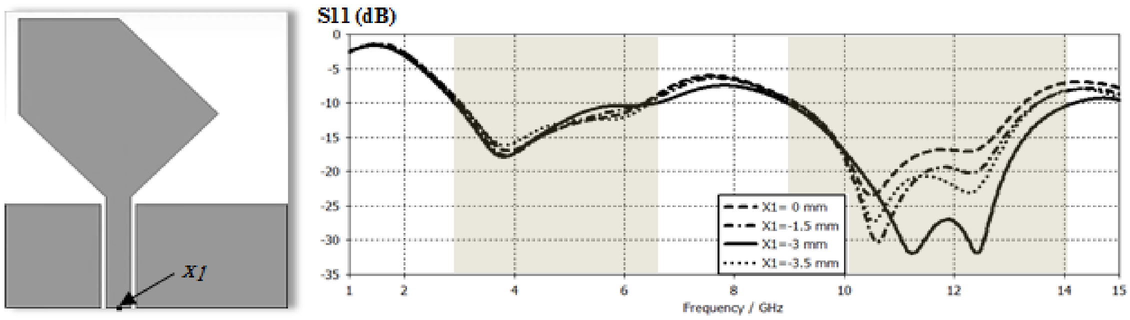

Fig 5: Simulation return loss as a function of frequency of the CPW irregular pentagonal patch antenna for different value of x1

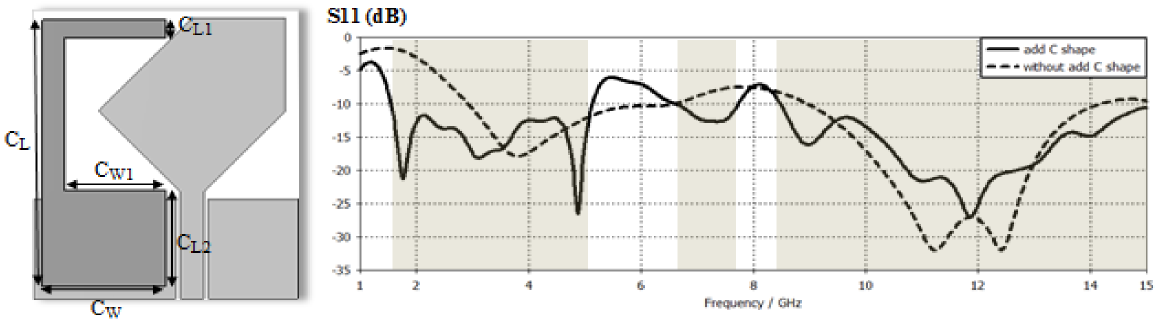

Fig 6: Simulation return loss as a function of frequency of the CPW irregular pentagonal patch antenna for adding C-shape piece

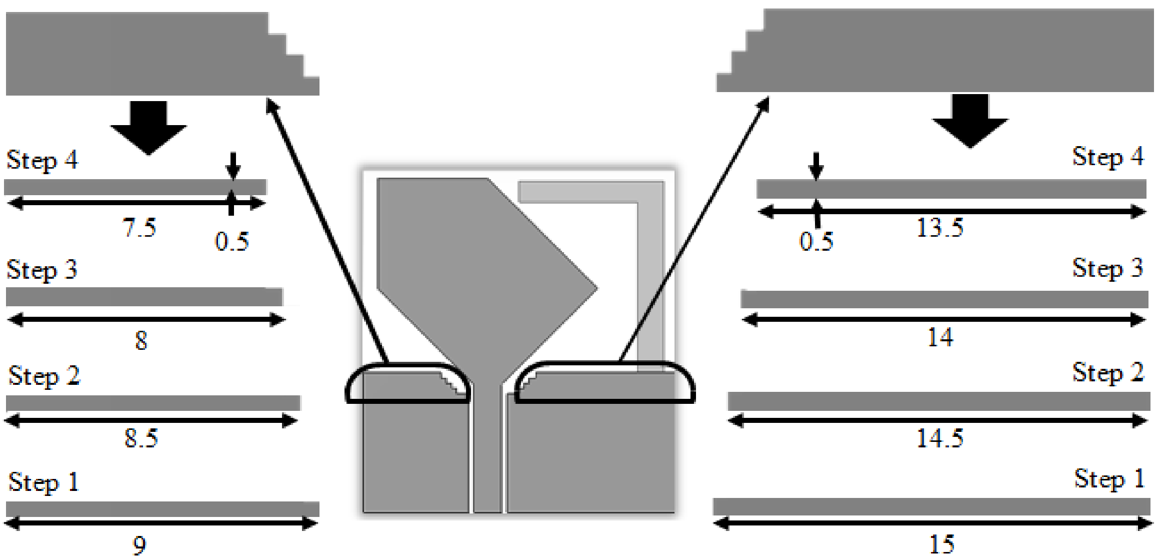

Fig 7: Top view of CPW irregular pentagonal patch antenna for add steps of stair to the ground plane

Figure 8 shows effect added each steps of stair on the return loss, so that add the all 4-steps to the ground plane lead to make the bandwidth extends from 1.48-14.2 GHz.

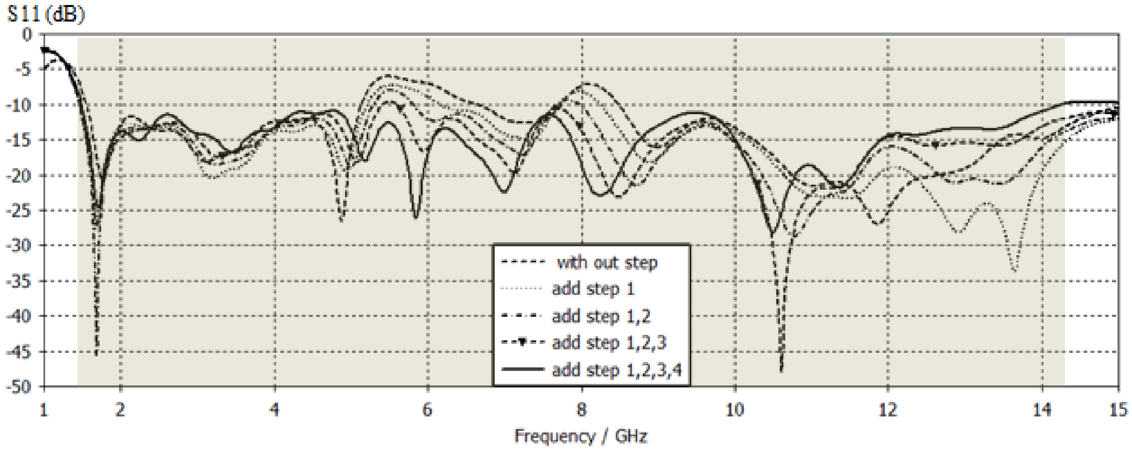

Fig 8: Simulation return loss as a function of frequency of the CPW irregular pentagonal patch antenna for add each one step of stair to ground plane

The optimal parameters of the CPW irregular pentagonal patch antenna are shown in table 1. The proposed CPW irregular pentagonal antenna that have optimal parameters with the 4-steps stair that added to ground plane and the C-shape independent piece that added to bottom of antenna is shown in Figure 9. The return loss of CPW irregular pentagonal antenna is shown in Figure 10.

Table 1: Optimal parameters of the CPW irregular pentagonal patch antenna

Parameter	Description	Value
Ls	Substrate length	33mm
Ws	Substrate width	30mm
X	Length of the pentagonal patch irregular	15mm
Lf	Feeder length	12.35mm
Wf	Feeder width	2.7mm
Lg	Ground plane length	11.5mm
g	Gap between feeder and ground plane	0.5mm
x1	Feed point position around the origin	-3 mm

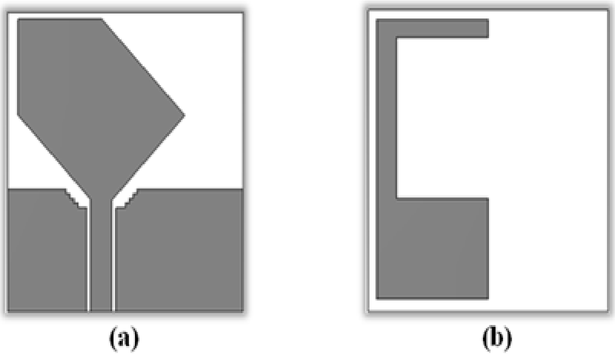

Fig 9: The structure of optimal CPW irregular pentagonal patch antenna, (a) Top view and (b) Bottom view

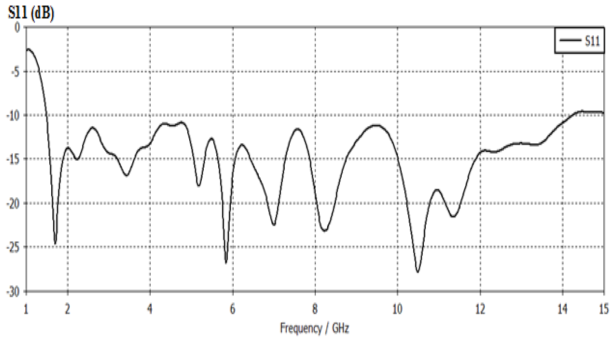

Fig 10: Simulated return loss of the proposed CPW irregular pentagonal patch antenna

The optimized CPW irregular pentagonal patch antenna is fabricated. The photograph of the manufactured antenna is shown in Figure 11.

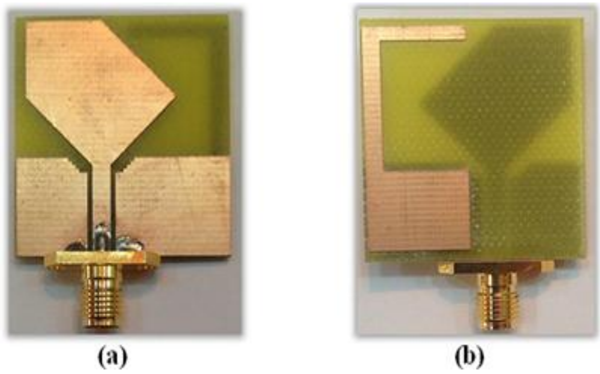

Fig 11: Photograph of the fabricated CPW irregular pentagonal patch antenna, (a) Front view, and (b) Back view

3. CHARACTERISTICS OF THE CPW IRREGULAR PENTAGONAL PATCH ANTENNA

3.1 Return Loss and VSWR

The fabricated antenna is tested using vector network analyzer (VNA) from the results found good agreement between the simulation and measured results. The simulated and measured of return losses and VSWR is shown in Figure 12 and 13 respectively.

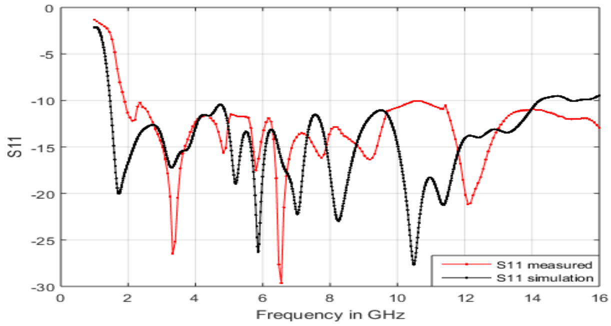

Fig 12: Simulation and measurement return loss of the CPW irregular pentagonal patch antenna

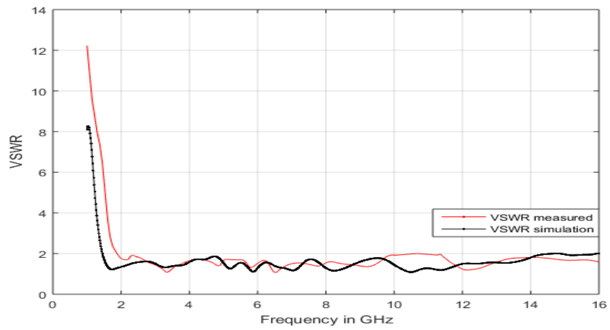

Fig 13: Simulation and measurement VSWR of the CPW irregular pentagonal patch antenna

3.2 Antenna Gain

The simulated antenna gain versus frequency plots is show in Figure 14. The simulated gain varies from 0dBi to 4.3dBi over the bandwidth 1.48-14.2 GHz, so that the antenna gives suitable gain for applications that operate in this bandwidth of frequencies.

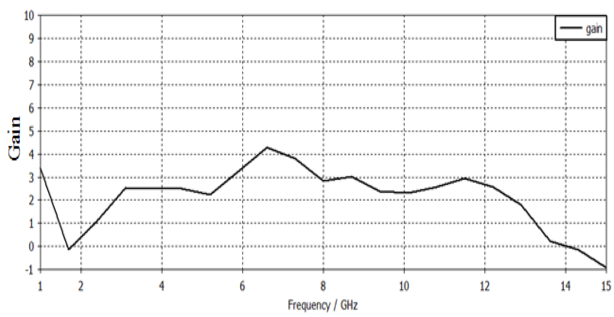

Fig 14: Simulated the gain of the CPW irregular pentagonal patch antenna

3.3 Input Impedance

The variations of the simulated and measured input impedances with frequency for the optimized antenna are given in Figure 15. It's observed that simulated the peak values of the impedance real and imaginary parts of the antenna are found to be 90Ω and 35Ω respectively and simulated the peak values of the impedance real and imaginary parts of the antenna are found to be 115Ω and 59Ω respectively.

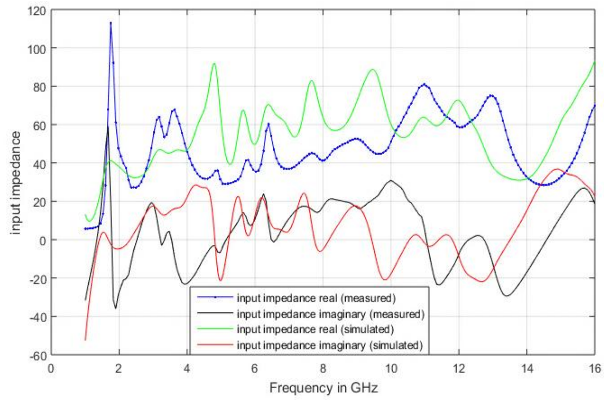

Fig 15: Comparison of the real and imaginary parts of the input impedance for CPW irregular pentagonal patch antenna (simulation and measured)

3.4 Current Distribution

The simulated current distribution of the optimize antenna structure is show in Figure 16, which shows distribution the current in the antenna in several different frequencies 1.8GHz, 5.8GHz and 10.5GHz. Figure 4.16 (a) show current distribution at f=1.8GHz, the concentration of current is all along the feeder. Figure 16 (b) show current distribution at f=5.8GHz, the concentration of current be in the lower part of feeder and lower edge of patch. Figure 16 (c) show current distribution at f=10.5GHz, the concentration of current be all along the feeder and lower edge of patch.

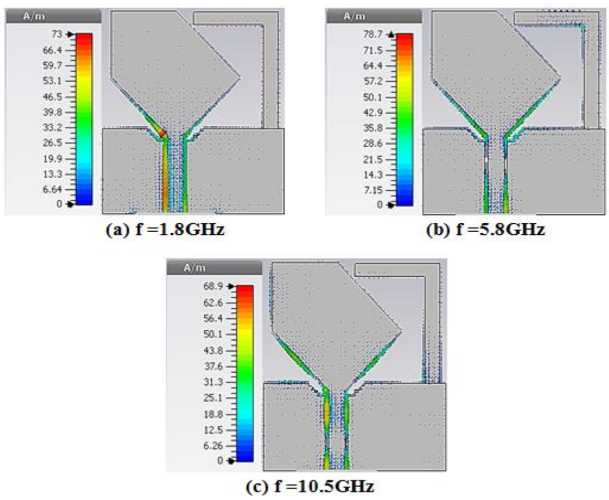

Fig 16: Current distribution of the CPW irregular pentagonal antenna at different frequencies

3.5 Far-Field Radiation Pattern

The simulated radiation patterns of the optimized antenna in the y-z plane (E-plane) and x-z plane (H-plane) shown in Figure 17, that utilized for three frequencies within pass band which are 1.8GHz, 5.8GHz and 10.5GHz. Figure 17(a), the radiation patterns at 1.8GHz, in the E-plane, the magnitude of main lobe is 1.36dBi in the direction -5° with the angular width (3dB) is 304.1°, in the H-plane, the magnitude of main lobe is 3.09dBi in the direction -75°, with the angular width (3dB) is 207.6°. Figure 17(b), the radiation patterns at 5.8GHz, in the E-plane, the magnitude of main lobe is

5.45dBi in the direction -5° with the angular width (3dB) is 67.9° and the side lobe level -5.3dB, where as in the H-plane, the magnitude of main lobe is 5.38dBi in the direction 0°, with the angular width (3dB) is 89.8° and the side lobe level -3.2dB.

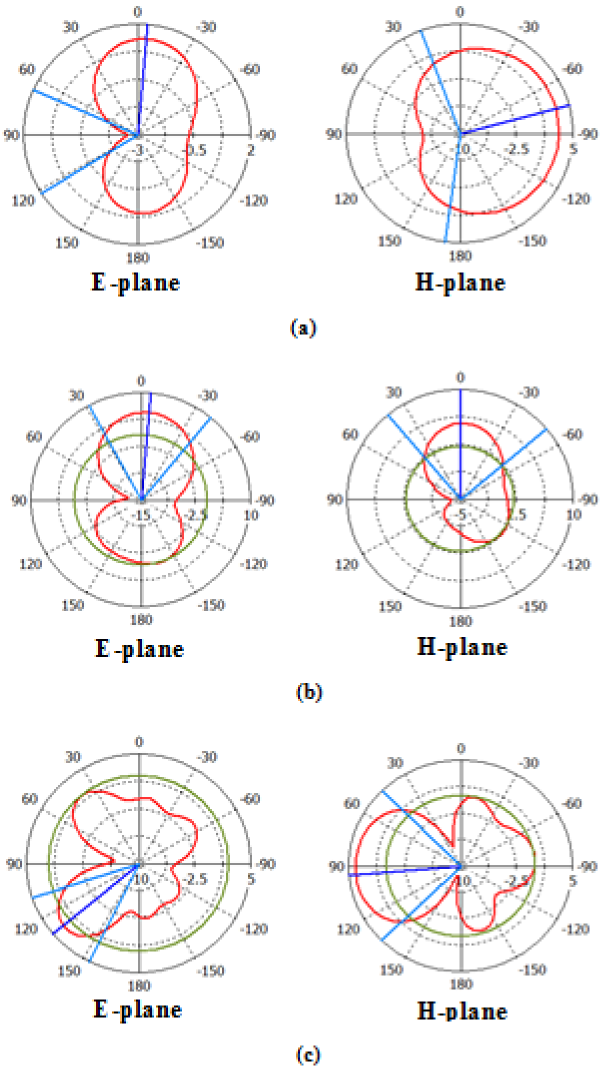

Fig 17: Radiation pattern of the CPW irregular pentagonal patch antenna at, (a) f=1.8GHz, (b) f=5.8GHz and (c) f=10.5GHz

Figure 17(c), the radiation patterns at 10.5GHz, in the E-plane, the magnitude of main lobe is 3.15dBi in the direction 130° with the angular width (3dB) is 45.6° and the side lobe level -1.1dB, where as in the H-plane, the magnitude of main lobe is 3.15dBi in the direction 130°, with the angular width (3dB) is 45.6° and the side lobe level -1.1dB.

3.6 3-D Radiation Pattern

The simulated 3-D radiation patterns of the CPW irregular pentagonal patch antenna at different frequencies 1.8GHz, 5.8GHz and 10.5GHz is shown in Figure 18. These plots show the directivity over the phi and theta angles for the proposed antenna. For the frequencies, 1.8GHz the maximum directivity is 3.42dBi, 5.8GHz the maximum directivity is 5.47dBi and 10.5GHz the maximum directivity is 5.55dBi.

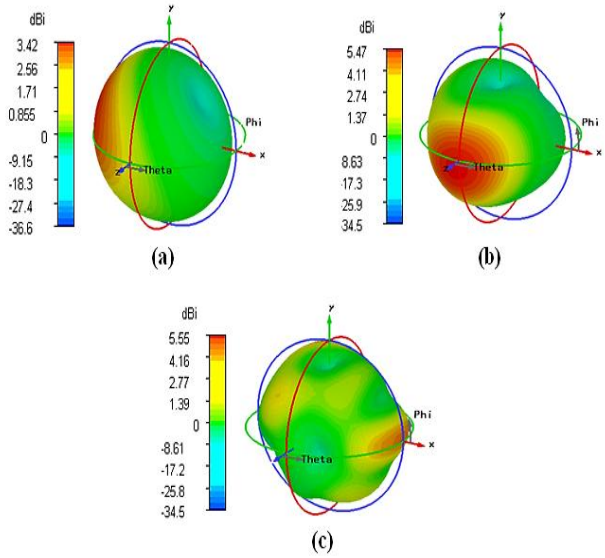

Fig 18: Simulated 3-D radiation patterns for the CPW irregular pentagonal patch antenna at, (a) f=1.8GHz, (b) f=5.8GHz and (c) f=10.5GHz

3.7 Group delay

The group delay of the CPW irregular pentagonal patch antenna is shown in Figure 19, from figure, it can be observed that the group delay is less than 0.5ns in almost all the ranges of frequencies.

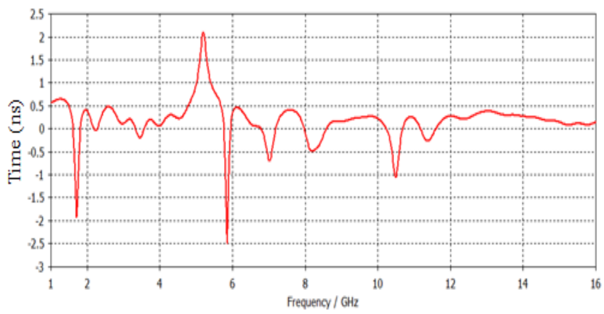

Fig 19: Group delay of CPW irregular pentagonal patch antenna

4. CONCLUSION

In the present work, design a CPW irregular pentagonal patch antenna operating in the frequency range 1.48-14.2 GHz. The proposed antenna gives gain varying from 0dBi to 4.3dBi. The CPW irregular pentagonal patch antenna is fabricated and tested practically using the vector network analyzer (VNA) and the results of S11, VSWR and input impedance are compared with the simulation results. It is observed that the practical results agrees (mostly) with simulation results and the slight difference is attributed to fabrication error.

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