

Resonance Characteristics Enhancement of Slot-loaded Microstrip Patch Antenna for GPS Application

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Abstract

For GPS application, a rectangular microstrip patch antenna has been designed and fabricated focusing on single resonant frequency at 1.575 GHz of the L-1 band. Slots are incorporated into the patch to fine-tune the resonant frequency, decrease the return loss, and increase the directivity and bandwidth. The proposed antenna has four rectangular slots of different sizes on the patch. The antenna is designed by commercially available simulation software. The simulation result shows that it resonates at 1.536 GHz with a return loss value of -50.72 dB having a bandwidth of 48.5 MHz and directivity of 7.13 dBi and the fabricated antenna has a resonant frequency of 1.5 GHz with return loss and bandwidth of -25 dB and 30 MHz, respectively. It is found that the proposed antenna perform much better than a conventional microstrip patch antenna.

Index terms— GPS, L-1 band, rectangular slot-loaded patch antenna.

1 INTRODUCTION

In this paper, we have proposed a new structure of a microstrip patch antenna which is designed for a single resonant frequency of 1.575 GHz. It is found that the resonance characteristics of the proposed antenna can be improved by using four rectangular slots of different sizes placed symmetrically into the patch. The return loss (?? 11) and bandwidth of the tetra-slotted rectangular MPA are increased remarkably in comparison with that of the conventional slot-less patch antenna. All the antennas are optimized and designed using CST Microwave Studio software for a various number of rectangular slots. The radiation pattern and In Section II the design procedure of optimization of tetra slotted MPA is described. The simulated and measured results of the proposed antenna are presented in Section III and IV, respectively. And finally, in Section V, we conclude by mentioning the research findings.

The schematic diagram of the proposed MPA and the dimensions of the incorporated slots have been II.

2 DESIGN OF THE PROPOSED MICROSTRIP PATCH ANTENNA

Global Positioning System (GPS) is a well-known technology to determine the exact position and provide navigation functionality to connected devices. A GPS antenna uses signals from multiple satellites to identify the three-dimensional location. To achieve accurate positioning, the radiation characteristics of GPS antennas should be circularly polarized and have broad beam width. These attributes can be attained mainly by two types of antennas such as quadrifilar helix and microstrip patch antenna (MPA) [1]. However, small size, mechanical robustness, low fabrication cost and easy installation process have made microstrip patch antennas more favorable than quadrifilar helix antennas for GPS navigation. Moreover, microstrip patch antennas have applications in cellular communication, satellite communication, medical sector, etc. [2,3]. Despite the advantages, MPAs have some drawbacks such as low gain, narrow bandwidth, multiple resonances, less efficiency and low power handling

4 SIMULATION RESULTS

42 capability [4][5] [7]. Researchers have been working on MPAs to overcome all these flaws. For G instance,
 43 the return loss characteristics, bandwidth, and gain are improved by designing MPAs of rectangular [7], circular
 44 [8], and E-shaped patches [9]. Slot-loaded MPAs have also been made to enhance the performance furthermore
 45 [10]. Different feeding The patch width, w is expressed as $w = \frac{2\delta}{\epsilon_r + 1} \sqrt{\frac{2\epsilon_r}{\epsilon_r + 1}}$ (1)
 46 where c is the free-space light velocity.

3 The expression for effective dielectric constant,

47 ϵ_{eff} is (2) $\epsilon_{eff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \left(\frac{w}{L} \right)^2$ (2)
 48 $\epsilon_{eff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \left(\frac{w}{L} \right)^2$ (3) $\epsilon_{eff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \left(\frac{w}{L} \right)^2$ (4)

50 The extended length of the patch is determined from the following expression:

51 $L_{eff} = L \left(1 + \frac{2.14}{\pi} \frac{\epsilon_r - 1}{\epsilon_r + 1} \right)$ (5)
 52 $L_{eff} = L \left(1 + \frac{2.14}{\pi} \frac{\epsilon_r - 1}{\epsilon_r + 1} \right)$ (6)

53 The expression for microstrip feed-line length (L_{feed}) is The design of our proposed MPA starts by
 54 observing the characteristics of a conventional MPA (without slots). Keeping all the structural parameters same,
 55 a conventional MPA is first simulated. According to calculation, the antenna has a dimension of 91.2 mm (7)
 56 For $\epsilon_r > 1$, which is satisfied for our chosen parameters given in Table-1, the length of the metallic patch, L
 57 is determined using the following equation: $L = \frac{L_{eff}}{\sqrt{\epsilon_r}}$ (6)

58 The value of the width of the microstrip feed-line (w) is found from the results of best fit. By varying
 59 w from $L/10$ to $L/5$, the best fit has been found at 7.5 mm (see Table-1).

60 The gap between the patch and the feed line is often called the notch width. We have denoted this notch
 61 width by g and taken its value to be of 0.6 mm. For an inset feed MPA, it is also customary to define
 62 the distance by how much the microstrip feed-line will insert into the patch. We have denoted this distance by
 63 d and the equation to determine this distance is mentioned below [15]: denoted by d_1 and d_2 , respectively.
 64 The signal is applied to the patch through an inset feed transmission line having a length of L_{inset} and a
 65 width of w . The feed line inset distance is represented by d_1 and is separated from the patch by
 66 a distance d_2 . The substrate is symmetrically divided into four quadrants by vertical and horizontal
 67 dashed lines as shown in Fig. 1. The patch has been placed in the middle of the substrate.

68 where L_{eff} is the effective length of the patch and L_{ext} is the extended length due to
 69 field fringing. The effective length L_{eff} is determined from the following equation:

70 To design both slot-less (conventional) as well as slot-loaded (proposed) MPAs we have assumed FR-4 substrate
 71 whose dielectric constant (ϵ_r) and height (h) are 4.3 and 1.6 mm, respectively [13]. For GPS application, the
 72 resonant frequency (f_r) of our proposed antenna is chosen at 1.575 GHz. With the aforementioned
 73 known parameters, the other unknown parameters such as patch length (L), patch width (w) and effective
 74 dielectric constant (ϵ_{eff}) are to be calculated by using the following equations [14]. by
 75 117.0 mm. To improve the attributes of the conventional MPA, we have introduced few slots of different sizes
 76 placed symmetrically on the patch as shown in Fig. 1. After several attempts of optimization, we have found
 77 that the characteristics of the MPA are remarkably enhanced by two pairs of slots having different dimensions;
 78 one pair of slots is 18.66 mm × 5.22 mm (1×2 ; large-slot), and the other pair is 4.79 mm × 3.61 mm (2×2 ;
 79 small-slot). $\epsilon_{eff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \left(\frac{w}{L} \right)^2$

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81 For the structural optimization and analysis of MPA, we have used CST Microwave Studio software. Simulation
 82 results of the resonant frequency, return loss, bandwidth, radiation pattern and directivity of MPA are presented in
 83 the following sections. The placement of the slots on the patch also plays a vital role in the overall performance of
 84 the antenna. The large-and small-slot pairs are described Figure 2 shows the return loss (S_{11}) of conventional
 85 (without slot) as well as proposed (with slot) MPA. Even though the designed parameters are set to have
 86 a resonant frequency of 1.575 GHz, we have found the main return loss peak at (1.575+0.015) GHz for the
 87 conventional (Fig. 2(a)) and at (1.575-0.039) GHz for proposed antennas (Fig. 2(b,c)). Several other return
 88 loss peaks appear at resonant frequencies of 2.42 GHz, 2.90 GHz and 3.11 GHz for the conventional MPA. By
 89 introducing slots, these other return loss peaks are completely suppressed as shown in Fig. 2(b) and 2(c).

90 In Fig. 2(b) and 2(c), the results of return losses are shown for two-slot and four-slot MPA, respectively. For
 91 two slots into the patch, there is only one resonant frequency at 1.544 GHz which is 0.031 GHz less than the
 92 desired resonant frequency of 1.575 GHz (see Fig. 2(b)). For four-slot MPA, the return loss peak is obtained at
 93 a frequency of 1.536 GHz which is 0.039 GHz shorter than 1.575 GHz (see Fig. 2 (c)). by the distances (d_1 ,
 94 d_2 , d_3) and (d_4 , d_5 , d_6), respectively from the edges of the patch (see Fig. 1.) For achieving a
 95 satisfactory result, the large-slot pair should be at a distance of $d_1 = 12.94$ mm, $d_2 = 14.00$ mm and $d_3 =$
 96 12.23 mm. Similarly, the small-slot pair should be placed at a distance of $d_4 = 23.83$ mm, $d_5 = 16.98$ mm
 97 and $d_6 = 6.15$ mm. The optimized values of the structural parameters which give best simulation results are
 98 shown in Table-1. The results of simulation and measurements of different MPAs are discussed in the following
 99 sections.

100 From Fig. 2 it is seen that the magnitude of return loss has been increased significantly for our proposed patch
 101 antenna. The magnitude of S_{11} is Found -21.94 dB for the conventional MPA (see Fig. 2(a)) whereas that

of ?? 11 is obtained -40.22 dB and -50.72 dB for two-slot and four-slot MPA, respectively (see Fig. 2 (b, c)). Thus our proposed antenna has only one dominant resonant frequency with a very large ?? 11 magnitude. In Fig. 3, the obtained simulation results of the radiation patterns are shown. The main lobe magnitude (i.e., gain) of the conventional antenna is found to be 2.28 dB (see Fig. 3(a)). Introducing slots into the patch, the main lobe magnitude is obtained very close to the conventional one. For our proposed two-slot and fourslot MPAs, the main lobe magnitudes are found 1.97 dB and 2.12 dB, respectively. The main lobe direction has remained same at 0.0 deg for all MPAs.

From Fig. 3, it is seen that -3 dB beamwidths of conventional, two-slot, and four-slot MPAs are found at 92.0, 91.8, and 91.2 degrees, respectively. Thus -3 dB beamwidth for four-slot MPA is the smallest which means directivity has increased in comparison to the conventional one. Also, the side lobe levels of conventional, two-slot, and four-slot MPAs are obtained -12.5, -12.5, and -12.6 dB, respectively. Therefore, our proposed MPA has the lowest value of side lobe level and its efficiency has increased.

The VSWR value decreases towards unity at or near desired resonant frequency for our proposed structure. The simulated values of VSWR are 1.17, 1.02 and 1.005 for conventional, double-slotted (two-slot) and tetraslotted (four-slot) MPA, respectively. Finally, the bandwidth and the directivity of our proposed tetraslotted antenna have been obtained 48.5 MHz and 7.13 dBi, respectively. The other directivities of the conventional and two-slotted MPA are quite similar to the proposed one.

5 MEASURED RESULTS

Among the simulation results of all three antennas, better characteristics are found for tetraslotted MPA which we have finally fabricated for experimental measurement. At first, the substrate has been cut into pieces having the dimensions of the antenna as given in Table-1. Then the patch antenna layout is printed on a tracing paper for photoresist masking. Lastly, chemical etching has been done to to be about -25 dB at 1.5 GHz. The deviation of return loss magnitude from simulated results may be due to the lossy FR-4 substrate and lack of precise fabrication of patch and slots with wet etching. At the resonant frequency, the bandwidth is found about 30 MHz. No significant return loss peaks at any other frequencies are found in the range of 1 GHz to 3 GHz. The measured radiation pattern is shown in Fig. ???. The main lobe radiation pattern is quite hemispherical, and the back lobe pattern is very small as obtained in simulation. Small back lobe characteristics represent that our proposed MPA has good directivity. All the measurements are taken in a room without the anechoic chamber. From Fig. ??? it is seen that the experimental results agree to a great extent with the simulated radiation patterns.

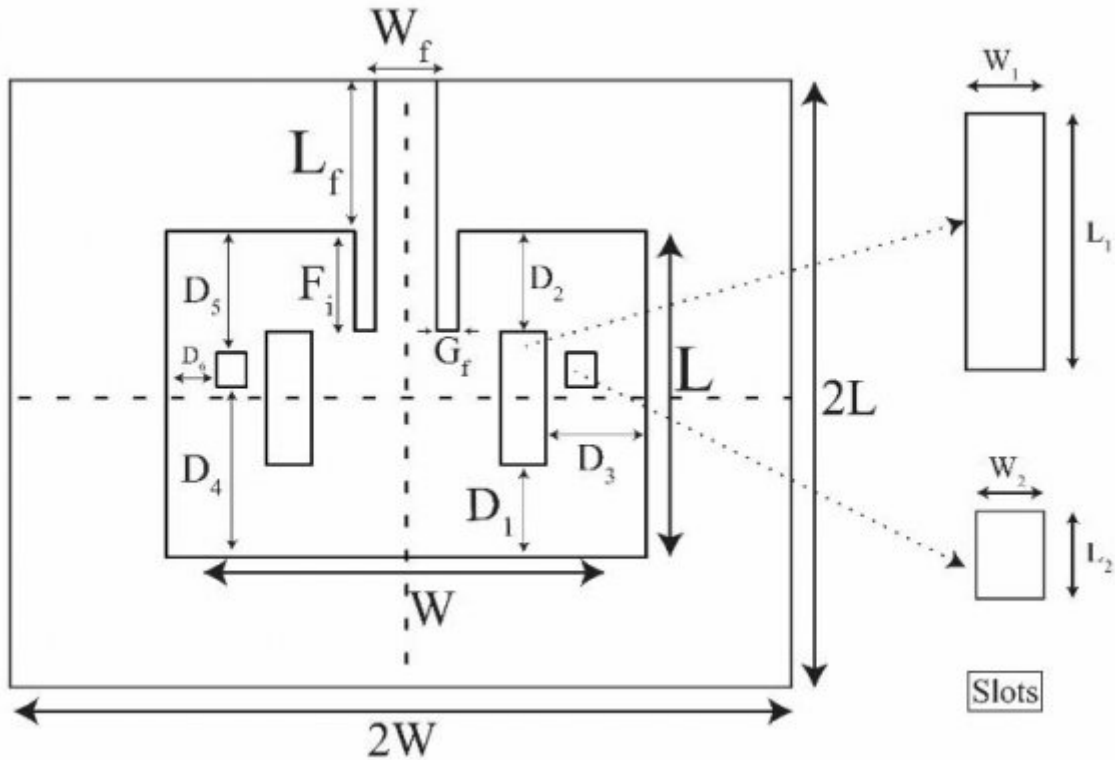


Figure 1: Fig. 1 :

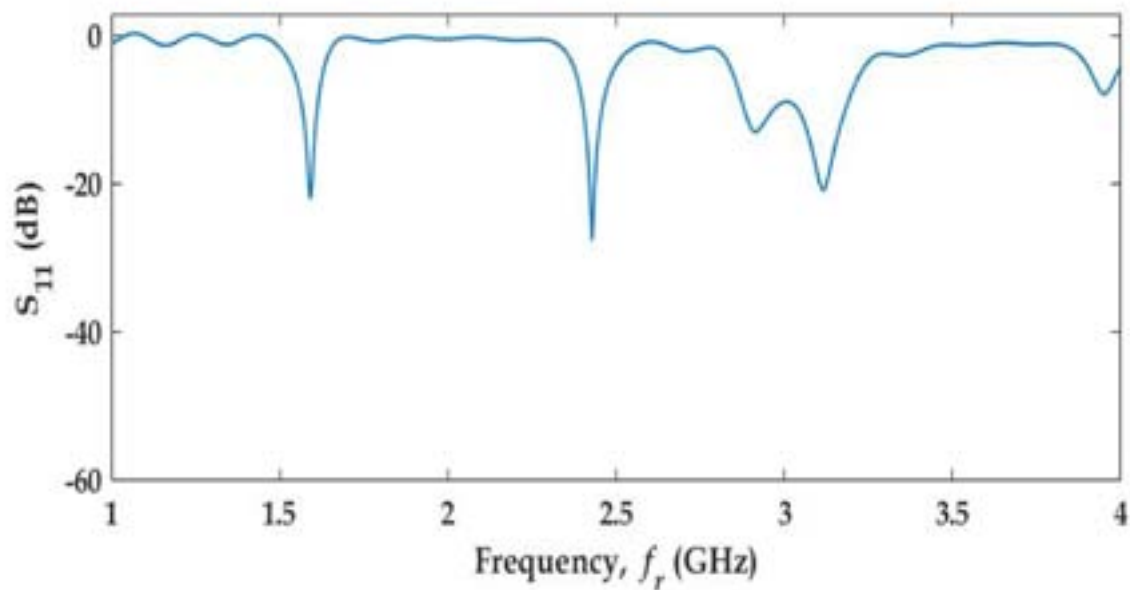
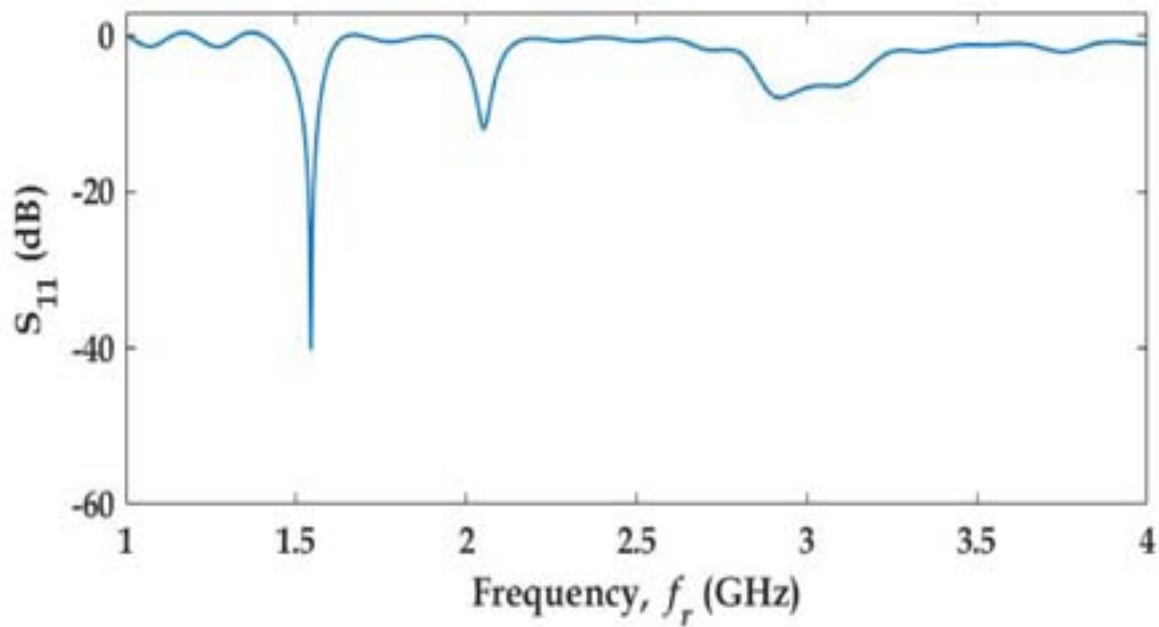
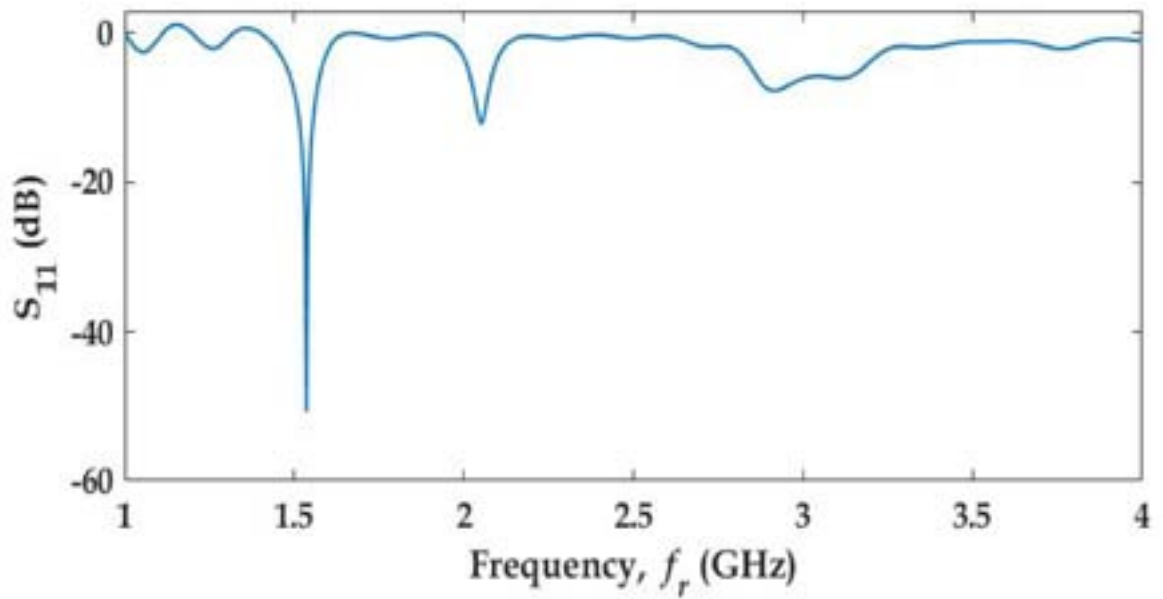


Figure 2: F



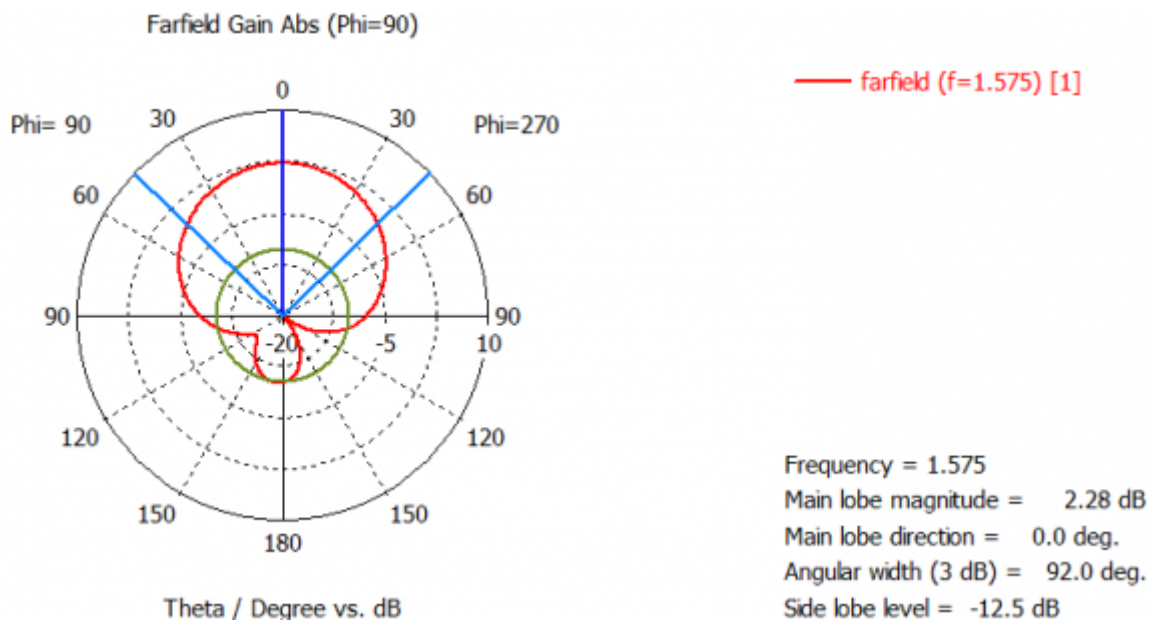
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Figure 3: Fig. 2 :F



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Figure 4: Fig. 3 :



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Figure 5: Fig. 4 :

5 MEASURED RESULTS

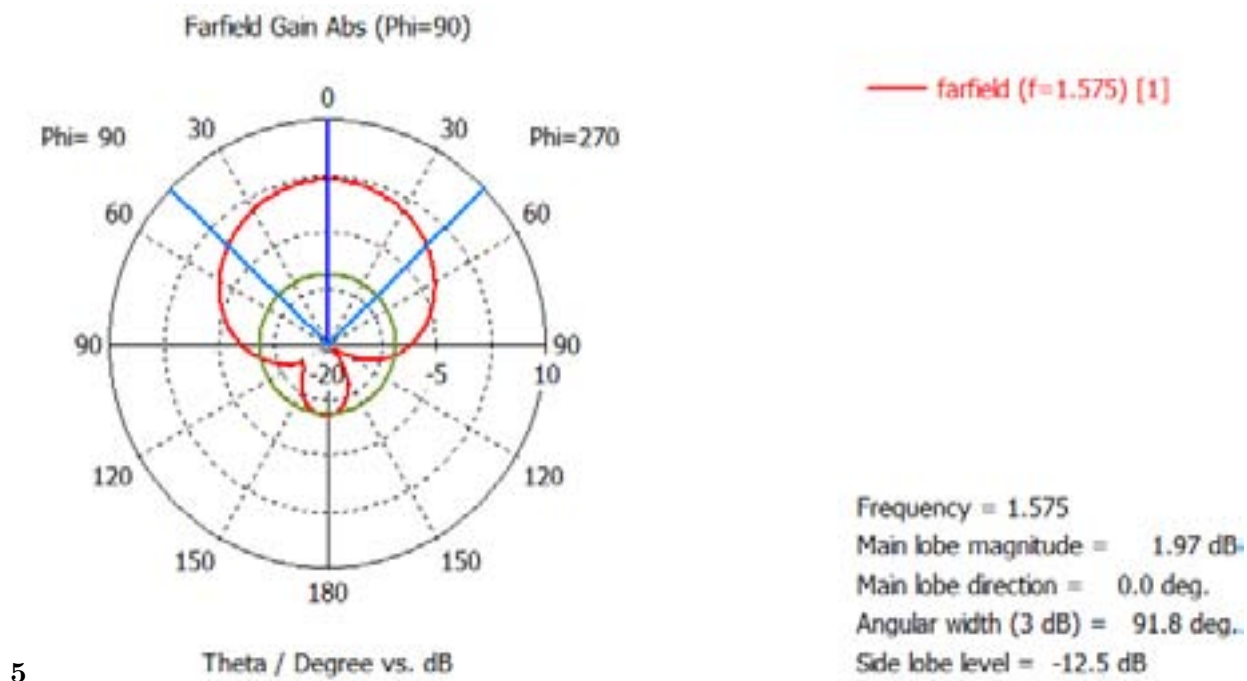


Figure 6: Figure 5 F

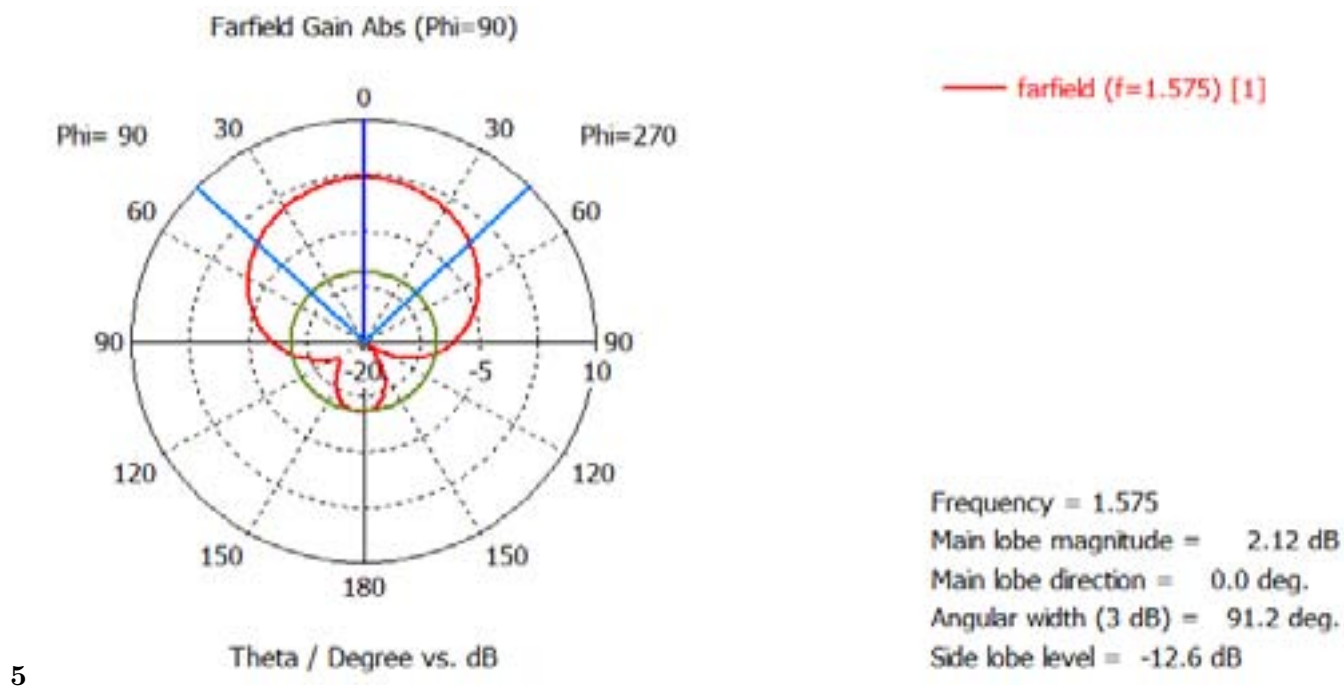


Figure 7: Fig. 5 :

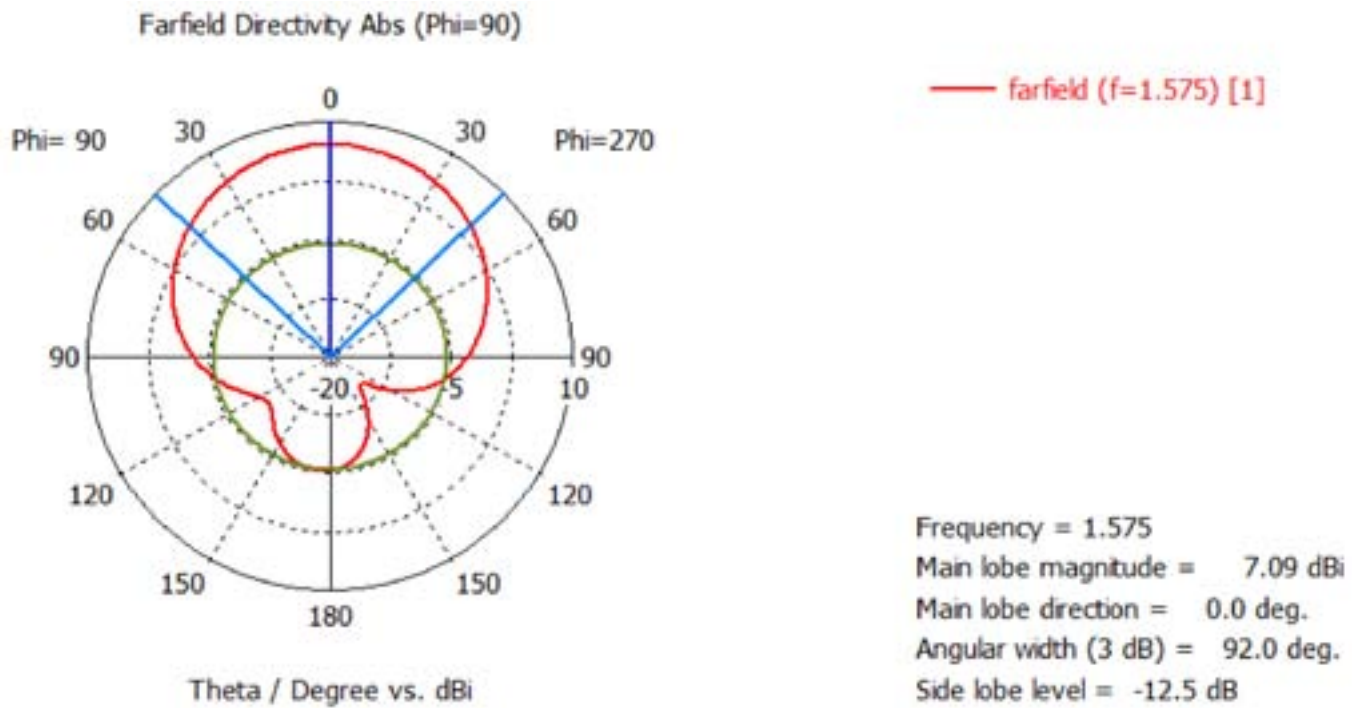


Figure 8:

1

$\{ \begin{matrix} 7 + \dots \\ \dots \end{matrix} \}$

Figure 9: Table 1 :

2

Parameters	Conventional MPA	MPA with two slots	MPA with four slots
Resonant Frequency, δ (GHz)	1.59, 2.42, 2.90, 3.11	1.54	1.54

Figure 10: Table 2 :

1.1 ACKNOWLEDGMENT

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[Hasan et al.] *With two types of slots, our proposed antenna gives satisfactory results regarding single resonant frequency with improved directivity. From the simulation results, the return loss (?? 11), VSWR, and directivity are found -50.72 dB, 1.005, and 7.13 dBi, respectively. The measured data of the tetra-slotted antenna are found very close to the simulated ones. The scope of precise fabrication and measurement in an anechoic chamber may have given improved data. Nevertheless, the antenna qualifies to work, Zahid Hasan , Ashiq Zaman , Dr Ahmed . (For GPS application in the L-1 band, a tetraslotted microstrip patch antenna is designed and fabricated at 1.575 GHz. The return loss characteristics are greatly enhanced by introducing four slots placed symmetrically on the patch in comparison to a conventional one without any slot. well in many applications related to GPS and other navigation systems)*