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RESONANCE CHARACTERISTICS ENHANCEMENT OF SLOT-LOADED MICROSTRIP PATCH ANTENNA FOR GPS APPLICATION

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

Rakib Hasan^α, Mustakim Ahmed Rahat^σ, Sakhawat Hussain^ρ & Anis Ahmed^ω

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.

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I. INTRODUCTION

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 capability [4-7]. Researchers have been working on MPAs to overcome all these flaws. For

instance, the return loss characteristics, bandwidth, and gain are improved by designing MPAs of rectangular [7], circular [8], and E-shaped patches [9]. Slot-loaded MPAs have also been made to enhance the performance furthermore [10]. Different feeding techniques with various substrate materials are also examined to overcome the limitations of the MPAs [11,12].

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 (S_{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 S_{11} of the proposed patch antenna are measured using Vector Network Analyzer or VNA (Rohde & Schwarz-ZVH8) and Wave and Antenna Training System (Man & Tel Co.). The antennas are fabricated on 1.6 mm thick FR-4 substrate. The S_{11} of the proposed tetra-slotted patch antenna are found -50.72 dB and -25 dB from simulation and measurement, respectively. Moreover, the measured values of other parameters such as resonant frequency, bandwidth, VSWR, and directivity allow us to conclude that the proposed antenna is well suited for the L-1 frequency band application.

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.

II. DESIGN OF THE PROPOSED MICROSTRIP PATCH ANTENNA

The schematic diagram of the proposed MPA and the dimensions of the incorporated slots have been shown in Fig. 1. The length and width of the patch are

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denoted by L and W , respectively. The signal is applied to the patch through an inset feed transmission line having a length of L_f and a width of W_f . The feed line inset distance is represented by F_i and is separated from the patch by a distance G_f . The substrate is symmetrically divided into four quadrants by vertical and horizontal dashed lines as shown in Fig. 1. The patch has been placed in the middle of the substrate.

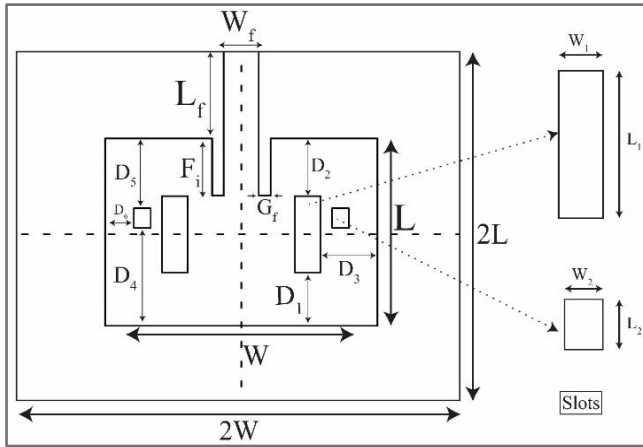


Fig. 1: Proposed structure of tetra-slotted microstrip patch antenna with slot dimensions

To design both slot-less (conventional) as well as slot-loaded (proposed) MPAs we have assumed FR-4 substrate whose dielectric constant (ϵ_r) and height (h) are 4.3 and 1.6 mm, respectively [13]. For GPS application, the resonant frequency (f_r) of our proposed antenna is chosen at 1.575 GHz. With the aforementioned known parameters, the other unknown parameters such as patch length (L), patch width (W) and effective dielectric constant ($\epsilon_{r_{eff}}$) are to be calculated by using the following equations [14].

The patch width, W is expressed as

$$W = \frac{v_0}{2f_r} \sqrt{\frac{2}{\epsilon_r + 1}} \quad (1)$$

where v_0 is the free-space light velocity.

The expression for effective dielectric constant, $\epsilon_{r_{eff}}$ is

$$\epsilon_{r_{eff}} = \frac{\epsilon_r + 1}{2} + \left[\frac{\epsilon_r - 1}{2} \right] \left[\left(1 + \frac{12h}{W} \right)^{-1/2} \right] \quad (2)$$

For $W/h > 1$, which is satisfied for our chosen parameters given in Table-1, the length of the metallic patch, L is determined using the following equation:

$$L = L_{eff} - 2\Delta L \quad (3)$$

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

$$L_{eff} = \frac{v_0}{2f_r \sqrt{\epsilon_{r_{eff}}}} \quad (4)$$

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

$$\Delta L = 0.412 h \times \frac{(\epsilon_{r_{eff}} + 0.3) \left(\frac{W}{h} + 0.264 \right)}{(\epsilon_{r_{eff}} - 0.258) \left(\frac{W}{h} + 0.8 \right)} \quad (5)$$

The expression for microstrip feed-line length (L_f) is

$$L_f = \frac{v_0}{4f_r \sqrt{\epsilon_r}} \quad (6)$$

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

The gap between the patch and the feed line is often called the notch width. We have denoted this notch width by G_f and taken its value to be of 0.6 mm. For an inset feed MPA, it is also customary to define the distance by how much the microstrip feed-line will insert into the patch. We have denoted this distance by F_i and the equation to determine this distance is mentioned below [15]:

$$F_i = 10^{-4} \{ F_{c7} \epsilon_r^7 + F_{c6} \epsilon_r^6 - F_{c5} \epsilon_r^5 + F_{c4} \epsilon_r^4 - F_{c3} \epsilon_r^3 + F_{c2} \epsilon_r^2 - F_{c1} \epsilon_r^1 + F_{c0} \} \frac{L}{2} \quad (7)$$

where $F_{c7} = 0.001699$, $F_{c6} = 0.13761$, $F_{c5} = 6.1783$, $F_{c4} = 93.187$, $F_{c3} = 682.93$, $F_{c2} = 2561.9$, $F_{c1} = 4043$, and $F_{c0} = 6697$.

The design of our proposed MPA starts by observing the characteristics of a conventional MPA (without slots). Keeping all the structural parameters same, a conventional MPA is first simulated. According to calculation, the antenna has a dimension of 91.2 mm by 117.0 mm. To improve the attributes of the conventional MPA, we have introduced few slots of different sizes placed symmetrically on the patch as shown in Fig. 1. After several attempts of optimization, we have found that the characteristics of the MPA are remarkably enhanced by two pairs of slots having different dimensions; one pair of slots is 18.66 mm \times 5.22 mm ($L_1 \times W_1$; large-slot), and the other pair is 4.79 mm \times 3.61 mm ($L_2 \times W_2$; small-slot).

The placement of the slots on the patch also plays a vital role in the overall performance of the antenna. The large- and small- slot pairs are described by the distances (D_1, D_2, D_3) and (D_4, D_5, D_6), respectively from the edges of the patch (see Fig. 1.) For achieving a satisfactory result, the large-slot pair should be at a distance of $D_1 = 12.94$ mm, $D_2 = 14.00$ mm and

$D_3 = 12.23$ mm. Similarly, the small-slot pair should be placed at a distance of $D_4 = 23.83$ mm, $D_5 = 16.98$ mm and $D_6 = 6.15$ mm. The optimized values of the structural parameters which give best simulation results are shown in Table-1. The results of simulation and measurements of different MPAs are discussed in the following sections.

Table 1: Parameters of MPA Obtained from Calculation

Parameters	Optimized Value	Parameters	Optimized Value
Frequency, f_r (GHz)	1.575	Thickness of Copper Layer, M_t (mm)	0.1
Wavelength, λ (mm)	190.476	L_1 (mm)	18.66 ($\cong 0.1\lambda$)
Dielectric constant, ϵ_r	4.3	W_1 (mm)	5.22 ($\cong 0.027\lambda$)
Substrate Height, h (mm)	1.6	L_2 (mm)	4.79 ($\cong 0.025\lambda$)
Patch Width, W (mm)	58.5 ($\cong 0.3\lambda$)	W_2 (mm)	3.61 ($\cong 0.018\lambda$)
Patch Length, L (mm)	45.6 ($\cong 0.23\lambda$)	D_1 (mm)	12.94 ($\cong 0.067\lambda$)
Substrate Width, $2W$ (mm)	117.0 ($\cong 0.61\lambda$)	D_2 (mm)	14.00 ($\cong 0.07\lambda$)
Substrate Length, $2L$ (mm)	91.2 ($\cong 0.47\lambda$)	D_3 (mm)	12.23 ($\cong 0.064\lambda$)
Microstrip Transmission Line Length, L_f (mm)	22.96 ($\cong 0.12\lambda$)	D_4 (mm)	23.83 ($\cong 0.125\lambda$)
Microstrip Transmission Line Width, W_f (mm)	7.5 ($\cong 0.039\lambda$)	D_5 (mm)	16.98 ($\cong 0.089\lambda$)
Microstrip Line Inset Feed Length, F_i (mm)	13.9 ($\cong 0.07\lambda$)	D_6 (mm)	6.15 ($\cong 0.032\lambda$)
Gap between patch and feed line, G_f (mm)	0.6 ($\cong 0.003\lambda$)		

III. SIMULATION RESULTS

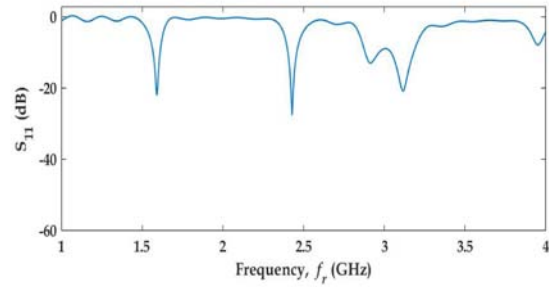
For the structural optimization and analysis of MPA, we have used CST Microwave Studio software. Simulation results of the resonant frequency, return loss, bandwidth, radiation pattern and directivity of MPA are presented in the following sections.

a) Return Loss

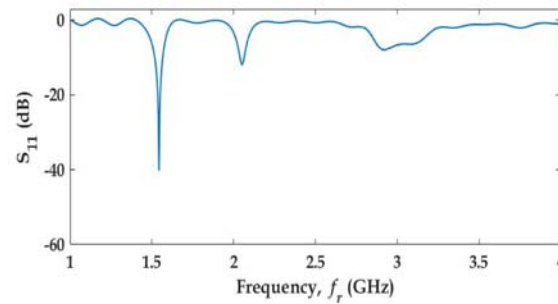
Figure 2 shows the return loss (S_{11}) of conventional (without slot) as well as proposed (with slot) MPA. Even though the designed parameters are set to have a resonant frequency of 1.575 GHz, we have found the main return loss peak at (1.575+0.015) GHz for the conventional (Fig. 2(a)) and at (1.575-0.039) GHz for proposed antennas (Fig. 2(b,c)). Several other return loss peaks appear at resonant frequencies of 2.42 GHz, 2.90 GHz and 3.11 GHz for the conventional MPA. By introducing slots, these other return loss peaks are completely suppressed as shown in Fig. 2(b) and 2(c).

In Fig. 2(b) and 2(c), the results of return losses are shown for two-slot and four-slot MPA, respectively. For two slots into the patch, there is only one resonant frequency at 1.544 GHz which is 0.031 GHz less than the desired resonant frequency of 1.575 GHz (see Fig. 2(b)). For four-slot MPA, the return loss peak is obtained at a frequency of 1.536 GHz which is 0.039 GHz shorter than 1.575 GHz (see Fig. 2 (c)).

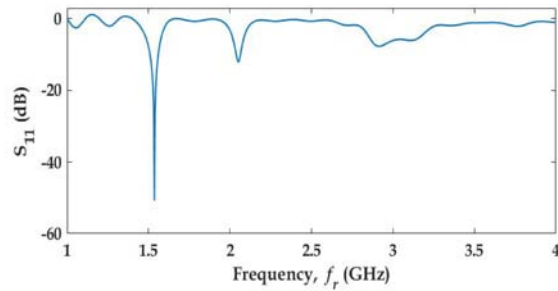
From Fig. 2 it is seen that the magnitude of return loss has been increased significantly for our proposed patch antenna. The magnitude of S_{11} is Found -21.94 dB for the conventional MPA (see Fig. 2(a)) whereas that of S_{11} is obtained -40.22 dB and -50.72 dB for two-slot and four-slot MPA, respectively (see Fig. 2 (b, c)). Thus our proposed antenna has only one dominant resonant frequency with a very large S_{11} magnitude.



(a)



(b)



(c)

Fig. 2: Simulated Return Loss Value of Simple MPA

(a) Conventional (without slot), (b) Proposed (with two-slot), (c) Proposed (with four-slot)

b) Far-Field Radiation Pattern

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 four-slot 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 tetra-slotted (four-slot) MPA, respectively. Finally, the bandwidth and the directivity of our proposed tetra-slotted 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.

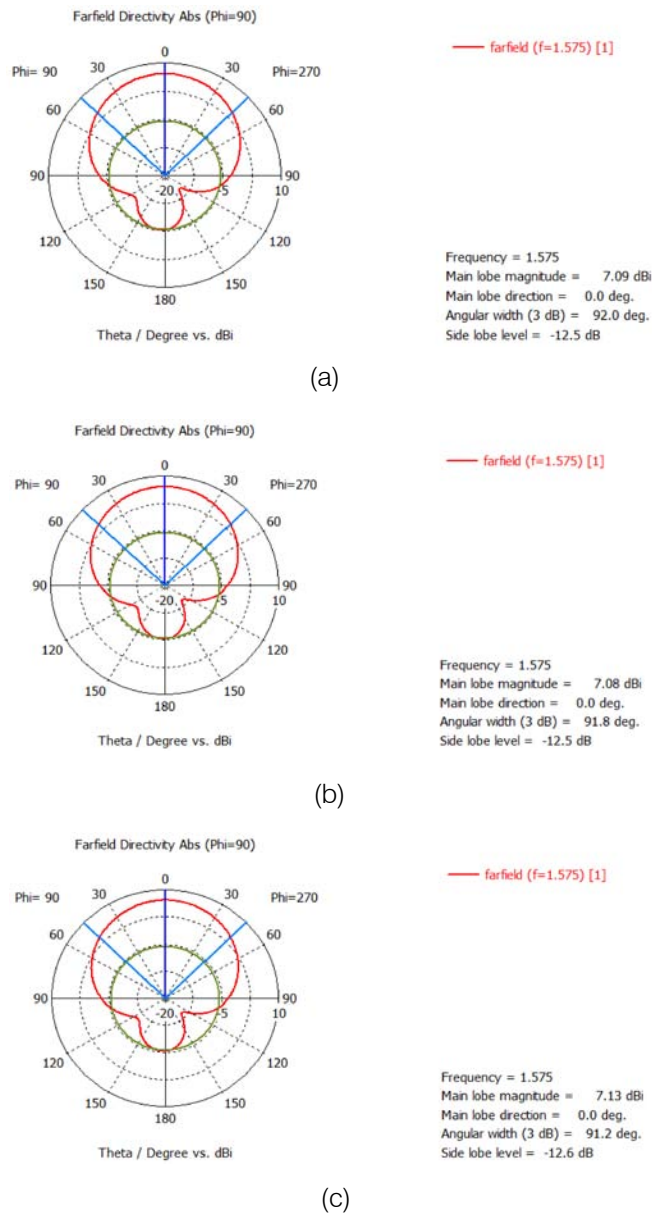


Fig. 3: Far-field Radiation Gain of Designed Antennas

(a) Without slot, (b) With Two Slots, (c) With Four Slots

All the results of simulation are shown in Table-2 for comparison. It is clear from Table-2 that the tetra (four) slotted MPA has better characteristics than other two antennas regarding resonant frequency, return loss and VSWR. But the main lobe magnitude, bandwidth, and directivity are somewhat comparable to the other two antennas. Thus our proposed four-slot microstrip patch antenna provides single resonant frequency in the range of 0 to 4 GHz range.

Table 2: Antenna Characteristics Obtained from Simulation

Parameters	Conventional MPA	MPA with two slots	MPA with four slots
Resonant Frequency, f_r (GHz)	1.59, 2.42, 2.90, 3.11	1.54	1.54
S_{11} (dB)	-21.94, -27.56, -14.17, -19.96	-40.22	-50.72
Bandwidth (MHz)	44.9, 52.6, 91, 119.1	48.8	48.5
VSWR	1.17, 1.09, 1.49, 1.22	1.02	1.005
Gain (dB)	2.28	1.97	2.12
Directivity (dBi)	7.09	7.08	7.13

IV. MEASURED RESULTS

Among the simulation results of all three antennas, better characteristics are found for tetra-slotted 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 complete the fabrication process. The SMA (Sub Miniature version A) connectors have been attached to the antenna port through an aluminum mount at our Central Science Workshop. Both front and back view of the fabricated tetra-slotted antenna are shown in Fig. 4. Return loss value (S_{11}) and radiation pattern of the fabricated antenna have been measured using VNA (Rohde & Schwarz– ZVH8) and Wave and Antenna Training System (Man & Tel Co.).

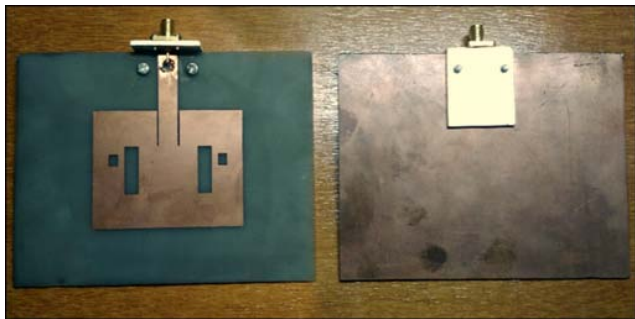


Fig. 4: Front Side (left) and Back Side (right) view of the proposed tetra slotted MPA.

Figure 5 shows the measured return loss characteristics of the proposed fabricated antenna. The return loss (S_{11}) value of the fabricated antenna is found

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.

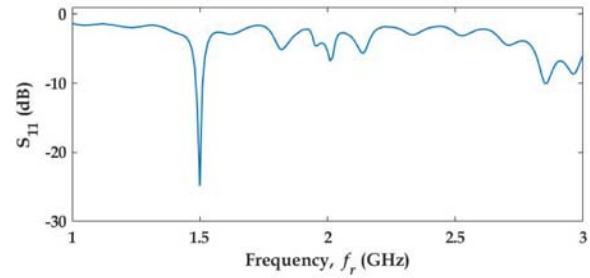


Fig. 5: Measured Return Loss (S_{11}) of the fabricated tetra slotted MPA.

The measured radiation pattern is shown in Fig. 6. 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. 6 it is seen that the experimental results agree to a great extent with the simulated radiation patterns.

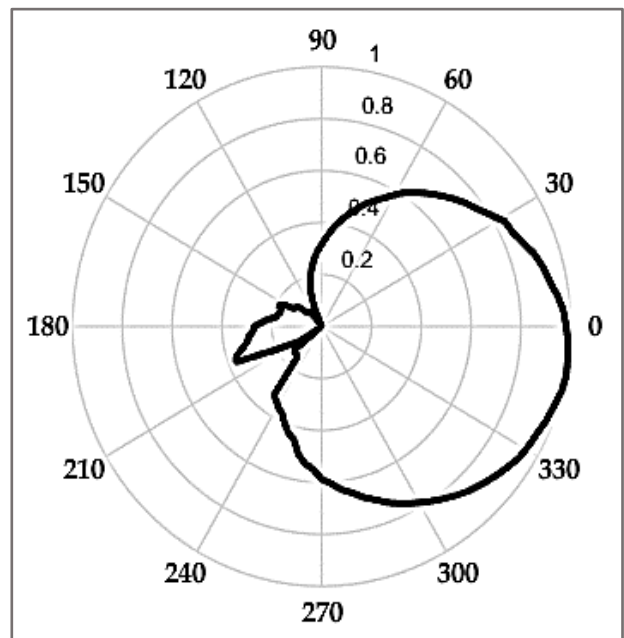


Fig. 6: Measured Radiation Pattern of the fabricated tetra slotted MPA.

V. CONCLUSION

For GPS application in the L-1 band, a tetra-slotted 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. 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 (S_{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 well in many applications related to GPS and other navigation systems.

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