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Design and Fabrication of a Circular Microstrip Patch Antenna for GPS Application

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Abstract

Nowadays GPS receivers are vastly used mainly for satellite navigation of vehicles, aircraft, ships, and cellular communication. The two most popular types of antennas used in GPS receivers are patch and quad helix. Microstrip patch antennas are appropriate antenna for GPS receiver because of their light weight, ease of installation, single hemispheric radiation pattern and low profile. This research work is focused on designing and fabricating a new type of inset feed Circular Microstrip Patch Antenna (CMPA). By introducing a circular slot at the center of the ground plane, enhanced characteristics of patch antenna can be achieved. Emphasis has been given on the optimization of the antenna structure at 1.8 GHz by using simulation software CST Microwave Studio. From simulation and measured results it is found that our proposed patch antenna shows improved performance compared to a conventional CMPA.

Keywords

GPS Antenna, Circular Microstrip Patch Antenna (CMPA), Circular Slot Patch Antenna.

I. Introduction

With the progress of electronic communication GPS application spreads into all aspects of national economic production and people's daily lives. Such applications are search and rescue operation, path finding, military and civilian aircraft control, missiles or rocket missions etc. [1]. The two most popular types of antennas used in GPS receivers are patch and quad helix. Among them microstrip patch antennas are suitable as GPS receiver antenna due to their light weight, ease of installation, and having less air-drag [2].

In order to make a GPS receiver work efficiently, a GPS antenna should fulfill two main requirements; one is good radiation pattern in upper half plane and another one is RHCP [3]. It can be added that these patch antennas also have some drawbacks such as low gain, narrow bandwidth, and low power handling capacity. To overcome these limitations many designed antennas are proposed such as U-shaped slotted patch [4], triangular patch [5], circular patch [6], rectangular patch [7], irregular Diamond Edge Slotted patch [8] etc. Moreover different substrate materials and different feeding techniques are also chosen to overcome those limitations [9-10].

In this paper, we have proposed a new structure of a Circular Microstrip Patch Antenna (CMPA) which is designed for a single resonant frequency at 1.8 GHz. To ameliorate the return loss, directivity, bandwidth, VSWR and other essential characteristics, a circular slot is introduced at the center of the ground plane. The characteristics of the proposed patch antenna are compared with that of a conventional CMPA without slot at the ground plane. Both the structures of patch antennas are optimized using CST software and then fabricated to measure different parameters by Vector Network Analyzer (Rohde & Schwarz–ZVH8) and Wave and Antenna Training System (Man &Tel Co.). The antennas are made on FR-4 substrate with thickness of 1.6 mm [11]. It is found that the performance of the patch antenna has improved greatly by introducing slot on the ground plane. According to the measured results it can be said that this proposed antenna will be a great help for cellular and other GPS applications. In Section II the design procedure of optimization of CMPA is described. The simulation results of conventional and proposed antennas are presented in Section III. Measured results of fabricated proposed antenna are given in Section IV with a conclusion in Section V.

II. Design and Optimization of CMPA

The schematic diagram of the patch (i.e. front view) and the ground plane (i.e. back view) of our proposed CMPA are shown in Fig. 1(a) and Fig. 1(b), respectively. The patch antenna is assumed to be fabricated on FR-4 substrate whose dielectric constant is 4.3 and thickness is 1.6 mm [11]. The length and width of the FR-4 substrate are represented by L and W, respectively.The radius of our circular patch is denoted by a and the signal is fed through an inset feed transmission line having width W_f. The feedline inset distance is denoted by F_i. As a new structure, a circular slot is added in the ground plane having radius W_f as shown in Fig.1(b). The impedance of inset feed transmission line at the input port is assumed 50 Ω.

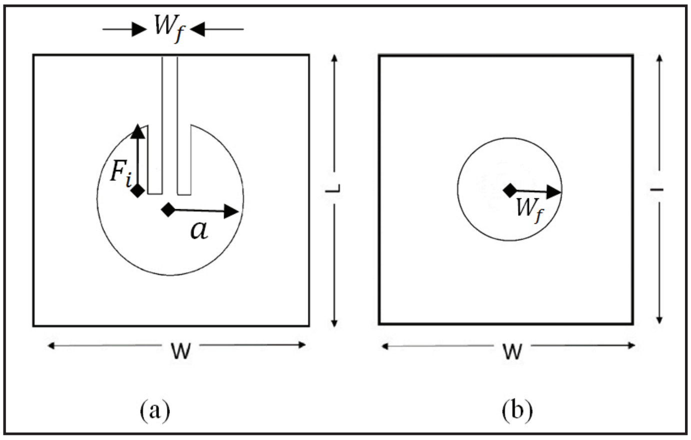


Fig. 1: Proposed Structure of CMPA (a) front view (b) back view.

For designing a CMPA some parameters such as - resonant frequency (f_r), substrate thickness (h) and relative dielectric constant (ε_r) are to be known, and some structural parameters such as circular patch radius (a), substrate length (L), substrate width (W) and feedline inset distance (F_i) should be calculated. The radius of the circular patch is expressed as [14]

$$a = \frac{F}{\sqrt{\left\{1+\frac{2h}{\pi\varepsilon_r F}\left[\ln\left(\frac{\pi F}{2h}\right)+1.7726\right]\right\}}} \quad (1)$$

where $F = \frac{8.791\times10^9}{f_r\sqrt{\varepsilon_r}}$.

Generally substrate length L and width W are taken two times larger than patch diameter ($2a$). So substrate length and width can be written as

$$L = 2 \times Patch\ Diameter = 2 \times (2a) \quad (2)$$

$$W = 2 \times Patch\ Diameter = 2 \times (2a) \quad (3)$$

The feedline inset distance can be expressed as

$$F_i = 10^{-4}(p - q.\varepsilon_r + r.\varepsilon_r^2 - s.\varepsilon_r^3 + t.\varepsilon_r^4 - u.\varepsilon_r^5 + v.\varepsilon_r^6 - w.\varepsilon_r^7)\frac{L}{2} \quad (4)$$

where the values of the parameters are $p = 6697$, $q = 4043$, $r = 2561.9$, $s = 682.69$, $t = 93.187$, $u = 6.1783$, $v = 0.13761$, $w = 0.001699$ [12]. Using the above equations we obtain, patch radius, a=23 mm, and feedline length, F_i = 14 mm.

Since Eqs.(1), and (2) are approximate equations, the desired characteristics of our CMPA are found not satisfactory when the above obtained values of the parameters are used in CST software. After several trials, it is found that by adjusting the values of a and F_i it is possible to improve the characteristics of the proposed CMPA. The optimized values of the structural parameters which give best results are given in Table-1.

Table 1: Design Specifications for both CMPA

Frequency	f_r	1.8GHz
Patch radius	a	22 mm
Substrate height	h	1.6 mm
Copper height	M_t	0.1 mm
Feedline width	W_f	3.0 mm
Feedline inset distance	F_i	18.2 mm
Dielectric constant	ε_r	4.3 mm
Substrate length	L	88 mm
Substrate width	W	88 mm

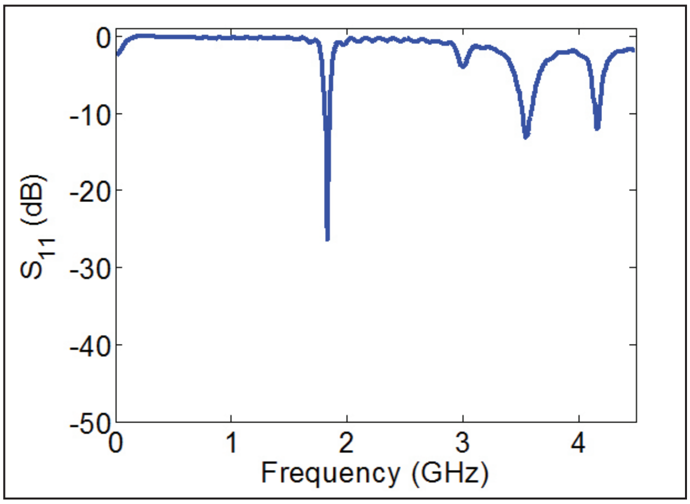
For the design of a conventional patch antenna, the data given in Table-1 are remain same. Main difference is a circular slot loaded at the center of the ground plane in the proposed structure. Results show that the addition of a back slot remarkably improve the characteristics of the circular patch antenna.

III. Simulation Results

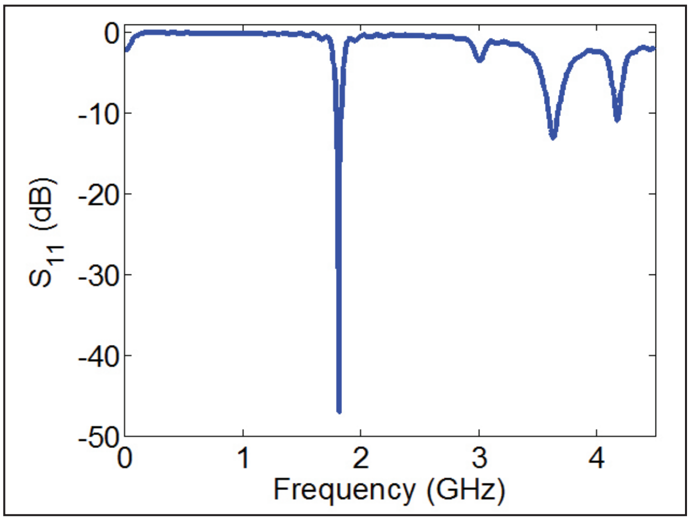
The design of conventional and our proposed circular microstrip patch antennas is carried out with simulation soft CST Microwave Studio. The final antenna structures of both patch antennas are determined by inputting the data obtained from empirical equations into the simulation soft. The substrate is assumed FR-4 whose electrical characteristics are also given in Table 1. The primary goal of simulation is to find optimized dimensions which can be easily fabricated by wet etching in our laboratory for measurement. For simulation of both types of patch antennas, the dimensions shown in Table-1 are kept same.

Generally the most important parameter of an antenna characteristics is the reflection coefficient S_{11} which represents how much power is reflected or accepted by the antenna [13]. All the applied power will be reflected from the antenna if S_{11} = 0 dB. So smaller the value of S_{11} is, better the antenna radiated-power is increased [15].

The reflection coefficient S_{11} of conventional circular patch antenna without a slot in the ground plane is shown in Fig. 2(a). The value of S_{11} is found about -27dB at the resonant frequency of 1.825GHz. But with our proposed structure, the value of S_{11} is decreased further as shown in Fig. 2(b). With a slot in the ground plane, the value of S_{11} is found near about -47dB at the resonant frequency of 1.813 GHz. It is seen that there are no dominant resonant peaks except the desired peak near 1.8 GHz.



(a)

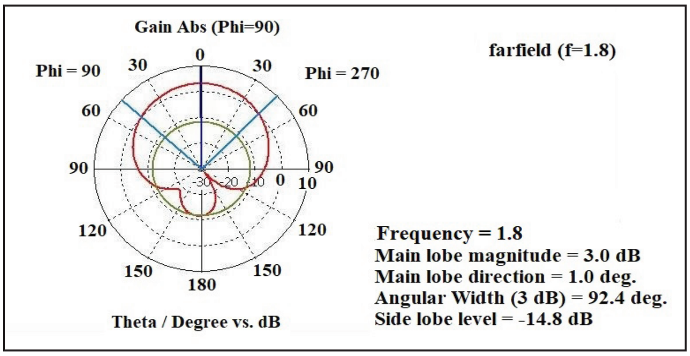


(b)

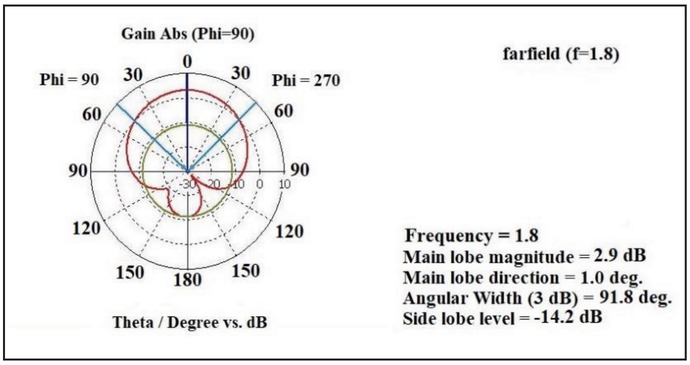
Fig. 2: Return Loss S_{11} of (a) conventional and (b) proposed CMPA.

The radiation patterns of the conventional and the proposed inset feed CMPA are shown in Fig.3(a) and Fig.3(b), respectively. From Fig.3(a), the main lobe magnitude (i.e. gain) and main lobe direction of the conventional antenna are found to be 3.0 dB and 1.0 deg. respectively. From the radiation pattern of our slot-loaded CMPA (see Fig.3(b)) it is seen that the main lobe magnitude and direction is almost same as the conventional patch, but beamwidth is slightly reduced. The VSWR of conventional patch and our proposed CMPA are found to be 1.1025 and 1.0089, respectively.

The obtained simulation results of conventional and our proposed CMPA are shown in Table-2. From this table it is found that the characteristics of the proposed patch antenna are better than that of the conventional patch. Especially return loss, VSWR and bandwidth of our proposed patch antenna are much better compared to the conventional CMPA.



(a)



(b)

Fig. 3: Radiation Patterns of (a) conventional (without slot), and (b) our proposed CMPA (with back slot).

From the simulation process it is also found that the ratio of patch-copper and ground plane-copper dominates the gain of patch antenna. As conventional CMPA has lower gain, the circular patch region has been considered without any slot which may reduce gain further. From the simulation results it is found that much higher return loss (–26.92 dB) and resonant frequency deviation are observed in the characteristics of the conventional CMPA. But our proposed configuration reduces return loss (–46.98 dB) remarkably with a resonant frequency very close to desired value of 1.8 GHz.

Table-2: Comparison of simulation results of conventional (without slot) and proposed CMPA (with slot).

Parameters	Conventional CMPA	Proposed CMPA
Return Loss Magnitude	–26.92 dB	–46.98 dB
Resonance Frequency	1.825 GHz	1.813 GHz
Bandwidth	39.7 MHz	42 MHz
Gain	3.0 dB	2.9 dB
Directivity	6.610 dBi	6.618 dBi
VSWR	1.102	1.008

IV. Measured Results

The optimized dimensions of our proposed antenna is presented in Table-1. In our laboratory, the proposed patch antenna has been fabricated by photolithographic method. After etching and cleaning, SMA connectors are fixed at the antenna port through an aluminum mount. In Fig. 4, the front side and back side of the fabricated CMPA are shown. Using Vector Network Analyzer (Rohde & Schwarz–ZVH8) and Wave and Antenna Training System (Man & Tel Co.) return loss (S_{11}) and radiation pattern of the fabricated antennas are measured.

From the return loss characteristics (see Fig. 5) of our patch antenna, the value of S_{11} is about -37 dB at 1.86 GHz instead of simulation resonant frequency of 1.813 GHz. It is important to be noticed that no secondary resonant peaks are found in range of 0 to 3 GHz in the return loss graph. Fig. 6 shows the radiation pattern of the fabricated CMPA. The radiation pattern is nearly same as simulation results. By comparing measured and simulation results, both are found very close and satisfactory.

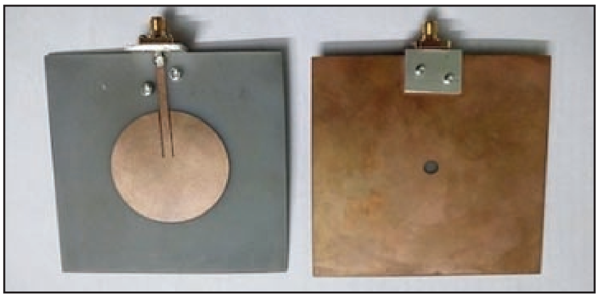


Fig. 4: Front side (left) and back side (right) of the fabricated CMPA fixed with SMA port.

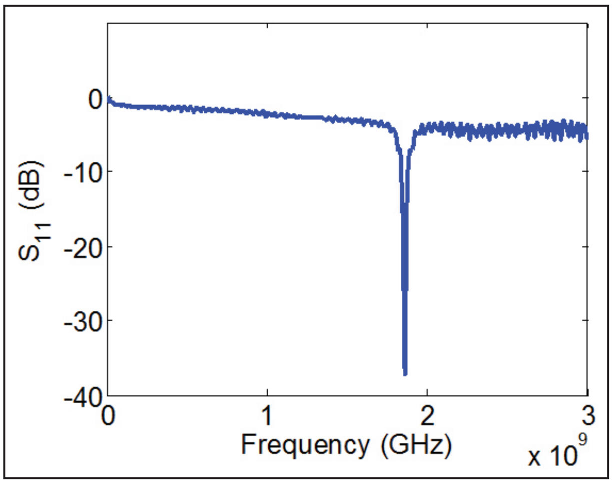


Fig. 5: Measured Return loss S_{11} of fabricated CMPA.

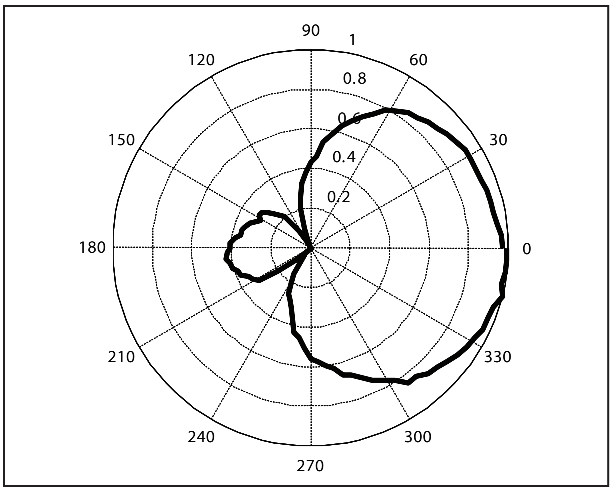


Fig. 6: Measured Radiation pattern of fabricated CMPA.

V. Conclusion

In recent years, automatic GPS tracking devices need antennas to operate in multi-frequency bands, including GSM, 3G, and new LTE bands. As microstrip patch antennas are suitable for GPS application due to their light weight, ease of installation and having less air-drag, many researchers are giving emphasis on it. To improve the characteristics of circular patch antenna, a circular slot in the ground plane is introduced. This proposed CMPA has only one resonant frequency at 1.8 GHz. From simulation, S_{11} of the conventional and proposed patch antennas are found to be -27dB and -47dB, respectively where as S_{11} of the fabricated antenna is -37dB. It is important to be noticed that no secondary resonant peaks are found in range of 0 to 3 GHz in the return loss graph. With the introduction of the slot in the ground plane, bandwidth, VSWR, beamwidth and the magnitude of return loss have improved. According to the measured results it can be said that the experimental data are in good agreement with the simulation ones and thus our proposed antenna will be very useful for GPS application.

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