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# A circular monopole patch antenna loaded with inverted L-shaped stub for GPS application

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**ABSTRACT**

This article introduces a planar monopole patch antenna for global positioning system (GPS) application. Our design has a circular patch with a stub of inverted L-shape which is used as the radiating portion and partial ground. Our proposed design of the stub allows the antenna to operate at a frequency of 1.5 GHz. The circular monopole is fed by an offset feeding to have an impedance match of 50 ohms. The compact antenna has been designed and simulated on RT Duroid 6006 material with relative permittivity ($\varepsilon_r$) of 6.15 and 0.0019 as the loss tangent. Our antenna has a dimension of 65 × 55 × 2.54 $mm^3$. A gain of 1.23 dB is observed at the resonant frequency of 1.5 GHz and the antenna exhibits dipole like radiation pattern both in E and H-plane. The antenna has better impedance matching, good gain and steady characteristics of radiation pattern across the operating bandwidth. High frequency structure simulator (HFSS) v.13.0 is used to carry out all the simulations.



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## 1. INTRODUCTION

Increasing numbers of researchers have used recent developments to build antennas that exhibit an increased gain, good efficiency, and are small in size with omnidirectional radiation patterns since the time wireless communication began to make major advances and began to gain popularity in everyday applications. Monopole antennas have become one of the worldwide elements of cellular and Internet networks. They are made a clear choice for developing countries by their relatively low cost and rapid implementation. The feature of the operation of these antennas in multiple bands to catering to the services of wireless local area network (WLAN), Wireless Interoperability for microwave access (WiMAX) and ultrawideband (UWB), motivates researchers in designing antennas that are compact and have triple or quad-band characteristics. The creation of slots in different positions results in varied radiation patterns and designs of novel antennas.

Literature reports numerou antennas in this regard. Ali et al. [1] have proposed a slot antenna for UWB applications. Ali [2] et al. have described the design of a slot reconfigurable fractal antenna in the shape of 'Koch' for WLAN/WiMAX operations. A truncated ground plane UWB antenna has been proposed by Saadh AW et al. [3] for GPS/Wi-Fi operation. A slot antenna has been created and tested by J. Dong et al. [4] for applications of mobile devices. Ali et al. [5] have presented a rectangular slot antenna with modified ground plane to work for UWB range thereby covering WLAN/WiMAX/MIMO applications. C. Rajagopal et al. [6] have presented a circular patch antenna with a T-shaped slot which can be used for multiple input multiple output (MIMO) applications.

The design of planar inverted F antenna (PIFA) antennas has been explored for various wireless applications by several researchers. M. Agarwal et al. [7] and A. M. Soliman et al. [8] have presented their designs of PIFAs for GPS and USB applications respectively. Fractal antennas have also been explored in literature for the design of various antennas for wireless applications. A trapezoidal shaped ring has been designed by V. Rajesh Kumar et. al [9]. S. Sivasundarapandian [10] has explored the domain of the UWB antenna design for cognitive radio by designing a Koch snowflake planar antenna. Yet another Sierpinsiki antenna has been designed and experimented for wireless applications by M. Ram et al [11].

The structural configuration of a defected ground plane has been explored in the following literature. A. Kunwar et al. [12] have designed an inverted L-slot antenna for WLAN and/ or WiMAX bands with a defected ground structure. J. Pei et al. [13] have designed a miniature antenna with a defected ground plane for UWB applications of WLAN and WiMAX.

Apart for this, monopole antennas of varied shapes such as inverted-L (Y. Xu et al. [14] and H. Chen et al. [15]), C-shaped strip (Li Kang et al. [16]), E-shaped radiator (M. A. Honarvar et al. [17]), bended strips (L. Wu et al. [18], K. Mondal et al. [19]), flower-shaped (S. Ullah et al. [20]), inverted G-shaped (W. Zaman et al. [21]), H-shaped (T. H. Chang [22]); have been explored and experimented for various wireless applications.

In this paper, a monopole antenna with a circular shape loaded with inverted L-shaped stubs with offset feeding is proposed. The antenna has a partial ground plane which helps in overall impedance matching at 1.5 GHz. The presented paper has the following main contributions:

- A compact circular monopole loaded with inverted L-shaped stubs with offset feeding is proposed for 1.5 GHz band thus, satisfying the need of GPS applications.
- The inverted L-shaped stub helps in shifting the resonance from 2.1 to 1.5 GHz. This stub primarily helps in achieving compactness and resonance at 1.5 GHz by changing the total surface current path length.
- The offset feeding and partial ground plane help in achieving better impedance matching performances thereby eliminating the requirement of external matching circuits.
- The main merit of the design is its compact size, planar structure, acceptable gain and simple configuration which make it very efficient to be integrated with various portable wireless handheld devices.

The next section of this article describes the design approach. Section III of this article presents the study of parameters related to the proposed design. Section IV of the article presents the results achieved and the discussion. Section V concludes the article.

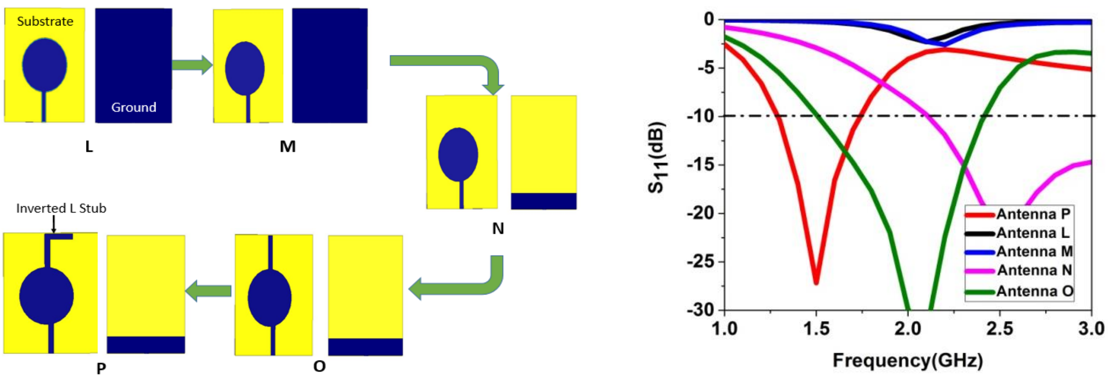
## 2. ANTENNA DESIGN METHODOLOGY

The proposed antenna is designed using HFSS v13.0 software. Initially, the antenna is designed using a circular patch with symmetrical feed line and full ground plane. It is termed as antenna L represented in Figure 1(a). Here antenna does not operate at any frequency. $S_{11}$ defines the reflection coefficient and its dB value reaches zero indicates that nearly all power fed is flowing back towards feed. So, the value must be negative as small as less than -10dB. The characteristic of antenna L tells that it does not match this requirement at 1.5 GHz band as illustrated in Figure 1(b).

In the next stage, the antenna is modified with asymmetrical (offset) feed line and termed as antenna M represented in Figure 1(a). In this stage also, the antenna does not operate at any band as depicted in Figure 1(b). For the next stage, the ground plane is etched into the partial ground according to a particular dimension. This antenna is named antenna N and represented in Figure 1 (a). Here, the antenna operates at 2.5 GHz with maximum $S_{11}$=-25 dB. To implement monopole, a partial ground plane is used as illustrated in Figure 1(b).

To shift the resonance from 2.5 GHz as obtained by antenna N to 1.5 GHz, in the next stage a vertical stub is introduced to circular monopole design. This antenna is referred as antenna O and is represented in Figure 1(a). At this stage, antenna operates at 2.1 GHz with maximum $S_{11}$=-35 dB as shown in Figure 1(b). As the antenna is almost near to the desired result, to tune this, a horizontal stub is introduced in the proposed antenna. Thus, the combination of these two stubs laid to the formation of stubs of inverted L-shape as illustrated in antenna P of Figure 1(a). Thus, antenna P forms the proposed design wherein it is seen that the antenna radiates at 1.5 GHz with maximum $S_{11}$=-28 dB. Thus, the introduction of

L-shaped inverted stubs affects the surface current distribution which causes an intervention to the total current length path, as a result, causing the antenna to exhibit the band at 1.5 GHz. The variation of the reflection coefficient with respect to the antenna L, M, N, O and P is shown in Figure 1(b).




(a) (b)

Figure 1. Proposed configuration, (a) Steps of design process, (b) $S_{11}$ results of design process

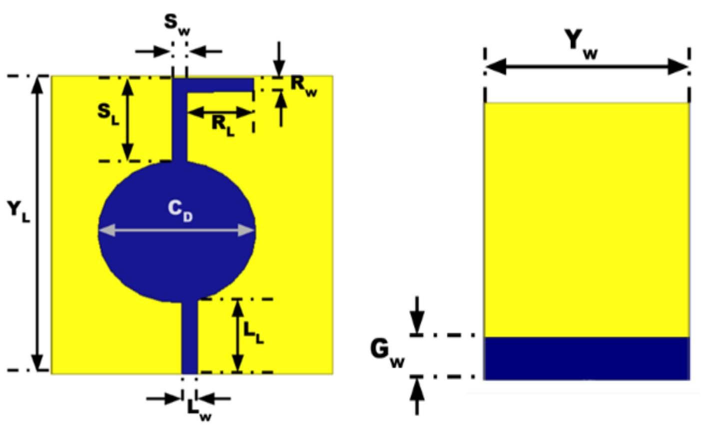
The detailed layout of the antenna is depicted in Figure 2. The antenna has a partial ground plane with ground plane width Gw, circular monopole with diameter $C_D$ and inverted L-shaped stub, with horizontal length $R_L$ and width $R_W$, and vertical length $S_L$ and width $S_W$. The resonance at 1.5 GHz is achieved by offset feed line and inverted L-shaped stub. The positioning of each structure (i.e. circular patch, offset feed line and inverted L-shaped stub) controls a given operating band. The antenna has dimensions of 65 x 55 x 2.54 $mm^3$ and the substrate material (with Length $Y_L$ and width $Y_W$) used is Rogers RT duroid 6006 (tm) with the dielectric constant of 6.15, h=2.54mm and loss tangent δ=0.0019. The proposed design detail dimensions are reflected in Table 1. The resonance frequency (i.e. 1.5 GHz) of the proposed GPS antenna can be calculated from (1).

$$f_r = \frac{c}{4\times Y_L \times 3.23 \times \sqrt{\varepsilon_{eff}}} \quad (1)$$

Where $c$ is the speed of light in free space, $Y_L$ is the maximum length of the antenna, $\varepsilon_{eff}$ is the effective dielectric constant given by (2) and 3.23 is a multiplying constant.

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}(1+12\frac{h}{W}))^{-0.5} \quad (2)$$

On calculation, $Y_L = 65, \varepsilon_{eff} = 5.64\ (as\frac{W}{h} > 1)$, $c = 3\times 10^8$ m/sec, the resonace frequency comes around to be 1.5 GHz.




(a) (b)

Figure 2. The layout of the proposed design, (a) Front, (b) Back

Table 1. Dimensional details of the proposed design

| Parameters | Dimensions (mm) |
|---|---|
| $Y_L$ | 65 |
| $C_d$ | 31 |
| LL | 18.6 |
| Sw | 3 |
| Rw | 3 |
| Yw | 55 |
| Gw | 10 |
| Lw | 3 |
| SL | 15.4 |
| RL | 13 |

The effect of the introduced stub on current density is illustrated in Figure 3. The current distribution at 1.5GHz is denser around the feed line and also at the inverted L-shaped stub. Thus, it provides better impedance matching at lower resonance.

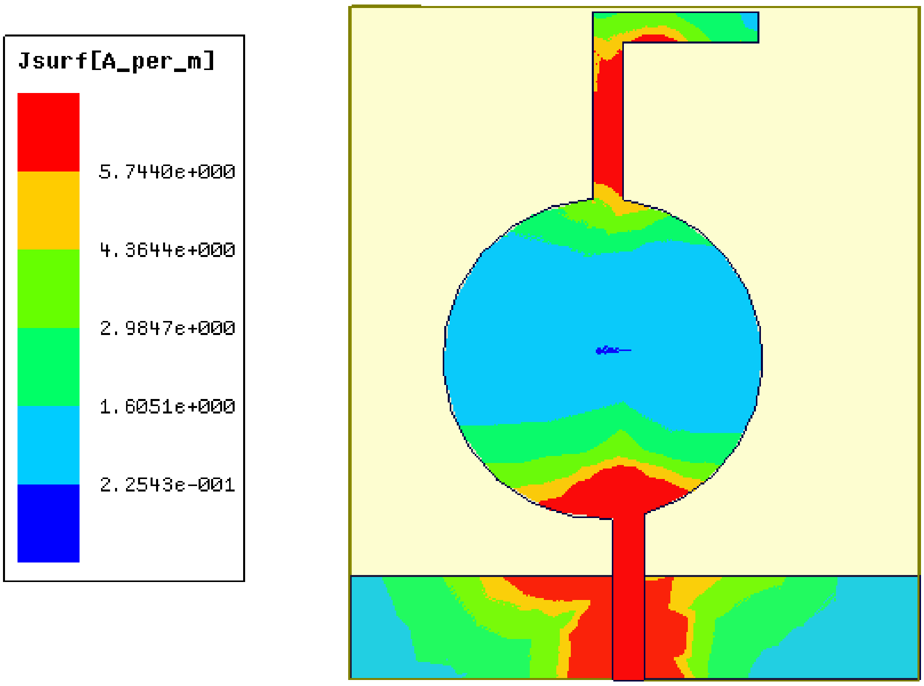



Figure 3. Current density at 1.5 GHz

## 3. PARAMETRIC STUDY OF THE DESIGN

To investigate the impact of the stub on the performance of the antenna, a parametric analysis is done. Since the performance of the design is influenced by the diameter of the circular patch, width of the ground plane, width of the vertical and horizontal stub. Hence, the study is completed for Cd, Gw, Sw and Rw respectively.

### 3.1. Effect of circular patch $C_d$

The effect of circular patch Cd on antenna impedance matching is observed. The study is completed by varying the diameter of the circular patch. The change of reflection coefficient with reference to Cd is as shown in Figure 4(a).

### 3.2. Effect of $G_w$

The effect of the width of the ground plane is studied by varying the dimensions of Gw and keeping other dimensions constant. The desired result is obtained for GW=10mm and is shown in Figure 4(b).

### 3.3. Effect of $S_w$

The effect of vertical stub width Sw on antenna impedance matching is observed. The study is done by varying the stub width Sw and keeping other dimensions constant. The change of the reflection coefficient with respect to Sw is shown in Figure 4(c).

### 3.4. Effect of *Rw*

The effect of horizontal stub width Rw on antenna impedance matching is observed. The study is done by varying the stub width Rw and keeping other dimensions constant. The variance of the reflection coefficient with respect to Rw is shown in Figure 4(d).

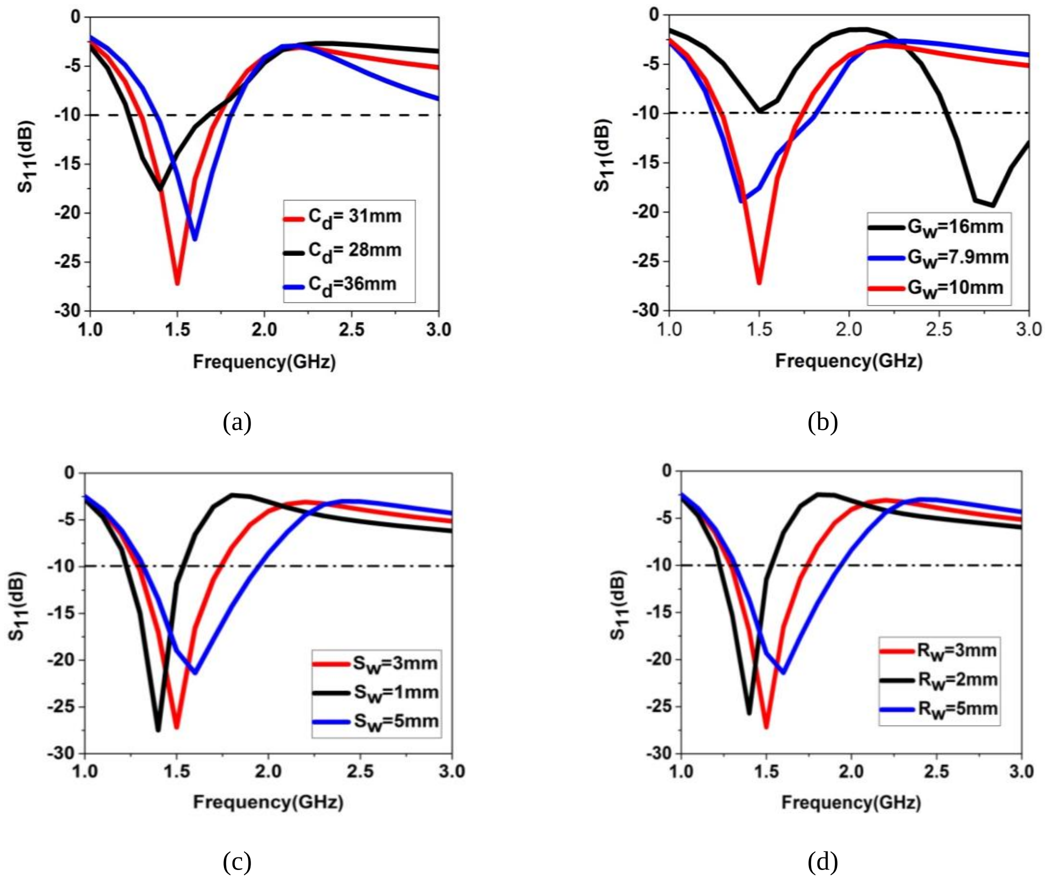



Figure 4. Study of parameters for (a) Cd, (b) Gw, (c) Sw and (d) $R_W$

## 4. RESULTS AND DISCUSSION

The simulation result for the proposed antenna is illustrated in Figure 5. The $S_{11} < -10$dB impedance bandwidth for the simulation is about 33.3% (1.27-1.77GHz). The obtained result and the optimized dimensions make it useful for GPS applications.

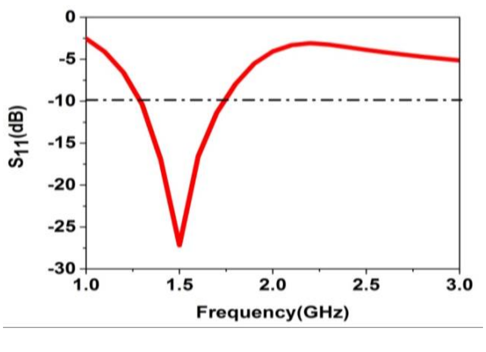



Figure 5. Reflection coefficient ($S_{11}$) of the designed antenna

### 4.1. Total gain

The total gain for the proposed antenna is illustrated in Figure 6. The antenna has a total gain of around 1.23dB at 1.5 GHz which is the operating frequency. Also, the gain plot gives information about the 3D radiation pattern.

### 4.2. Radiation pattern

The radiation pattern of the designed antenna in 2 D is illustrated in Figure 7. The antenna has a figure-of-eight pattern in E-plane and zero like pattern in H-plane. A comparison is drawn between our antenna and its similar types which are illustrated in Table 2. It can be observed that our design has the advantage of better gain and size over its counterparts.

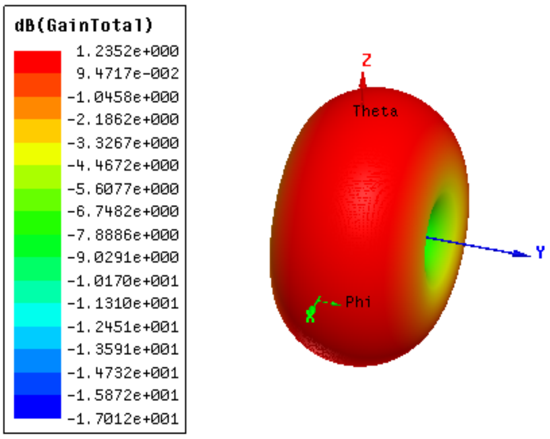



Figure 6. Total gain of the designed antenna

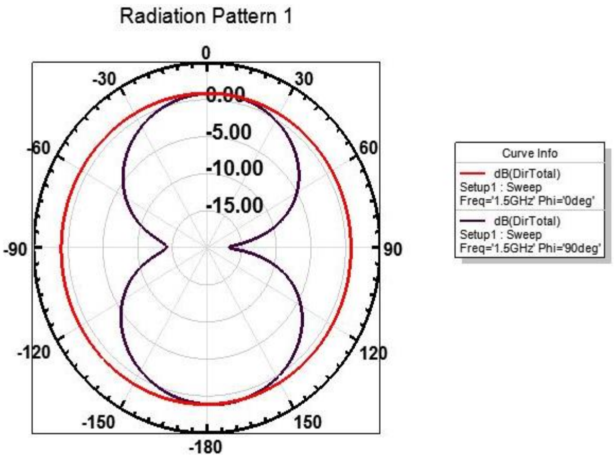



Figure 7. The radiation pattern of the proposed antenna (red line: -H-plane, black line: -E-plane)

Table 2. Comparative Analysis of the proposed antenna and antennas in the existing literature

| Reference | Size ($mm^2$) | Bandwidth | Gain (dB) | Application |
|---|---|---|---|---|
| [23] | 115 × 42 | 376 MHz | 0.8 | GSM |
| [24] | 115 × 60 | 271 MHz | 2.5 | GSM, WLAN |
| [25] | 70 × 50 | 206 MHz | - | WiMAX |
| [26] | 44 × 56 | 90 MHz | -2 | GPS |
| [27] | 88 × 88 | 40 MHz | -0.7 | GSM |
| [28] | 140 × 75 | 262 MHz | - | LTE |
| Our design | 65 × 55 | 500 MHz | 1.23 | GPS |

## 5. CONCLUSION

In the discussed paper a circular monopole antenna with an inverted L-shape for GPS application is proposed. The antenna utilizes offset feeding and partial ground plane to attain good impedance matching for the criteria $S_{11} < -10$ dB. Antenna demonstrates a dipole like pattern and also attains an acceptable value of gain for the desired band. From the parametric investigation, it is noted that by varying the value of optimized dimensions there is a considerable consequence on the antenna's impedance matching. Better impedance matching, good gain and steady radiation performances make the proposed configuration suitable for GPS applications.

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