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Design and Implementation of a Compact Circularly Polarized GPS Antenna for Vehicular Navigation

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Abstract: *Automotive communication has witnessed a remarkable growth in recent years due to modern communication technologies and the advent of new radio frequency (RF) receivers. The microstrip antenna is popularly used in the navigation system due to their simple profile and ease of integrating with the vehicle body. This paper presents the design and implementation of a compact circularly polarized GPS microstrip antenna for vehicular navigation. The microstrip antenna was designed using Flame Retardant-4 (FR-4) substrate material with a dielectric constant of 4.4. The design was based on the transmission line model and simulated using Computer Simulation Technology (CST) Microwave Studio. The initial simulation resulted in a linearly polarized antenna. To achieve CP, the antenna was further modified and tuned by embedding two circular slots of different sizes separately into the radiating element and the ground plane for size reduction. Truncating diagonal edges improved the axial ratio of the antenna. The optimized results of the antenna gave a return loss of -36 dB, an Axial Ratio (AR) of 1.52 with AR bandwidth of 23 MHz and a gain of 5.71 dBi. The photolithographic technique was used to shape the metallization on the PCB and the prototype was measured using a Vector Network Analyzer. The antenna offered a measured AR of 1.81 dB, AR bandwidth of 20 MHz from 1.56 to 1.58 GHz, a 2:1 VSWR bandwidth from 1.564 to 1.584 GHz (20 MHz) and gain of 5.62 dBi.*

Keywords: *microstrip antenna; GPS antenna; circular polarization; circular slot; truncated edges; vehicular navigation*

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I. Introduction

Automotive communication has witnessed tremendous growth in recent years due to modern communication technologies and the advent of new radio frequency (RF) receivers. Value-added services are included in automobiles with the intent to increase passenger comfort and safety. An antenna is an interface between radio waves propagating through space and electric currents circuit of a transmitter or receiver. Antennas play a critical role in wireless technologies. Modern cars are equipped with more number of information and entertainment. The choice of antenna technology for vehicular navigation depends on the antenna's performance with respect to the intended application and the location where the antenna is to be placed in the vehicle.

Owing to its simple profile, microstrip antennas have received more attention from manufacturers while designing antenna systems for cars. The printed antennas can easily be integrated with the vehicle's body and making it hidden thus improving the aesthetics of the vehicle. Receiving antennas suitable for the navigation satellite system requires circularly polarized and wideband characteristics [1]. Polarization is the orientation of the electromagnetic wave in space and for optimum reception, the orientation of the transmitting and receiving antennas must be matched. This poses a challenge for moving vehicles.

Antenna design with circular polarization is usually employed to mitigate the multipath effects [2]. Microstrip antennas have been widely used in much circular polarization (CP) applications due to low profile, low weight, and useful radiation characteristics. Many ways are adopted to realize circular polarization. Common methods producing circular polarization are truncating corners [3] - [4], notching, opening slots, and adding tuning stubs [5] - [10]. In [11], two pairs of square ring slots are etched along the diagonals of the patch to realize circular polarization, and via holes are used to realize miniaturization.

In this research, the design of a CP square patch antenna for global positioning systems (GPS) is presented. To achieve good CP radiation at 1575 MHz, however, two circular slots of dissimilar sizes are embedded separately into the radiating element and the ground plane. This CP design possesses advantages such as simple in structure, uncomplicated fine-tuning technique, and ease in manufacturing tolerances.

II. Antenna Design

The transmission line model is adopted in this paper to calculate the dimensions of the antenna patch. The patch and substrate are square with the relative dielectric constant of ε_r thickness of h and the central frequency of f_r. For an efficient radiator, a practical width that leads to good radiation efficienciesis given by the following formula:

$$W = \frac{c}{2f_r}\sqrt{\frac{2}{\varepsilon_r + 1}} \qquad (1)$$

where *c* is the speed of light, ε_r is the relative permittivity of substrate and f_r is the operating frequency

The length of the patch looks electrically slightly larger than the usual length of the design, because of the fringing field along the patch width, and this parameter can be calculated by:

$$L_{eff} = \frac{c}{2f_0\sqrt{\varepsilon_{reff}}} \qquad (2)$$

The value of the effective dielectric constant is computed as in the following formula:

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-\frac{1}{2}} \qquad (3)$$

The added length of the patch is given by:

$$\Delta L = 0.412h\frac{(\varepsilon_{reff} + 0.3)\left(\frac{W}{h} + 0.264\right)}{(\varepsilon_{reff} - 0.258)\left(\frac{W}{h} + 0.8\right)} \qquad (4)$$

After the calculation of each of effective and extended lengths of the patch, the actual value of the patch length (L) is calculated by:

$$L = L_{eff} - 2\Delta L \qquad (5)$$

The geometry and dimensions of the GPS Antenna are presented in figure 1. It is designed using the same substrate material as that of the Conventional Antenna but with different dimensions. Printed on the upper side of the substrate is a $39\,mm \times 39\,mm$ square patch top-loaded centrally by a circular slot (CS_1) with radius $R1 = 8\,mm$. Notably, the size of CS_1 will allow the antenna to resonate at the desired frequency at 1575.42 MHz. Printed on the bottom side of the substrate is a $45\,mm \times 45\,mm$ ground plane embedded by a circular slot (CS_2) with radius $R2 = 4.5\,mm$. The position of this CS_2 is referenced to the coordinates as depicted in Figure 1. Here, the central of CS_2 must be located near to the circumference of CS_1, and the parameter $Ls = 19.5\,mm$ along the y-axis is vital to the frequency variation and axial ratio (AR) value of the CP radiation. To allow a right-hand circular polarization (RHCP) radiation for GPS L1 band, the probe-fed position is located off-central along the x-axis, and its coordinates.

By optimizing the parameters of the antenna shown in Fig. 1, the overall dimensions are: *Lg= 45mm, Wg= 45 mm, Wp = 39 mm, Lp = 39 mm, tr = 2 mm, Ls = 17.5 mm, Ws = 20 mm, R1 = 7.9 mm, R2 = 4.6 mm, coaxial feed points (xf = 13.2, yf = -0.25).*

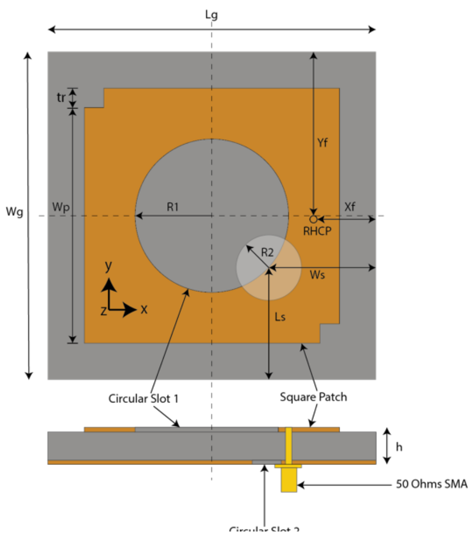


Fig. 1: Geometry of proposed Circular Polarized GPS antenna.

III. Results And Discussion

A prototype of the antenna was fabricated on a substrate of $\epsilon r = 4.4$ and $h = 1.6mm$. The measured reflection coefficient of the antenna given in figure 3 is validated by simulations. The measured impedance bandwidth of the antenna is about 5% from 1.5652 to 1.5673GHz which covers the GPS L1 band. A prototype of the proposed antenna is shown in figure 2.As a result of error due to imperfections in fabrication, loss SMA connector, and measurement environment, it can be seen that the measured results are less compared with that of the simulated results. But both results are in agreement.

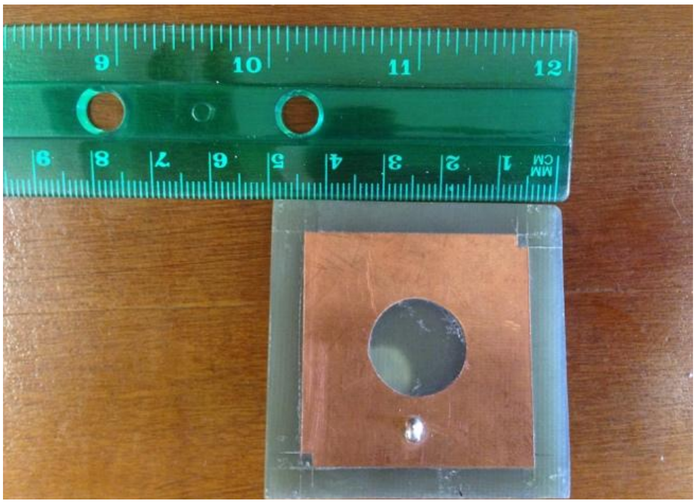


Fig. 2: Fabricated prototype of the proposed antenna

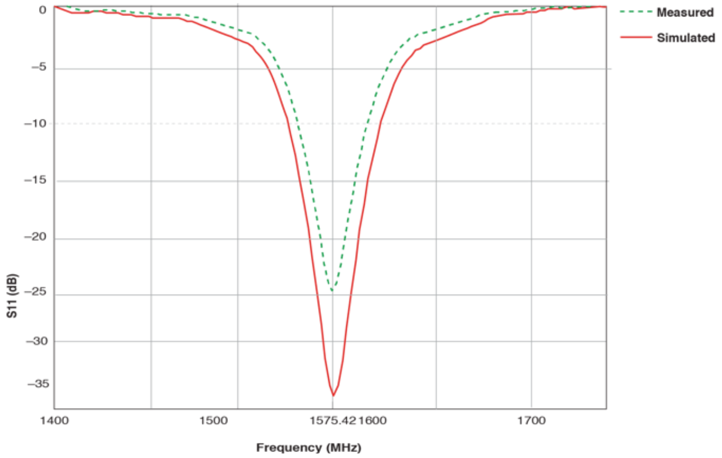
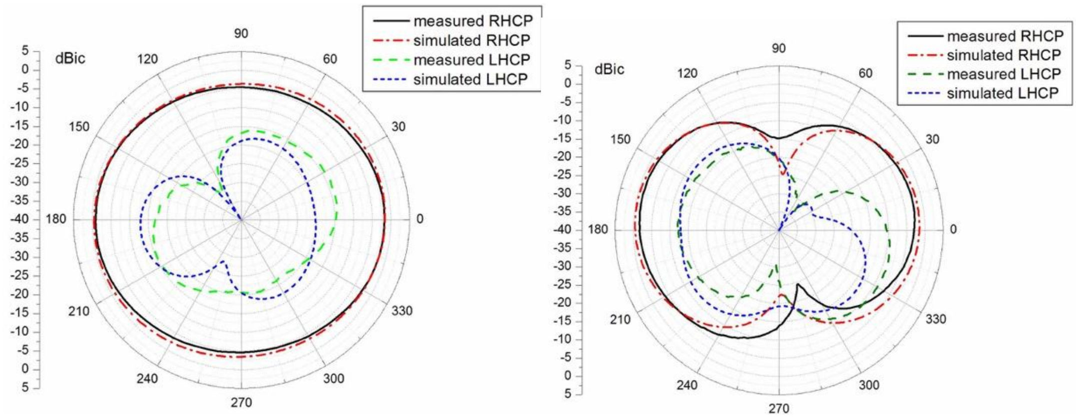


Fig. 3: Simulated and measured reflection coefficients of the proposed GPS antenna.

Figure 4 (a) and (b) show the measured and simulated radiation patterns of the CP antennaat L1, in the ϕ = 0° and ϕ = 90° planes respectively. It can be seen that at broadside for ϕ = 0° the measured gain of 3.62 dB and for ϕ = 90°, 5.62 dB is achieved. Other characteristics of these patterns are: axial ratio of 1.82 dB at 0 = 0°, half power beamwidth (HPBW) of about 86°, null to null beamwidth (FNBW) of 110°, and a front to back ratio (FBR) of 7dB. The measured gain is plotted in figure 4. The antenna exhibits an average gain of 5dBi in the entire band with stable broadside radiation characteristics. The radiation patterns of the proposed antenna in two orthogonal planes at 1.575GHz are shown in figure 4 (a) and (b) respectively. The 3 dB beamwidths of the antenna in both XZ and YZ plane are about 75º and a good left-hand CP radiation is observed.

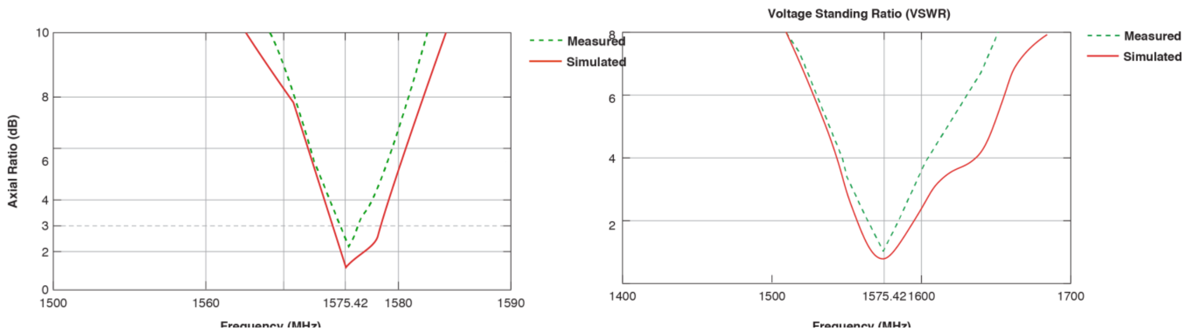


(a) **(b)**

Fig. 4: (a) The measured and simulated CP gains at higher frequency in xz-plane (φ = 0° cut). Simulated curve shown for 1.575 GHz and measured 1.567 GHz. (b) The measured and simulated CP gains at higher frequency in xz-plane(φ = 90° cut).

The axial ratio graph of the antenna in the broadside direction is presented in figure 5 (a). The dotted lines represent the measured result, while the solid represents the simulated result. The measured circular polarization determined from 3 dB axial ratio is 1.81 and bandwidth of 20MHz or about 2% from 1.56 to 1.58GHz. From the results, it can be seen that there is good agreement with the simulated results.

Figure 5 (b) shows the measured and simulated VSWR of the antenna, it is observed that the measured VSWR exhibit a good response with a bandwidth of $VSWR<2$ from 1.5625 GHz to 1.5885 GHz (26 MHz) and a value of 1.03.



(a) **(b)**

Fig. 5: (a) Measured and Simulated Axial Ratio (b) Measured and Simulated VSWR

IV. Conclusions

This paper presents the design and implementation of a compact CP GPS microstrip antenna for vehicular navigation applications. The microstrip antenna was designed for a resonant frequency of 1575.42 MHz using Flame Retardant-4 (FR-4) substrate material with a dielectric constant of 4.4. The design was theoretically analyzed using a transmission-line model which results in a linearly polarized antenna. To achieve CP, the antenna was further modified and tuned by embedding two circular slots of different sizes separately into the radiating element and the ground plane for size reduction and truncating diagonal edges improved the axial ratio of the antenna. The simulation process with initial modeling of the design and the optimization of the model using the parametric tool in CST Microwave Studio. The optimized results of the antenna gave a return loss of -36 dB, an axial ratio of 1.52 with AR bandwidth of 23 MHz and gain of 5.71 dBi. The photolithographic technique is used to shape the metallization on the PCB and the prototype was measured using a mini VNA. The measured and simulated results were in close agreement. The final structure enabled a size reduction of 43.3% compared to the initial design. The antenna offered a measured AR of 1.81 dB, AR bandwidth of 20 MHz (2%) from 1.56 to 1.58 GHz, a 2:1 VSWR bandwidth from 1.564 to 1.584 GHz (20 MHz) and gain of 5.62 dBi.

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