Implementation of the GPS microstrip circular patch antenna

S. H. Fadhil¹, and R. H. Thaher²
¹,²Department of Electrical Engineering, Mustansiriyah University, Baghdad, Iraq.
Email: ¹Suheir.hazem@gmail.com, ²Raadthaher55@gmail.com

Abstract. A new design of the Global Positioning Systems (GPS) microstrip antenna for the military use at L2-band (1.227 GHz) is introduced. Some slots are etched in the circular patch of the designed antenna to enhance the reflection coefficient (i.e. $S_{11} \leq -10$ dB). The patch was printed on epoxy substrate with relative dielectric constant $\varepsilon_r = 4.3$ and loss tangent ($\tan\delta = 0.025$) with overall dimensions (70×70×1.6) mm³. The antenna was manufactured and checked with the help of the Vector Analyzer Network (VNA). It was found that there is a reasonable acceptance between the simulation and practical results.

Keywords: Microstrip Antenna (MSA), GPS, Return Loss, VNA.

1. Introduction
The Global Positioning System (GPS) is a satellite technology dependent navigation system [1]. It can also be defined as a dual-use system. Originally GPS was designed for military applications, then later became available for civilian use [2,3]. The GPS uses triangulation approach to detect location by measuring time, position and speed information [4]. GPS currently operates fully and meets the criteria for the optimum positioning system laid down in the 1960s [5]. The advancement of tiny integrated antennas is a major contribution to the rapid expansion of civil and military communications apps, GPS for instance [6]. The need for antenna coverage is continuously on the rapid increase with the advancement of navigation systems, mapping and satellite communications to easily obtain the low satellite signals [7]. Most receiver antennas of the GPS need circular polarization, so microstrip patch antennas (MPAs) are ideal for that [6,8]. The MPA have benefits of far too many, for example a low profile, small volume, reduced size, inexpensive, easy to mass produce using printed system technology, which means the antenna can be made for flat and non-planar surfaces and is suitable for Microwave Integrated Circuit designs (MICs) [7, 9-15]. Nonetheless, limited bandwidth, low efficiency and weak polarization are some of the negatives [9,10].

The rapid expansion in telecommunications has at the same time led the creation of portable antenna designs for the GPS, which are becoming increasingly realistic for mobile devices [16]. Over the past few years, antenna theory and design were among the most modern topics. [9,15]. In the early 1950s, started the notion of the MSA. When G.A. Deschamps proposed it in USA, and patent in France from Guttan and Baissinot. There was little interest in MSA antenna growth over the next 15 years. Because of the lack of sufficient microwave substrates and a great deal of attention paid to waveguide plates. In 1973 a huge interest started on the microstrip antenna [9,10,15,17,18,19].

There are many various types of MSAs, which can be constructed with specific geometrical shapes and sizes as per their physical features, can be classified into four major categories. The microstrip dipoles, wave traveling antennas, printed slot antennas and patch antennas [20,21].

A number of researchers for L2-Band GPS published in [12,22]. In this research work a new design of circular patch antenna with coaxial feeding technology for GPS apps working at 1.227 GHz.
operating frequency (L2-Band is proposed and manufactured. The parameters used to construct the MPA can be written as follow [10].

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

(1)

Where:

\[ F = \frac{8.791 \times 10^9}{f_r \sqrt{\varepsilon_r}} \]  

(2)

Where:

\( a \) is the actual patch radius.
\( h \) is the substrate thickness (cm).
\( \varepsilon_r \) is the relative dielectric constant of the substrate.
\( f_r \) is the resonance frequency.

2. Configuration of the proposed Antenna.

The antenna has a radiating circular patch with a radius equals to 33 mm calculated according to equations (1) and (2) and etched on FR4 substrate (Flame Resistant 4) with \( h=1.6 \) mm and has relative permittivity \( (\varepsilon_r=4.4) \). there is also a conduction material termed a ground layer at the lower part of the substrate as it shown in the Figure 1. Some slots are etched in the patch to improve the antenna return loss and add a square slot in the ground layer. The designed antenna located in the x-y plane where the feeding point position in the x-axis is (9.5 mm, 0.0 mm) from the centre point of origin. The overall size of the designed antenna is \((70 \times 70 \times 1.6) \) mm\(^3\). The antenna parameters are summarized in Table 1.

![Image](image.png)

**Figure 1.** The configuration of the designed antenna (a) Patch plane and (b) Ground plane.

| Table 1. The designed Antenna Parameters. |
|-------------------------------------------|
| Parameter   | W  | L  | R  | Z  | N  | M  | F  | S  | D1 | D2 | D3 | K  | h  | T  | A  | X  |
| Value (mm)  | 70 | 70 | 33 | 13 | 2.5| 3.5| 3  | 3.1| 8  | 5  | 2  | 5  | 8  | 23.5| 23.5| 8  |

A parametric study such as changing the circular patch radius (R) and the feeding point position (P) to get the best results of the reflection coefficient of the proposed circular patch antenna has been carried out as follows:
2.1. Effect of Circular Patch Radius Change (R).
By changing the patch radius (R) it can be noticed from the Figure 2, there is a significantly changing on the reflection coefficient. When the value of the R equals to 33 mm, the best reflection coefficient was obtained where the value of S11= -61.853 dB at resonance frequency equals to 1.217 GHz.

![Figure 2](image1.png)

Figure 2. The Effect the Radius of the proposed antenna.

2.2. The Effect of Changing the Position of the Feeding Point (P).
The antenna is in the x-y plane and is cantered at the point of origin. The position of the feeding point on the x-axis (P+4.5, 0.0) mm. From Figure 3, it is obvious that the best value for the reflection coefficient can be obtained when the value of P=5 mm (i.e. S11= -61.853 dB).

![Figure 3](image2.png)

Figure 3. The Effect of the feeding point position.

The circular patch antenna is fabricated and tested practically by VNA as shown in Figure 4. The practical results are reasonably acceptable where the value of measured reflection coefficient equals to -34.749 dB (i.e., S11≤ -10 dB) at frequency f=1.25 GHz. Although there is a slight difference
compared to simulation results and this is due to manufacturing errors like the possibility of oxidizing the antenna’s material by exposure to air (i.e. variation of $\varepsilon_r$ with frequency). The measured results of the reflection coefficient have been compared with the results of the simulation as shown in Figure 5.

![Figure 4. The manufactured antenna Photograph (a) Top view (b) Bottom view](image)

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![Figure 5. The results of the Measured and simulation of the designed antenna.](image)

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The comparison of simulation and the measured VSWR results are shown in Figure 6. The value of simulation VSWR equals to 1.0016169 at $f= 1.217$ GHz, while the measured value of VSWR equals to 1.50031 at $f= 1.25$ GHz.
Figure 6. Measured and simulated results of VSWR.

Figure 7a illustrates a comparison of the results of the real part of the antenna impedance with the results of the simulation where the value of the last one equals to 49.983 Ω at the frequency 1.217 GHz, while the measured value is equal to 42.002Ω at the frequency 1.25 GHz. While in the Figure 7b the measured value for the imaginary part of the designed antenna impedance equals to 0.00021 Ω at f= 1.2466 GHz, on the other hand, the simulation value equals to 0.00790764 Ω at f= 1.217 GHz.

Figure 7. Comparison of Input impedance of the designed antenna (a) Real part (b) Imaginary part.
Figure 8. Current distribution of the designed circular patch antenna.

The current distribution is illustrating in the Figure 8. in which the maximum value equals to 62.4037 A/m. The current is distributed in most areas of the radiation patch from the middle of the patch to the edges. The shape shows a good distribution of the current, which produce resonance at the frequency 1.217 GHz.

Figure 9 illustrates the antenna's radiation pattern. Figure 9a illustrates the E-field pattern, the main lobe is 15 V/m in the direction 0.0 deg. with angular diameter (3 dB) is 102.2°. While Figure 9b illustrates the H-field where the main lobe magnitude equals to −36.6 A/m in the direction 0.0 deg. and the angular diameter (3 dB) is 102.2°.
3. Conclusions

A circular patch antenna is designed for GPS apps to operates at L2-Band 1.217 GHz. The reflection coefficient of the designed antenna is $S_{11} = -61.853$ dB at $f = 1.217$ GHz, VSWR = 1.0016169 at $f = 1.217$ GHz and the real part of input impedance equals to 49.983 Ω at $f = 1.217$ GHz. The antenna is manufactured and tested practically and found the value of $S_{11} = -34.749$ dB at $f = 1.25$ GHz, VSWR =1.50031 at $f =1.25$ GHz and real part of input impedance equals to 42.002 Ω at $f=1.25$ GHz. From these results, can be noticed there is a reasonable acceptance between the simulation and the measured results, the slight difference is attributed to the manufactured errors and the variation of $\varepsilon_r$ with frequency. As a suggestion for future work, one can redesign the antenna to operate at 1.557 GHz for commercial apps.

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