Circularly Polarized Rectangular Patch Antenna with Slot for GPS Applications

Kanawat Nuangwongsa
Faculty of Engineering, Rajamangala University of Technology Isan, Khon Kaen Campus,
Khon Kaen, Thailand
E-mail: kanawat.nu@rmuti.ac.th

***Abstract*—In this paper, a circularly polarized rectangular patch antenna with slot is proposed for GPS applications. The geometric structure of the antenna is a rectangular shape with transmission line feed to the rectangular patch. The rectangular patch with slot is designed from an inexpensive FR4 double-sided PCB. The dimensions of rectangular patch with slot for circularly polarized antenna is 60mm, 120mm and 2mm in width (W_g), length (L_g) and height (h_a), respectively, to propagate the GPS frequency band of 1.575GHz. On this rectangular patch surface, we have designed a small grooving technique with a width of 2mm and a tilt angle to create a circular polarization. In addition, we also designed this antenna to increase bandwidth by using bandwidth enhancement techniques by grooving the U-slot on the ground plane of the antenna. Based on the results of this antenna simulation, we used to obtain the best proposed antenna parameters and this circular polarization rectangular patch antenna was fabricated and thoroughly tested, respectively. The antenna gain from the simulated results is 3.85dBi and measured at 3.55dBi. The simulated and measured axial ratio (AR) ≤ 3dB cover the operating frequency band (1.563-1.587GHz). And this antenna has the half power beam width (HPBW) in the XZ-plane and the YZ-plane is greater than 65 ° covering the GPS band. In addition, the results of the simulation compared with the measured results show that it is a good agreement for applying this circularly polarized rectangular patch antenna to the GPS applications.**

Keywords—rectangular patch, slot, circular polarization, bandwidth enhancement and axial ratio.

I. INTRODUCTION

Over the last years Global Positioning System (GPS) applications are very popular among some professional users in determining the location that requires high accuracy, such as wireless signal testing and exploring the area in the wilderness, mapping, navigation system, tracking system, transportation management, etc. Which the GPS system is consist of three parts: The first part: Space Segment, The second part: Control segment and the third part: User segment [1-2]. In this third part, this is easiest part that we can enhance the system.

The most important element in the GPS system is that the connection between the satellite transmitter and receiver is the receiving antenna. There for, we have to design the antenna to be most effective with the goal of the antenna design must be designed to have good performance with a frequency band that covers the GPS system and has a corresponding polarization. In general, the GPS system has right hand circularly polarized [3]. From our goal to get circular polarization antennas requires many techniques such as slot-loaded conducting patch, reactive impedance surface (RIS) layers, V-slot loaded rectangular micro-strip patch, Folded square patch, multi-cut of radiating element horns and Circular Micro-strip Patch Antenna (CMPA), etc.

In [4], a compact dual-band antenna designed for GPS bands with small slot-loaded and proximity-fed technique. The overall structure of this antenna consists of 2 main parts: the first part is a single slot-loaded conducting patch design on top of two stacked dielectric layers. The first part is the GPS antenna element designed from 3 types of materials: Rogers TMM10i board; $\varepsilon_r = 9.8$, ceramic puck; $\varepsilon_r = 45$ and ECCOSTOCK; $\varepsilon_r = 15$. And this part is designed to reduce the antenna size by using the meandered slots technique to get an antenna that covers the 1.227 GHz and 1.575GHz bands. The second part is feeding circuit designed form the FR-4 board; $\varepsilon_r = 4.4$. This part is used to hold all 4 antennas together and also a feeding point to the compact dual-band antenna as well. A novel compact GPS antenna design was utilized to obtain the right hand circular polarization covering 1.227 GHz and 1.575GHz with the gain of 3.5dBi. However, the structure of this compact dual-band antenna was quite complexity of the geometry because it requires 4 types of materials to assemble this antenna.

The technique of a reactive impedance surface (RIS) layers into the multi-system circularly-polarized square micro-strip patch antenna was used in [5]. This antenna consists of an RIS unit consisting of three layers of surface. And the reactive impedance surface is consists of an array of metals that are stacked together in the form of unit cells. And the patch mentioned here must have a fixed size printed on the ground substrate, which is very complicated. The structure of this antenna is all 3 layers is the first layer that is designed from an inexpensive FR-4 substrate. On the second layer, this was designed by RIS unit. Next is the third layer, designed from the Rogers4003 substrates. From this research, it is found that this antenna can be used to cover GNSS multi-system navigation. However, the geometric structure of this antenna is the relatively complicated with a compact size of 70× 70×4.6mm^3. This antenna can produce operating frequencies including B3 (1.26GHz) and B1 (1.57GHz), representatively. Moreover, the maximum gains are about 2.38dB and 5.24dB in B3 and B1 frequency band, respectively.

And another interesting technique is a rectangular micro-strip antenna is enhanced by V-slot loaded rectangular patch [6]. The components of this antenna are only one printed circuit board, but there are many parameters and there are also complex circuit patterns. From the results of this research, it is obvious that bandwidth of rectangular micro-strip antenna is increased when the antenna has v slot loaded and a rectangular cut techniques. From this research, it is found that this antenna can cover the frequency of 1.338 to 2.953 GHz in GPS band. And also found that the proposed antenna gain of up to 4.19dBi. Although this antenna has only one component, it is a single

978-1-7281-3361-4/19/$31.00 ©2019 IEEE

piece of PCB. But this antenna also has a linear polarization which is also a limitation for use in GPS systems.

In [7], a novel miniature folded square patch antenna is proposed and developed for Global Positioning System (GPS) receivers to achieve the GPS frequency band (1.566–1.586 GHz). From this research, it was found that the folded square patch antenna components consisted of 3 sheets of FR-4. And also found that this research has designed 2 substrate sheets that are at the top connected by cross slotted square patch. And also using slot patch and meander strips to connect between patch as well. From this design, it was found that the antenna with circular polarization (AR ≤ 3dB) covers the GPS frequency band (L_1: 1.575GHz). However, the structure of the antenna is very complex and the size of the antenna structure is relatively large (ground plane; r=50mm).

In [8], the authors proposed Car Micro-strip GPS Antenna to achieve the GPS frequency band (L_2: 1.227GHz). In the design phase of this research, there are 2 steps: the first step is to fine the position of the antenna installation on the windscreen of the passenger car. The second step is to design the antenna that must be used one of the simpler models to be easy to design. From this research, it is found that this antenna uses the technique of a printed antenna with a rectangular patch with undercuts (Multi-cut of radiating element horns) to provide ellipse polarization. And also found that it was difficult to design the antenna with this structure with circular polarization.

And another interesting technique is a design and fabrication of a circular micro-strip patch antenna for GPS application to achieve the GPS frequency band [9]. The structure of this antenna consists of circular micro-strip patch antenna (CMPA) and a circular slot in the ground plane. The circular micro-strip patch antenna is designed on FR-4 substrate with dielectric constant is 4.3. From this research, it is found that this antenna can cover the frequency of 1.8 GHz. The advantage of this antenna is its uncomplicated structure. Nevertheless, the polarization of the antenna is linear and the structure of this antenna is fairly large (88 × 88mm^3).

This paper has thus a circularly polarized rectangular patch with slot antenna proposed as a receiver antenna of the GPS applications. The proposed circularly polarized antenna consists of rectangular patch with slot (radiating patch), grooving the U-slot on the ground plane of the antenna. And feed with a transmission line connected to a 50 ohm SMA connector. In this paper, the rectangular patch with slot circularly polarized antenna is 60mm, 120mm and 2mm in width (W_g), length (L_g) and height (h_a), respectively, to propagate the GPS (L_1) frequency band of 1.575GHz and axial ratios (AR) are < 3dB cover the frequency band. The proposed antenna is for GPS receiver communication and thus requires a circularly polarized antenna. In the design of the receiving antenna, we chose to design at a frequency of 1.57542 GHz (L_1) that is the original GPS band.

In the design of the antenna, the initial parameters are based on a simple antenna design model, which is a transition model. In order to find the size of a rectangular patch according to the transmission model, we have to calculate the parameters according to the equation (1)-(2). Which the width (W) and length (L) of this rectangular patch are the most important parameters that describe the antenna design.

$$W = \frac{1}{2f_r\sqrt{\mu_0\varepsilon_0}}\sqrt{\frac{2}{\varepsilon_r+1}} \tag{1}$$

$$L = \frac{1}{2f_r\sqrt{\varepsilon_{eff}}\sqrt{\mu_0\varepsilon_0}} - 2\Delta L \tag{2}$$

Where ε_{eff} is an effective dielectric constant, which for analysing rectangle antennas can be determined by using equation (3).

$$\varepsilon_{eff} = \left(\frac{\varepsilon_r+1}{2}\right) + \left(\frac{\varepsilon_r-1}{2}\right)\left(1+\frac{12h}{W}\right)^{-1/2} \tag{3}$$

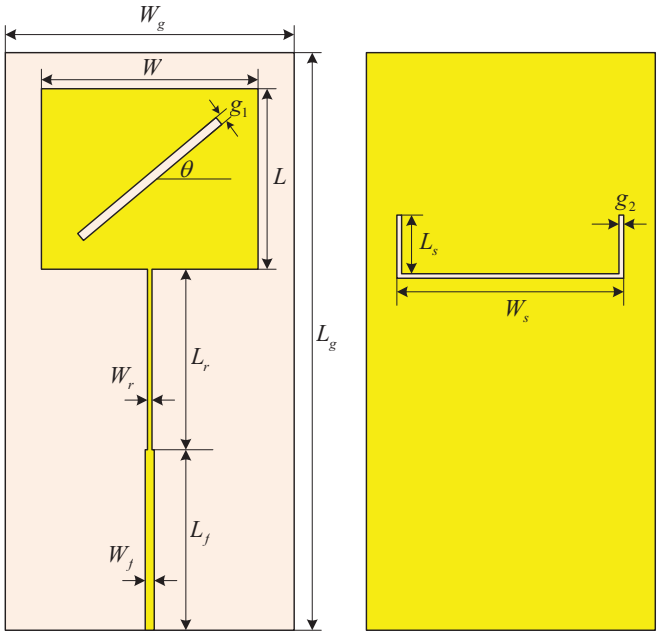


Fig. 1. Geometry of the proposed antenna.

II. Antenna Design

The appearance of the components in the geometric structures of a circular polarization antenna is a name that can be interpreted directly. The circularly polarized rectangular patch with slot antenna is designed to operate in GPS (L_1) applications at the frequency of 1.575GHz as shown in Fig. 1.

The circularly polarized rectangular patch with slot antenna consists of PCB double sides; radiating patch, ground plane and feed with a transmission line connected to a 50 ohm SMA connector. The proposed circularly polarized rectangular patch antenna is made of double sides FR4 substrate with a thickness is 2mm and dielectric constant is 4.3.

- Front side is the circularly polarized rectangular patch that has been grooving a slot on the PCB of the FR4 plate. A slot on the PCB must be tilted to the right angle in order to produce circular polarization. The center frequency of 1.575GHz is designed for rectangular patch with widths and lengths W=64mm, L=51mm and slot with the dimension is g_1=2mm, respectively.

- Ground plane side is designed for increase bandwidth by using bandwidth enhancement techniques by grooving the U-slot opposite side of the PCB of the FR4 plate.

The transmission line connected to a 50 ohm SMA connector is used to excite the rectangular patch with slot antenna.

TABLE I. ANTENNA PARAMETERS

Antenna Parameters	Dimension (mm)
Antenna width (W_g)	72
Antenna length (L_g)	125
Rectangular patch width (W)	64
Rectangular patch length (L)	51
Feed line step 1 width (W_f)	3.3
Feed line step 1 length (L_f)	31
Feed line step 2 width (W_r)	1.3
Feed line step 2 length (L_r)	33
Patch slot (g_1)	2
Ground slot (g_2)	2
Ground slot width (W_2)	68
Ground slot length (L_2)	17

III. ANTENNA PARAMETERS

The proposed rectangular patch with slot circularly polarized antenna consists of widths and lengths W=64mm, L=51mm and slot with the dimension is g_1=2mm, respectively. And more importantly, on this rectangular patch surface, we have designed a small grooving technique with a width of 2mm and a tilt angle to create a circular polarization. Ground plane is a U-slot groove designed to increase bandwidth to cover the GPS frequency according to the purpose. The circularly polarized rectangular patch with slot antenna parameters is listed in Table. I.

Fig. 2 the simulated $|S_{11}|$ (dB) circularly polarized rectangular patch with slot antenna for various rectangular patch width (W) and length (L). The results show that W and L have influence on the value $|S_{11}|$ (dB). In addition, the optimal rectangular patch width and length in Fig. 2 are W is 64mm and L is 51mm, at which the simulated $|S_{11}|$ (dB) ≤ -10dB cover the frequency of 1.575GHz band, respectively.

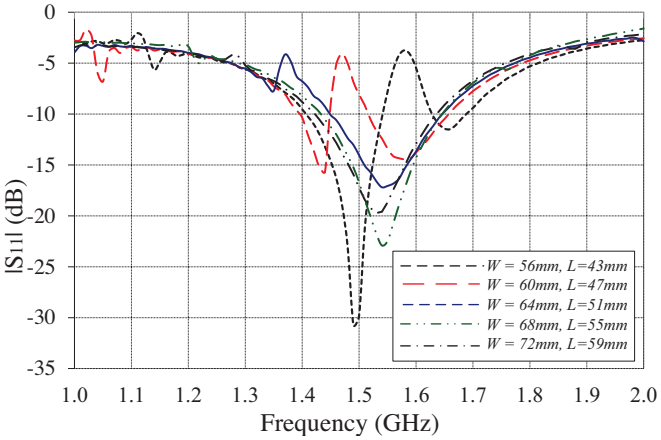


Fig. 2. Simulated $|S_{11}|$ (dB) for various rectangular patch width (W) and length (L)

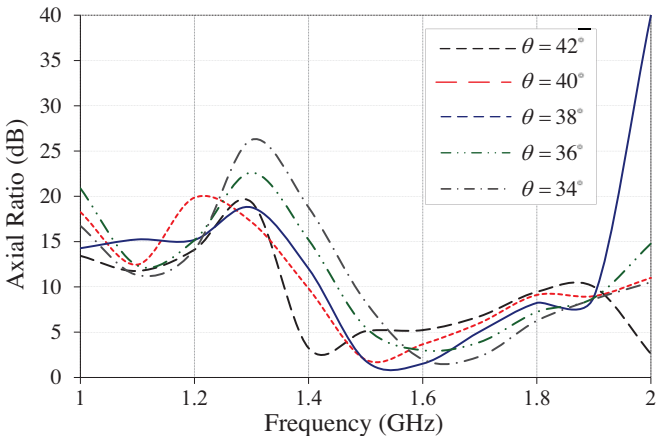


Fig. 3. Simulated axial ratio (AR) for various slot tilted angle (θ)

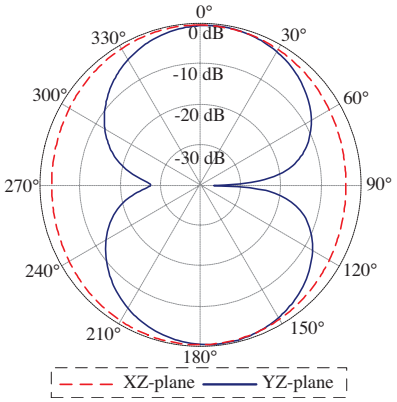


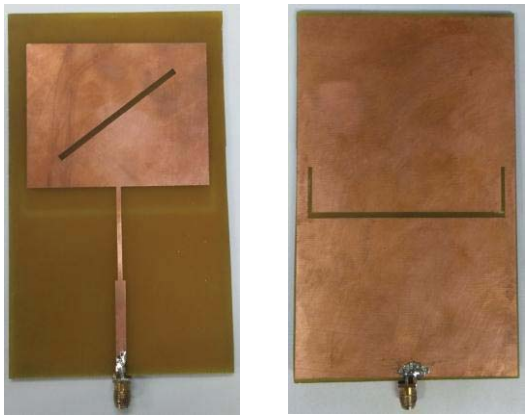
Fig. 4. Simulated radiation pattern at 1.575GHz

The simulated ratio (AR) of the proposed antenna for various slot tilted angle (θ) of the rectangular patch as shown in Fig. 3. In addition, the optimal slot tilted angle in Fig. 2 is $\theta = 38^{\circ}$, at which the simulated axial ratio (AR) ≤ 3dB cover the frequency of 1.575GHz band.

Fig. 4 shows the radiation pattern of the proposed antenna at the center frequency. Based on the results of this paper, it is clear that the radiation pattern of the proposed antenna is bi-directional. And also found that the HPBW of this antenna is equal to 65º/154º in XZ-plane and YZ-plane, respectively. In this topic, we found that the electrical properties of this antenna are suitable for use in GPS systems.

IV. EXPERIMENTAL RESULTS

The photographs of the rectangular patch with slot circularly polarized antenna as shown in Fig. 5. The PCB is an inexpensive double-side FR4 substrate dielectric constant; ε_r=4.3 with a thickness of 2mm. The comparison results between measured and simulated $|S_{11}|$ (dB) of the proposed antenna are shown in Fig. 6.



(a) Front view (b) Ground plane

Fig. 5. The photograph of the proposed Antenna

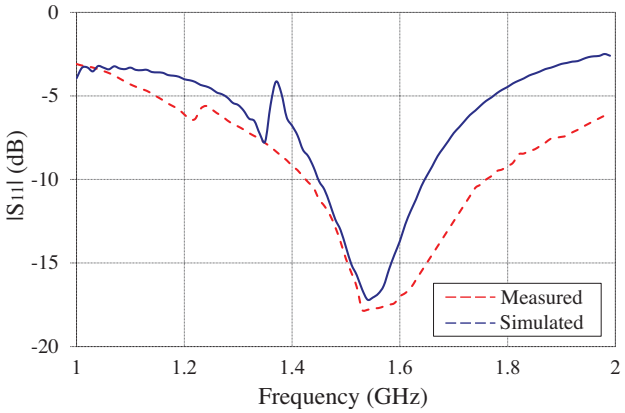


Fig. 6. Measured and simulated $|S_{11}|$ (dB) of the proposed antenna

V. Conclusions

This paper has proposed the rectangular patch with slot circularly polarized antenna for GPS applications. The proposed antenna consists of a square patch with a slot to allow circular polarization on the FR4 substrate and the ground plane with U-shaped grooves to expand the operating bandwidth. The proposed antenna is 27mm, 125mm and 2mm in width (w) length (l) and height (h_a), respectively, to propagate the GPS frequency band of 1.575GHz.

The simulated and measured $|S_{11}|$ (dB) less than -10 dB cover the frequency of 1.44-1.64GHz and 1.43-1.76GHz. The simulated half power beam width (HPBW) in the XZ and YZ-plane are 65°/154°, respectively. The axial ratios (AR) are < 3dB cover the frequency of 1.563-1.587GHz. The antenna gains from the simulated and measured results are, respectively, 3.85dBi and 3.55dBi. And additionally, the simulation compared with the measured results show that it is a good agreement for applying this circularly polarized rectangular patch antenna to the GPS applications.

Acknowledgment

This work was supported by the Faculty of Engineering, Rajamangala University of Technology Isan, Khon Kaen Campus.

References

[1] M. Z. Hoque, "Basic Concept of GPS and Its Applications", IOSR Journal Of Humanities And Social Science (IOSR-JHSS), vol. 21, issue 3, pp. 31-37, Mar 2016.

[2] E. D. Kaplan and C. J. Hegarty, Understanding GPS: Principles and Applications: Second Edition, 2005.

[3] H. Dai, X. Wang, H. Xie, S. Xiao and J. Luo, Spatial Polarization Characteristics of Radar Antenna; Analysis, measurment and anti-jamming applications, Springer Singapore, 2018.

[4] M. Chen and C. C. Chen, "A Compact Dual-Band GPS Antenna Design", IEEE Antennas and wireless propagation letters, vol. 12, pp. 245-248, 2013.

[5] F. Lu, L. Zhi-gang, C. Jie and Z. Shou-zheng, "Design of a Multi-system Circularly-Polarized Square Microstrip Patch Antenna for GNSS Navigation", Asia-Pacific Conference on Antennas and Propagation, pp.476-479, July 2014.

[6] S. Kumar, A. Chaudhary and N.S. Beniwal, "Design and Bandwidth Enhancement of V-slot loaded Rectangular Microstrip Patch Antenna for Broadband Applications", International Journal of Advanced Research in Computer and Communication Engineering, vol. 3, issue 6, pp. 7279-7282, June 2014.

[7] H. M. Chen, Y. F. Lin, C. H. Chen, C. Y. Pan and Y. S. Cai, "Miniature Folded Patch GPS Antenna for Vehicle Communication Devices", IEEE Transactions on Antennas and Propagation, vol. 63, no. 5, pp.1891-1898, May 2015.

[8] M. Wnuk and L. Nowosielski, "Car Microstrip GPS Antenna", Progress In Electromagnetics Research Symposium-Fall (PIERS-FALL), pp.444-448, November 2017.

[9] Z. Hasan, A. Zaman and A. Ahmed, "Design and Fabrication of a Circular Microstrip Patch Antenna for GPS Application", Internation al Journal of Electronics & Communication Technology (IJECT), vol. 8, issue 3, pp.54-57, July - September 2017.