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A High-Gain Circularly Polarized Patch Antenna Using a Circular Ring Reflector for GNSS

P. Boontamchauy*(1), N. Supreeyatitikul(1), N. Teerasuttakorn(1), and P. Wongsakulphasatch (1)
(1) Aeronautical Engineering Division, Civil Aviation Training Center of Thailand
1032/355 Phaholyothin Road., Jatujak, Bangkok 10900, Thailand

Abstract

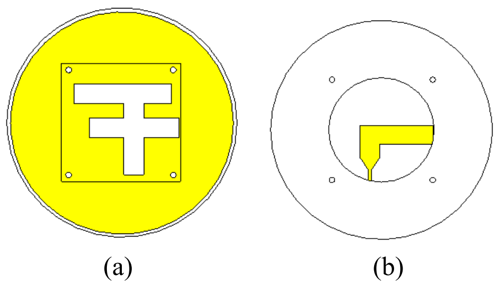
A design of circular ring reflector is presented to accomplish a high-gain antenna with circular polarization for GNSS application instead of using an LNA. The measured directivity reveals an enhancement of gain by back-lobe reduction. The reflection coefficient, appears $-10\ dB$, is 71.51 %BW from 1.06 to 2.24 GHz. The axial ratio, under the area of $3\ dB$, is 36.14 %BW over 1.142 - 1.646 GHz. The average gain is 6.86 dBi overall GNSS band, while the maximum gain is 7.43 dBi at 1.314 GHz.

1 Introduction

The micro-strip antenna has a vast range of applications, such as Radio Frequency Identification (RFID), Radio Detection and Recovery (RADAR), and even Global Navigation Satellite System (GNSS). Since these application are long-range applications, so the RF front end of a receiver is such a key component with highly integrated in between antenna and Low Noise Amplifier (LNA) to get a better signal. In a navigation systems, a weak signal due to the severe weather and the atmosphere attenuation can cause an inaccuracy navigation service. Thus the RF front-end comes to play as an important rule for gaining up the signal, but if the antenna and LNA are not design to work with each other at the first place, then the incompatible gain response between them will cause a defect to the system. In order to reduce such a problem while gaining up the signal, the antenna with high and stable gain can be a solution without LNA. However a micro-strip antenna has a lot of advantages such as light weight, inexpensive and low profile, but their weaknesses are low gain, low efficiency and lossy design. Many techniques have been published to enhance the performance of the micro-strip antenna, such as partial substrate removal in multiple layer dielectric substrate patch [1], addition of a side parasitic patch [2], replacing conventional substrate with air or EBG substrates [3]-[4]. The proposed antenna is designed by cross and bar slot with invert L-shape feed line [5], to perform a right hand circular polarization (RHCP), which has a major capability to transmit and receive signal without antenna alignment. Moreover RHCP antenna also has a severe weather penetration and Faraday Effect resistance. For gaining up a weak received signal by the proposed antenna, a well-known reflecting layer with a circular ring technique has come into view. The technique is a related concept of a rectangular ring antenna technique [6]-[7]. The circular ring reflector has the same material, which is used by an excited element. To be inductive and forming directional pattern, the size of the reflector is designed to be larger than the radiated element while keeping a circularly polarized property. Although a patch antenna is very difficult to have CP property over a wideband, but the antenna parameters and structure are studied, in order to get the circular polarization, which two orthogonal modes are excited with the exactly same amplitude but 90 degrees of phase shift. An application of the proposed antenna is a navigation satellite system, that is a combination of 4 satellite constellations (GPS, GLONASS, Galileo, and Compass). A wide reflection coefficient or return loss bandwidth (RLBW) and wide axial ratio bandwidth (ARBW) with circular polarization over 1.146 – 1.616 GHz are the requirements of the antenna to receive the GNSS signal. In this paper, a wideband circularly polarized patch antenna with high and stable gain using a circular ring reflector for GNSS application is proposed. CST Studio Suite simulator has been using to analyze the antenna performance for overcoming $RL \leq -10\ dB$ and $AR \leq 3\ dB$ over the GNSS frequencies.

2 Description of geometry and mechanism

The proposed antenna comprises of a radiator and a reflector. The excited element is a cross and bar slot over invert L-shape feed line. While a circular ring reflector, having an inner radius (a) and an outer radius (b), is presented under the radiator by an air gap (ag) distance. The element and substrate of the reflector are the same shape as a circular ring. Both of radiator and reflector are fabricated on an inexpensive FR4 printed circuit board with a thickness (h) of 1.6 mm, a relative permittivity (ε_r) of 4.4 and a loss tangent $(tan\ \delta)$ of 0.02. The antenna pieces are attached together by four rigid rods (Polytetrafluoro-ethylene) with a diameter (d) at each of radiator corner, as shown in a Figure 1. The geometry of the proposed antenna is presented on a Table 1 and in a Figure 2.



(a) (b)

Figure 1. The structure of the proposed antenna (a) Top view, and (b) Bottom view.

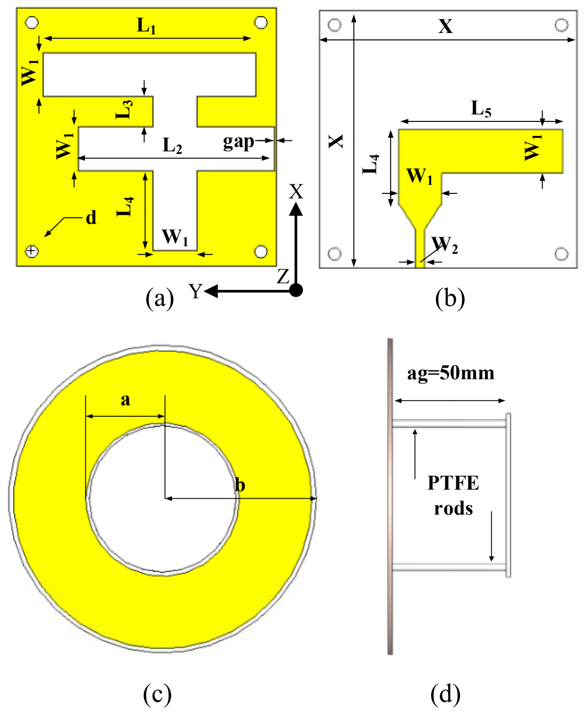


Figure 2. The geometry of the proposed antenna (a) Top view of radiator, (b) Bottom view of radiator, (c) Top view of reflector, and (d) Side view.

Table 1. The optimized geometry (mm) of the proposed antenna.

X	67	a	33	L_2	50.5
W_1	11.5	b	63	L_3	8
W_2	2.5	gap	0.5	L_4	21
d	2.5	L_1	55	L_5	43

3 The antenna and ring reflector design

The structure of the proposed antenna without reflector provides a bi-directional radiation pattern both on left and right hand circular polarization, but in an opposite direction over GNSS frequencies of 1.146 – 1.616 GHz. The polarization can be noticed by surface current distribution, with time varying in a propagation direction for 0 to 180 degrees of an input signal and a reversed direction will be presented for 180 to 360 degrees of a feeding signal. In order to enhance and maintain the antenna forward gain while obtain the directional radiation pattern, the circular ring reflector comes with total area approximately to $\lambda_0/4 \times \lambda_0/4$ horizontally. The antenna radiator and reflector compatibility can be described by the current distribution on both of them. The current distribution on the invert L-shape feed line is a circular motion to prove a circular polarization, while the current distribution on the bar-cross slot and circular ring reflector are clockwise and anti-clockwise (Figure 3). From the simulation, the high surface current distribution are presented not only at the feeding point, but also the boundary of the slot. Thereby the operating frequencies might be shifted, if the structure around a high current distribution point is changed.

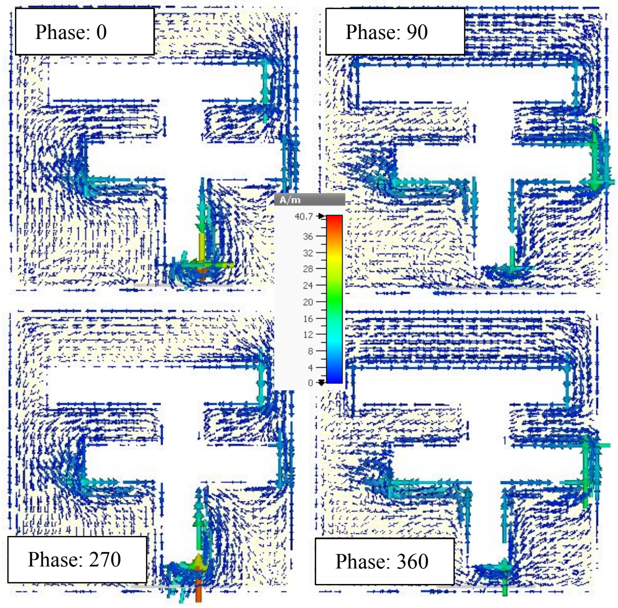


Figure 3. The surface current distribution on a radiator.

4 The antenna analysis and optimization

The interesting structure and parameters, including center-notch, an inner radius (a) and an outer radius (b) of circular ring reflector and the air gap (ag) are analyzed in this section. The principle to improve the gain of patch antenna by reflector can be described by reduced back radiation. Normally the reflector is always placed at a quarter wavelength $(\lambda_0/4)$ underneath the radiator in the direction of back radiation. Due to the reflector direction and position, the wave is travelling against to the reflector with half wavelength distance then reflected phase will be shifted to 180 degrees, so the reflected wave will be driven the field in forward direction. A closed separation air gap (ag) can cause a wave cancellation in between traveled and reflected wave, while a wide separation air gap (ag) can provide more lobes in unwanted direction. [8]

A reflector is usually in form of a metal plane. The square reflector was the first design (Figure 4-a), but the simulated result reveals that some GNSS frequencies cannot work well with such a solid reflector (Figure 5) where the return loss is above $-10\ dB$. The second model (Figure 4-b) comes up with a center-notch to solve the previous defect of the first model. However the square ring reflector cannot provide a CP $(AR \leq 3\ dB)$ at a low GNSS band as shown in Figure 6. After the structure optimization, the third antenna model, as shown is a Figure 4-c, meets the GNSS requirements with the highest gain.

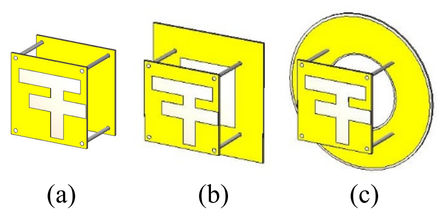


Figure 4. The evolution of the proposed antenna model (a) Model 1, (b) Model 2, and (c) Model 3.

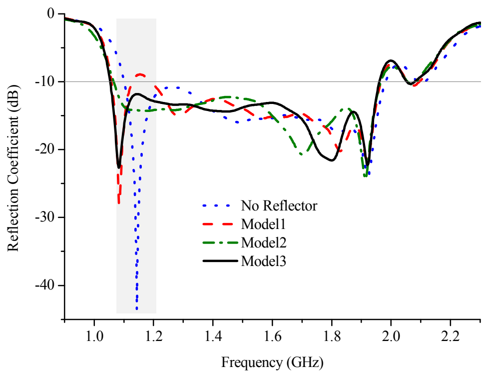


Figure 5. The variation of simulated reflection coefficient due to the evolution of antenna model.

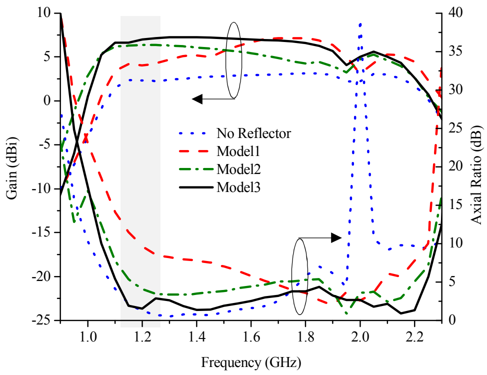


Figure 6. The variation of simulated gain and axial ratio due to the evolution of antenna model.

The proposed antenna is simulated and analyzed for studying some important parameters which affect to gain enhancement, CP property and return loss. The first studied parameter, the air gap (ag) is a reflected wave phase changer, so gain enhancement can be observed by air gab variation and a proper air gap can provide a satisfying gain and axial ratio at the same time (Figure 7). The second, the inner radius (a) and the outer radius (b) of the circular ring reflector are related to each other, because they affect directly to current distribution on the reflector surface. In addition, the smaller ring is set, the higher gain is obtained. Unfortunately CP property is not satisfying when the ring gets smaller, a Figure 8. On the other hand the reflection coefficient has no significant change and it is acceptable $(RL \leq -10\ dB)$ for GNSS as shown in a Figure 9.

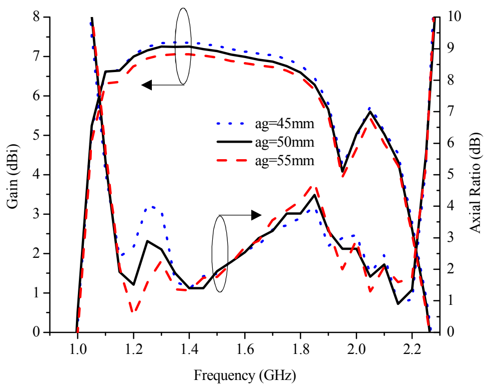


Figure 7. The study of gain and axial ratio due to a variation of air gap (ag).

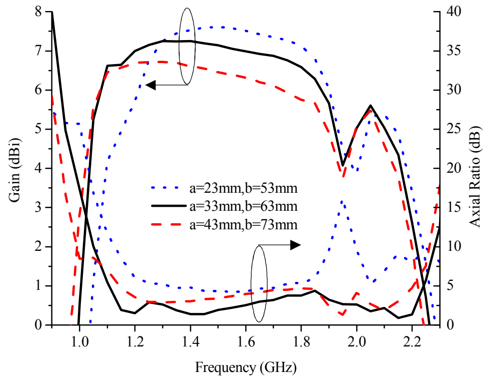


Figure 8. The study of gain and axial ratio due to a variation of the inner radius $(\boldsymbol{a})$ and the outer radius $(\boldsymbol{b})$.

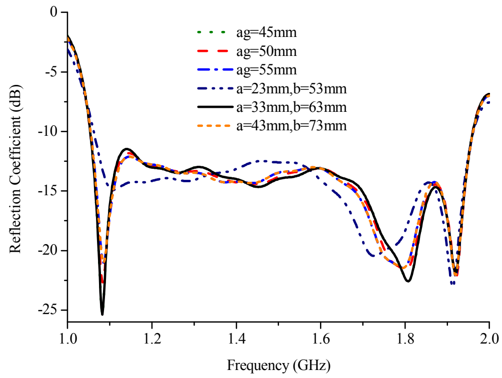


Figure 9. The study of the reflection coefficient due to a variation of air gap $(\boldsymbol{ag})$, the inner radius $(\boldsymbol{a})$ and the outer radius $(\boldsymbol{b})$.

5 Experimental Verification

Experiment of the proposed circular polarized patch antenna using a circular ring reflector for gain enhancement in the GNSS is conducted. A prototype is fabricated and measured to verify the design. The photograph of fabricated prototype under test is shown in Figure 10.

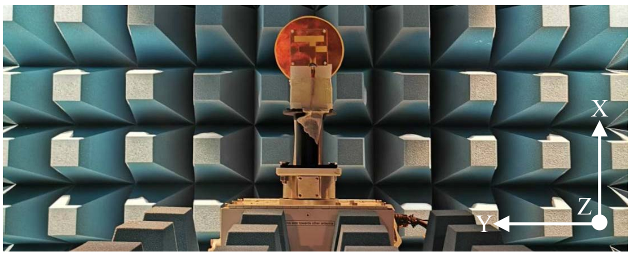


Figure 10. The photo of an under-test prototype.

The simulated and measured results of gain and axial ratio are well concordance as shown in a Figure 11**,** the measured gain is 7.43 dBi (maximum) at 1.314 GHz and is 6.86 dBi (average) with low deviation over the GNSS band, which can compare the results to the others CP antenna with different techniques for the GNSS application, on the Table 2. The axial ratio measurement, which can be used to verify a CP property, is satisfying $(AR \leq 3\ dB)$ over 1.142 - 1.646 GHz. The reflection coefficient is presented in a Figure 12, the measurement $(RL \leq -10\ dB)$ is 71.51 %BW from 1.06 to 2.24 GHz. The radiation pattern or directivity, which is measured in a standard anechoic chamber, is unidirectional pattern that agree well with the simulation. Their comparison is plotted together in polar form, as shown in a Figure 13.

Table 2. The comparison of gain with the others work for GNSS application.

Previous work	Freq. (GHz)	Gain (dBi)
Stacked Patch [9]	1.164 - 1.610	0
Reconfigure Slot [10]	1.140 - 1.650	3
Cross-Slot [11]	1.360 - 1.660	3.8
Shorting Load [12]	1.250 - 1.500	6
This work	1.142 - 1.646	7.43

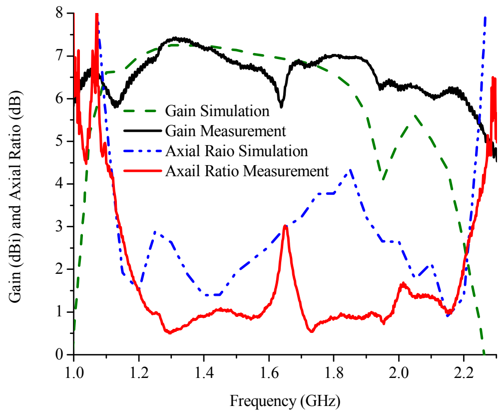


Figure 11. The comparison of simulated and measured result in term of gain and axial ratio.

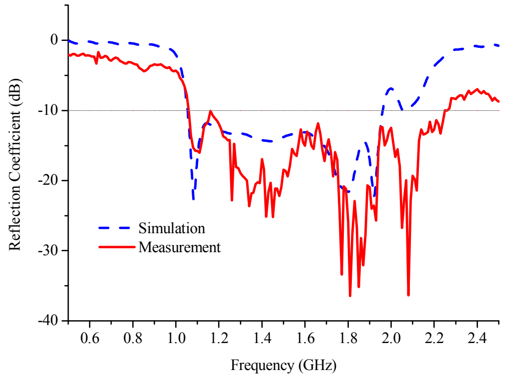


Figure 12. The comparison of reflection coefficient between simulation and measurement.

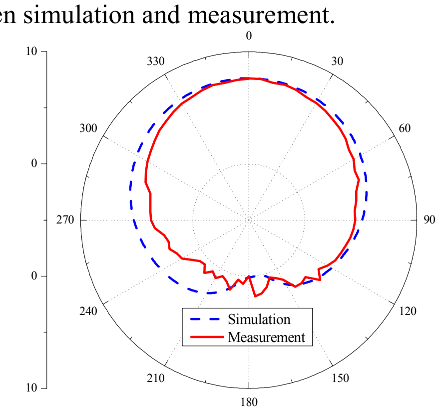


Figure 13. The comparison of radiation pattern between simulation and measurement, on x-y plane at 1.38 GHz.

6 Conclusion

To enhance the receiver antenna gain for GNSS application, the circular ring reflector is placed beneath the cross and bar slot with invert L-shape feed line micro-strip antenna, instead of ask for help from LNA to accomplish a signal quality, since LNA is custom design, costly, and quite a bit vulnerable. Finally the measured result reveals that the proposed antenna can get the better of the GNSS requirements over 1.142 - 1.646 GHz with the average gain of 6.86 dBi and the maximum gain of 7.43 dBi at 1.314 GHz.

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8 References

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