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# NEW DESIGN OF COMPACT SHORTED ANNULAR STACKED PATCH ANTENNA FOR GLOBAL NAVIGATION SATELLITE SYSTEM APPLICATION

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**Abstract**—A new design of a compact circularly polarized shorted annular stacked patch antenna has been introduced for Global Navigation Satellite System (GNSS) in this paper. The wideband characteristic is achieved by employing L-probe coupled feeding structure. The antenna is fed by four-output-ports strip line feeding network composed of three normal Wilkinson power dividers. As a result, the designed antenna has an effective bandwidth of 94.3% from 0.7 GHz to 1.95 GHz for VSWR $< 2$, and 57.1% 3-dB axial ratio bandwidth from 1.0 GHz to 1.8 GHz, respectively. The designed antenna has a compact size of 100 mm $\times$ 100 mm $\times$ 13 mm. The final antenna provides very good circularly polarized radiation for GNSS including GPS, GLONASS, Galileo and Compass.

## 1. INTRODUCTION

Nowadays, Global Navigation Satellite System (GNSS) is used worldwide. The GNSS needs antennas not only have wideband characteristic, but also provide good circularly polarized radiation. Quadrifilar helical antennas have exciting radiation characteristics of broad beam width [1]. However, their inherent disadvantages of big size and narrow bandwidths limit their applications. Microstrip patch antennas [2, 3, 15–19] are often used in the applications needing circular polarization because they offer attractive features of light weight, low profile, easy fabrication, etc. However, microstrip antennas have narrow bandwidth. There are mainly three methods to achieve broadband performance of microstrip antennas, they are using two or more radiating structures which work at different but contiguous

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resonant frequencies [4, 5], using coupling feeding scheme [6] and adding external matching circuits [7]. Several multi-band or wideband low-profile antennas have been designed in the literature [8–12] for GPS or GNSS application. However, few of them can obtain broad beam width and good axial ratio at low elevation, which are useful to suppressing multipath interferences.

It is well known that the shorted annular patch antenna has been considered very useful for GNSS applications [20] because of its good multipath suppressing properties and excellent radiation pattern symmetry. In this paper, a new design of L-shape probe-fed shorted annular stacked patch antenna for GNSS application has been proposed. The designed antenna is characterized by the following features: 1) printed L-probes are connected to four-output-ports feeding network composed of three normal Wilkinson power dividers, which can easily obtain broadband impedance and AR bandwidths. 2) Strip lines are introduced in this design. In this case, the network can be fed by an SMA connector from the bottom of substrate, which is propitious to feeding the array. 3) The feeding network is arranged along the diagonal of the substrate, helping to optimize the space utilization. 4) Some excellent characteristics example for stable gain bandwidths, broad beam width and good axial ratio at low elevation can be obtained by usage of shorted annular stacked patch as radiator instead of conventional circular patch.

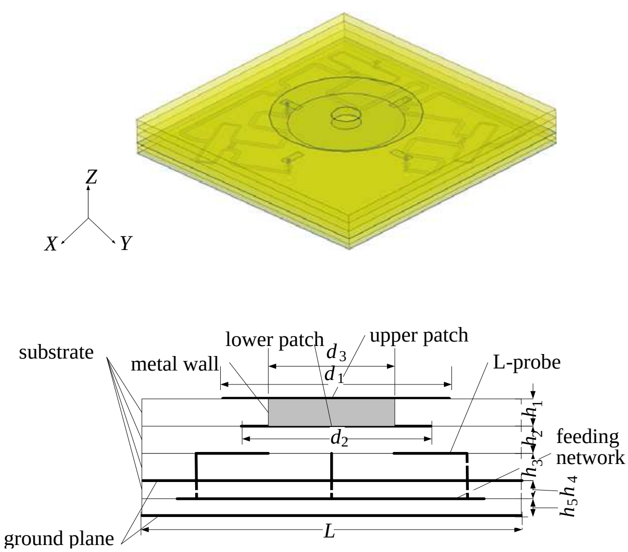



**Figure 1.** The structure of the proposed antenna.

## 2. ANTENNA CONFIGURATION AND DESIGN

Figure 1 shows the structure of the designed shorted annular stacked patch antenna. The proposed antenna includes four layers. The upper annular patch is printed on the top of the first substrate layer and the lower annular patch is printed on the back, furthermore, the upper and lower patch are shorted by the metal wall. The second substrate layer supports and isolates the lower patch and L-probe. The L-probes include four square metal strips which are printed on the top of the third substrate and the posts, which go through the substrate and are connected to the output ports. The strip line feeding network is printed in the fourth substrate layer, it is composed of three normal Wilkinson

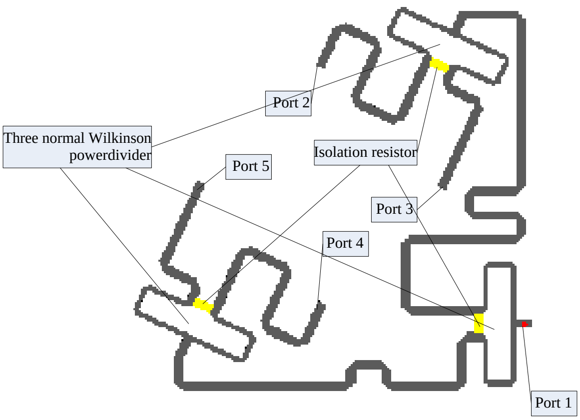



**Figure 2.** The layout graph of the feeding structure.

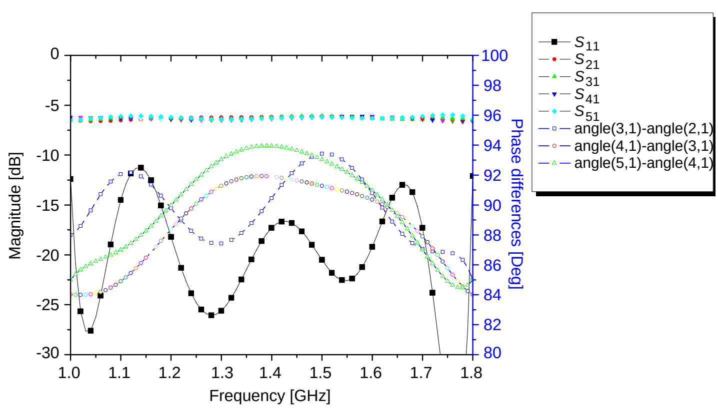



**Figure 3.** Measured performances of the feeding network.

**Table 1.** Key dimensions of the structure.

| $L$ | $\varepsilon_r$ (all substrate layer) | $d_1$ | $d_2$ | $d_3$ |
|---|---|---|---|---|
| 100 mm | 4.4 | 52 mm | 40 mm | 10 mm |
| $h_1$ | $h_2$ | $h_3$ | $h_4$ | $h_5$ |
| 3 mm | 3 mm | 3 mm | 2 mm | 2 mm |

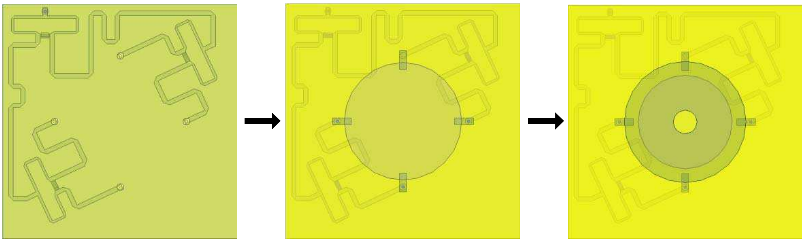


**Figure 4.** The design procedure of the proposed antenna.

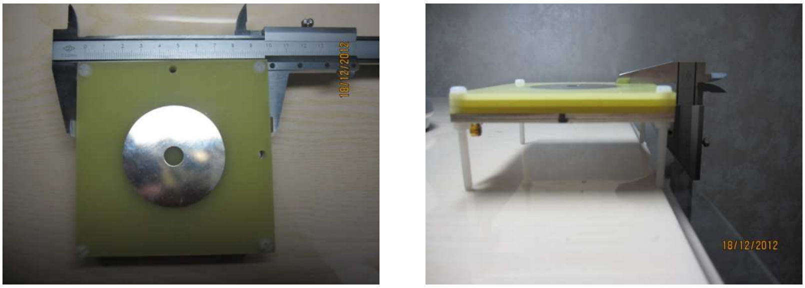
power dividers. In this case, the complexity of the feeding network can be reduced extremely. The structure of the feeding network can be seen in Figure 2. Figure 3 displays the measured return loss, magnitude response and phase differences of the feeding network. It is observed that the magnitude error is less than 0.6 dB and the phase shift unbalance is less than 5° in the band of 1.1–1.6 GHz using the proposed feeding network. It is important for the antenna design to obtain excellent circular polarization performances.

The key dimensions of the structure are shown in Table 1.

Figure 4 shows the design procedure of the proposed antenna. At first, the broadband four-output-ports feeding network composed of three normal Wilkinson power dividers are designed and optimized to obtain small magnitude variation and phase shift unbalance in the GNSS bands; then the circular patch is designed as radiating patch to work at the GNSS bands, the height of the first, second and third substrate ($h_1$, $h_2$ and $h_3$) are optimized to obtain the widest VSWR and AR bandwidth; at last, the shorted annular patch acts as the radiating element instead of conventional circular patch to obtain broader beam width and better axial ratio at low elevation.

## 3. RESULTS AND DISCUSSION

Figure 5 shows a photo of the fabricated antenna. The overall size of the antenna is 100 mm × 100 mm × 13 mm. Figure 6 presents the variety




(a) (b)

**Figure 5.** Photo of the designed antenna. (a) Front view. (b) Side view.

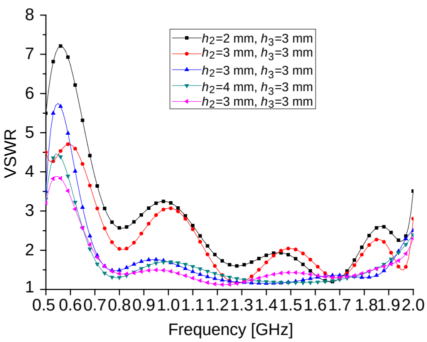



**Figure 6.** Simulated return loss of the proposed antenna for various $h_2$ and $h_3$.

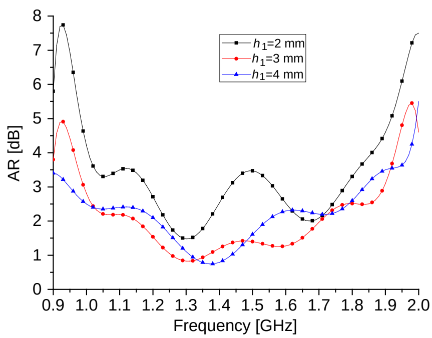



**Figure 7.** Simulated AR of the proposed antenna for various $h_1$.

of VSWR affected by the height of the second substrate ($h_2$) and the third substrate ($h_3$). As can be seen in the figure, when $h_2 > 3$ mm and $h_3 > 3$ mm, VSWR $< 2$ in the designed bands (1.1–1.6 GHz). Figure 7 shows the variety of AR affected by the thickness of the first substrate ($h_1$). From the figure, the AR of the designed antenna are better than 3 dB in the GNSS bands when $h_1 > 3$ mm. Consequently, in order to get a relative smaller antenna size, we choose the values of $h_1$, $h_2$ and $h_3$ as 3 mm. The measured VSWR collected from Agilent E8363B network analyzer along with simulated results using HFSS are presented in Figure 8. It can be observed that the measured impedance bandwidth for VSWR $< 2$ is 94.3%, ranging from 0.7 to 1.95 GHz.

The radiation performances were measured in an anechoic chamber. Two Archimedean spiral antennas were used to measure

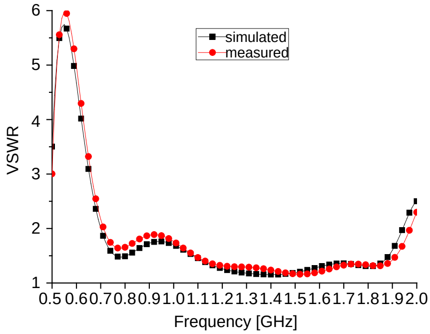



**Figure 8.** Simulated and measured VSWR.

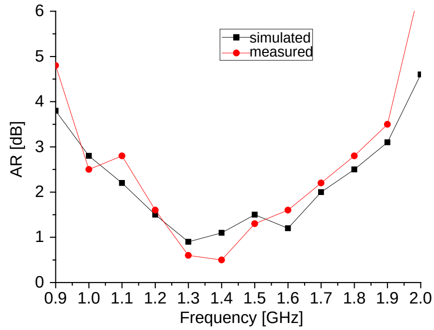



**Figure 9.** Simulated and measured AR.

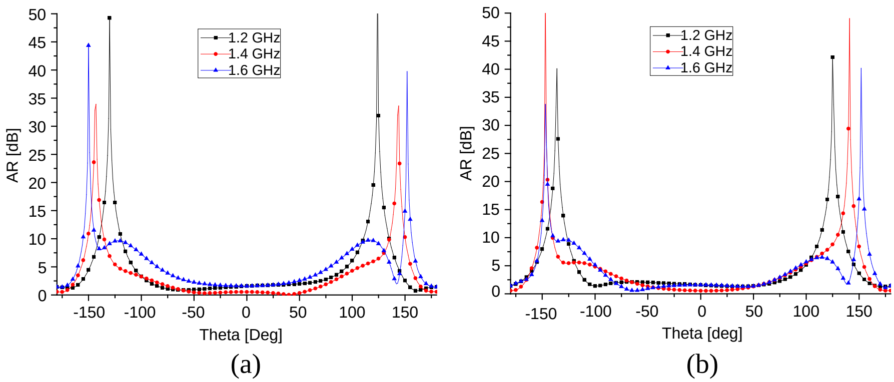



**Figure 10.** Measured AR patterns at 1.2, 1.4 and 1.6 GHz. (a) $X$-$Z$. (b) $Y$-$Z$.

right-hand circular polarization and left-hand circular polarization radiation, respectively. From Figure 9, the measured 3-dB AR bandwidth of the proposed antenna is 57.1% from 1.0 to 1.8 GHz. As can be seen in the figure, the impedance and AR bandwidths are sufficient to cover GNSS frequencies. It owes to applying four ports L-probes coupling feeding schemes, which enhance the impedance and AR bandwidth extremely. The measured AR patterns in the $X$-$Z$ and $Y$-$Z$ planes at 1.2, 1.4 and 1.6 GHz are presented in Figure 10. As seen, the elevation angles for AR $< 5$ dB are $-108°$–$95°$ at $X$-$Z$ plane and $-118°$–$100°$ at $Y$-$Z$ plane respectively at 1.2 GHz, $-121°$–$108°$ at $X$-$Z$ plane and $-103°$–$97°$ at $Y$-$Z$ plane respectively at 1.4 GHz, $-85°$–$80°$ at $X$-$Z$ plane and $-100°$–$94°$ at $Y$-$Z$ plane respectively at 1.6 GHz. The asymmetry of the AR patterns is mainly due to the

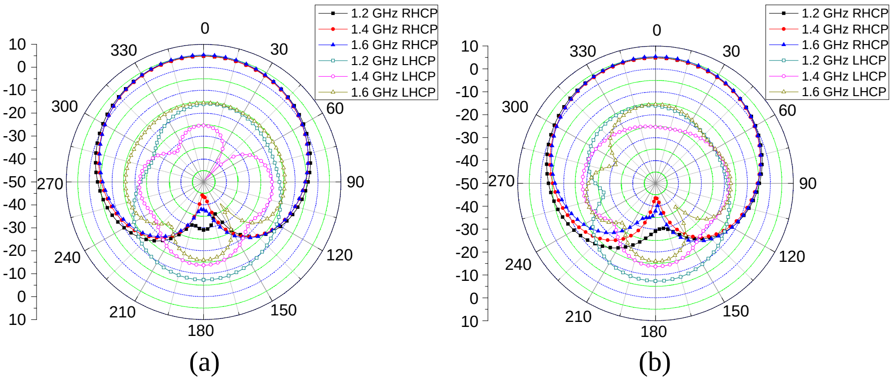



**Figure 11.** Measured radiation patterns at 1.2, 1.4 and 1.6 GHz. (a)$X$-$Z$. (b) $Y$-$Z$.

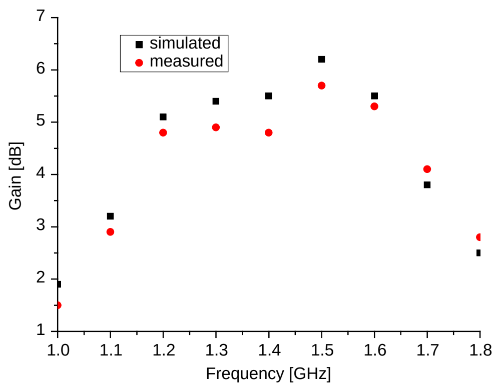



**Figure 12.** Simulated and measured gain of the proposed antenna.

machine and measurement errors. Figure 11 shows the measured radiation patterns in the $X$-$Z$ and $Y$-$Z$ planes at three different frequencies 1.2, 1.4 and 1.6 GHz. Broad pattern coverage and high gain at low elevation angles (more than $-5$ dBi at elevation angles $> 5°$) are achieved. The excellent performances of the antenna are mainly due to the shorted annular stacked patch structure and four ports proximity-coupled probe-fed feeding mechanisms. Axial ratio and gain characteristics at low elevation are better than the other structures designed for GPS or GNSS application [8–14], which are compared in Table 2. The simulated and measured RHCP gain of the antenna at different frequencies are presented in Figure 12, and it is observed that the stable gain bandwidth can be obtained for gain $> 2.5$ dBi in the GNSS bands.

**Table 2.** Axial ratio and gain characteristics at low elevation.

| Literature | Elevation angles ($\Delta$) for gain $> -5$ dBi | Elevation angles ($\Delta$) for AR $< 5$ dB |
|---|---|---|
| 8 | About $\Delta > 20°$ | Not mentioned Not more than 15° |
| 9 | About $\Delta > 20°$ | Not mentioned Not more than 15° |
| 10 | About $\Delta > 15°$ | Not mentioned Not more than 15° |
| 11 | Not mentioned Not more than 20° | Not mentioned Not more than 20° |
| 12 | About $\Delta > 30°$ | Not mentioned Not more than 20° |
| 13 | About $\Delta > 30°$ | Not mentioned Not more than 15° |
| 14 | About $\Delta > 30°$ | About $\Delta > 15°$ |
| Proposed | $\Delta > 5°$ | $\Delta > 10°$ |

## 4. CONCLUSION

In this paper, a new compact strip line L-shape probe-fed circularly polarized shorted annular stacked patch antenna has been designed and fabricated for GNSS application. Using the proposed structure, the antenna exhibits an effective bandwidth of 57.1% from 1.0 to 1.8 GHz for VSWR $< 2$ and AR $< 3$ dB. Moreover, the proposed antenna not only has a compact size of 100 mm × 100 mm × 13 mm, but also can provide stable gain bandwidths, broad beam width and good axial ratio at low elevation. Measured parameters show good agreement with the modeling and conform that such antennas can be successfully used for GNSS applications.

## ACKNOWLEDGMENT

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