Two Miniaturized Microstrip Patch Antenna for Chinese Compass Navigation Satellite System Based on High-permittivity Substrate

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Abstract— With the rapid development of navigation satellite systems, China is accelerating the pace of development of its own Compass Navigation Satellite System (CNSS for short). In CNSS system, miniaturized antennas are more attractive. However, conventional CNSS antennas work at low operation frequency (L band, 1.616 $\pm$ 5 MHz and S Band, 2492 $\pm$ 5 MHz) which lead to large scale by using low-permittivity ceramic substrate. Consequently, in this paper, we present two miniaturized CNSS microstrip antennas based on high-permittivity ($\varepsilon_r = 16$) ceramic substrate. One is corner-cut-patch structure, and the other is two-pair-slot-patch structure. They work at S Band (2492 $\pm$ 5 MHz, right-handed circular polarization, RHCP) to receive position information. An experiment was carried out to verify our design. For corner-cut structure, numerical results show that impedance bandwidth ($S_{11} < -10$ dB), 3 dB axial ratio bandwidth and gain are about 62 MHz, 15 MHz, and 3.48 dB, and measured results shows that impedance bandwidth ($S_{11} < -10$ dB) and 3 dB axial ratio bandwidth are about 66 MHz, 12 MHz, respectively. Meanwhile, for slot structure, numerical results show that impedance bandwidth ($S_{11} < -10$ dB), 3 dB axial ratio bandwidth and gain are about 94 MHz, 23 MHz, and 3.96 dB, and measured results shows that impedance bandwidth ($S_{11} < -10$ dB) is about 132 MHz and 3 dB axial ratio bandwidth is much larger than 22 MHz, respectively. Obviously, the characteristics of slot-patch structure are better than the characteristics of corner-cut structure. Measured results fit well with the simulation results. The two antennas can fully meet the requirement of CNSS. Meanwhile, comparing with the conventional low-permittivity substrate antennas, the two antennas remain their well performances with a reduced size by 75% to 80%. Such advantages make it proper to practical applications.

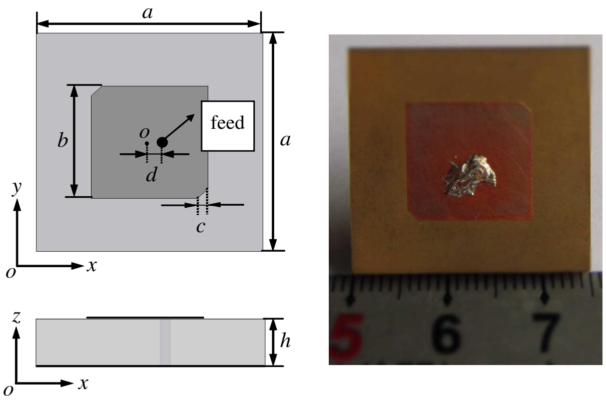
1. INTRODUCTION

Microstrip patch antennas (MPAs) has been widely used in modern communication and weapon systems for their irreplaceable advantages such as low profile, light weight, and easily to be implemented and integrated characteristics [1–3]. With the rapid development of Chinese Compass Navigation Satellite system (CNSS for short), the demand for CNSS terminal microstrip antennas is quite urgent [4–6]. In CNSS system, antennas work at low operation frequency (L band, 1.616 $\pm$ 5 MHz and S Band, 2492 $\pm$ 5 MHz) which lead to large scale by using low-permittivity substrate. The reason is shown in equation $L = c/2f\sqrt{\varepsilon_r}$, where L is the size of the square radiation patch, c is the velocity of light, f is the central frequency of the antenna, ε_r is the relative permittivity of the substrate. It is obviously that using high-permittivity substrate is an effective way to achieve minimized antennas.

In communication systems, circularly polarized antennas are more attractive. Linear polarized antenna can only receive part or none of the signal, which significantly lowers the antenna's efficiency. The common methods to achieve a circularly polarized microstrip patch antenna are to truncate corners or slots on the radiation patches [7, 8]. In this paper, two miniaturized CNSS microstrip patch antennas are present. One is corner-cut-patch structure, and the other is two-pair-slot-patch structure. By using high-permittivity ceramic ($\varepsilon_r = 16$) as the substrate, the antennas keep their performances with a reduced size by 75% to 80% comparing with the conventional ones using low-permittivity substrate. The proposed antennas and results are presented and discussed as follows. In Section 2, the geometries of the proposed antennas are presented. Simulated and measured results including S_{11}, axial ratio and radiation pattern are given in Section 3. Conclusion is provided in Section 4.

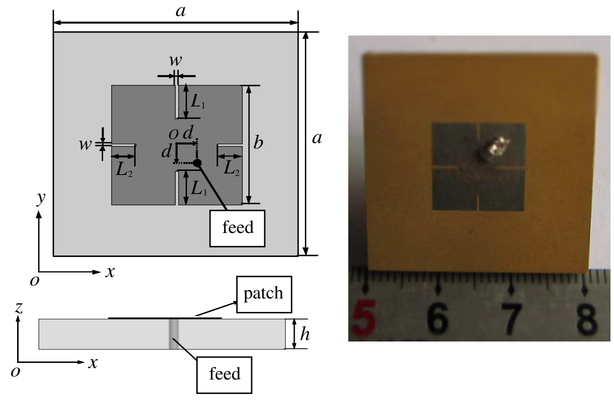
2. ANTENNA DESIGN

The geometry of the corner-cut-patch structure antenna at S band is shown in Figure 1. A low-cost substrate with $\varepsilon_r = 16$, $\tan\delta = 0.001$ and $h = 4$ mm was chosen. A parametric study was carried out using High Frequency Structure Simulator (HFSS) to achieve optimal performances,



(a) (b)

Figure 1: The geometry of the corner-cut-patch structure antenna. (a) The designed antenna. (b) The fabricated antenna.



(a) (b)

Figure 2: The geometry of the two-pair-slot-patch structure antenna. (a) The designed antenna. (b) The fabricated antenna.

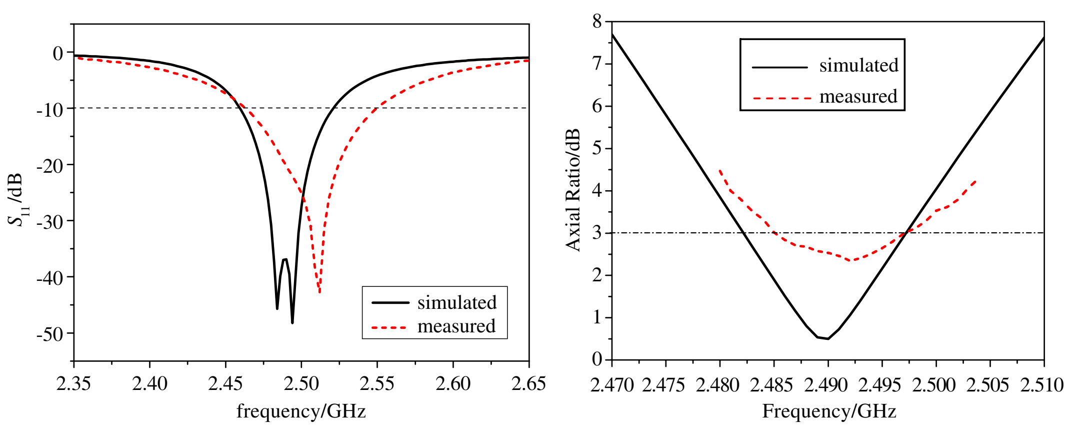
and the geometric dimensions of the proposed antenna are as follows: $a = 25$ mm, $b = 12.85$ mm, $c = 1.15$ mm, $d = 1.6$ mm.

The geometry of the two-pair-slot-patch structure antenna at S band is shown in Figure 2. It is composed of two pairs of slots, and the slots are etched on the patches to realize right handed circularly polarizations (RHCP) or left handed circularly polarizations (LHCP) states. Such differences lie on the length ratio of the slot in x- and y-directions. A low-cost substrate with $\varepsilon_r = 16$, $\tan\delta = 0.001$ and $h = 4$ mm was chosen. By the optimization, the geometric dimensions of the proposed antenna are as follows: $a = 30$ mm, $b = 12.12$ mm, $L_1 = 3.4$ mm, $L_2 = 2.28$ mm, $w = 0.3$ mm, $d = 1.4$ mm.

3. SIMULATED AND MEASURED RESULTS

We used the full wave simulation software High Frequency Structure Simulator (HFSS) version 12.0 to calculate its performances, and use Vector Network Analyzer (VNA) to measure its performance. The reflection coefficient is closely related to the transmission coefficient. Meanwhile, in general, when the axial ratio is lower than 3 dB, we can consider that this antenna achieved excellent circularly polarized performance.

Figure 3 shows the simulated and measured S_{11} and Axial Ratio (AR) results of the corner-cut-patch structure antenna, the real line is the simulated results curve and the dashed line is the measured results curve. From Figure 3, we can see that the simulated and measured impedance bandwidth ($S_{11} < -10$ dB) are 62 MHz and 66 MHz, the simulated and measured 3 dB axial ratio bandwidth are 15 MHz and 12 MHz.



(a) (b)

Figure 3: The simulated and measured S_{11} and Axial Ratio (AR) results of the corner-cut-patch structure antenna. (a) The S_{11}. (b) The Axial Ratio (AR).

Figure 4 shows the simulated and measured normalized radiation pattern at 2.492 GHz, the real line is the simulated results curve and the dashed line is the measured results curve. Due to the lack of normative horn antennas at S band, it is difficult for us to measure the gain of this antenna. The simulated gain at S band is 3.48 dB.

Figure 5 shows the simulated and measured S_{11} and Axial Ratio (AR) results of the two-pair-slot-patch structure antenna, the real line is the simulated results curve and the dashed line is the measured results curve. The simulated and measured impedance bandwidth ($S_{11} < -10$ dB) are 94 MHz and 132 MHz, the simulated and measured 3 dB axial ratio bandwidth are 23 MHz and

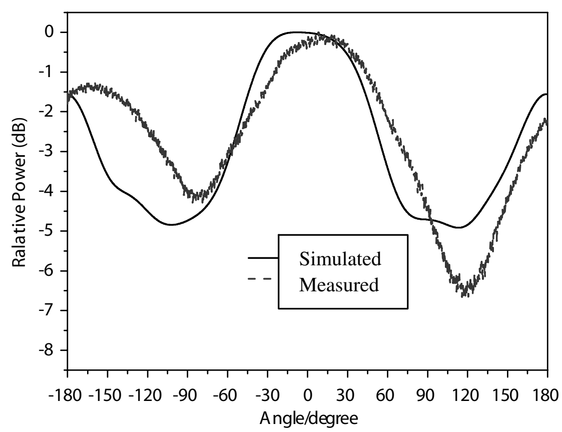


Figure 4: The simulated and measured normalized radiation pattern at 2.492 GHz.

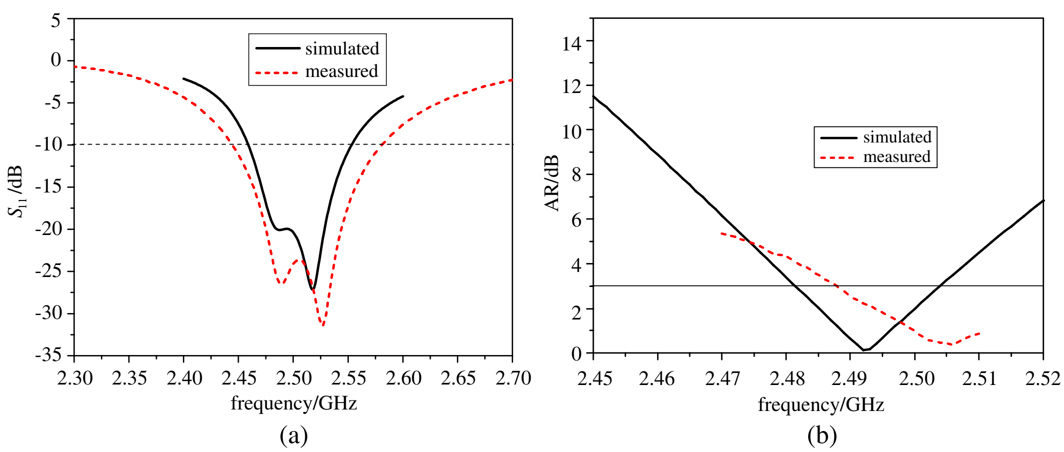


Figure 5: The simulated and measured S_{11} and Axial Ratio (AR) results of the two-pair-slot-patch structure antenna. (a) The S_{11}. (b) The Axial Ratio (AR).

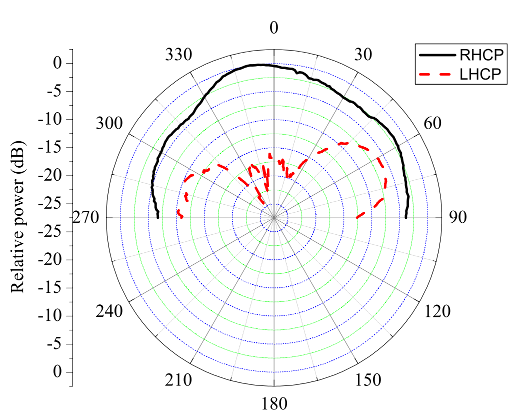


Figure 6: The simulated and measured normalized radiation pattern at 2.492 GHz.

larger than 22 MHz.

Figure 6 shows the simulated and measured normalized radiation pattern at 2.492 GHz, the real line is the simulated results curve and the dashed line is the measured results curve. The simulated gain is 3.96 dB.

4. CONCLUSION

In this paper, we present two minimized RHCP microstrip antennas at S band for CNSS. The measured results agree well with the simulated ones. Meanwhile, the characteristics of slot-patch structure are better than the characteristics of corner-cut structure. Comparing with the conventional low-permittivity substrate antennas, the two antennas remain well performances with a reduced size by 75% to 80%. Such advantages make it proper to practical applications.

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REFERENCES

1. Nakamura, T. and T. Fukusako, "Broadband design of circularly polarized microstrip patch antenna using artificial ground structure with rectangular unit cells," *IEEE Transactions on Antennas and Propagation*, Vol. 59, No. 6, 2103–2110, 2011.
2. Roy, A., P. K. Choudhary, S. Anand, and P. P. Sarkar, "A novel approach on miniaturization of microstrip patch antenna with loaded strips," *ICECI Proceeding*, 2014.
3. Sun, D., W. Dou, and L. You, "A broadband proximity-coupled stacked microstrip antenna with cavity-backed configuration," *IEEE Antennas and Wireless Propagation Letters*, Vol. 10, 1055–1058, 2011.
4. Tian, X. Q., S. B. Liu, Y. S. Wei, and X. Y. Zhang, "Circularly polarized microstrip antenna with slots for Beidou (COMPASS) navigation system," *ISSSE Proceeding*, 2010.
5. Li, B., Y. Guan, Y. Jiang, and A. Zhang, "Compact dual band and circularly polarized microstrip antenna for CNSS," *Cross Strait Quad-Regional Radio Science and Wireless Technology Conference*, 2011.
6. Yuan, H., J. Zhang, S. Qu, H. Zhou, J. Wang, H. Ma, and Z. Xu, "Dual-band dual-polarized microstrip antenna for compass navigation satellite system," *Progress In Electromagnetics Research C*, Vol. 30, 213–223, 2012.
7. Tiang, J.-J., M. T. Islam, N. Misran, and M. Singh, "Circular microstrip slot antenna for dual-frequency FRID application," *Progress In Electromagnetics Research*, Vol. 120, 499–512, 2011.
8. Yang, S. S., K.-F. Lee, A. A. Kishk, and K.-M. Luk, "Design and study of wideband single feed circularly polarized microstrip antennas," *Progress In Electromagnetics Research*, Vol. 80, 45–61, 2008.