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Wideband Circularly Polarized Ku-Band Patch Antenna

Dushmantha N. Thalakotuna⁽¹⁾, Karu P. Esselle⁽¹⁾, Shakil Bhuiyan⁽¹⁾ and Khushboo Singh⁽¹⁾

(1) School of Electrical and Data Engineering, University of Technology Sydney, Australia

Abstract— A wideband circularly polarized patch antenna design optimized for Ku-band frequency range is presented. The antenna employs an aperture-coupled stacked patch configuration simplifying the antenna construction and making it a planar design. Wideband performance is achieved in terms of return loss, axial ratio (AR) and gain bandwidths. Stacked patch radiators with microstrip feed loading is utilized to enhance the return loss bandwidth. In addition, modifications to radiating patch are used to further improve the return loss and axial ratio bandwidths. The proposed design provides right hand circular polarization radiation with a return loss bandwidth of 20% and a 3-dB AR bandwidth of 11.5%, while providing a gain of 9dBi \pm 0.4dB across band of interest with >15 dB front-to-back ratio. The proposed design can be extended to provide dual circular polarization and can be used as a unit/base radiating element for a wideband Ku-band phased array antenna.

I. INTRODUCTION

The growing demand for Ku-band circularly polarized antennas in satellite communication systems necessitates the development of simple, low-profile, and easy-to-fabricate designs. Patch antennas are widely favored [1-3] for their simplicity, compact form factor, and ease of integration. However, they inherently suffer from narrow impedance bandwidths, typically in the range of 2–5%.

Various techniques, such as stacked patches and slot loading, have been investigated to enhance bandwidth. Nevertheless, achieving simultaneous wide impedance bandwidth, gain bandwidth, and axial ratio (AR) bandwidths remains a significant challenge. For instance, a cross-slot-fed patch antenna in [4] achieves an impressive 3-dB AR bandwidth of 48% and a 15 dB return loss bandwidth exceeding 60%. However, the reported 3dB gain bandwidth is limited to 13–15%, and the design suffers from low radiation efficiency due to excitation asymmetry. Additionally, this design employs only a single patch as a radiator.

In [5], a dual-linearly polarized stacked patch design achieves a 10 dB return loss bandwidth of 24%. This design employs a cross-slot to excite the patch and uses two stacked patches to enhance the bandwidth. Similarly, [6] reports a dual-linearly polarized stacked patch design with cross-slot excitation, achieving a 10 dB return loss bandwidth of 52% and a gain of 7.4 dBi \pm 0.4 dB. In both designs, a microstrip split feed is used to excite the patch, which improves impedance bandwidth. However, both [5-6] are limited to linear polarization.

The design proposed in this work achieves circular polarization while utilizing a similar cross-slot excitation for aperture coupling. The proposed design maintains a simple feed structure, straightforward fabrication process, and low profile. To enhance AR bandwidth, the radiating patch shape is optimized. The antenna is designed to operate in the 11–13 GHz frequency range, meeting the requirements for Ku-band satellite applications.

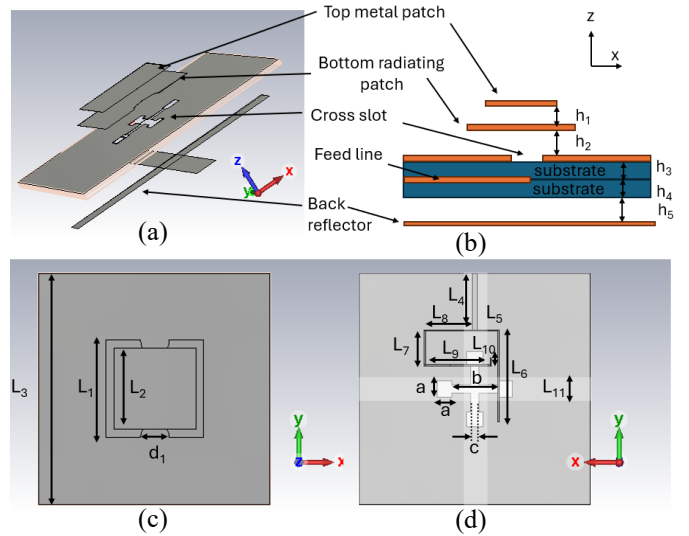


Figure 1. (a) perspective view, (b) side view, (c) top view of the patches, (d) feed structure view of the proposed antenna design. Dimensions: $h_1=1\text{mm}$, $h_2=1.9\text{mm}$, $h_3=0.2\text{mm}$, $h_4=0.2\text{mm}$, $h_5=3\text{mm}$, $L_1=8.4\text{mm}$, $L_2=7\text{mm}$, $L_3=20\text{mm}$, $L_4=5\text{mm}$, $L_5=2\text{mm}$, $L_6=8\text{mm}$, $L_7=3.11\text{mm}$, $L_8=4.17\text{mm}$, $L_9=5.85\text{mm}$, $L_{10}=0.714\text{mm}$, $L_{11}=2\text{mm}$, $a=1.4\text{mm}$, $b=4\text{mm}$, $c=0.7\text{mm}$, $d_1=2.5\text{mm}$

II. ANTENNA DESIGN

The antenna structure is illustrated in Fig. 1. It consists of a microstrip feed that excites a concentric cross-slot printed on opposite sides of a 0.2 mm thick Rogers RO3003C substrate. This substrate has a dielectric constant of 3.55 and a loss tangent of 0.0027. Two concentric square stacked patches are positioned above the cross-slot, as shown in Fig. 1(b). The bottom patch is suspended 1.9 mm above the slot, while the top patch is placed 1 mm above the bottom patch. Both patches are thin metal sheets suspended in air using spacers, although foam can also be used to maintain the required spacing. The use of a low-dielectric-constant material, such as air, enhances the operating bandwidth. Additionally, a back reflector is incorporated to reduce

backward radiation and improve the front-to-back ratio. The total antenna thickness is 6.3 mm.

Several techniques were implemented to enhance both the return loss bandwidth and the AR bandwidth. To improve the return loss bandwidth, stacked patches were employed, and their dimensions were carefully optimized. In addition, the microstrip feedline is loaded with another 0.2 mm thin RO3003C substrate layer. The cross-slot location was optimized, and it was determined that a concentric cross-slot configuration provided the best bandwidth. Further improvements were achieved by refining the slot into a dumbbell shape, which significantly enhanced return loss bandwidth with minimal impact on the AR.

Circular polarization is achieved using the split-feed mechanism, as depicted in Fig. 1(c). The input feedline, a microstrip line, is designed with a $50\ \Omega$ impedance at the feed point. It splits into two $100\ \Omega$ lines, each exciting one polarization. One of the split feedlines includes an additional length of approximately $\lambda/4$ (at 11 GHz) to excite the slot oriented along the Y-direction, generating the desired right-hand circular polarization. The inherent AR bandwidth of square stacked patches is narrow. To address this, the bottom radiating patch was modified by adding semicircular cutouts along the X-oriented sides. These cutouts significantly improve the surface currents required to generate right-hand circular polarization, thereby enhancing the AR bandwidth.

III. RESULTS AND DISCUSSION

Simulated return loss for the patch antenna is depicted in Fig. 2, which also illustrates the impact of the cutout modification on the return loss performance. Incorporating a 1.25 mm radius cutout, as shown in the figure, significantly enhances the 10 dB return loss bandwidth. In the absence of the cutout, the antenna achieves a return loss greater than 10 dB over the frequency range of 10.8 GHz to 12.2 GHz, corresponding to a bandwidth of 12.2%. With the cutout modification, this range is extended to 10.7 GHz to 13.1 GHz, resulting in a bandwidth improvement to 20%.

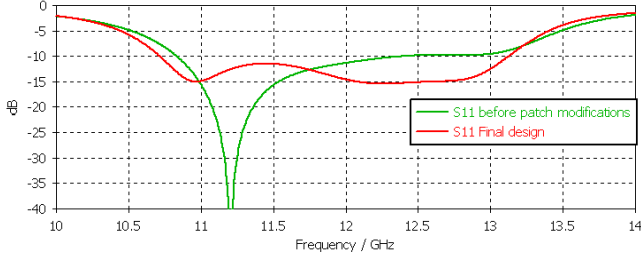


Figure 2. Simulated return loss of the antenna

The semicircular cutout not only improves the return loss but also significantly enhances the AR bandwidth. The AR performance in the boresight direction is illustrated in Fig. 3, both with and without the cutout modification. Without the cutout, the AR remains below 3 dB only within a narrow range from 11.9 GHz to 12.2 GHz, corresponding to a bandwidth of just 2.4%. However, with the inclusion of the cutout, a substantially wider AR bandwidth ($AR < 3\ \text{dB}$) is achieved, extending from 11.4 GHz to 12.8 GHz, which equates to an 11.5% bandwidth.

For applications with more relaxed circular polarization requirements, such as those accepting $AR < 4\ \text{dB}$, the bandwidth can be further extended to approximately 14%. Across the 11–13 GHz frequency range, the maximum AR observed is about 6.5 dB.

The surface current distribution on the bottom patch at 12 GHz for various phases is shown in Fig. 4, illustrating the mechanism responsible for generating RHCP. For better visualization, the surface currents have been scaled and clamped in the figure to clearly highlight the direction. It was observed that the cutout has a more pronounced effect on the bottom patch compared to the top patch, as the intensity of the induced currents is significantly higher on the bottom patch. The top patch primarily contributes to improving the return loss of the antenna.

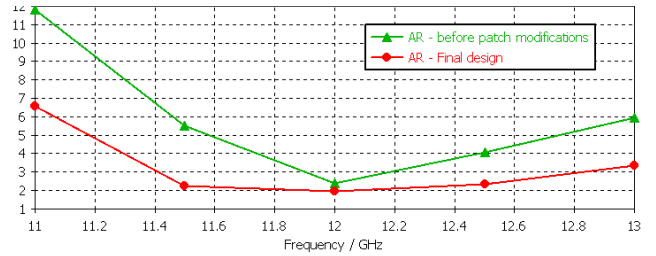


Figure 3. Simulated Axial Ratio at the boresight direction with frequency

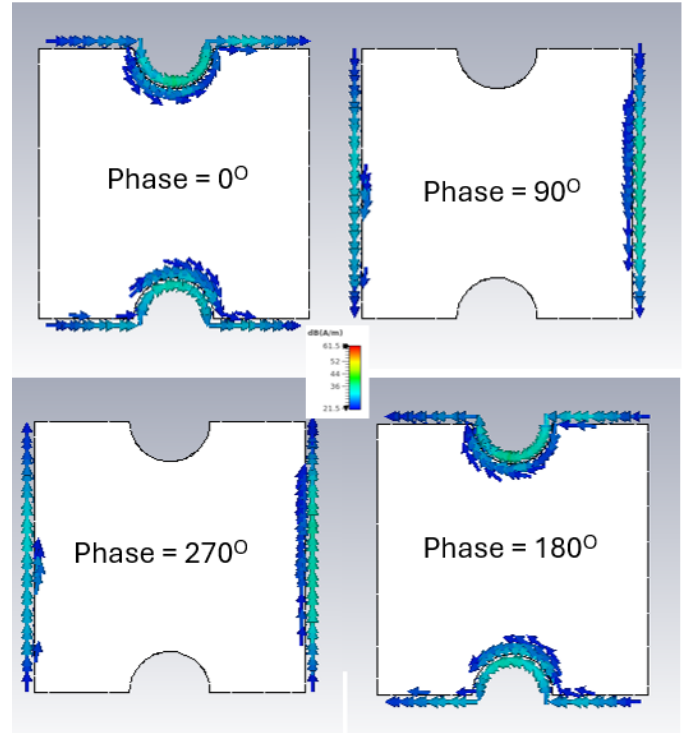


Figure 4. Currents on the bottom radiating patch at different phase values.

The radiation patterns at several frequency points are presented in Fig. 5. The 3 dB beamwidth remains consistently within the range of 62° – 64° across the 11–13 GHz frequency band. A front-to-back ratio exceeding 15 dB is achieved throughout the band, aided by the incorporation of back reflectors.

The AR performance across the 3-dB beamwidth is a critical parameter. The AR for the major E- and H-plane cuts of the antenna is shown in Fig. 6. It is observed that within a $\pm 32^\circ$ range, the AR is maintained below 4 dB in the 11.5 GHz–12.5 GHz frequency range. The gain of the antenna is depicted in Fig. 7, demonstrating excellent stability across the band of interest, with a variation of $9\text{dBi} \pm 0.4\text{dB}$. Additionally, the antenna exhibits a total efficiency exceeding 90% throughout the operating frequency range.

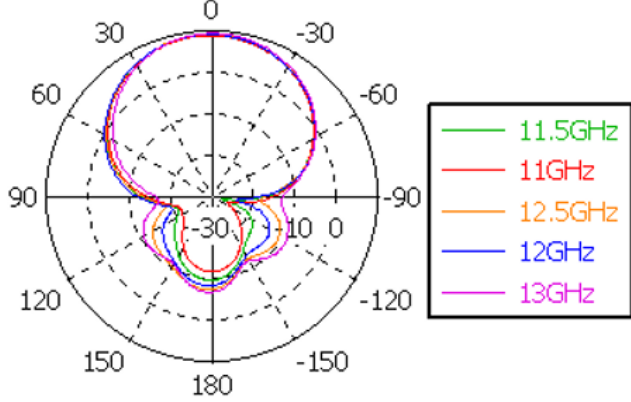


Figure 5. Radiation patterns at selected frequencies

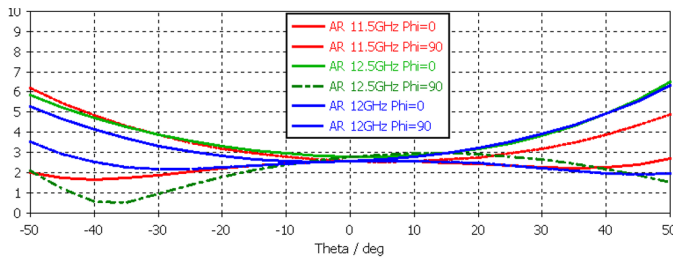


Figure 6. Change in axial ratio in the H and V plane cuts of the radiation pattern for selected frequencies.

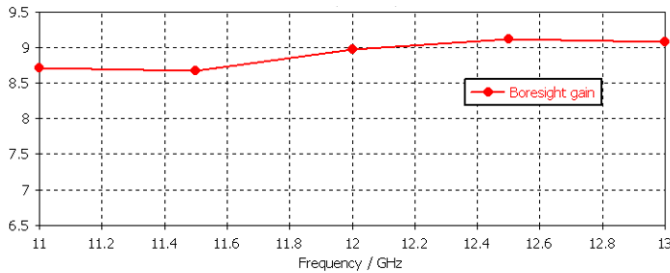


Figure 7. Boresight gain variation with the frequency.

IV. CONCLUSION

The proposed wideband circularly polarized patch antenna demonstrates excellent performance across the Ku-band frequency range, making it a strong candidate for satellite communication antenna systems. The conventional aperture-coupled stacked patch configuration is used to achieve circular polarization. The semicircular cutouts on the bottom patch enhance the AR bandwidth by improving surface current distribution, while the dumbbell-shaped slot and optimized feedline contribute to wide impedance bandwidth and circular polarization. A return loss bandwidth of 20% and a 3 dB axial ratio (AR) bandwidth of 11.5% are achieved. Additionally, the antenna exhibits a stable gain of $9\text{dBi} \pm 0.4\text{ dB}$ and maintains a total efficiency exceeding 90% within the operational bandwidth. The antenna's design also ensures a consistent 3 dB beamwidth of $62^\circ\text{--}64^\circ$ and a front-to-back ratio exceeding 15 dB across the band.

With its low profile, simple construction, and high efficiency, the proposed design is well-suited for modern satellite applications. Furthermore, its versatility allows for potential extensions, such as dual circular polarization or integration into phased array systems, providing a robust foundation for future development in Ku-band communication systems.

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