

# Design of a Stacked Circularly Polarized Slot-Patch Antenna for X-band Applications

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**Abstract**— This paper introduces a numerical investigation of a compact stacked Circularly Polarized (CP) slot-patch antenna designed to operate in X-band (8 -12 GHz). The proposed solution features a coaxially fed circular radiating patch etched on a dielectric substrate, which includes two sector notches positioned on opposite sides at a 45° inclination to achieve circular polarization. Two additional dielectric substrates are placed on the top of the radiating patch, with a parasitic passive patch positioned on each, with the aim of enlarging the overall operating bandwidth. The numerical results demonstrated that the configuration is able to cover a 2.2 GHz band, achieving a minimal Axial Ratio (AR) of 1.2 dB and a gain of 7.4 dB at 10 GHz.

## I. INTRODUCTION

In the ever-expanding landscape of connectivity, the Internet of Things (IoT) emerged as a breakthrough technology, reshaping the human perception and interaction with the physical world, transforming commonplace objects in smart devices, capable of sensing, communicating, and dynamically responding to the environment. As a matter of fact, satellite communications technology assumes a pivotal role in extending the reach of IoT ecosystems, connecting devices seamlessly and bridging communication gaps. This ensures an uninterrupted connectivity, making IoT satellite user-terminals indispensable in scenarios where conventional infrastructure is deemed impractical. Thus, the spectrum of IoT applications can be significantly broaden, encompassing diverse sectors such as remote sensing, precision agriculture, mining, asset tracking and logistics, smart cities, and emergency and disaster response. Compact IoT devices, enabling the LEO-based satellite radio link, are frequently deployed in substantial numbers. Therefore, IoT satellite user-terminals necessitate of antenna systems that are cost-effective and low-profile, possessing adaptable beam steering capabilities and sufficient gain [1]. Flat panel phased array antennas, capable of flexibly manipulating signal phases without necessitating physical relocation, aptly fulfill this requirement. While optimization procedures at the architectural level can be conducted to optimize the design of a phased array [2], nevertheless its performance heavily relies on the meticulous design of the individual antenna element. Circularly Polarized (CP) microstrip patch antennas are commonly favored in satellite communication systems due to their compact size, lightweight construction, and cost-effectiveness. Different methodologies can be utilized to confer circular polarization to patch antennas. In this context, the approach suggested in [3] is

one of the most popular, entailing the introduction of geometric perturbations to the antenna patch. In this context, CP is obtained by internally generating orthogonal modes with equal amplitude and in quadrature phase relationship through slight perturbations in the symmetric geometry.

Within this paper, the design of a single-feed circularly polarized slot-patch antenna operating in the X band (8-12 GHz) is presented<sup>(a)</sup>. Achieving the desired bandwidth is accomplished through the manipulation of physical parameters, including radius, thickness, and the choice of dielectric substrate [3]. The introduction of patch slots facilitates the attainment of circular polarization, while the integration of parasitic passive patches acts to enhance the antenna's bandwidth [5]. The remaining of the paper is organized as follows: Section II introduces the geometry and design choices of the proposed antenna, while Section III outlines the obtained results. Lastly, Section IV offers concluding remarks.

<sup>(a)</sup>No new data were created or analysed during this study. Data sharing is not applicable to this article.

## II. ANTENNA DESIGN TECHNIQUE

The proposed electromagnetically coupled stacked-patches antenna is illustrated in Figure 1. The structure is designed and analyzed through the full-wave simulation software CST Microwave Studio (Dassault Systemes, France).

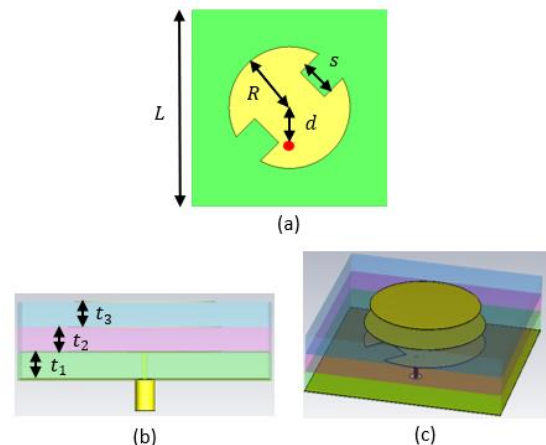


Figure 1 Geometry of the proposed antenna: (a) top view of the actively fed, circularly polarized patch. Cross-sectional view (b), and perspective view (c) of the entire set-up, including the parasitic passive patches.

It comprises an actively fed, circular radiating patch positioned over a single layer of a grounded dielectric substrate with a relative permittivity of 3.5 and a dielectric loss tangent of 0.002. The substrate material is characterized by a length  $L$  of 15 mm and a thickness  $t_1$  of 1.6 mm. The metal employed for both the patch and ground plane is copper, with a thickness of 35  $\mu\text{m}$ . The circular patch, with a radius  $R$  of 4.6 mm, features two square slots with a side length  $s$  of 2.5 mm at its boundary, strategically inserted at a  $45^\circ$  inclination to influence the on-patch current distribution. In particular, the optimization of the circularly polarized (CP) operating frequency and of the axial ratio (AR) is achieved by adjusting the dimensions of the two slots and the position of the single feeder. A  $50\text{-}\Omega$  coaxial probe serves as the feeding for the patch antenna, positioned at a distance  $d$  of 2.8 mm from the patch center.

With the aim of broadening the operating bandwidth, a tuning effect is introduced by adding parasitic and passive elements. Hence, two circular parasitic patches are positioned above the fed patch with the insertion of two foam layers with thicknesses  $t_2$  and  $t_3$  (both equal to 1.5 mm) in between (see Fig. 1(b)). Differently from the lower actively fed patch, the upper ones are passive and present a radius  $R$  equal to 4.4 mm and 3.8 mm, respectively. They are parasitically fed by electromagnetic coupling with the lower patch. Indeed, stacked patches increase bandwidth over a single patch because of the increased overall thickness, the decrease in effective dielectric constant, and the multiple resonances. Specifically, the upper parasitic patch is smaller than the lower one, thus presenting close but different resonance frequencies, yielding a broadband effect.

### III. NUMERICAL RESULTS

The simulated reflection coefficient of the proposed electromagnetically-coupled stacked-patches antenna is reported in Figure 2. The structure exhibits a reflection coefficient magnitude below -10 dB from 8.3 GHz to 10.5 GHz, resulting in a 2.2 GHz bandwidth (i.e., a 23% fractional BW).

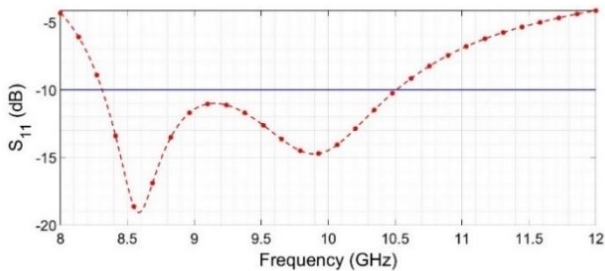


Figure 2 Simulated Reflection Coefficient of the proposed antenna.

Conversely, the antenna characteristics in terms of CP are examined by evaluating the 3-dB Axial Ratio. The Axial Ratio trend versus Frequency is illustrated in Figure 3. The minimum achieved value of Axial Ratio is 1.2 dB, while an acceptable CP bandwidth is accomplished in a 0.4 GHz band. As for this antenna radiative properties, the realised gain is analyzed at 10 GHz. Figure 4 shows the gain obtained on the  $xz$  and  $yz$  planes, which corresponds to a maximum value of 7.4 dBi in the broadside direction for both the cases.

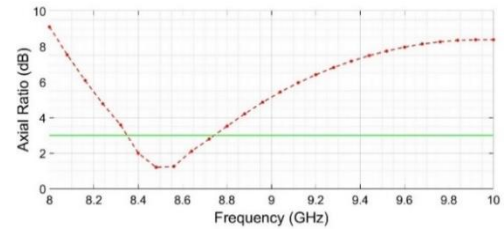


Figure 3 Simulated Axial Ratio of the proposed antenna.

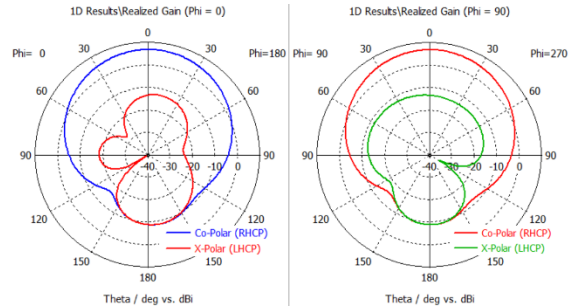


Figure 4 Radiation pattern for  $\phi=0^\circ$  ( $xz$  plane) and  $\phi=90^\circ$  ( $yz$  plane), respectively.

### IV. CONCLUSIONS

An electromagnetically-coupled stacked-patches antenna has been designed and presented in this paper. The proposed structure comprises a coaxially fed circular radiating patch, featuring two sector notches to achieve circular polarization (CP). Additionally, the stacking patches technique is employed to increase the operating bandwidth, by introducing two passive and parasitic patches above the fed one. Favorable results, particularly in bandwidth and gain, have been observed, attributed to a thorough fine-tuning process of the geometrical parameters. Further investigation will be devoted to CP optimization and to the antenna integration in a phased array architecture.

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