Dual Circularly Polarized Waveguide Antenna

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***Abstract*—This paper introduces a novel dual circularly polarized (CP) antenna for the 4.8 GHz to 5.7 GHz band, featuring a compact and readily manufacturable design. The antenna integrates a chamfered-corner square waveguide polarizer, a dual-coaxial feed, and a conical horn. Right-hand (RHCP) and left-hand (LHCP) circular polarization are achieved by selectively exciting fundamental modes within the square waveguide using the dual-coaxial feed. The conical horn, optimized using Antenna Magus and integrated with the polarizer, achieves target gain specifications. CST Studio Suite simulations validated the design, and measurements of the fabricated prototype confirm an axial ratio below 4 dB and a gain of approximately 12 dBi to 15 dBi across the band. The proposed antenna offers a promising solution for satellite communications, radar, and related wireless applications requiring dual CP operation.**

***Index Terms*—Circular polarization, waveguide polarizer, dual feed, conical horn antenna, hexagonal waveguide, eigenmode analysis, electromagnetic simulation.**

I. Introduction

Dual circularly polarized (CP) antennas are essential components in various wireless systems, including satellite communications and radar, requiring both right-hand (RHCP) and left-hand (LHCP) polarization capabilities [1], [2]. Waveguide-based polarizers offer a robust solution for achieving dual-CP operation due to their inherent ability to support two orthogonal, degenerate modes. This introduction briefly reviews existing waveguide polarizer techniques and introduces a novel, easily manufacturable design approach. A subsequent section will detail the polarizer design itself.

Traditional waveguide polarizers for generating circular polarization typically fall into three main categories: dielectric vane, septum, and iris polarizers [3], [4], [5]. Dielectric vane polarizers, while simple to implement, suffer from narrow bandwidths and dielectric losses, limiting their power handling capabilities [6]. Septum polarizers offer good power handling and dual-CP generation but can be bulky and complex to reconfigure [7], [8]. Iris polarizers, capable of higher power operation, often face challenges with overmoding and require intricate design for wideband performance [9], [10], [11]. Recent work has explored alternative waveguide geometries, including elliptical and those with shaped metallic inserts, to leverage mode dispersion for polarization control [12], [13], [14], [15], [16], [17].

This paper presents a novel dual-CP antenna operating in the $4.8\,\mathrm{GHz}$ to $5.7\,\mathrm{GHz}$ band. The antenna system integrates a specially designed square waveguide polarizer, a dual-coaxial feed, and a conical horn. The core of the design lies in the polarizer, which achieves the required 90-degree phase shift between orthogonal modes through geometric modifications to the waveguide cross-section, inspired by approaches used in patch antennas [18]. This approach offers a balance between performance, compactness, and ease of fabrication. The dual-coaxial feed provides the necessary excitation for both RHCP and LHCP operation, while the conical horn provides the desired gain characteristics. The design was validated through electromagnetic simulations using CST Studio Suite [19], and experimental results from a fabricated prototype demonstrate excellent agreement with simulations. Key performance metrics include an axial ratio below $4\,\mathrm{dB}$ and a gain of approximately $12\,\mathrm{dBi}$ to $15\,\mathrm{dBi}$ across the operating band.

The remainder of this paper is organized as follows: Section II details the design of the proposed polarizer. Section III describes... [Continue with the structure of your paper].

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II. Polarizer Design

The proposed dual-CP antenna utilizes a novel square waveguide polarizer design based on introducing geometric modifications to the waveguide cross-section. This approach, inspired by techniques used in patch antennas [18], involves inserting simple shapes into opposing corners of a standard square waveguide. Specifically, triangular prisms are used, forming a hexagonal-like cross-section similar to structures explored in [14]. This geometry was chosen for its relative ease of fabrication compared to curved inserts, while offering effective field manipulation for polarization control. A trade-off for this manufacturability is a moderately wide operating bandwidth, as the principle relies on mode dispersion induced by the resonant nature of the inserts.

The fundamental principle relies on breaking the degeneracy of the fundamental TE_{10} and TE_{01} modes of the square waveguide. The inserted prisms perturb the fields, resulting in two new orthogonal eigenmodes with distinct propagation constants, k_1 and k_2. This difference in propagation constants, Δk_L, causes a differential phase shift, $\Delta \phi_L$, to accumulate between the two modes as they propagate along the polarizer length L. The design objective is to achieve the differential phase shift of approximately $\pi/2$ across the desired operating band while maintaining approximately equal amplitudes for the two modes. By definition, achieving the first condition yields elliptical polarization. Furthermore, simultaneously fulfilling the latter condition corresponds to circular polarization with low axial ratio (AR), i.e., high polarization purity. Due to the diagonal symmetry of the structure, achieving optimal performance for one sense of CP (e.g., RHCP from TE_{01}) inherently ensures similar performance for the opposite sense (LHCP from TE_{10}) [20].

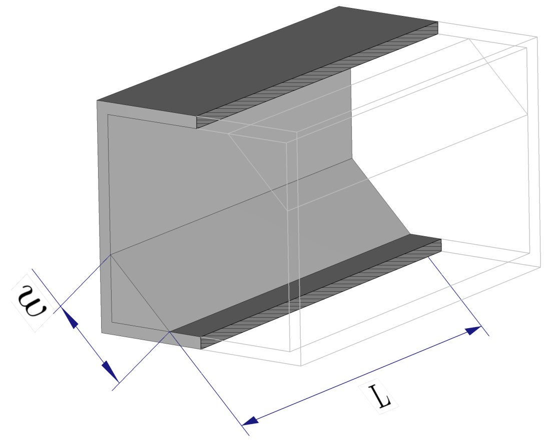

Fig. 1. Perspective view of the square waveguide polarizer.

Initial investigations comprised the eigenmode analysis using CST Studio Suite of square waveguides with triangular prisms for inserts and circular waveguides with cylindrical segments. Assuming uniform waveguides, the key metrics evaluated were the specific phase shift and the amplitude ratio of the modes. While both geometries showed similar mode cutoff frequency dispersion, the square waveguide configuration demonstrated superior phase dispersion characteristics while maintaining a lower amplitude dispersion gradient across the target frequency band. Consequently, the square waveguide with triangular inserts was selected for further development. The specific design targets the $4.8\,\mathrm{GHz}$ to $5.7\,\mathrm{GHz}$ band, relevant for satellite communications and radar applications. An initial square waveguide side length of $a = 50\,\mathrm{mm}$ was chosen, corresponding to the standard WR-187 waveguide [21], though the inserts modify the cutoff frequencies. Eigenmode simulations confirmed this dimension provides adequate bandwidth considering the lower cutoff frequency introduced by the inserts.

A parametric sweep varying the chamfering width w was performed. The goal was to find a cross-section facilitating an acceptable trade-off between the polarizer length required to achieve sufficient mode dispersion at the output (i.e., to fulfill the condition on circular polarization), while maintaining close-to-equal mode amplitudes. Based on the sweep results (summarized in Fig. 2), a chamfering width of $w = 23\,\mathrm{mm}$ and a polarizer length of $L = 2.2\lambda \approx 126\,\mathrm{mm}$ were selected.

To validate the design, a full-wave simulation of the finalized polarizer section, connected between two standard $a \times a$ square waveguide sections (input and output), was performed. The input was fed with the fundamental TE_{10} or TE_{01} mode, providing the necessary excitation to evaluate the far-field axial ratio from the radiated fields at the output waveguide aperture. The results, shown in Fig. 3, confirm excellent performance, with the AR remaining below $3\,\mathrm{dB}$ across the entire $4.8\,\mathrm{GHz}$ to $5.7\,\mathrm{GHz}$ band and reaching near $0\,\mathrm{dB}$ around the center frequency. Representative radiation patterns further confirm the generation of high-purity CP waves and the diagonal symmetry of the polarizer structure assumed earlier.

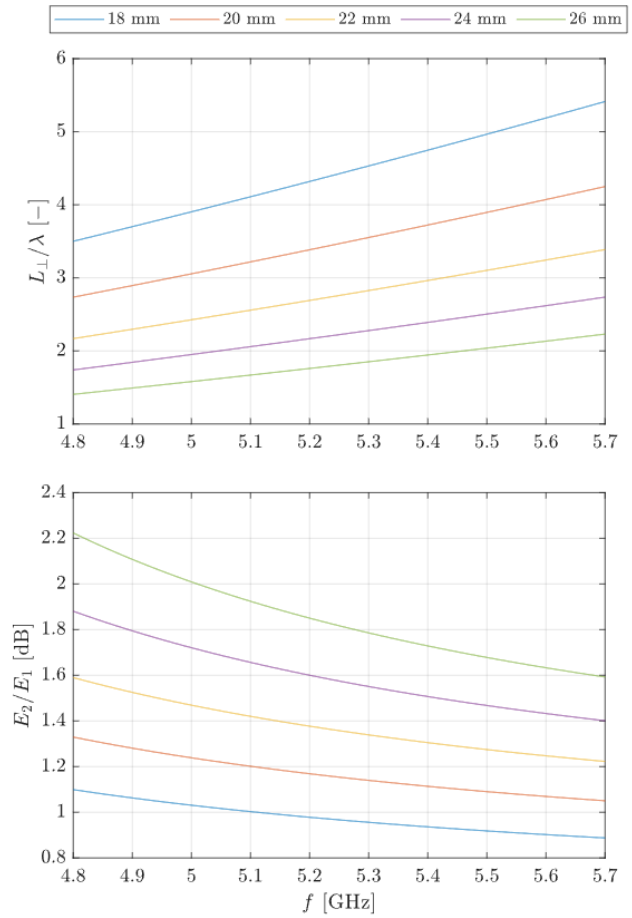

Fig. 2. Performance of the square waveguide polarizer cross-section. The quantity $L_\perp$ represents the length required for a $\pi/2$ phase shift between the two modes.

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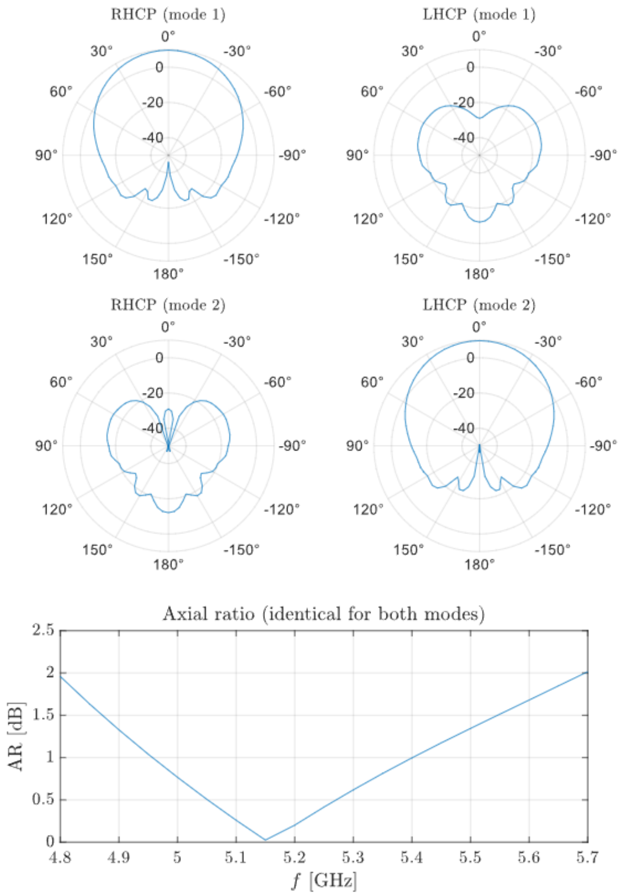

Fig. 3. Hello.

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