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Design of Broadband H-plane Horn Antenna with High-Order Mode Based on Substrate Integrated Waveguide (SIW) Technology

LiBo Wang(1), Shu Lin*(1), Tong Xu(1), Xingqi Zhang(2), and Xinyue Zhang(3)

(1) School of Electronics and Information Engineering, Harbin Institute of Technology, Harbin, China (linshu@hit.edu.cn)
(2) Department of Electrical and Computer Engineering, University of Alberta, Edmonton, Canada (xingqi.zhang@ualberta.ca)
(3) Department of Electronic Engineering, Maynooth University, Maynooth, Ireland (xinyue.zhang@mu.ie)

***Abstract*—This paper presents the development of a high-order mode, low-profile, broadband H-plane horn antenna utilizing substrate integrated waveguide (SIW) technology to increase its bandwidth. The design strategically modifies the antenna's horn dimensions and incorporates high-order modes, thereby introducing resonant frequencies over a range of bands and significantly broadening its operational bandwidth. Furthermore, enhancements in the antenna's bandwidth and radiation properties are achieved through the extension of the waveguide aperture, modification of electromagnetic boundary conditions, and integration of impedance-matching structures. The antenna demonstrates a notable performance, with a reflection coefficient below -10 dB in the 30-52 GHz range, and a relative bandwidth of 53.6%. Additionally, it maintains a consistent gain of over 10 dBi across the operating frequency band with excellent directional radiation characteristics. The proposed SIW-based high-order mode H-plane horn antenna offers high bandwidth, low profile, and ease-of-manufacturing attributes, making it suitable for millimeter-wave applications in the Ka-band.**

I. Introduction

With the advancement of printed circuit board (PCB) processing technology, substrate integrated waveguide (SIW) technology has gained widespread attention due to its advantageous features, including a low profile, light weight, and cost-effectiveness. Within the realm of its numerous applications, the H-plane horn antenna, which employs SIW technology, is particularly noteworthy. However, its application has been somewhat constrained by its inherent narrowband characteristics [1–2]. When compared to fundamental mode waveguides, high-order mode waveguides present a more complex electric field and current distribution. The integration of radiating structures like slots can be strategically utilized to adjust various antenna performance parameters, including bandwidth, radiation pattern, polarization, among others [3–5].

This paper presents the design of an H-plane horn antenna based on SIW technology, with a focus on utilizing high-order modes. This design strategy enables the antenna to exhibit low-profile, multi-mode, and multi-frequency radiation characteristics. Enhancements such as enlarging the waveguide aperture and adding periodic metallic strips to a substrate with a high dielectric constant have been employed. These modifications contribute to the antenna's broadband, high-gain, and directional radiation capabilities. This innovative approach can offer a novel perspective in expanding the bandwidth capabilities of low-profile waveguide antennas.

II. Antenna Structure

The SIW high-order mode horn antenna is fed by the fundamental mode of SIW. To ensure the transmission of the feeding TE_{10} mode, a width (w_1) of 10 mm is chosen. Additionally, to induce high-order modes in the antenna, a width (w_2) of 20 mm is selected. The SIW high-order mode horn antenna and the SIW waveguide resonant cavity are fabricated on a substrate with a thickness of 1.6 mm and a dielectric constant of 2.2. At the front end of the antenna, an SIW waveguide resonant cavity with a length of 30 mm is loaded to alter the boundary conditions of radiated electromagnetic waves, thereby optimizing the antenna's operational bandwidth and radiation characteristics. At the rear end, an impedance-matching structure is implemented, consisting of eight metallic strips with a width of 1.5 mm arranged in a periodic spacing of 0.4 mm on a substrate with a constant dielectric of 4.4. The substrate's length is 30 mm. The antenna structure is illustrated in Figure 1.

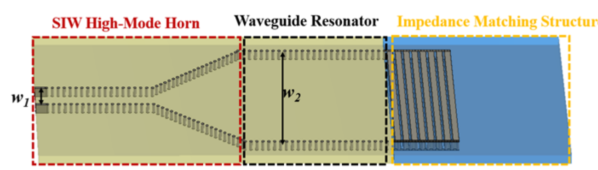

Fig. 1. Antenna structure schematic.

III. Simulation Results

Simulation comparisons were conducted for the SIW high-order mode H-plane horn antenna before and after extending the waveguide aperture to alter electromagnetic boundary conditions and loading an impedance matching structure. The results indicate that by adjusting the antenna dimensions to introduce high-order modes, the bandwidth of the SIW H-plane horn antenna is expanded. At 41 GHz, it exhibits excellent directional radiation characteristics. However, certain frequency points within the entire operating frequency range show a reflection coefficient greater than -10 dB, and at specific points, such as 38.5 GHz, the radiation pattern experiences sidelobes. After modifying the boundary conditions and loading the matching structure, the antenna demonstrates improved performance. In the 30-52 GHz range, the overall reflection coefficient is below -10 dB, with gains consistently exceeding 10 dBi. Furthermore, the directional radiation characteristics are enhanced, achieving high-gain axial radiation. The simulation results for the reflection coefficient before and after changing the boundary conditions and loading the impedance matching structure are depicted in Figure 2. The gain curve is presented in Figure 3, and the radiation patterns at 38.5 GHz and 41 GHz are shown in Figure 4.

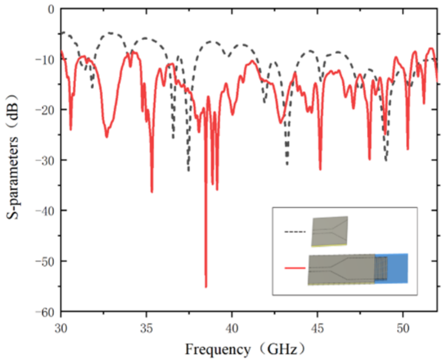

Fig. 2. Reflection coefficient before and after modifying boundary conditions and loading impedance matching structure.

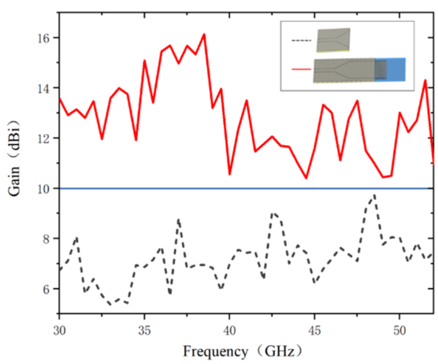

Fig. 3. Gain curve before and after changing boundary conditions and loading impedance matching structure.

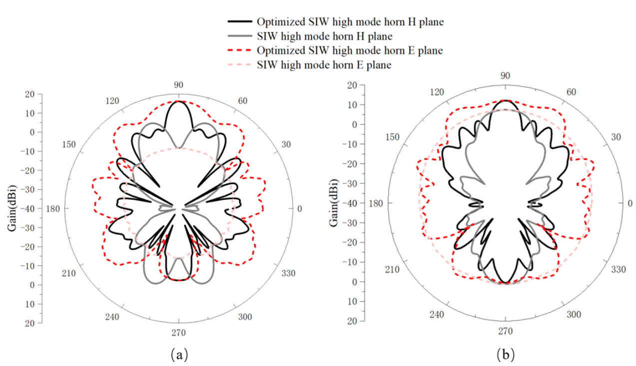

Fig. 4. Radiation patterns before and after altering boundary conditions and loading impedance matching structure. (a) 41 GHz. (b) 38.5 GHz.

IV. Antenna Analysis

By analyzing the electric field distribution in the axial cross-section of the antenna, it is observed that the TE_{10} mode fed through the SIW waveguide forms a semi-mode resonance of different harmonic modes within the antenna cavity at various frequency points. The antenna exhibits broadband operational characteristics. For instance, at 41 GHz, the $TE_{109.5}$ mode is formed internally. Moreover, the electromagnetic energy of different high-order modes is regulated at the waveguide aperture through impedance matching structures and a high dielectric constant substrate, achieving high-gain axial radiation characteristics. The internal electric field distribution of the antenna at 41 GHz is illustrated in Figure 5.

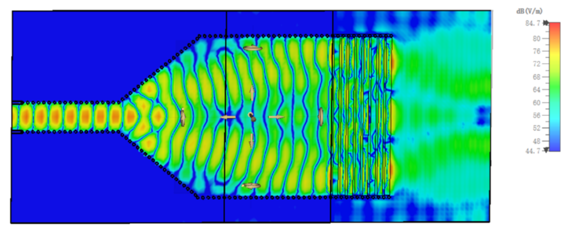

Fig. 5. Internal electric field distribution of the antenna at 41 GHz.

V. Conclusion

This paper addresses the challenge of limited bandwidth in SIW low-profile H-plane horn antennas. A high-order mode H-plane horn antenna based on SIW technology has been developed, significantly enhancing bandwidth capabilities. The antenna achieves a remarkable operating bandwidth of 53.6%, with a gain exceeding 10 dBi within the bandwidth. It exhibits high-gain axial radiation characteristics and is suitable for millimeter-wave applications. The antenna's operational mechanism has been investigated through simulations of the internal electric field distribution. This research contributes valuable insights into expanding the bandwidth of low-profile waveguide antennas and broadens the potential applications for this type of antenna technology.

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