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A SIW Based Leaky Wave Antenna for Aerospace Applications in X Band

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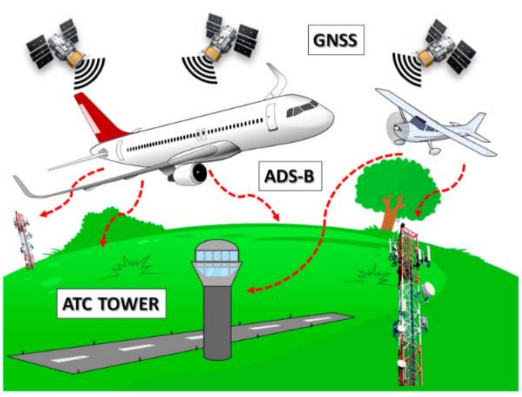
Abstract— In the rapidly advancing field of aerospace communication and radar systems, the demand for high performance antennas operating in the X-band frequency range has increased significantly. For high speed communication, precise navigation, and accurate detection the antenna in X band is required. In this paper, the design and analysis of a substrate integrated waveguide (SIW)-based antenna for aerospace applications operating at a frequency of 10.5 GHz. The proposed antenna design integrates the benefits of SIW technology, such as low loss, compact size, and compatibility with planar fabrication techniques, making it suitable for space-constrained aerospace platforms. The antenna had gain of 9.34 dBi, s11 of design is -28.3 at 10.5 GHz. The radiation pattern is approximately omnidirectional.

Keywords-Substrate Integrated Waveguide; Leaky Wave Antenna; X-Band; Circular C-Type Slots; Gain; Reflection Coefficient; Aerospace Applications.

I. INTRODUCTION

Antennas are important part of aircraft and various other aerospace applications which are operating in the frequency range of X band (8-12 GHz). X-band antennas enable reliable and high-speed data transfer between airborne platforms and ground stations or satellites.[1-3] These antennas facilitate vital functions such as voice communication, data exchange, weather information dissemination, and real-time aircraft tracking. With the growing demand for improved connectivity and enhanced data transmission rates, X-band antennas are essential in meeting the ever-increasing communication needs of modern aircraft. X-band radar systems are critical for aerospace applications, including air traffic control, weather monitoring, terrain mapping, and collision avoidance.[4-5] X-band radar antennas provide precise detection and tracking capabilities, enabling pilots and ground control operators to navigate safely through congested airspace and adverse weather conditions. The high-frequency characteristics of X-band antennas offer enhanced resolution and accuracy, making them indispensable for maintaining situational awareness and ensuring the safety of aircraft. Antennas operating at X band, find significant use in remote sensing applications within the aerospace domain.[6-10] Satellites equipped with these antennas facilitate the collection of high-resolution imagery and data for scientific research and environmental monitoring purposes. They support missions related to climate analysis, disaster management, land mapping, and resource exploration. The high-frequency capabilities of 10.5 GHz antennas enable accurate and detailed remote sensing, providing valuable insights into the Earth's surface and atmosphere. [11-16] Figure 1 shows connectivity of antennas and satellite for aerospace applications.



.Figure 1. Use of Antennas for connectivity

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Table 1 compares the parameters of antennas used for aerospace applications. Different types of antennas are studied and compared in terms of gain, frequency and return loss (s11).

Table 1.Various antennas used for aerospace applications in X band

Antenna	Gain (dBi)	Type	S_{11} (dB)	Frequency (GHz)	Applications
Microstrip Patch Antenna [16-19]	5.9	Microstrip	-18.9	X-band (8-12)	Satellite communication, radar systems, aerospace telemetry
Slotted Waveguide Antenna [20-22]	5.2	Waveguide	-16.8	X-band (8-12)	Satellite communication, radar systems, aerospace applications
Horn Antenna[23-25] (Silver painted)	8.2	Waveguide	-24.2	X-band (8-12)	Satellite communication, radar systems, spacecraft applications
Reflect array Antenna[26-28]	40	Reflect array	-22.8	X-band (8-12)	Satellite communication, radar systems, aerospace applications
Dielectric Resonator Antenna[29-31]	5.8	Dielectric Resonator	-13.4	X-band (8-12)	Satellite communication, radar systems, aerospace applications
Planar Array Antenna [32-36]	6.3	Planar Array	-19.9	X-band (8-12)	Satellite communication, radar systems, aerospace applications

II. SUBSTRATE INTEGRATED WAVEGUIDE BASED LEAKY WAVE ANTENNA

Substrate integrated waveguide based structures have better performance and are suitable for better solution for advanced wireless communication, radar systems and various applications of aerospace. These “antennas combine the advantages of substrate integrated waveguide structures with the beam scanning capabilities of leaky wave antennas, offering compact form factors, high directivity, and efficient radiation performance. By leveraging the leaky wave phenomenon within the SIW structure, these antennas provide enhanced beam control and scanning capabilities, enabling them to adapt to changing communication requirements and improve system performance. In this introduction, we will explore the concept of substrate integrated waveguide based leaky wave antennas, their unique characteristics, and the underlying equations that govern their operation. The equations of SIW structure design are”[35,36]

$$f_c = \frac{c}{2a_d} \quad (1)$$

where ad is the width of the waveguide structure, c is the speed of light, and fc is the cutoff frequency. The Design equation is given by

$$a_s = a_d + \frac{d^2}{0.95p} \quad (2)$$

Where p is the distance between vias, as is the width of the via rows as illustrated in Figure 2

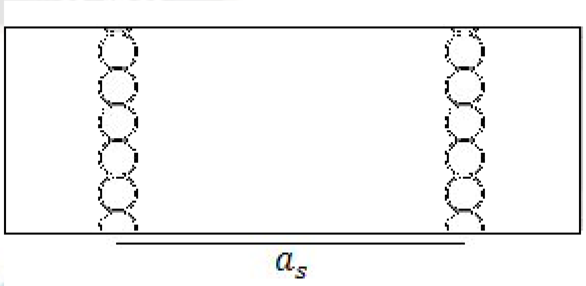

Figure 2. Top view of the waveguide

III. DESIGN AND MODELING

In the proposed model for a substrate integrated wave (SIW) leaky wave antenna, Figure 3 shows the top view geometry. The SIW structure allows for the spread of perpendicular current along the walls through an array of vias. The TE_{10} mode is open in the SIW structure, enabling the desired antenna operation. To achieve the desired beam characteristics, Circular C-type slots are incorporated on the upper metal plane during the modeling process.

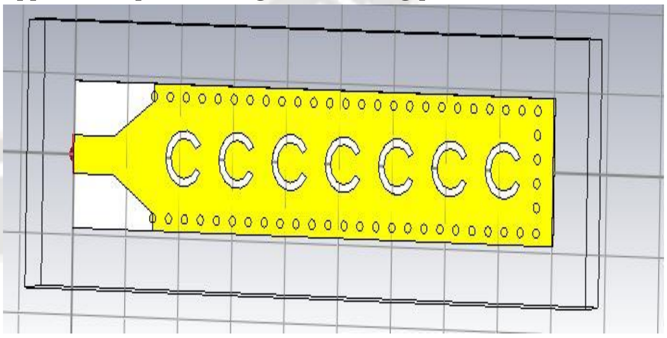

Figure 3. Design of SIW based Leaky wave antenna

In this design, the width of the slots does not significantly impact the antenna's performance. To steer the beam towards the center, a gap between the slots equal to λ/2 (where λ represents the wavelength) is chosen. It is important to ensure that the slots are not parallel to avoid their merging into a larger slot. The longitudinal slots, denoted as Jx, cut the transverse current to achieve the desired antenna radiation pattern.

Figure 4 provides a 3D representation of the antenna design, illustrating its physical structure and dimensions. Table 2 presents various parameters that have been considered in the design process, helping to define the specific characteristics and performance of the SIW leaky wave antenna.

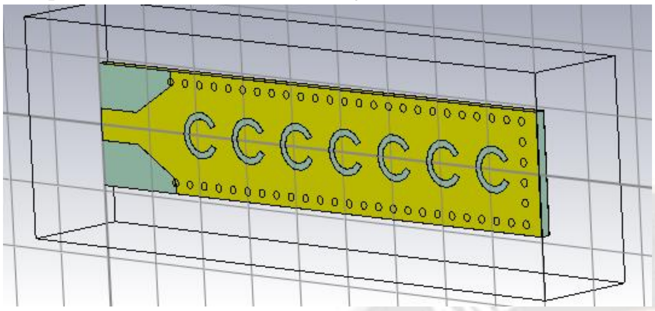

Figure 4. 3D view of SIW based leaky wave antenna

Table 2. Design parameters of proposed SIW based LWA

Description	Value
Dielectric Constant	2.2
Thickness of Substrate	1.55 mm
Via Diameter	1.2 mm
Width of waveguide	14.44 mm
Length of SIW	89.99 mm
SIW effective width	13.94 mm
Slot Width	1mm
Slot length	18 mm
Slot Gap	5.5 mm
Copper Thickness	0.035
Strip Width	4.8 mm

IV. RESULTS AND DISCUSSIONS

A design was modeled in CST 2019, on a processor with a speed of 4x2.60GHz. The simulation process required a total of 4.9 GB of physical memory. The design was modeled in the electromagnetic frequency domain, specifically with a frequency range from 8 to 13 GHz applied to the lumped port. A tetrahedral meshing technique was employed, using approximately five elements per wavelength. The meshing resulted in 28,760 prisms, 16,796 triangles, 1,902 edge elements, 54 vertex elements, 1,340 quadrilateral elements, effectively meshing 157,107 tetrahedron values. The gain, s11 and voltage standing wave ratio (VSWR) is calculated. The gain of antenna is shown in figure 5.

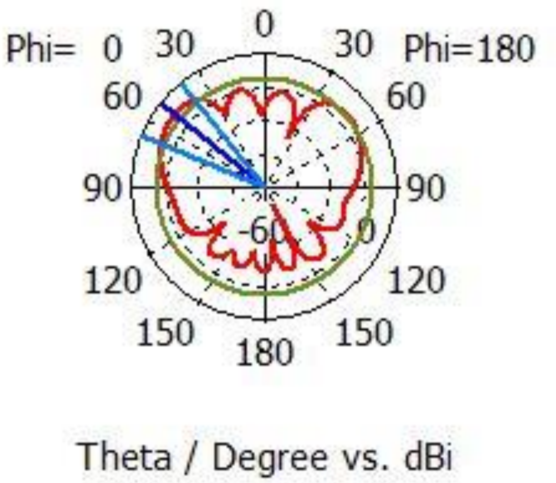

Figure 5. 2D Radiation pattern of antenna

From the figure 5, it is observed that the radiation pattern is similar to omnidirectional pattern. The design has gain of 9.34 dB. Figure 6 shows return loss of antenna and figure 7 shows VSWR plot of antenna. It can be observed that antenna has s_{11} of -28.3 at frequency of 10.5 GHz. It can also be observed that the antennas shows multiband characteristics where the first band lies between 10.003 to 10.0049 GHz, second band lies in 10.441 to 10.556 and third band lies in 11.055 to 11.138 GHz.

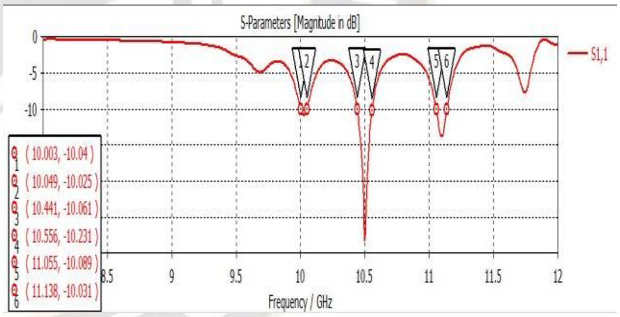

Figure 6. s_{11} plot of modeled antenna

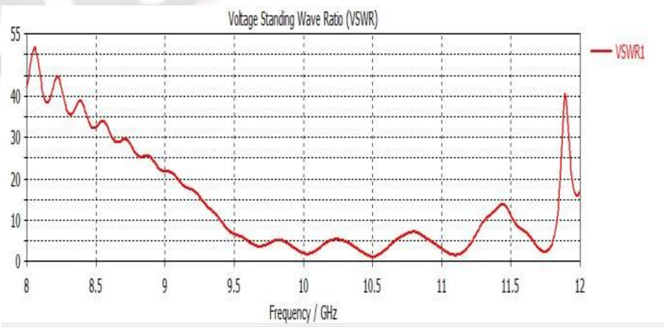

Figure 7. VSWR plot of antenna

Table 2 compares the modeled antenna with previous study of design. It can be seen that the modeled design shows better

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performance than other type of antennas. If compared to reflect array antenna, the size of our proposed antenna is small which can be easily integrated on aircrafts in arrays.

. Table 2. Comparison of different antennas

Antenna	Gain (dBi)	Type	S11 (dB)	Frequency (GHz)
Microstrip Patch Antenna	5.9	Microstrip	-18.9	X-band (8-12)
Slotted Waveguide Antenna	5.2	Waveguide	-16.8	X-band (8-12)
Horn Antenna	8.2	Waveguide	-24.2	X-band (8-12)
Reflect array Antenna	40	Reflect array	-22.8	X-band (8-12)
Dielectric Resonator Antenna	5.8	Dielectric Resonator	-13.4	X-band (8-12)
Planar Array Antenna	6.3	Planar Array	-19.9	X-band (8-12)
Proposed Antenna	9.34	SIW based	-28.3	X-band (10.5 GHz)

V. CONCLUSION

A novel substrate integrated waveguide (SIW)-based leaky wave antenna design with circular C-type slots for aerospace applications in the X-band frequency range is modeled and analyzed. The antenna addresses the growing demand for high-performance antennas in aerospace systems, offering reliable communication, precise navigation, and accurate detection capabilities. By integrating SIW technology and incorporating circular C-type slots, the antenna achieves enhanced radiation characteristics, including a gain of 9.34 dB and a return loss of -28.3 dB (S11). The antenna is compared with existing design of antennas. The prposed antenna showed better result. Its compact size, low-profile design, and excellent radiation performance make it an ideal choice for seamless integration into existing aerospace communication and radar systems.

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