ANTENNA DESIGN USING SIW TECHNOLOGY FOR MILLIMETER APPLICATION

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Abstract — **The evolution of wireless communication has a need of an appropriate radiating element to cover the D–band frequency range. A slot antenna for high-speed wireless communication systems is designed for the D- band and proposed in this paper. This work offers a thorough examination of the planning, analysis, and performance assessment of a wideband slot antenna utilizing Substrate Integrated Waveguide (SIW) technology tailored specifically for D-Band applications. Leveraging the benefits of SIW, the proposed antenna design aims to address the challenges posed by the stringent requirements of D-Band communication systems, including broad operational bandwidth, high gain, and efficient radiation characteristics. The designed antenna is meticulously optimized to achieve a wide bandwidth, high gain ensuring to cover the D-Band spectrum. It has higher radiation efficiency of 90% and return loss as less than -35dB. The SIW-based slot antenna facilitates ease of integration with other circuit components, enabling seamless integration into complex communication systems.**

Keywords—Slot Antenna, D Band, SIW Technology, High gain, radiation efficiency

I. INTRODUCTION

The exponential growth of wireless communication technologies [1] has propelled the demand for high-frequency systems operating in the millimeter-wave spectrum, particularly in the D-Band frequency range [2,3]. Applications such as 5G and beyond, radar systems, and high-capacity data links require efficient and compact antennas capable of supporting wideband operation in this challenging frequency range. To address these demands, a novel design approach is introduced for a Wideband Substrate Integrated Waveguide (SIW)-Based Slot Antenna tailored specifically for D-Band applications[4]. The D-Band, with its vast available spectrum and unique propagation characteristics, offers promising opportunities for high-data-rate communication systems, high-resolution radar applications, and point-to-point links for backhaul networks. However, harnessing this potential requires the development of antennas capable of operating across the wide frequency span of the D-Band while maintaining high efficiency and compact form factors.

One potential remedy is Substrate Integrated Waveguide (SIW) technology [5] for realizing high-performance antennas in the millimeter-wave frequency range. SIW offers low-loss transmission characteristics, ease of fabrication, and integration compatibility with planar circuitry, making it an ideal platform for designing antennas for D-Band applications. By exploiting the advantages of SIW technology, this paper presents a novel approach to designing a wideband slot antenna capable of addressing the challenges posed by the D-Band spectrum. The proposed antenna design aims to achieve a wide impedance bandwidth while ensuring efficient radiation characteristics and high gain across the D-Band frequency range. This necessitates careful optimization of the antenna geometry and structure to overcome the inherent challenges associated with high-frequency operation, such as substrate losses, dispersion effects, and parasitic coupling. The results demonstrate the antenna's suitability for a wide range of D-Band applications, including 5G wireless communication systems[6,7], radar imaging, and high-capacity data links.

This paper presents a pioneering method for creating wideband antennas for D-Band applications, leveraging the unique advantages of Substrate Integrated Waveguide (SIW) technology. The proposed antenna design offers a promising solution to meet the demanding requirements of high-frequency communication systems, paving the way for the advancement of D-Band technologies in various domains..

II. LITERATURE SURVEY

A wideband SIW- "Slot Antenna for D-Band Application is proposed by Amir Altaf [8]. They have obtained a wide response, produced by the six resonance frequencies that are at rest and are closely mixed. Two of them relate to the activation of the TE310–TE120 and TE120–TE220 modes are detected at 114.25 GHz and 134.75 GHz, respectively, are produced by combining the TE310 and TE120 modes. Vanden bosch et al.[9] presented the design of a novel high-gain multi-layer antenna for terahertz communication systems. This antenna works in the 8-13 THz frequency band. A suggested rectangular metal surface construction environment has been employed to increase the antenna's gain. Many plastic bases, which have no negative impact on the antenna's emission pattern, have utilize to reinforce and link the layers Greater than 10.5 dB greater gain was obtained with the suggested rectangular metal surface construction medium compared with a traditional antenna. A wideband substrate integrated waveguide-fed open slot antenna is proposed by Yi and Wong.[10] Antenna powering an integrated waveguide (SIW) feed with a broad bandwidth is the goal of a novel open slot antenna design. The two short sides of the slot are open and not attached to any metal, in contrast to conventional slot antennas. By functioning as a low-Q-single-mode resonator, the open structure contributes a significantly wider bandwidth than standard slot antennas while still ensuring stable radiation performance. Comprehensive parametric studies were conducted in order to provide design guidelines.

Yang [11]et. al proposed a single-layer SIW slots array mono-pulse antenna excited by a dual-mode resonator. A large portion of the antenna aperture is occupied by the traditional mono-pulse comparator, which is made up of a power divider, a typical 3dB-coupler, and a 90_degree phase shifter. As such, there is minimal efficiency. This communication proposes, builds, and measures a substrate integrated waveguide (SIW) slots array mono-pulse antenna that is solely powered by square dual-mode SIW resonators. The goal is to maximize the antenna's aperture efficiency while maintaining a planar single-layer structure. When the feeding cavity runs in two high-order modes, the resulting beams are the sum and difference beams.

Kannadhasan Suriyan and Jacob Abraham [12] proposed a Multiband antenna using SIW technology for wireless communication in Contemporary innovations in engineering and management. An antenna array with a double-layer 2D substrate integrated waveguide mono-pulse slot is suggested by this work. The port solution offered by dual-mode mono-pulse comparator (DMCs) is far superior. The antenna forms "sum" and "difference" pattern in the orthogonal axis using two DMCs. The elevation plane tracking DMC that feeds the slot array through two coupling slots is located in the bottom layer, while the azimuth plane tracking DMC and the radiating 4*4 slots are located in the top layer. Four ports have a measured-10dB common impedance bandwidth of 6.1% (9.4 - 10 GHz), with more than 27 dB of isolation between them. A Review of the D-band Antennas [13] is done by Amir Altaf and Munkyo Seo. The survey indicates that wireless circularly polarized antennas have less attention than linearly polarized antennas. The road towards 6G: A comprehensive survey was also performed by Jiang, B. Han, M.A Habibi, and H.D. Schotten [14]. A wide range of disputes, including requirements, architecture, key performance indicators and supporting technologies for sixth generation system are discussed in the survey.

III. ANTENNA DESIGN

The SIW-based slot antenna is built on a FR4 core substrate with a thickness of 0.454 mm. By connecting the top, using arrays of vias, each with a diameter of *d* and a period of *p* so that *p 2 d*, the SIW line, cavity, and bottom metal layers are formed, ensuring a radiation loss of 0.08 dB throughout the whole D-band. The top metal is etched to form a rectangular slot that is *ls* in length and *w* in width. It is separated by *s* from the shorted by wall. The SIW cavity is rectangular in shape, with length measurements of $ls + 2 \times t$ and via-via width measurements of $r + w + s$. Selecting the PCB width takes into account the width of the final geometry of the rectangular waveguide transition.

The choice of antenna configuration is crucial for achieving wideband performance and efficient radiation characteristics. In this case, a slot antenna based on SIW technology is selected due to its suitability for high-frequency applications. The slot antenna design offers advantages such as compact size, ease of integration, and potential for wideband operation. Selecting an appropriate dielectric substrate is essential to minimize signal losses and dispersion effects. Common substrate materials for SIW antennas include high-frequency laminates such as Rogers RT/Duroid with low loss tangent and high dielectric constant. The substrate material should also provide mechanical stability and compatibility with standard fabrication processes.

Designing the SIW waveguide structure involves determining the dimensions of the waveguide, including width, height, and spacing, to achieve the desired transmission line properties. The SIW waveguide provides the guiding structure for the slot antenna and ensures efficient propagation of electromagnetic waves within the substrate. Careful design of the SIW waveguide is essential to minimize losses and optimize impedance matching. The slot geometry on the SIW substrate is optimized to produce effective radiation characteristics and wideband impedance matching Parameters such as slot length, width, and shape are adjusted through electromagnetic simulation tools to achieve the desired performance metrics.

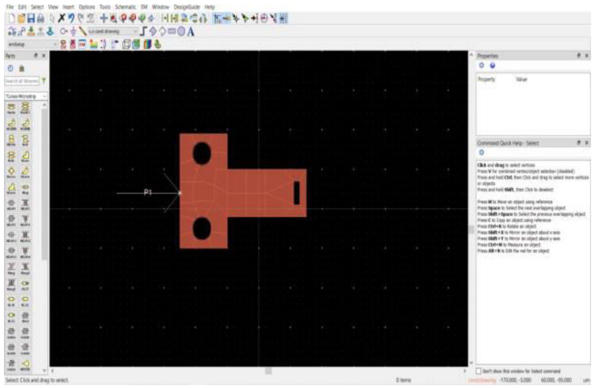

Fig 1. Antenna Top metallic surface

Designing the feeding network involves coupling the input signal from the transmission line to the slot antenna element efficiently. This may require the design of microstrip-to-SIW transitions or other impedance matching techniques to ensure proper impedance matching and minimize signal loss. The feeding network design should also consider factors such as power handling capacity, bandwidth, and radiation efficiency. when the wave port is positioned with 8.515 mm at the reference plane in Fig 1.

The D-band is a promising option for the next generation of high-speed communication systems because it provides a large bandwidth and wide spectrum, spanning from 110-170 GHz. A primary obstacle to the complete implementation of these systems is their ability to communicate with the external environment. Systems that operate at frequencies higher than 100GHz present a considerably greater difficulty, as traditional packaging techniques would not be effective at such frequencies. A number of methods are suggested in the literature to connect the millimeter-wave frequencies of the RF transmission to the MMIC. Using a micro-strip to achieve a Substrate Integrated Waveguide (SIW) transition is one method. A direct link to the outside world is not offered by such a transition, though. To offer an interface with a typical air-filled waveguide, an additional transition must be implemented, which will ultimately increase the system's overall loss. Additionally, SIWs experience dielectric loss, which could be prevented with effective direct radiation. Slot antennas operating at millimeter-wave frequencies have various applications due to their compact size, high efficiency, and ease of integration. Some key applications include:

Millimeter-wave slot antennas are used in wireless communication systems, such as 5G networks, where they provide high data rates and support massive connectivity due to their ability to form narrow beams and handle high frequencies efficiently. Slot antennas operating at millimeter-wave frequencies are employed in radar systems for applications such as automotive radar, airport security scanning, and weather radar. Millimeter-wave slot antennas are utilized in imaging and sensing applications, including medical imaging, security screening, and environmental monitoring. Slot antennas operating at millimeter-wave frequencies are used in wireless backhaul systems to provide high-capacity links between base stations and core networks.

Overall, millimeter-wave slot antennas play a crucial role in enabling various wireless communication, radar, imaging, and sensing applications due to their compact size, high efficiency, and ability to operate at millimeter-wave frequencies. The flexibility of SIW technology allows for the customization of slot antenna designs to meet specific performance requirements and operating frequencies. Engineers can tailor the dimensions, substrate materials, and fabrication processes to optimize antenna performance for various applications, including wireless communication systems, radar systems, satellite communication, and sensing applications. Slot antennas integrated with SIW technology offer a compelling solution for achieving high-performance antennas within a compact footprint.

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The proposed antenna is designed a top metallic surface with the help of SIW in D band application in order to implement in millimeter application and the top view and side view of the proposed slot antenna designed using ADS as shown in Fig 2.

SIW technology allows for the miniaturization of slot antennas by integrating waveguide structures into planar substrates. This result in a reduction in size compared to our existing waveguide-based slot antennas, making them suitable for applications where space is limited. Secondly, the process of SIW technology was implemented by setting up the suitable substrate. The E-field and H-field Magnitude Distributions are shown in Fig 3 and Fig 4. SIW technology offers flexibility in the design of slot antennas, allowing engineers to tailor the antenna's dimensions, substrate materials, and fabrication processes to meet specific performance requirements and operating frequencies. Omnidirectional radiation patterns can be challenging due to the inherent directional characteristics of slot structures. However, there are design techniques and configurations that can be employed to enhance the antenna's radiation characteristics in omni-direction.

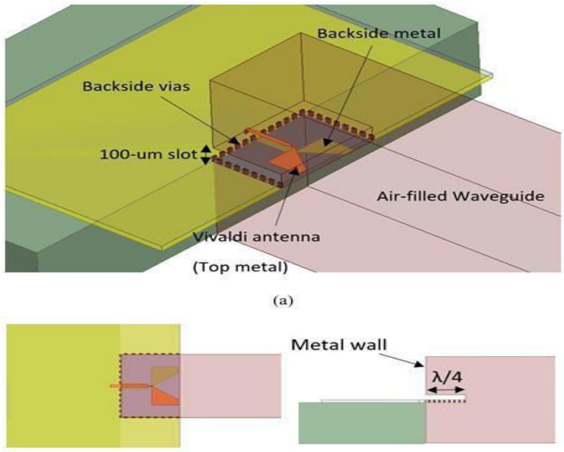


Fig 2 (a) Top View and (b) side view of the D Band Antenna

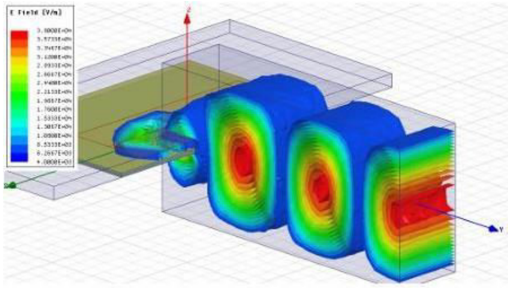


Fig3. E Field Magnitude Distribution

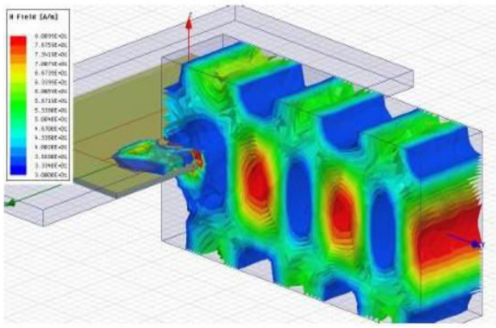


Fig4. H Field Magnitude Distribution

Slot antenna with multiple slots by employing slots around the circumference of the antenna to create a more uniform radiation pattern in the azimuth plane. The arrangement and sizing of these slots can be optimized to achieve the desired omnidirectional coverage.

Symmetrical Design ensuring the slot antenna design is symmetrical can help in achieving omnidirectional radiation patterns. Symmetry in both the slot geometry and the feed arrangement can aid in producing radiation that is consistent in all directions. Hence, the proposed slot antenna (Fig5) was designed with greater number of star slots, circular slots and longitudinal slots in order to transmit the data Omni-directionally. SIW structures exhibit low loss characteristics, similar to traditional waveguides, which can result in improved efficiency and performance of slot antennas. The guided wave propagation within the SIW substrate helps minimize energy loss, leading to higher antenna gain and improved signal-to-noise ratio.

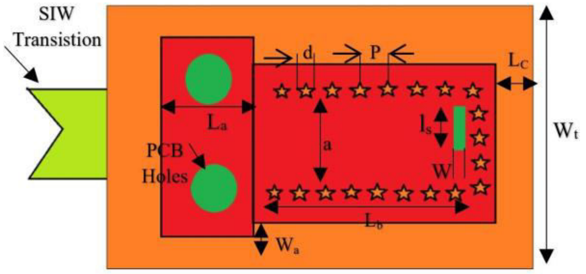


Fig5. Proposed slot antenna

La - Length of the PCB hole
d - diameter of the star hole
P – Distance between two adjacent stars
Lc- Length between the top metallic layer and bottom layer
a - Area between adjacent star holes
Lb – Length of the vertically placed star holes
Wa - Width
W - Width of the rectangular slot
Ls – length of the rectangular slot
Wt – Width of the whole antenna

IV. RESULTS AND DISCUSSION

The proposed slot antenna is designed and obtained a gain of 17 dBi with a directivity of 7.8 as illustrated in fig 6.

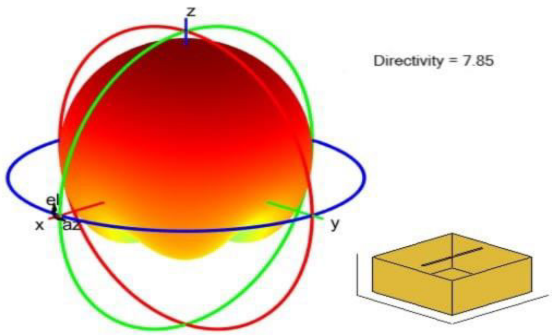
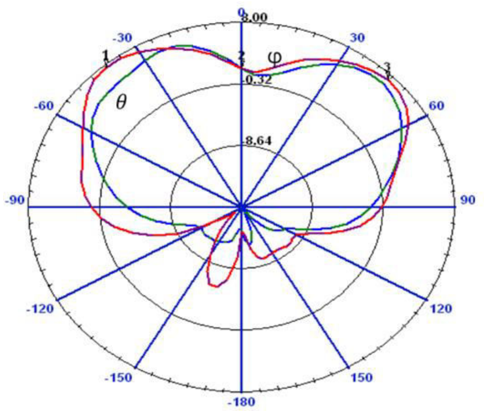


Fig 6. Directivity of the proposed slot antenna

The radiation pattern of a slot antenna refers to the spatial distribution of radiated power in three dimensions Slot antennas can be designed to have directional or omni-directional radiation patterns depending on their geometry and feeding mechanism.



= Radiation pattern in φ vertical plane.
= Radiation pattern in horizontal plane.

Fig7. Radiation pattern of the proposed slot antenna

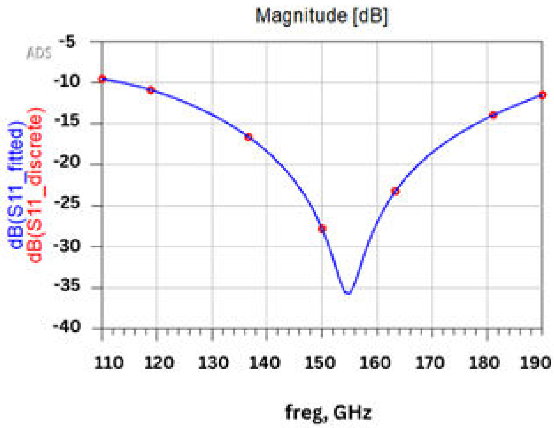


Fig 8 Magnitude Plot for S Parameter

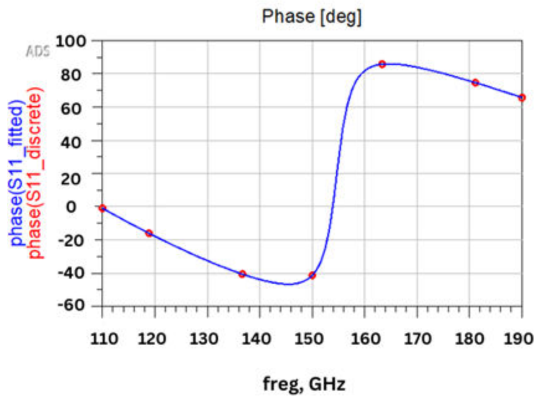


Fig.9 Phase Plot for S Parameter

The radiation pattern of the proposed design antenna is shown in the fig 7. Also the Magnitude and phase plots for the S-parameter of the proposed antenna are shown in Fig 8 and Fig 9.

V. CONCLUSION AND FUTURE SCOPE

Design and analysis of a slot antenna based on a wide substrate that is optimized for D-band applications. The suggested antenna design has been demonstrated to have a wide bandwidth. Good radiation characteristics and high efficiency over the whole frequency range with a gain of 17 dBi through rigorous optimization and simulation. The simulated results demonstrate that the antenna achieves a return loss of less than -35 dB, indicating superior impedance matching and efficient power transfer. The obtained radiation pattern exhibits stable broadside radiation with low side lobe levels, ensuring reliable signal coverage and communication links in D-Band applications. Additionally, the antenna demonstrates high gain, linear polarization characteristics, and exceptional radiation efficiency exceeding 90%, highlighting its suitability for various communication and radar sensing tasks.

The proposed SIW-based slot antenna presents a promising solution for addressing the growing demands of high-frequency communication systems, radar imaging, and millimeter-wave sensing in the D-Band spectrum. Its compact form factor, wideband performance, and compatibility with integrated circuitry make it well-suited for integration into next-generation wireless communication networks, radar systems, and data links operating in the millimeter-wave frequency range.

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