Cavity Backed Multiband SIW Antenna for X Band Applications

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***Abstract*—**This article designs, tests, and produces a substrate integrated waveguide based antenna with copper patches in the micro strip in a totally planar construction utilising microstrip technology. The performances of this SIW antenna, as well as geometrical antenna aspects, are investigated in the X-band at frequencies ranging from 5 to 10 GHz. The efficiency and directivity of the substrate integrated waveguide antenna have been improved, and the side lobe level has been increased, making it highly promising. SIW technology seems to be the most viable option for millimeter-wave integrated circuits and systems in the next decade. This article gives an overview of SIW technology research in academia and industry, as well as its current state and future potential. The development of numerical tools for SIW component modelling and design, as well as the investigation of new compact and broadband interconnects and the discovery of design solutions for loss reduction, are all current research priorities. It consists of two connected quarter-mode SIW resonant cavities and one half-mode SIW resonant cavity. This groundbreaking technology combines a considerable bandwidth boost with a tiny footprint and existing PCB manufacturing procedures at a cheap cost, making it ideal for 5G high-speed wireless applications. SIW technology provides a robust antenna basis, enabling for the integration of high-density active electronics without the possibility of damaging coupling.

Index Terms—Substrate integrated waveguide antenna, X-band, 5G mobile devices

I. Introduction

Microwave and millimetre wave systems that are small, wide-band, and smart have gained a lot of attention in recent years. The desire for satellite communication (SATCOM) [1] applications including internet access [2] in remote locations, defense, satellite phones, satellite, entertainment, and so on has spurred this growth. Satellites and radar applications mostly utilise the microwave domains of the Ku and K bands. A high Q and low loss are two benefits of the rectangular waveguide (RWG). It is, however, complex to construct, costly to mass produce, and time consuming to integrate with planar circuits. Due to large transmission losses, the planar approach cannot be used at higher frequencies. Higher frequencies, the substrate-integrated waveguide (SIW) technique [3] may be a feasible solution. SIW technology, rather than conventional microstrip designs, is emerging as the future answer for planar transmission lines due to its ease of integration and small size [4].

A substrate integrated waveguide bandpass filter's bandwidth may be increased in a variety of methods. Chen et al. developed a multiple-mode resonator with a large passband (MMR). The top layer of a SIW cavity was etched with U-shaped grooves [5]. A SIW hollow has dumbbell holes etched into the bottom and top metallic surfaces. Cutting rectangular form holes in the top metallic plane of a SIW cavity [6] resulted in a millimetre-wave wideband bandpass filter with broad bandpass response. To accomplish broad band operation, a bandpass filter with modified dumbbell defective ground structure (DGS) cells and SIW was described. They devised and constructed a tiny wideband quarter mode SIW band pass filter in the same year, demonstrating how slot length and location affect bandwidth. In order to attain sufficient bandwidth, SIW antenna designs for the 60 GHz band [7], [8] must make unavoidable concessions. SIW slot arrays have been demonstrated to have high impedance bandwidths, but their form factors are excessively large [9]-[12]. To manufacture air cavities [13] or thick substrates [14]-[16], multilayer PCB technology or low temperature co-fired ceramic are often used, resulting in a considerable increase in complexity and production expense. The impedance bandwidth of stack patch antennas is also rather large. Because SIW topologies allow for minimal antenna/platform separation, SIW technology is a good choice for high-density integration in 5G mobile devices.

Because mm-waves limit the use of broadband and high-resolution techniques, mm-wave technology advancements are crucial for wireless system expansion. The availability of a cost-effective technology that is suitable for mass-production of components and systems is critical in the majority of these systems. According to the projection, high-density amalgamation technologies paired with a low-cost production approach will enable a broad variety of options for mm-wave commercial applications. Local oscillators, mixers, and perhaps low-noise amplifiers make up the active element of these systems. For a reasonable price, such components may

Manuscript received March 15, 2022; revised October 12, 2022.
doi:10.12720/jcm.17.11.956-960

now be integrated into the outward appearance of chip sets. Several semiconductor companies are presently working on chip sets that run at frequencies of 45 GHz or higher [17]-[19]. In mm-wave systems, on the other hand, incipient components are needed since they can't fit into the chip-set because they're either too big or can't provide the requisite performance with integrated components like antennas, power amplifiers, and selective filters. Adipose tissue is the common name for these adipose components. They may seem to be nothing more than the chip set's packaging, yet they are critical system components. As a result, a platform that can combine all of these components with high-performance, low-cost, and reliable technology is required for the successful development of mm-wave wireless systems.

II. Design of SIW Antenna Strutcture

In order to increase antenna performance, several factors have been examined. The number of slots etched on the SIW antenna's top plane and the width of Hilbert slot etching are the most important criteria. These data are used to determine the size of slots and the spacing between them in order to provide the antenna with the best possible performance. The use of the Hilbert form as the slot has two advantages: miniaturization and dual or multi-band features. A revolutionary low-profile planar slots SIW antenna design technique is presented. The antenna, comprising Hilbert slots and the feeding element, is fabricated on a single substrate using the SIW technique with a microstrip line structure. The experiment was carried out to ensure that the design idea was correct. The antenna features a broader dual resonant frequency bandwidth while keeping the superior radiation performance of typical planner slots antennas, such as strong dual-band frequency gain. It offers all of the benefits of standard planar antennas, such as a low profile, light weight, compact size, and complete integration with the planar circuit. Using a standard single layer PCB technique, it's simple and affordable to produce. In addition, the substrate integrated waveguide antenna's efficiency and directivity are enhanced while its physical size is reduced. Finally, the 0.75 ellipse ratio rectangular patches are connected and realised. As a consequence of design and optimization efforts, this study improves numerous aspects that exhibit exceptional performance of the suggested antenna. Fig. 1 shows the completed antenna design (a) A micro strip is bonded with copper patches in the form of an ellipse in the proposed substrate integrated waveguide based antenna. The latter entails bringing all of the previously created cells together.

The goal is to design, optimise, and build a rectangular cell on a planar substrate with the least amount of loss possible. Using 3D modelling, specifically HFSS, the antenna element is developed and optimised as a single rectangular patch with inset-fed strip line matching. Between measured and simulated parameters, there is a high degree of agreement. To attain the best results, antennas with different properties (ellipse ratio) were developed. The planar design, modelling, and implementation of a substrate integrate waveguide-based antenna for wireless applications in the X-band at 10 GHz are shown in this study. To begin, the HFSS programme is used to build a SIW antenna. Following that, the identical task was completed and optimised. A single cell with four elliptical patches positioned between the vias makes up the antenna. The main basic components, elliptical patches, are measured to validate modelling and simulation approaches. The high level of agreement in simulations implies a good design. Finally, the SIW antenna is simulated and optimised in the X-band to meet the needed characteristics. Efficiency, directivity, and return loss are all enhanced while the physical size is reduced. This verifies the antenna's specifications and demonstrates that it outperforms what has previously been reported in the field.

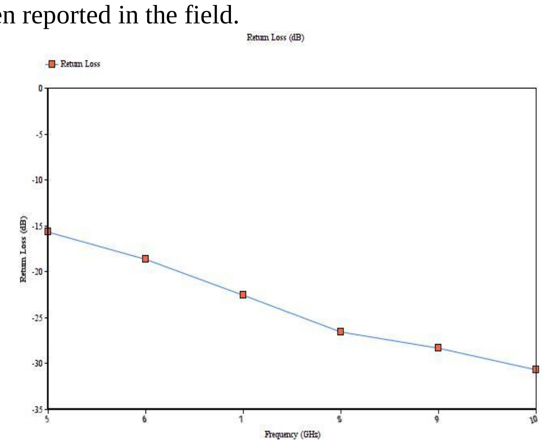


Fig. 1. Return loss of the proposed antenna

Individual system components are often developed and manufactured individually, necessitating the use of a range of fabrication processes to guarantee that each component is effectively implemented. Microwave and millimeter-wave components may be implemented using a variety of manufacturing processes. Microstrip line and coplanar waveguide are two printed planar technologies that may be used to manufacture a range of microwave-frequency passive components, interconnects, and antennas. These methods enable the creation of small, low-profile, light-weight components using low-cost manufacturing procedures. Printed components, on the other hand, may suffer severe losses, particularly at MM-wave frequencies; they are also susceptible to radiation leakage and unwanted coupling between neighbouring parts, as well as having limited power handling capabilities. The Substrate Integrated Waveguide (SIW) is constructed and modelled in this dissertation. They're also used in SIW antennas. SIW antennas with slotted and leaky waves are both modelled. The dielectric material is FR4/Glass epoxy with a relative dielectric constant of 4.2, and the substrate is 1.6 mm thick. The modelling programme is HFSS version 12.

For the 60 GHz frequency band, a wideband substrate integrated waveguide (SIW) antenna is proposed. It consists of two quarter-mode SIW resonant cavities joined by a half-mode SIW resonant cavity. A wideband substrate integrated waveguide (SIW) antenna is ideally suited to the 60 GHz frequency range. It consists of a half-mode SIW resonant cavity and two quarter-mode SIW resonant cavities. SIW technology enhances antenna platform isolation, allowing high-density active electronics to be integrated without the possibility of damaging coupling. As the demand for broadband wireless applications has grown quickly in recent years, channel capacity requirements have become increasingly rigorous. Because end users need ever-increasing data rates, 5G mobile communication is an excellent illustration of this tendency. Electronic gadgets, particularly end-user equipment, are becoming more compact. As a result, designing novel wideband antenna topologies with tiny footprints and adhering to standard manufacturing methods is critical for simple and compact integration into end-user devices such as smartphones. The unlicensed 7 GHz band of the 60 GHz IEEE 802.11ad spectrum is well-suited to 5G wireless communication systems' severe channel capacity and number of networked users requirements. The air absorption peak is suitable for secure, low-interference communication between several wireless devices operating on the same frequency. Because of its better shielding capabilities, outstanding loss performance, and compatibility with regular printed circuit board (PCB) manufacturing techniques, Substrate Integrated Waveguide (SIW) technology has already achieved a breakthrough in the mmWave research field. Antennas, filters, and couplers have become more common in recent years. The thickness of the substrate is 1.6 mm. The design makes use of a wave port. Because the corresponding rectangular waveguide is 16mm wide, the two rows of cylinders are spaced 12mm apart. The slotted SIW antenna evolved from the first SIW antenna. The slots are etched onto the top metallization plate of the SIW. On both sides of the symmetric plane, the slots are symmetrically positioned. The slots are 8 millimetres in width and 3 millimetres in depth. The length is equal to half of the guide's wavelength. Because the related SIW's cutoff frequency is about 5 GHz, the SIW slotted antenna resonates at that frequency.

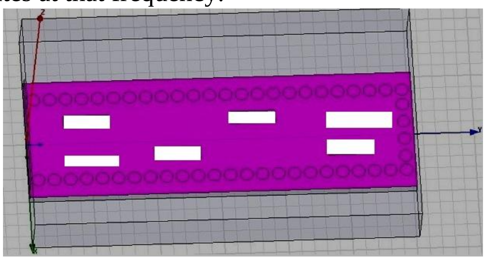


Fig. 2. Substrate Waveguide Structure (QMSIW)

Fig. 2 shows the proposed wideband antenna design. Two quarter-mode SIW resonant cavities (QMSIW) and one half-mode SIW resonant cavity (HMSIW) are found in a single antenna element. This one-of-a-kind design crams three independent antenna components into the footprint of a standard half-wavelength SIW antenna, resulting in a significant form factor decrease. When the three tiny holes shown in Fig. 2 are near together, they produce three connected resonant cavities. Mode bifurcation arises as a result of the connection. As a result, the whole system, which consists of one HMSIW and two QMSIWs, has three distinct resonances, whose frequencies are governed by the size and connection of the miniaturised cavities. Only the half-mode SIW is supplied by an external feed line in this system since the HMSIW is the feeding cavity. The HMSIW stimulates the QMSIWs because of their close relationship. As a result, they operate as parasitic resonators. To construct three resonances in the required frequency range, the first step in the design process is to determine the size of the HMSIW and the two QMSIW cavities. Surface wave propagation is problematic due to SIW technology's shielding properties, which limit electromagnetic fields inside cavities. As a result, the HM- and QMSIW antennas are excellent candidates for integration with large antenna arrays or active electronics in 5G mobile user equipment.

III. Results and Discussion

The simulated return loss resonant at 5GHz and 10GHz is shown in Fig. 1, together with the dielectric and conductor losses. As indicated in the figure, radiation is only generated at the suitable frequencies throughout a large band range. The recommended antenna has enough bandwidth for broadband usage. This attribute qualifies it for certain applications that need a highly isolated antenna to reject out-of-band interference signals. SIWs are manufactured by glueing two parallel metal plates together and implanting two rows of conducting cylinders or slots in a dielectric substrate, similar to how waveguides are formed. The schematic is shown in Fig. 2. This approach may be used to transform a non-planar rectangular waveguide into a planar waveguide that can be processed using standard planar processing techniques. Traditional rectangular waveguides have field pattern and dispersion properties that SIW structures have.

Return loss after the substrate integrated waveguide's cutoff frequency of 5 GHz is less than -15.68 dB, -18.65 dB after 6GHz, -22.56 dB after 7GHz, -26.56 dB after 8GHz, -28.32 dB after 9GHz, and -30.68 dB after 10GHz, according to the S11 Vs frequency curve in Fig. 1. The slotted SIW antenna's VSWR curve is shown in Fig. 3. The antenna has a maximum return loss of -30.68dB and a minimum return loss of -15.68dB at its resonant frequency. The broad band behaviour of this SIW antenna may be examined. Fig. 4 depicts the gain curve of the SIW leaky wave antenna. The SIW leaky wave antenna are identical to those in the intended SIW, with the exception that one side through spacing has been increased. The multiband behaviour of this SIW leaky wave antenna may be examined at various resonant frequencies. The leakage energy in this SIW leaky wave antenna vias has been modified such that it travels through the dielectric as a surface wave travels less. The SIW antenna has a VSWR of 1.4 at 5GHz, 1.5 at 6GHz, 1.7 at 7GHz, 1.8 at 8GHz, 1.7 at 9GHz, and 1.8 at 10GHz, according to the manufacturer. At different resonant frequencies, the multiband behaviour of this SIW leaky wave antenna may be investigated. Fig. 5 depicts the SIW leaky wave antenna's dimensional radiation pattern with vias changed. The behavior differences between the SIW slotted antenna and the leaky wave antenna are shown in this figure. The vias on the leaky side relocated to the edge, preserving the SIW's width. The SIW antenna has a gain of 4.5dB at 5GHz, 5.6dB at 6GHz, 6.7dB at 7GHz, 7.2dB at 8GHz, 8.2dB at 9GHz, and 8.5dB at 10GHz, according to the manufacturer. The result is shown in terms of induced voltage in this figure. The pattern illustrates the radiation pattern after a fire has been extinguished. This antenna has a superb radiation pattern when compared to SIW slotted and SIW leaky wave antennas where the slot positioning is not changed.

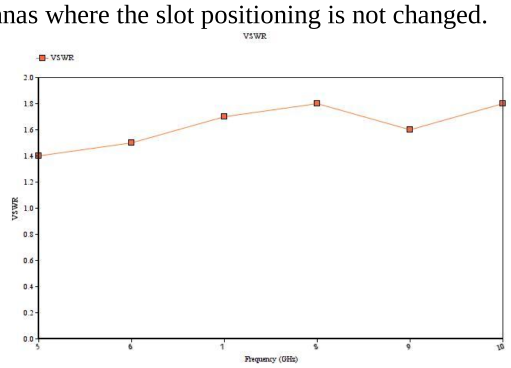


Fig. 3. VSWR of the proposed antenna

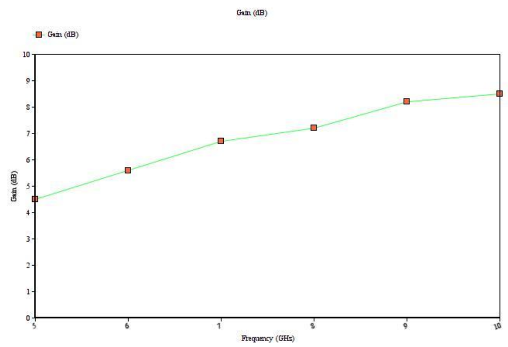
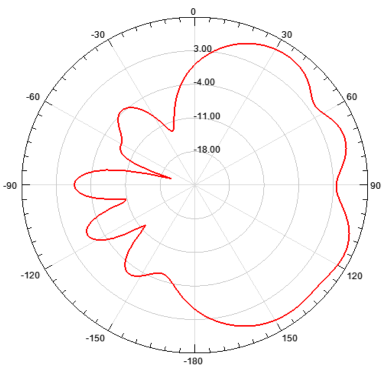
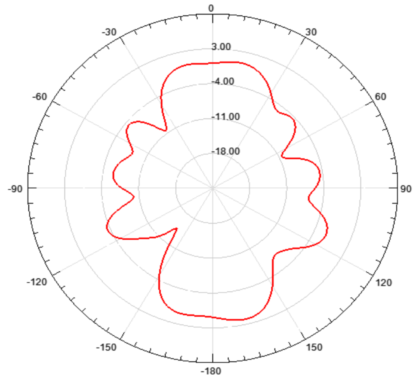


Fig. 4. Gain of the proposed antenna



(a)



(b)

Fig. 5. Radiation pattern of the proposed antenna

IV. Conclusion

The influence of various dielectric substrates on the propagation of electromagnetic waves in SIW is investigated using simulations. To assess the influence of dielectric material, the experiment employed three distinct substrates: PCB, mica, and silicon. For frequencies spanning from 5 to 11 GHz, S-parameters such as return loss and transmission gain were computed. SIW is a low-loss waveguide with a variety of advantages over microstrip and DFW for higher-frequency transmission. The amount of money lost as a consequence of leakage, on the other hand, might be significant. To investigate electromagnetic wave propagation through structure, a simulated experiment is conducted out utilising a built substrate integrated waveguide. The s-parameter was computed and evaluated once the electric field was created. The suggested design might be useful for 5G communication, Ultra-Wide Band Antenna, and other uses.

Conflict of Interest

The authors declare no conflict of interest

Authors Contributions

M. Vijay studied the existing literature and designed the antenna structure and contributed to the writing of the manuscript, drawn all of the figures. M. Roopa compared the advantages of the proposed system the antenna performance, and contributed to the writing of the manuscript, drawn all of the figures. All authors had approved the final version

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