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INVESTIGATION OF AN ARRAY BASED ON SIW TECHNOLOGY ACCORDING TO THE KIND OF SLOT FOR 5G APPLICATION

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ABSTRACT

The new technology referred to as substrate integrated waveguide (SIW) is considered to be appropriate for fifth-generation (5G) networks. In the presented work, SIW antenna with two slots was developed at 28GHz for improving the antenna's parameters. The distance between vias was controlled for minimizing the antenna's losses. SIW technology was developed at higher frequency, also has compact size and good performance. Yet, SIW antennas have losses at high frequencies due to the distance between vias. The radiating patch of antenna that is being provided depending on without and with slots. For increasing the antenna's bandwidth and gain, two types of slots—zigzag and straight—were etched onto the patch. Low losses, significantly high gain and efficiency, also overall structural size of 7.11 x 14.8, both without and with slot, were attained with the suggested design. Straight slot as well as zigzag antennas that are suggested resonate at 28 GHz. The measured results have shown that the proposed antenna could provide 95% efficiency, 8.1 dB gain, also huge band-width of at least 3.1GHz at 28GHz. For boosting the antenna's primary parameters, single antenna was transformed into 1x4 array that was simulated as well as measured. SIW antenna is suitable for 5G applications base stations, according to measurement results.

Keywords: 5G application, SIW technology, millimeter wave, zigzag slot.

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INTRODUCTION

The number of users is growing daily, and network generations like 4G, 3G, and Long-Term Evolution Advanced (LTE-A) were enhanced for accommodating all users and run a number of massive applications. 5G technology will offer substantial improvements. High data speeds are more important than ever since 5G will be prioritizing augmented reality, gaming, machine-to-machine communication, industrial automation, and other fields, while earlier generations have been limited to mobile communications [1-6]. Because of this, millimeter wave (mm-wave) bands, such as 28, 26, and 38.0GHz, are intended to be the frequency spectrum related to 5G systems. In mm-waves, SIW-based components are favored over their microstrip counterparts because of their numerous advantages. In comparison to microstrip or planar components, (SIW)-based components provide greater isolation, high-quality factor, a large power handling capability, and low losses [7–11]. SIW technology has a large size at lower frequencies since its size is dependent on the typical waveguide technology dimensions. Since SIW depend on WR28 or WR34, which are conventional dimensions with low b and a value of waveguide size, its size will decrease at higher frequencies [12–15]. In spite of being more popular due to their unidirectional emission pattern, high gain, low profile, and high polarization purity, SIW slot antennas have narrow band-width—generally no more than 8%. Numerous techniques for expanding the bandwidth of SIW slot antennas were described over time [16–19]. Up to 10% more bandwidth could be achieved through attaching antenna to thin wall regarding SIW cavity that is dielectric-loaded. Because slots are shifted out from SIW cavity center, arrays show dual resonance as well as improved impedance band-width of 12% and 14%, respectively. In [20–24], inductively coupled SIW cavity-backed slot antenna arrays were introduced. A technique using multilayer antennas is introduced. In [25], cavity-backed micro-strip patch is excited by SIW slot antenna, which leads to 16% improvement in bandwidth. A simple antenna configuration featuring two longitudinal slots as well as metallic post is described in [26]. On the axis of broad wall were two slots, one slightly off-center and the other serving as passive radiator. A 20% broadband can be generated with such system. In [27], cavity-backed slot antenna with maximum bandwidth of 22% operates in higher-order cavity modes. In [28], multi-layer SIW slot antennas are used for the purpose of exciting micro-strip patch for enhancing bandwidth. On the other hand, [29] addresses multi-layer SIW antenna with 30% broader band-width by using stacked SIW cavities, a cavity-backed SIW with a greater band-width. This operates in TE-120, -110, -310, and -210 modes and matches using shorting pins. Comparably, [30] increases bandwidth by employing higher-order resonant modes in modified dumbbell-shaped slot. For enhancing band-width, it requires some effort for tuning high mode resonant frequencies closer to main one; extra matching devices, like tapered feeds or vias, are needed. With the use of tuning vias, single slot with configurable frequency ratio resonated at two frequency values in [18]. While [31] utilize triangular slot but still suffers losses due to the distance between vias, [29–35] use dual-layer, rigged SIW. For examining as well as determining the best type of slot at high frequency depending on antenna's parameters, including bandwidth, gain, efficiency, and a directive beam with low losses at 28GHz, SIW antenna was designed in the presented work at millimeter frequency using two types of slots: straight and zigzag slots between at the center of radiation patch.

RESEARCH METHOD

SIW is new technology, it is planer structure similar with microstrip technology and it has metallic vias indicated to the narrow wall of waveguide, several studies have been designed at millimeter wave and it achieved good performance at certain frequency. Three SIW designs have been simulated by CST software and fabricated in next sections.

Design Two Different Cavity Slots and A Slot Without

Figure-1 illustrates the two primary metallic vias on right and left sides regarding traditional SIW structure. Dielectric substrate is inserted between two metallic planers, each of which has specific thickness determined by the substrate's type.

Depending on the conversional structure related to SIW, three SIW antennas were built. Substrate, RT Roger 5880, has relative permittivity (ε_r) of 2.20, the loss tangent is 0.009, a 0.508mm thickness, diameter for each via is 1 mm depending on equations below:

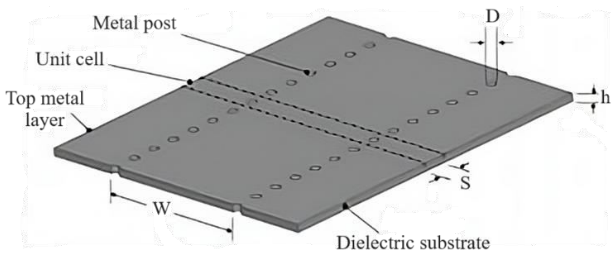

Figure-1. Geometry design of a substrate-integrated waveguide.

$$fc = \frac{c}{2a} \quad (1)$$

where a represents rectangular waveguide's overall broad side dimension. Next, ad represents the dielectric field waveguide (DFW) width [24].

$$\text{ad} = \frac{\text{a}}{\sqrt{\varepsilon \text{r}}} \quad (2)$$

The distance between via rows (center to center) is the design equation for SIW that WSIW found.

$$W_{SIW} = ad + \frac{d^2}{0.95\ P} \quad (3)$$

The radiation loss as well as return loss are thus controlled by the following equations for separation distance "S" and diameter "D":

$$\lambda g = \frac{c}{f\sqrt{\varepsilon r}} \quad (4)$$

$$d \leq \frac{\lambda g}{5} \quad (5)$$

$$\text{P} \leq 2\text{d} \quad (6)$$

Roger RT 5880 substrate has been used to design signel SIW antenna at millimterwave frequency, full ground plane used as reflector, radiation patch antenna has been inserted to the top of substarte with metallic visa at right and left side of patch as can shown in figure-2(a) indicatef to SIW antenna without slot, v1 and v2 have been inserted at the top of patch to guide the signel.
Figure-2(b) (c) illustrates the second steps regarding the presented study cavity straight as well as zigzag slot inserted at the top of radiation patch. The specification parameters with regard to SIW antenna at high frequencies for 5 G application are shown in Table-1. The antenna's dimensions have been listed in Table-2. A total of four Zigzag-shaped slots is placed in radiation patch antenna center for increasing the efficiency and gain at 28 GHz. To begin with, a radiation patch antenna above substrate and inserting 2 different slot types: zigzag and straight. The radiation patch antenna's two edges were after that fitted with vias. The design resulted in the development regarding wave-slotted SIW antenna pattern for reducing the overall size related to the structure and excite the slots.

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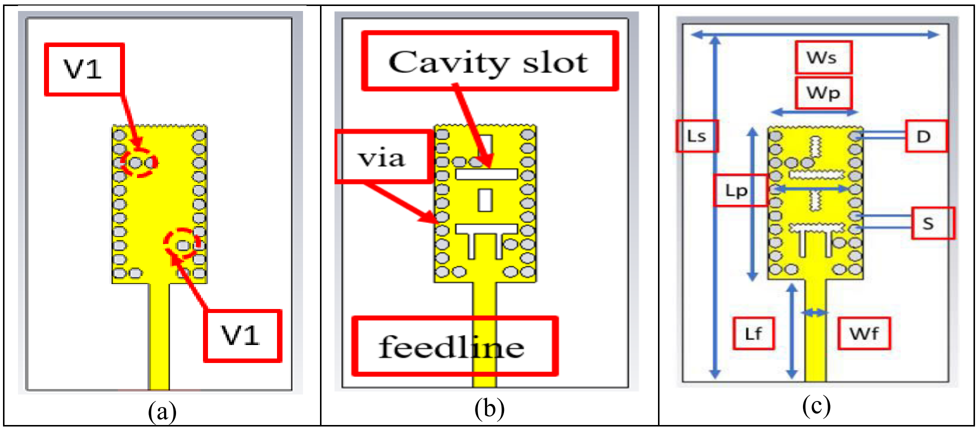

Figure-2. Proposed SIW Design (a) SIW with no slot (b) SIW with a straight slot (c) SIW with a Zigzag slot.

Table-1. The specification of the SIW antenna.

Parameters	Desired value
Frequency	28GHz
Reflection coefficient	<-1-dB
Bandwidth	>1GHz
Gain	>5dB
Efficiency	>90%

Table-2. Dimensions of the antenna.

Variable	Name	Size (mm)
W_S	The substrate width	20
L_S	The substrate length	35
W_P	The patch width	7.11
W_S	The patch length	14.7
W_{Siw}	Width of SIW	6
D	Diameter	1
S	Space between vias	1.3
Wf	The Feed Line Width	1.57
Lf	The Feed Line Length	10
Thickness of the substrate		0.508

RECOMMENDATION OF REFLECTION COEFFICIENT

We investigate performance of suggested antenna with using CST Microwave Studio. The presented work's first goal is suggesting an antenna design that uses SIW technology, both without and with slots and with different slot forms. SIW antenna without slot resonates at 27.70GHz of -25dB with 1.50GHz band-width, but it still has limited band-width as well as gains at high frequency values, as shown in Figure-3(a), which compares the reflection confection related to the designs without and with slot.

In the middle of radiation patch antenna, straight slot with two slot width values (0.4mm and 1mm) was made. It has -15dB resonance at 28.25GHz as well as a band-width of 2.8GHz. With broader bandwidth of 3.10GHz, reflection confection resonates at 28.0GHz of -21.50dB when zigzag slot is inserted in the middle of radiation patch antenna.

The suggested antenna with no slot is 7.90dB and with straight slot is 8dB, figure-3(b) shows the way that the design maintained the more substantial gain with a zigzag slot of 8.29 dB. Additionally, efficiency of the proposed design is 90% with no slot, 96% with a zigzag slot at 28GHz, and 92% with a straight slot, as shown in figure-3c. Figure-3d clearly shows the VSWR related to the three designs. At a specific frequency, VSWR of SIW with the zigzag slot is still less than 2dB.

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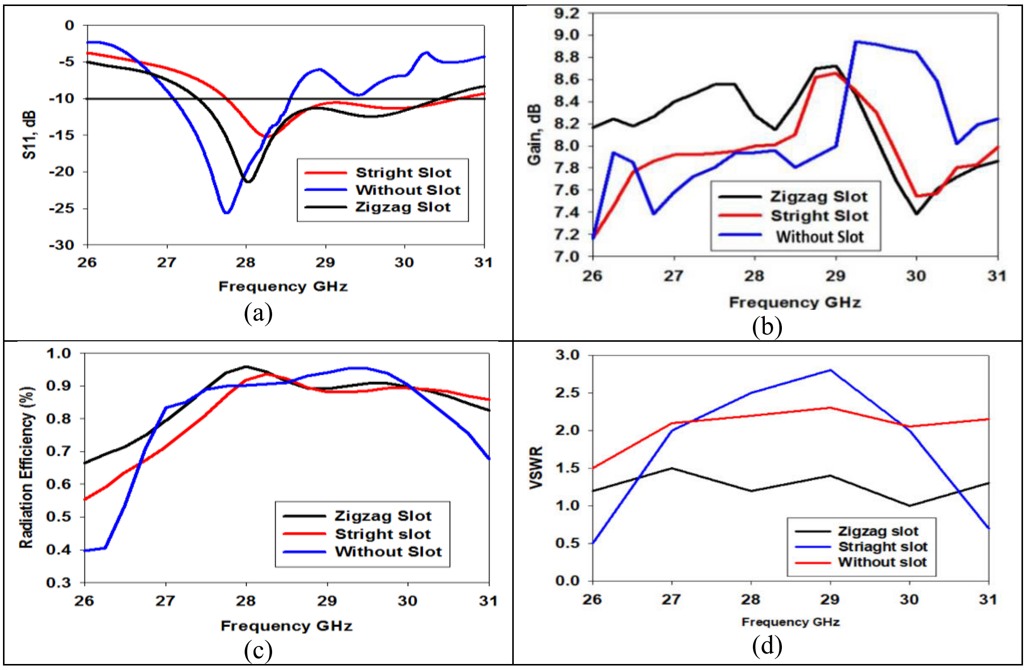

Figure-3. Main results of three designs, (a) reflection coefficient, (b) gain, (c) efficiency, (d) VSWR.

FABRICATION AND MEASUREMENT

A. Single Antenna

The front and back views of the suggested manufactured antenna are depicted in Figure-4(a) and Figure-4(b), respectively. A standard single-layer PCB technique has been used to build the proposed prototype. The matching measured and simulated |S11| is can be seen from Figure-5. The simulation as well as experimental findings indicate that a suitable impedance matching resonates within −10dB range at 28GHz, with just one feeder port on antenna.

Figure-6 displays simulated H-plane as well as E-plane patterns calculated at 28 GHz. Figure-6(a), with all of the beams being directed and set to 0o, shows radiation pattern regarding the design's E plane without and with slots. As seen in figure-6(b), zigzag slot measurement results have been put to comparison with radiation pattern related to design's H plane without and with slots, which is a prerequisite for 5G applications.

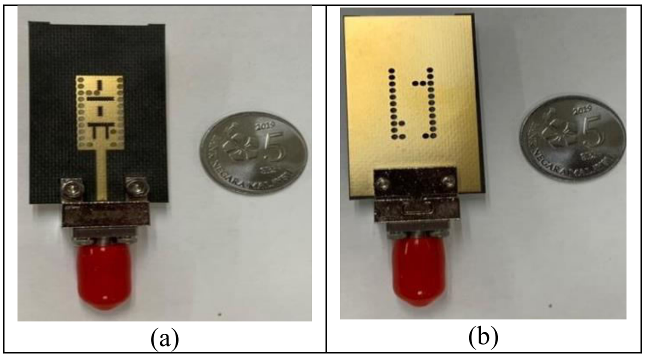

Figure-4. SIW antenna fabrication (a) front and (b) back views.

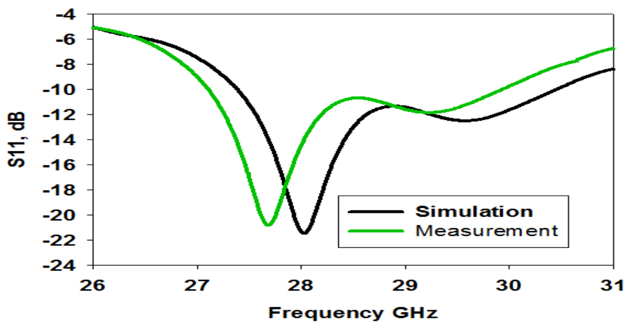

Figure-5. Comparison based on the reflection coefficient of the SIW antenna with zigzag slot.

Antenna radiation is usually constructed from patch's edges. However, with SIW, as illustrated in Figure-7(a), the primary structure's slots in figure-7(b) are where the majority of radiation's 3D dimension comes from. The results showed that the form of slots produced beams

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directed at 0°; the highest beams directive is shown by the red region for 3D radiation pattern in figure-7(c). Figure-7(d) displays the scale. In terms of bandwidth, return loss, and gain, Table-3 contrasts the findings of the presented study with those related to single SIW antennas used in earlier research at 28 GHz. Table 3 shows that the related work's bandwidth is still narrow band as well as that the retune loss is still not truly resonating at a certain frequency. Due to losses resulting from distance between the metallic vias regarding SIW, the gain of related work is about 5dB of certain papers.

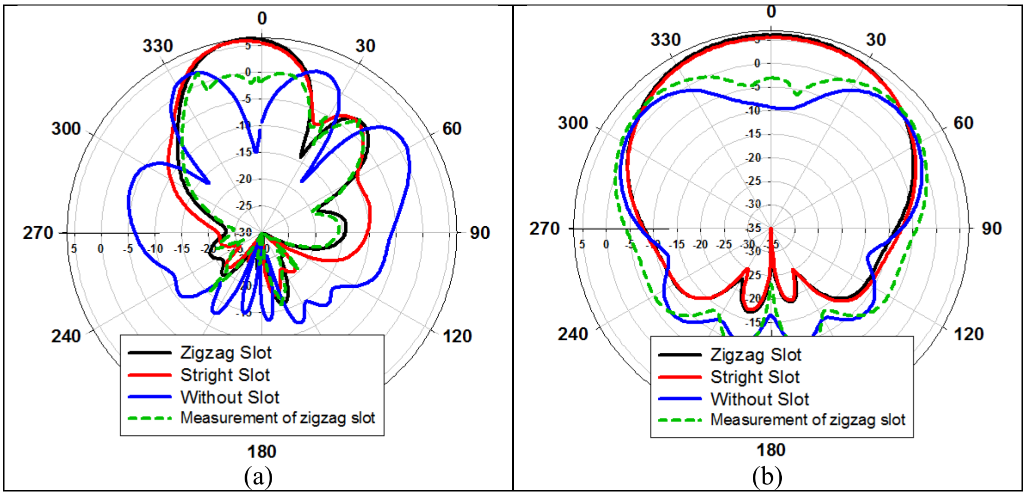

Figure-6. 2-D radiation pattern (a) E &(b) H planes.

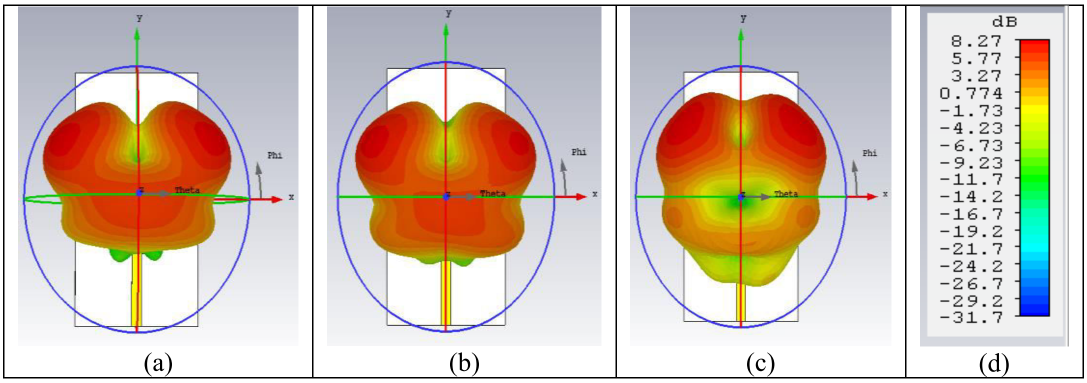

Figure-7. 3-D radiation patterns (a) zigzag slot, (b) straight slot, (c) without slot, and (d) scale.

Table-3. Comparison with SIW antennas for previous studies.

Ref	Freq. (GHz)	Return loss (dB)	Bandwidth (GHz)	Gain (dB)
[30]	28	-<10	0.45	5.2
[31]	28	-17	0.9	7.05
[32]	28	-32.5	1.7	7.6
[33]	28	-33	1.3	6.4
This work	28	-21.5	3.1	8.27

B. 1×4 Array Antenna

5G applications need high performance to achieved it features, an array antenna has high performance specially operating at millimetre frequency, after designed single SIW antenna at 28 GH and optimize it, single antenna has been processed to develop single antenna upgrade it to an array antenna and optimize it to achieved good performance at millimetre wave frequency, optimization such as impedance matching, radiation efficiency, and gain. the distance between two elements from one centre to another is half wavelength; to avoid interference between each element, this makes an antenna more efficient and more reliability at millimetre-wave frequencies. Figure-8 refer to the proposed SIW array

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antenna. Table-4 indicated to all dimensions of an array antenna. Fabricated SIW antennas combine the low-loss benefits of traditional waveguides with the compact, planar structure of printed circuits. Slot or radiating element placements are critical for achieving efficient radiation patterns, impedance matching, and bandwidth at 28 GHz. This antenna likely demonstrates high gain, directional beamforming, and compatibility with mmWave communication standards. Figure-9 illustrates the proposed manufactured antenna

The measured and simulated reflection coefficient (S11) of 1 x 4 SIW antenna array constructed at millimeter wave frequency is shown in Figure-10. Excellent impedance matching is indicated by the simulated findings, which show resonant response at 28GHz with reflection coefficient of −20dB at that frequency. Although there might be slight variations because of fabrication tolerances or measurement conditions, the measured findings were similar to simulated results. The antenna is suitable for 28 GHz applications like 5G as well as millimeter-wave communication systems because it achieves large bandwidth, as demonstrated by the return loss staying below −10 dB for substantial section of the band. SIW array's design and manufacturing process are validated by the high agreement between simulation as well as measurement.

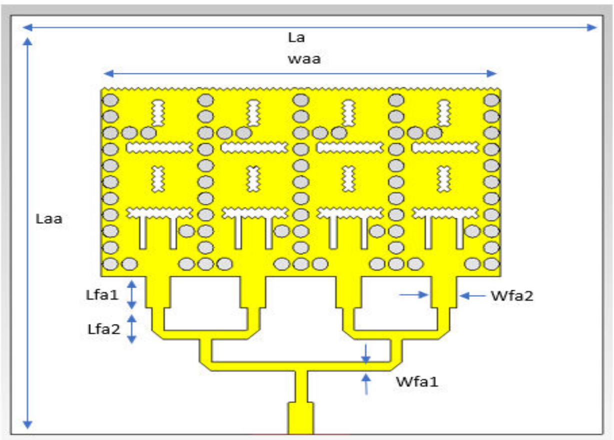

Figure-8. An array SIW antenna at millimetre wave frequency.

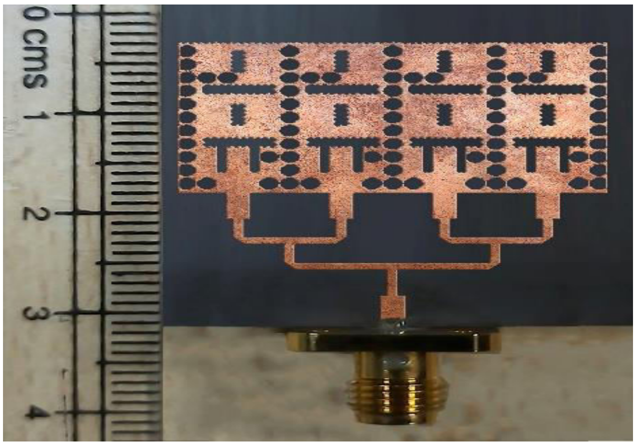

Figure-9. Fabrication of the proposed array antenna.

Table-4. Indicated for all dimensions of an array antenna.

Variable	Name	Size (mm)
La	Width of substrate	37.3
Waa	Width of patch	25.1
Laa	Length of substrate	33.25
Lfa1	Length of feedline	2.5
Lfa2	Length of feedline	1.75
Wfa1	width of feedline	0.75
Wfa2	width of feedline	1.57

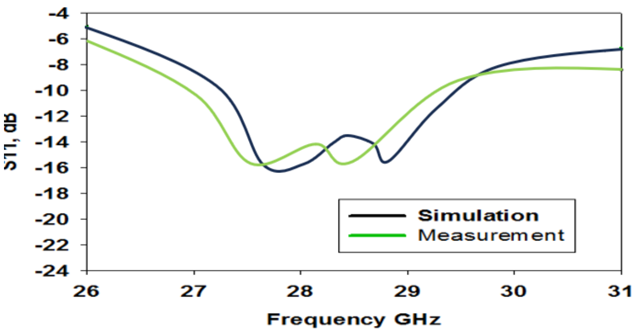

Figure-10. The reflection coefficient of 1×4 an array antenna.

Figure-11 simulated and measured E- and H-plane radiation patterns of a 1×4 SIW antenna array operating at 28GHz. In figure-11(a) the E-plane pattern, both simulation and measurement show a simlar-reults at main lobe at 0° with consistent sidelobe levels, demonstrating good directional performance. Figure-11 (b)The H-plane pattern similarly exhibits a symmetrical beam with a main lobe aligned at 0°, though slight deviations in sidelobe structure between simulation and measurement may arise from fabrication tolerances or alignment inaccuracies.

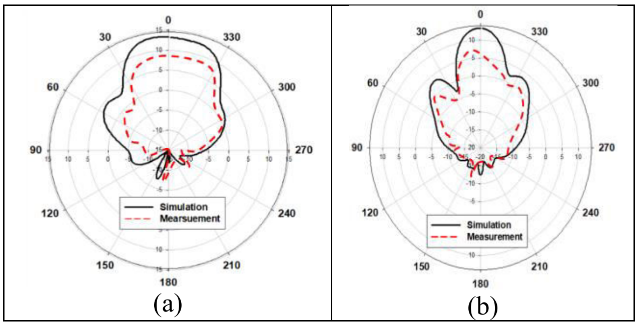

Figure-11. Refer to the radiation pattern polar, (a) E plane, (b) H plane.

CONCLUSIONS

At high frequencies, SIW technology has proven to be effective. The presented work 's suggested antenna was created using metallic vias. With substrate known as Roger RT 5880, which has 2.2 relative permittivity, 0.508mm thickness, and a lost tangent of 0.00090, the research offers two slots: zigzag and straight. Through reflection confection modeling as well as measurement, zigzag slot at radiator patch, resonating at 28.0GHz for 5-G applications, demonstrated better results when compared to straight slot. SIW antenna offers a high gain of 8.27 dB at 28GHz and 3.10GHz band-width as well as high efficiency of 96% with zigzag slot. The recommended SIW antenna with zigzag slot is suitable for 5G applications, according to positive results. Fabrication and losses are the primary challenges regarding SIW antennas at high frequencies; with more control over the distance between vias as well as high-quality fabrication process, the antenna will radiate with high gain and low loss. Following the proposed design was modified to create a 1x4 array antenna, the array antenna's gain and efficiency increased to 11.9dB and 96%, respectively. The proposed design performed well in terms of band-width, gain, and efficiency at 28GHz, which are suitable for 5G applications.

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