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Design zigzag edge of S shape slot antenna by using SIW technology for 5G application

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ABSTRACT

This study offers a 5G substrate integrated waveguide (SIW) antenna with vertical S zigzag shape slot. The suggested antenna's radiating patch depends on the shape of the slot. Two types of slots have been used, straight and zigzag S shape slot with vertical and horizontal direction, slots are etched on the patch to increase the antenna's overall bandwidth and gain. The suggested straight and zigzag SIW S slot antennas both resonate at 28 GHz, and the overall structure size is 7.10×14.93 mm. The presented design could achieve high gain, efficiency, and minimal losses, which are all important concerns. The presented antenna may produce a gain of 9.48 dB, a 95% efficiency, and a wider bandwidth of no less than 3.25 GHz at 28 GHz.

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1. INTRODUCTION

The future 5G technology will be a quantum leap forward from present technologies such as LTE-A, 3G, and 4G. Dissimilar to previous generations, which focused solely on mobile communication, 5G will prioritize gaming, augmented reality, machine-to-machine connectivity, industrial automation, and other applications. As a result, larger data rates are required now more than any other time. With this in mind, the 5G systems are focusing on millimeter wave bands like 28 GHz, 38 GHz, 64 GHz, and 71 GHz for frequency spectrum [1]. Waveguide-based components are popular in millimeter waves due to various benefits compared to their microstrip counterparts [2]. Compared to microstrip or planar components, waveguide-based components have a higher power handling capacity, lower losses, a higher quality factor, and better isolation. The integration of traditional wave-guide components with planar circuits, on the other hand, is a difficult issue. Substrate integrated waveguide (SIW) solves this problem by providing planar alternative for the waveguide-based devices like filters, antennas, and couplers. While SIW slot antennas are more important due to the fact that they have unidirectional radiation pattern, high gain, good polarization purity, and low profile, their bandwidth is limited, usually less than 8% [3].

Over the years, a variety of strategies for increasing the bandwidth of SIW slot antennas were documented [4]. A dielectric-loaded SIW cavity-backed antenna connected to the SIW's narrow wall is shown, resulting in a 10% increase in bandwidth [5]. Inductively linked SIW cavity backed slot antenna arrays have been indicated by [6], [7]. In the two arrays, slots have been moved from the SIW cavity's center, resulting in dual resonance and a 12% and 14% increase in impedance bandwidth, respectively. A multilayer antenna configuration in which a cavity-backed micro-strip patch is activated by a SIW slot antenna, leading to a 16% increase in bandwidth [8]. A metallic post and two longitudinal slots are employed in a basic antenna shape [9]. One of the slots had played the role passive radiator and was located on broad wall's axis, whereas the other was significantly displaced from it.

With this architecture, a 20% wide band can be obtained. A cavity-backed slot antenna that functions in higher-order cavity modes is reported; the greatest bandwidth achievable by this approach is 22% [10]. The multi-layer SIW slot antennas have been utilized for exciting micro-strip patch in order to increase bandwidth in [11]–[13]. Comparably, in [14], a multi-layer SIW antenna with a 30% band-width is studied employing stacked SIW cavities. A bandwidth-improved SIW cavity backed cross slot that operates in TE120, TE110, TE310, and TE210 modes and uses shorting pins for the matching [15]. A modified dumbbell-shaped slot is employed to increase bandwidth by utilizing higher-order resonant modes [16]. To increase bandwidth, higher mode resonant frequencies must be tuned closer to the primary one, which necessitates the use of extra matching mechanisms such as vias or tapered feeding.

Jiang *et al.* [17] uses tuning vias to allow a single slot for resonating at 2 frequency values with tunable frequency ratio. Wei *et al.* [18], a dual-layer, rigged SIW is utilized for controlling the higher mode, while in Ashraf *et al.* [19], a triangular slot with embedded patch has been employed for dual-band operation. To improve bandwidth and gain. Tuib *et al.* [20] used cavity two slots with complex design and results of design achieved higher band after increase number of antenna. Researchers [21], [22] design waveguide antenna at 26 GHz with higher gain but design was bully. In this paper, zigzag and straight S shape slot used to design at the middle of patch with two directions vertical and horizontal to enhance gain and bandwidth. SIW technique is applied to realize the low-profile property. the concept of SIW antenna has been designed and analyzed at 28 GHz frequency for future 5G application.

2. RESEARCH METHOD

The suggested antenna is made out of RT Roger 5880 and has a thickness of 0.508 mm, with loss tangent and relative permittivity (r) values of 0.009 and 2.2, respectively. The design of the proposed SIW antenna starts with vias at left and right side of antenna as conventional SIW antenna as can see in Figure 1 with diameter of vias 1 mm. Four designs investigated according to the shape and direction of the slot as shown in Figure 2. First design etching a vertical S zigzag shape as a slot on the radiation patch of the antenna as shown in Figure 2(a), the second design etching a horizontal S zigzag shape slot as shown in Figure 2(b), the third design etching vertical S shape with a straight edge of a slot as shown in Figure 2(c), the fourth design etching horizontal S shape with a straight edge of a slot as shown in Figure 2(d). the proposed design with zigzag and straight slot have been calculated based on the equation in [5], Figures 3(a) and (b) refer to the shape of the S slot on the radiation patch, and Table 1 refer to all dimension of the proposed design.

At the begging radiation patch antenna has been created above substrate with two kind of slot (straight and zigzag S shape) slot and then vias have been inserted vias at both edge of the radiation patch antenna, two zigzag S shape slot is inserted at the middle of patch to achieve better gain and efficiency at 28 GHz. Two S shape slots with rectangular SIW antenna are embedded on the patch as can see in Figure 3, the width of S zigzag slot is (wsz=0.18 λ mm), length of slot is (Lsz=0.22 λ mm) and (Hsz=0.052 λ mm) presents the highest of S slot. This design achieves a wave slotted SIW antenna arrangement. In order to excite the slots as much as possible.

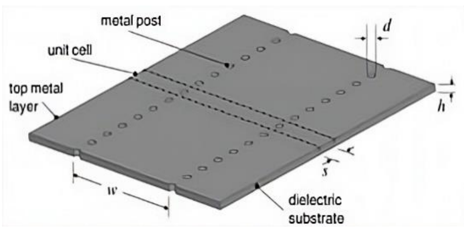


Figure 1. The prospective general structure of the substrate integrated wave-guide

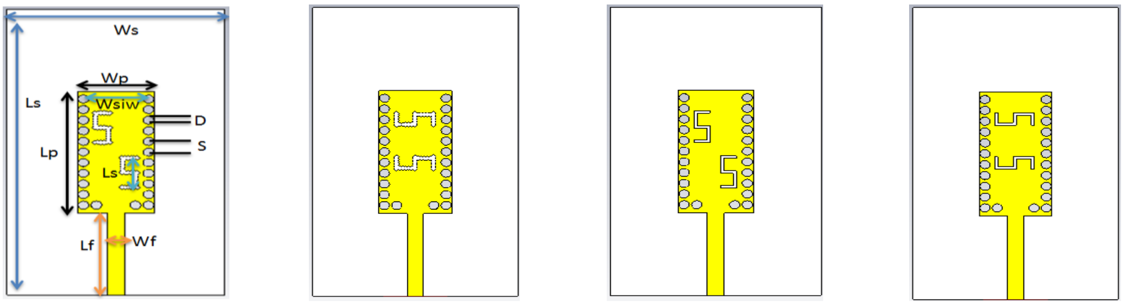


Figure 2. SIW design with S shape slot: (a) vertical zigzag, (b) horizontal zigzag, (c) vertical straight, and (d) horizontal

Figure 3. S shape slot: (a) zigzag slot and (b) straight slot

Table 1. All dimension of design

Variables	Names	Size (mm) (λ)
WS	Substrate width	1.86
LS	Substrate length	3.26
WP	Patch width	0.66
LP	Patch length	1.39
Wsiw	SIW width	0.56
D	Diameter	0.093
S	Space between vias	0.121
WF	Feed line width	0.146
LF	Feed line length	0.933
Ls	S shapes slot	0.36
Thickness of the substrate		0.04

3. RESULTS AND DISCUSSION

The performance regarding the proposed antenna has been investigated with the use of the CST microwave studio. The design of this proposal used SIW technology with two different S shape of slots which are straight and zigzag with two direction horizontal and vertical. Figure 4 show the comparison of reflection confection when the design has a straight slot and zigzag slot, the first case, the reflection confection of SIW antenna with straight horizontal S shape slot resonate at dual band which is 27.3-29 GHz of -52 dB and -28 dB with narrow bandwidth, when design has straight vertical slot the reflection coefficient resonates at two frequencies which are 26.5-29 GHz of -18 dB and -21 dB. second case of this paper when design has zigzag horizontal S shapes slot the reflection coefficient have shifted to higher frequency started resonate from 28.3 GHz to 30.5 GHz which not cover 5G frequency, the reflection coefficient of SIW design with zigzag vertical S shape slot stared resonate from 27 GHz to 30.39 GHz of -30 dB, which achieved wider bandwidth at 28 GHz. Figure 5 show the gain of the proposed antenna with straight horizontal S shape slot is 8.2 dB, and vertical is 9.2 dB, the gain of the second case when design has zigzag horizontal S shapes slot is 9.1 dB, the design kept the gain higher with straight vertical S shape slot is 9.4 dB. in addition, the efficiency of the proposed design with straight S shape slot vertical and horizontal direction are 92% and 84%, while the radiation efficiency of SIW antenna with zigzag edge of S shape slot with vertical and horizontal direction at 28 GHz are 78% and 95% as can see in Figure 6.

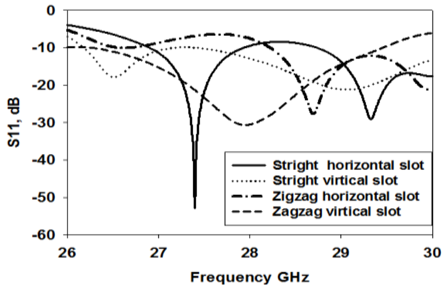


Figure 4. The reflection confection of SIW antenna

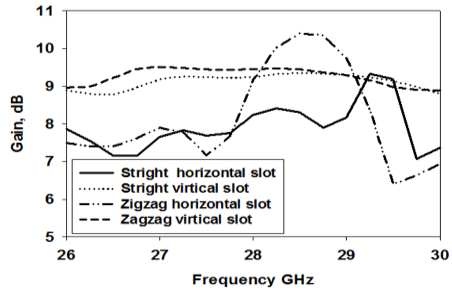


Figure 5. Gain of SIW antenna

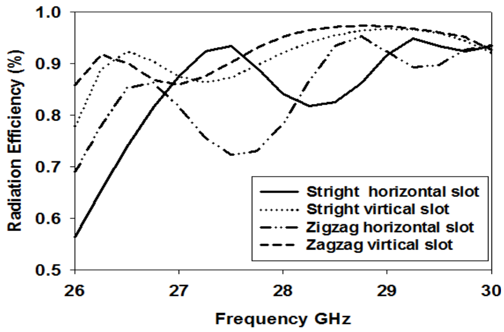


Figure 6. The radiation efficiency of SIW antenna

4. FABRICATION

The suggested structure (prototype) was created using a standard single-layer printed circuit board (PCB) method, as illustrated in Figure 7, and their matching simulated and measured of reflection coefficient is represented in Figure 8. Because the antenna only has one feeder port, both the measured and simulated findings show that good impedance matching resonates at 28 GHz under the threshold of −10 dB. The E plane and H plane patterns that have been calculated at 28 GHz according to 360 degree, the radiation pattern E plane of the design with all kind of slots and without slots depict in Figure 9(a) with simulation results of zigzag and straight slot all the beams directive and set at 0̊, Figure 9(b) refer to the radiation pattern H plane of zigzag and straight slot with all kind of slots by compare with measurement result of zigzag slot. this is one of the requirements for 5G application.

The measured radiation patterns in the E and H planes for the proposed SIW zigzag S-shaped slot antenna at frequency 28 GHz as shown in Figure 10. Figure 10(a) refers to the measurement results of the E-plane and Figure 10(b) refers to the measurement results of H plane, Broadside and stable radiation patterns are observed. The measured first sidelobe levels of radiation patterns are lower than -11 dB across the bandwidth. The slight discrepancy between the measured and simulated first sidelobe levels mainly results from fabrication tolerance and the influence of the feeding setup near the antenna in measurement.

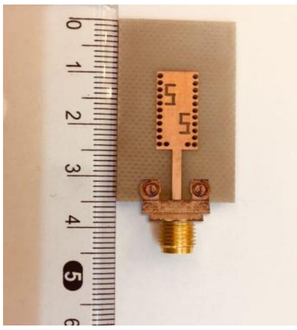


Figure 7. Fabrication of SIW antenna

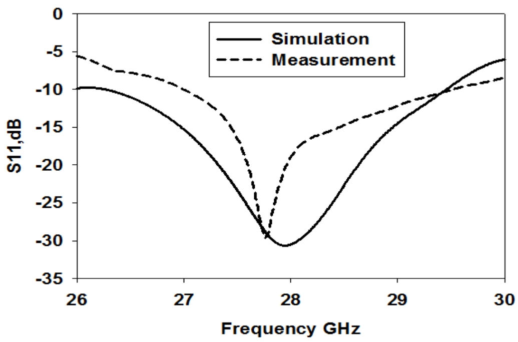
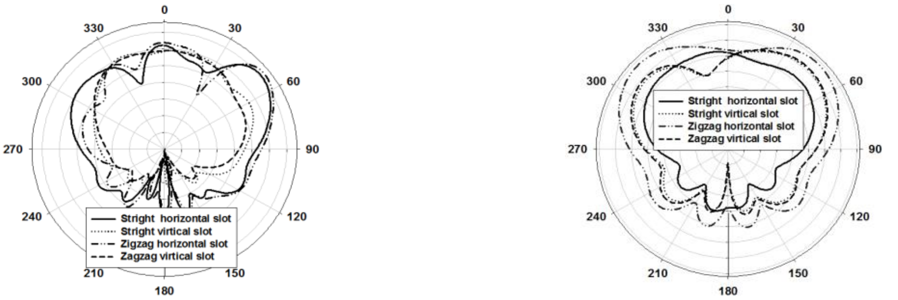
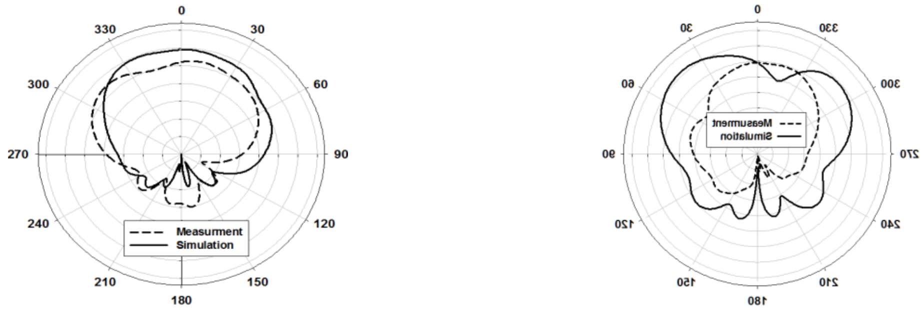


Figure 8. Capamer the reflection confection between simulation and measurement of SIW antenna which has zigzag slot



(a) (b)

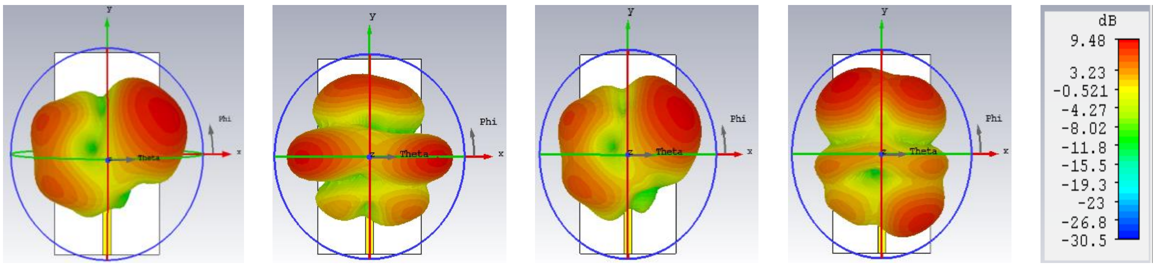
Figure 9. 2-D radiation pattern, (a) E plane and (b) H plane



(a) (b)

Figure 10. Comparation results between measurement and simulation of radiation (a) E plane and (b) H plane

Typically, the antenna's radiation originates from the patch's edges as shown in Figure 11, yet for SIW, the radiation comes from the main structure slots, as shown in Figure 11(a) and (b) refers to the 3D radiation pattern of an antenna with zigzag slots with vertical and horizontal direction slot. The results proved directive beams because of the shape of slots created directive beams at 0°, the red zone of the 3D radiation pattern refers to the maximum directive of beams. Figure 11(c) and (d) refers to the 3D radiation pattern of an antenna with straight slots with vertical and horizontal direction slot. Table 2 refers to the previous work at 28 GHz and compares their results with this paper according to the return loss, bandwidth, and gain.



(a) (b) (c) (d)_

Figure 11. 3D radiation pattern of S shape slot, (a) vertical zigzag, (b) horizontal zigzag, (c) vertical straight, and (d) horizontal

Table 2. Comparison with previous works

Ref	Freq (GHz)	Return loss (dB)	Bandwidth (GHz)	Gain (dBi)
[19]	28	-<10	0.45	5.2
[23]	28	-17	0.9	7.05
[24]	28	-32.5	1.7	7.6
[25]	28	-33	1.3	6.4
This work	28	-30.5	3.2	9.48

5. CONCLUSION

SIW antenna with two different edge of S shape slot which are straight and zigzag with two direction which are horizon and vertical are proposed in this paper. Roger RT 5880 is utilized as substrate with permittivity of 2.20, thickness of 0.508 mm and lost tangent of 0.0009. zigzag edge of S shape slot with virtual direction with SIW technology has been achieved better results than straight edge of S shape slot at 28 GHz. the reflection confection simulation and measurement of zigzag edge of S shape slot resonated at 28 GHz which is 5G application. SIW antenna with zigzag of S shape slot has achieved higher gain is 9.48 dB at 28 GHz and bandwidth 3.2 GHz with higher efficiency 95%.

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