Design of Hilbert Slot Substrate Integrated Waveguide (SIW) Antenna

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ABSTRACT
In this paper, a new design of miniature, dual-band Hilbert SIW slot antenna is introduced. The antenna is printed on a h=1mm thick dielectric substrate with dielectric constant (ε_r=4.3). The slot antenna is cut on the top plane of the substrate and fed using a microstrip transmission line. The proposed antenna possesses a miniature size with a slot side length of about half the guided wavelength. Furthermore, the antenna performance curves show that it offers a multiband behavior with enhanced bandwidths. The proposed three Hilbert slots SIW antenna resonates at 4.6 and 9.3 GHz with bandwidths of 3.7 and 6.77 % within a return loss of -23.4 and -40.12 dB respectively. The simulation results show gains of 4.41 and 5.76 dB_i, with radiation efficiency of -1.360 and -0.7283 dB. Such antennas can be ideal candidates for C and X-band applications.

Keywords
a slot antenna, dual-band, substrate integrated waveguide (SIW).

1. INTRODUCTION
With the rapid development of radar and satellite communication systems, there is a huge demand to design multiband antennas among the researchers [1, 2]. Slot antennas are one of the popular choices for implementing multiband antennas due to their inherent advantages such as low profile, higher bandwidth etc. [3–5]. Much multiband and broadband planar slot antennas have been developed recently [6–9]. However, many of these planar slot antennas produce bidirectional radiation pattern which limits its performance in certain applications. Recently, substrate integrated waveguide (SIW) technology has emerged as an attractive solution since it implements waveguide based circuits in the planar substrate by using rows of metallic vias to realize metallic sidewalls in planar substrate [10]. Several techniques have been reported to improve bandwidth performance of SIW cavity-backed slot antenna [11–13]. However, all these designs are still narrowband for use in practical applications. To further improve the bandwidth performance of the SIW slot antenna while maintaining its unidirectional characteristics, the excitation of hybrid modes in SIW cavity is introduced in [14]. Many designs have been reported recently to generate dual band and broadband performance in SIW cavity-backed slot antenna [15, 16]. SIW cavity backed bow-tie slot was proposed to improve the bandwidth of the antenna up to 9.4% [17]. In [18,19] hybrid modes are excited to produce dual-band and broadband performance of the planar SIW cavity-backed slot antenna

In this paper, a novel design technique is proposed to implement dual-band frequency with the low value of return loss (high matching) and with enhancement in the bandwidth of the SIW slot antenna. The proposed design uses three slots that etched at top plane of SIW antenna.

2. ANTENNA DESIGN PROCEDURE and SIMULATION RESULTS
The configuration of Hilbert slot is shown in Figure 1 and the proposed three Hilbert slots SIW antenna is shown in Figure 2. The proposed antenna is completely constructed at a single substrate. Its rectangular slotted SIW is realized by two rows of metalized vias arrays. In order to make the SIW cavity be equivalent to the conventional metallic cavity, 50 Ω microstrip line is adopted as feeding element to stimulate the slotted SIW antenna. The set of design rules for choosing the geometrical dimensions of SIW structures [20]. The first condition is when the diameter d of the metalized cylindrical holes cannot exceed their longitudinal spacing p, and therefore p > d. The second condition is needed to avoid any band-gap in the single-mode frequency band of the waveguide and can be expressed as $p/\lambda_c < 0.25$. to minimize radiation leakage, the gap size should be small, and therefore the ratio between the spacing p and the post diameter d is limited by the condition p/d < 2. Finally, the last condition is defined to avoid over-perforated substrates: by setting $p > \lambda_c/20$.To summarize, the four conditions.

$$p > d \quad (1)$$

$$p/\lambda_c < 0.25 \quad (2)$$

$$p/d < 2 \quad (3)$$

$$p > \lambda_c /20 \quad (4)$$

The proposed SIW Cavity dimensions are 19.5 mm X 17.8 mm while the overall antenna dimensions are 26 mm X 19 mm using substrate material of FR4.

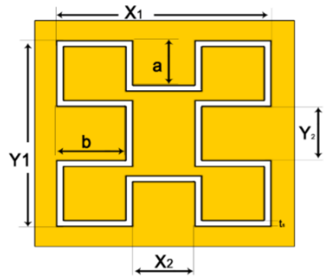


Fig 1: structure of Hilbert slot.

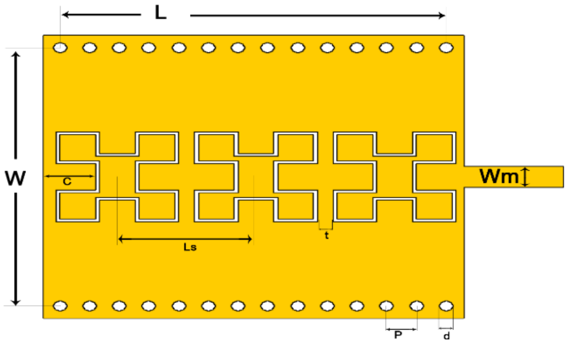
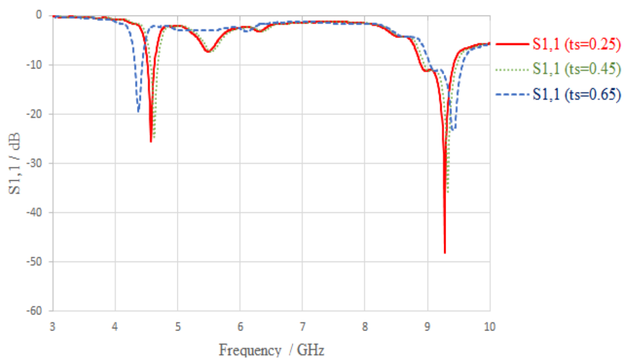


Fig 2: The layout of the modeled three Hilbert slots SIW antenna.

Many parameters have been studied to get better antenna performance. The most effective prameters are the width of etching of Hilbert slots (ts), and the number of slots that etching on the top plane of SIW antenna as shown in Figure 3. Table 1 summarizes the dimensions of the proposed model antenna from studying parameters. According to these results, the dimensions of slots and the gaps between them are selected to give the best performance of the antenna. The advantages of using Hilbert shape as the slot is for miniaturization and getting dual or multi-band characteristic



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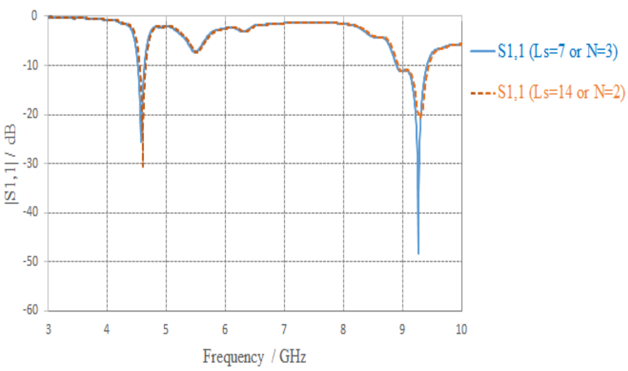


(b)

Fig 3: The simulation S_{11} response of the proposed antenna with (a) t_s as a parameter (b) L_S as a parameter

Table 1. Dimensions of SIW antenna with three Hilbert slots.

Parmeter	Value (mm)	Parmeter	Value (mm)
L	19.5	$X_1 = Y_1$	6.25
W	17.8	$X_2 = Y_2$	2.25
P	1.5	A	1.5
d	0.8	b	2
W_m	1.4	t_s	0.25
C	2.4	L_S	7
t	0.75		

Its simulated return loss resonant at 4.6 and 9.3 GHz has been plotted in Figure 4, in which dielectric and conductor loss6es have been counted. From the figure, we can find that radiation is only generated at the required frequencies within a wide band range. The proposed antenna has enough bandwidth for broadband application. This characteristic makes it suit for some applications in which highly isolated antenna is required for rejecting interference signal at out-band. Surface current distribution diagrams of the proposed antenna at 4.6 and 9.3 GHz is given in Figure 5. It can be observed that at this resonant frequency, the maximum current density is appearing around the Hilbert slots structure especially at the coupling gaps between Hilbert structures. As can be seen, the maximum current density is concentrated around the Hilbert slots and at the input port of antenna. The surface current distribution has a high value at 9.3 GHz with compare to the first resonant frequency 4.6 GHz, because of more matching (low S_{11}-parameter) at 9.3 GHz. Fig. 6 shows the simulation results of gain, radiation and total efficiency of dual resonant frequency.

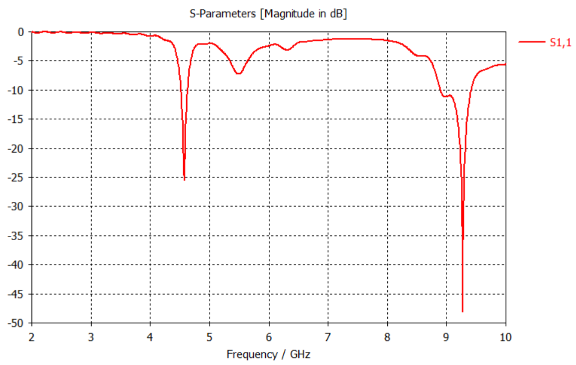
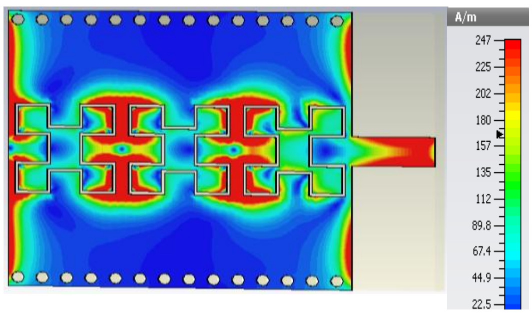


Fig 4: The simulated S_{11} -response of the SIW antenna with three Hilbert slots.



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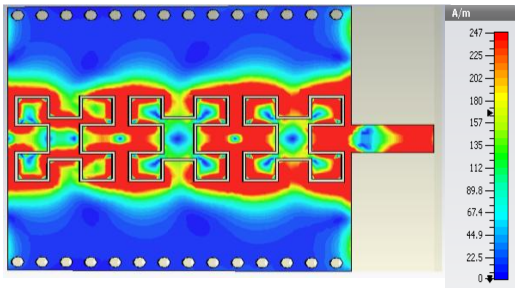

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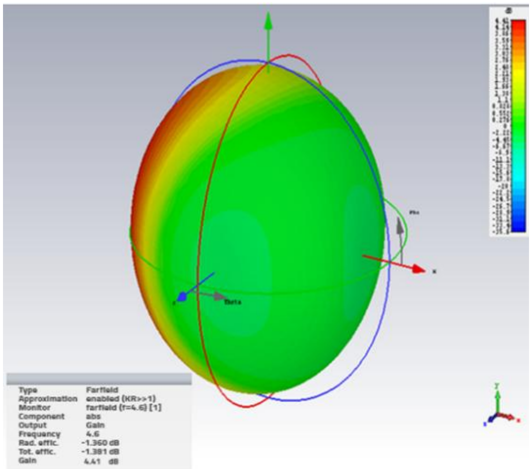
Fig 5: Surface current distribution of proposed antenna at (a) 4.6 GHz and (b) 9.3 GHz.



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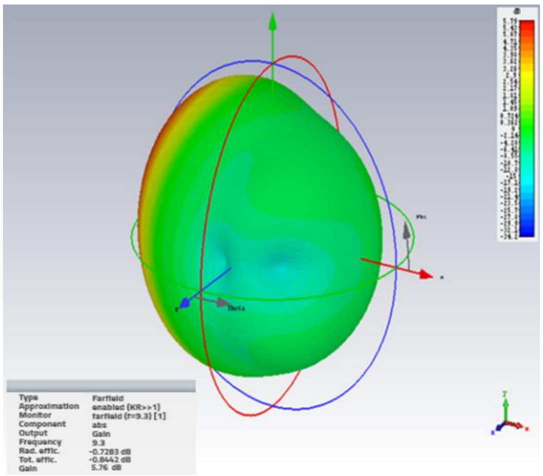
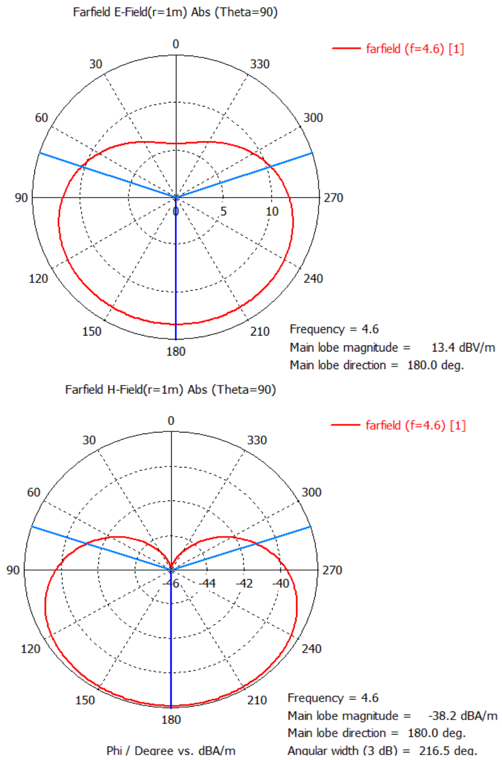


(b)

Fig 6: Farfield 3D-plot gain of three Hilbert slots SIW antenna (a) 4.5 GHz (b) 9.3 GHz

The polar plot radiation pattern of E-field and H-field at first resonate frequency 4.6 GHz in three planes XOY, YOZ, and XOZ are shown in Figure 7.



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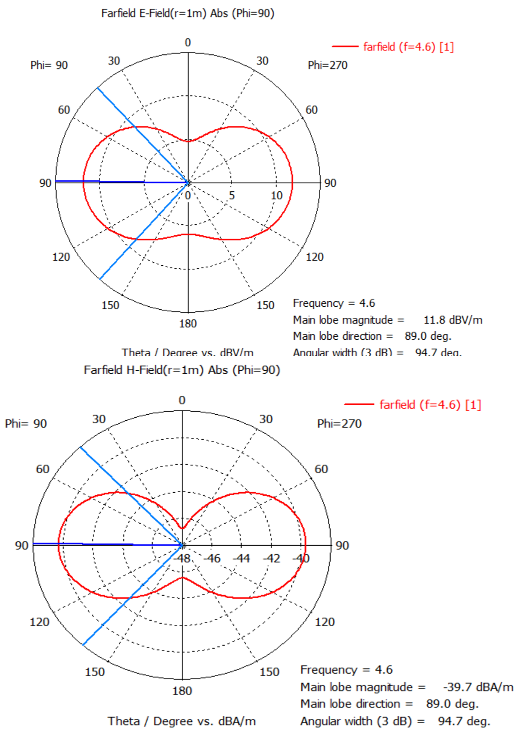

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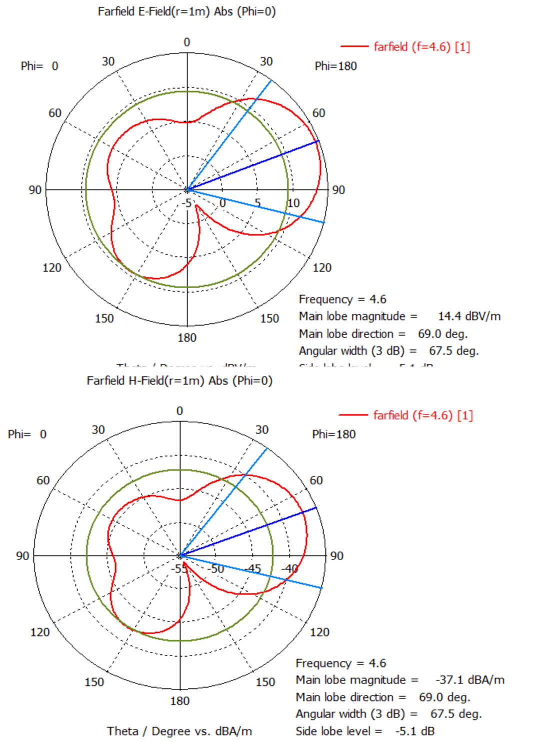
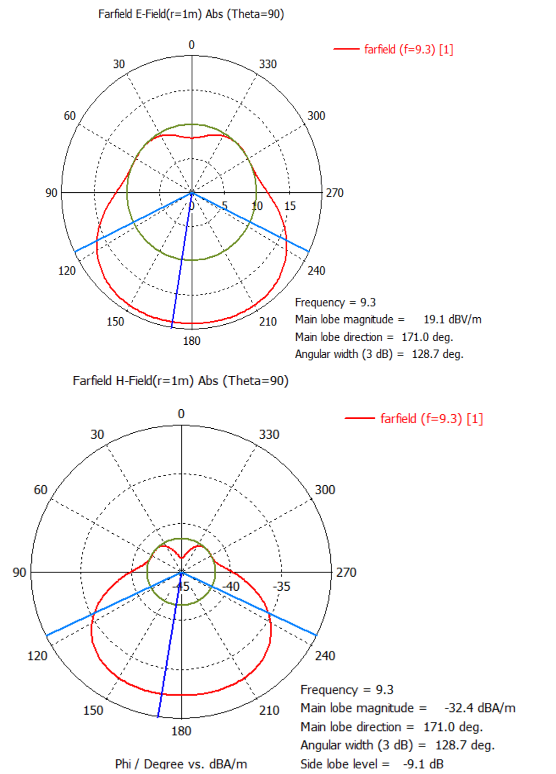


(C)

Fig 7: Simulation polar plot of the radiation pattern in E-plane and H-plane at 4.6 GHz (a) XOY plane (b) YOZ plane (C) XOZ plane.

The polar plot radiation pattern of E-field and H-field at first resonate frequency 9.3 GHz in three planes XOY, YOZ, and XOZ are shown in Figure 8.



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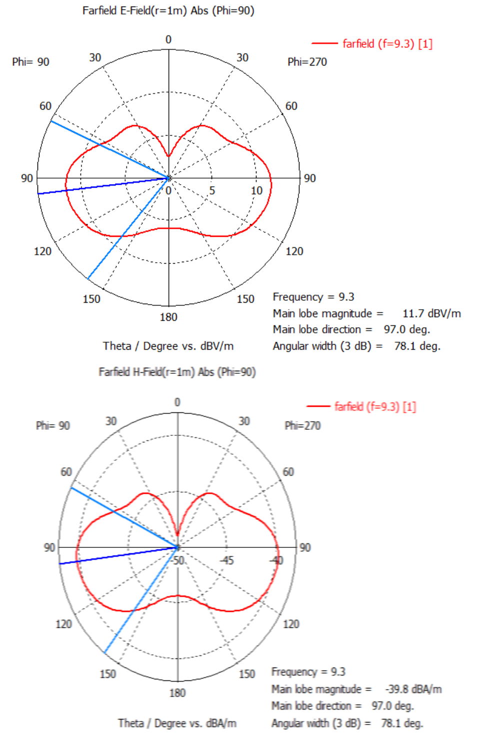

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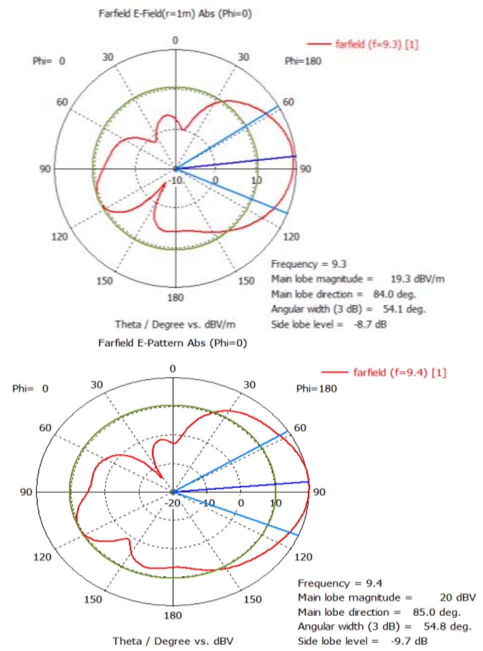

(c)

Fig 8: Simulation polar plot of theradiation pattern in E-plane and H-plane at 9.3 GHz (a) XOY plane (b) YOZ plane (C) XOZ plane

3. ANTENNA IMPLEMENTATION and COMPARISON BETWEEN THE MEASUREMENT and SIMULATION RESULTS

Based on the analysis and simulations described in this paper, an experimental three Hilbert slots SIW antenna has been implemented. Figure 9 shows the photograph of the fabricated prototype of proposed antenna.

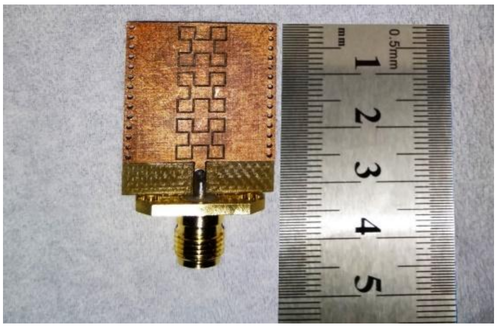

Fig. 9 Photograph of the fabricated prototype of the three Hilbert slots

Figure 10 represents the simulated and measured results of the of the proposed antenna. The experimental results are in a good agreement with EM simulation results. For the 4.6 GHz band, measured S_{11}-parameter is -23.4 dB. A fractional bandwidth of about 170 MHz 3.7 %. For the 9.3 GHz band, measured S_{11}-parameter is -40.12 dB. A fractional bandwidth of about 630.6 MHz 6.77 %. The BW of the second band is increased from the simulated results but the center frequency is not affected. The return losses are increased in both bands, this is probably due to the unspecified values of ε_r and possible fabrication errors. It is clear that center frequency at first band frequency is reduced by 10% due to fabrication inaccuracy and the additional loss from SMA (SubMiniature version A) connector, which has not included in the simulation result.

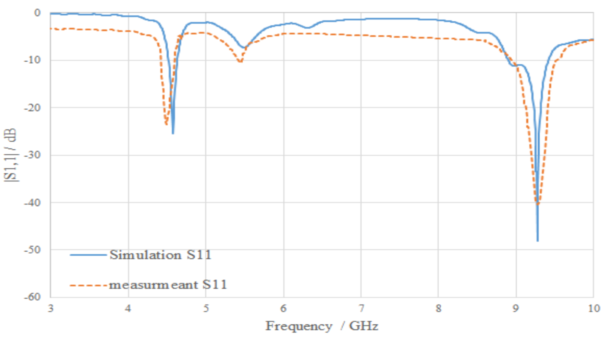

Fig 10: Comparison between the simulated and the measured S_{11}-parameters for fabricated three Hilbert slots SIW antenna.

Table 2 summarizes the comparison of the proposed SIW antenna between the simulated and measured results. It can be clear that there is a good agreement between results.

Table 2. Comparison between the simulated and measured results of three Hilbert slots SIW antenna

Parameter / Results	Resonant frequency (GHz)	BW (%)	S_{11} (dB)
Simulation results	4.6/9.3	2.6/6.02	-25.5/-48.12
Measured results	4.5/9.3	3.7/6.77	-23.4/-40.12

4. CONCLUSION

A new design method of low profile planar slots SIW antenna is presented in this paper. The whole antenna including Hilbert slots and feeding element is completely constructed at a single substrate by using SIW technique and microstrip line structure. The experiment was carried out to validate this design concept. The fabricated antenna has an enhancement in the bandwidth of dual resonant frequency 3.7/6.77% and keeps the high radiation performance of conventional planner slots antenna such as high gain of dual-band frequency. It still has advantages of conventional planar antennas such as low profile, light weight, reduction in size and whole integration with the planar circuit. It can be easily implemented by normal single layer PCB process with very low cost.

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