Cavity Backed Slot Antenna with SIW

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Abstract **- A low profile planar cavity backed slot antenna (CBSA) with Substrate Integrated Waveguides (SIW) operating at 4.78GHz for wireless applications has been described in this paper. This antenna is completely designed at a single substrate which is a FR-4 with dielectric constant, ε_r = 4.4 and 1.6mm thickness. The design consists of a SIW antenna with patch, feeding and cavity backed. Grounded co-planar waveguide (GCPW) is used as feeding element to stimulate the SIW cavity to replace microstrip line feeding. The proposed antenna have been designed, simulated and measured using CST Microwave Studio Software and Vector Network Analyze (VNA) respectively. Antenna parameters result such as return loss (S_{11}), radiation pattern, directivity, gain and VSWR are investigated, compared and analysed. The tuning length of slot and GCPW length have also been analyzed.**

Keywords: Low profile, Substrate Integrate Waveguide (SIW), cavity back, slot antenna, grounded co-planar waveguide (GCPW).

I. INTRODUCTION

In recent years, the tremendous demand in wireless communication, the Substrate Integrated Waveguide (SIW) technology show the good option and it's rapidly technique applied in planar microwave design and millimeter-wave systems [1]-[3]. Low profile antenna mostly used in wireless, aircraft, radar and satellite application because its provides a good radiation performance.

Basically, SIW is constructed with two rows of via holes in the upper and lower metallization to create an artificial waveguide. The common keys design in SIW antenna is metallic via holes diameter *d*, width of dielectric filled metallic waveguide *ar* and center of the metallic via holes to the other center neighboring metallic via holes *p* also known as pitch as shown in Fig.1.

SIW technology design provide the advantages of conventional metallic waveguides, like as high Q-factor, high selectivity, cutoff frequency characteristic, and high power capacity. It also has the advantages of low profile, low cost, easily integrated with planar circuits by replacing the basic conventional microstrip and strip line [4]. Besides, the SIW can be easily implemented using common printed circuit board (PCB) fabrication methods and it was introduced as laminated waveguides that has been presenting in [5].

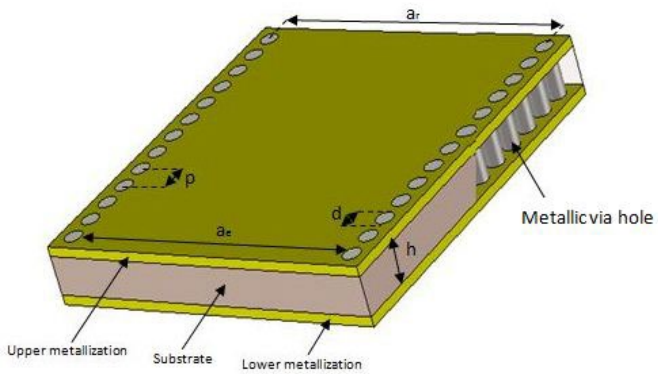


Fig. 1. Basic SIW structure realized on a dielectric substrate

The cavity backed can be integrated with planar as conventional waveguide by using metallic via holes over a single substrate. This conditions and rules of $d/p \geq 0.5$ and $d/\lambda_g \leq 0.1$ must be satisfied to make SIW cavity equivalent to the conventional metallic cavity.

Slot antenna is extensively studied and its trend in many design combination with SIW technologies. The reducing size of cavity backed slot antenna at the backed layer had been discussing in [6]. A slot at the backed is the radiating element of the whole antenna but one of the lacking slot antenna is bidirectional radiation when the slot was etched at ground plane and it can be radiate at any side. When the dominant electric field at the two sides of the slot has opposite phase, SIW cavity in the TE_{120} resonating mode. In order, energy can radiate into space by the slot when the transverse electric field across the slot [7].

This paper presents the combination of the design cavity backed slot antenna based on the SIW technique and grounded co-planar waveguide (GCPW) structure. A 50Ω GCPW is adopted on the center of square patch (upper layer) while a slot embedded at the backed of antenna (lower layer). SIW planar slot antenna cavity backed has been realized in [8] and proposed by Wu [9], [10]. The others similar design of this concept has been realized in [11].

II. DESIGN PROCEDURE

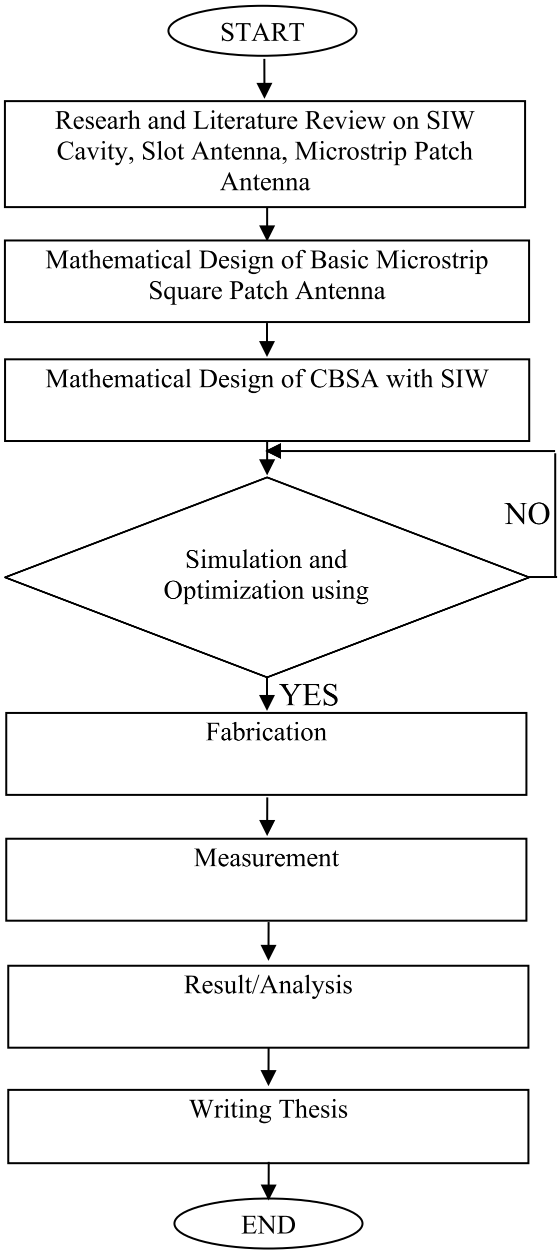


Fig. 2. Flow chart of antenna design process

TABLE I: SPECIFICATIONS OF SIW ANTENNA

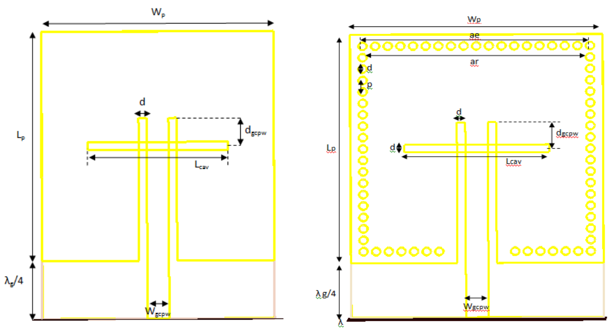
Parameters	Specification
Cut-off Frequency, f_c	4.78Ghz
Return Loss, S_{11}	< -10dB
VSWR	< 1.5
Substrate Material/Thickness	FR-4
Substrate Thickness	1.6mm
Dielectric Constant, ε_r	4.4
Loss Tangent, δd	0.025

From Fig.2, firstly design a single square patch antenna without cavity backed with dimensions in Table II and proceed to the others step to accomplish the proposed CBSA with SIW. The last step is tuning the length of cavity backed before the proposed antenna completely designed. The specifications of the proposed antenna are tabulated by Table 1.

A. SIW DESIGN

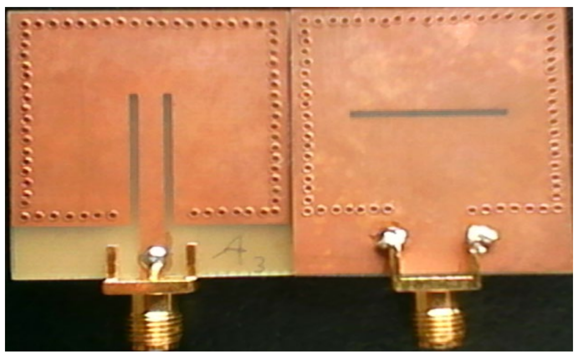
All configuration and dimension of the proposed CBSA with SIWis shown in Fig.3 and Table II respectively. The design of a SIW antenna is completely designed at a single substrate using FR-4 with dielectric constant, ε_r = 4.4 and thickness,*h of* 1.6mm.

TM mode is not exist in SIW structure and there is only TE_{n0} mode with n = (1, 2…) is validate in design SIW because the design consists vias at the sidewalls. The currents surface is proportional produce with the mode in some guide-wave structure. When the slot cut the current, it will produce the large amount radiation while the radiation slightly produce when the slot cut the direction of the flowing currents. For designing SIW at TE_{10} mode, the high of the substrate is not important as it does not affect the cut off frequency of the waveguide. Therefore, the substrate can be at any thickness because it only affects the dielectric loss.



(a) (b)

Fig. 3. Geometry of designed antenna (a) basic square patch antenna cavity backed (b) CBSA with SIW



(a) (b)

Fig. 4. Photograph of the proposed CBSA with SIW (a) front side (b) back side

The proposed cavity backed slot antenna (CBSA) with SIW is consider as the structures fabricated by using the conducting cylinders (rod) over the single substrate that is connect two upper and lower metallization plate respectively. In order, the slot embedded at the backed plate and it's as the radiation elements. The key parameters of SIW design are metallic via holes diameter d width of dielectric filled metallic waveguide ar and center of the metallic via holes to the other neighboring metallic via holes p, also known as pitch, and the equivalent SIW width ae. The pitch and metallic via holes diameter control the radiation loss and return loss, while the integrated waveguide width a_r determine the cut-off frequency and propagation constant of the fundamental mode [2]. The important rules design related to metallic via holes diameter, d and pitch, p given in [12].

$$d < \frac{\lambda_g}{5} \tag{1}$$

$$p \leq 2d \tag{2}$$

$Where\ \lambda_g\ is\ wavelength\ of\ SIW$

$$\lambda_g = \frac{C}{f\sqrt{\varepsilon_r}} \tag{3}$$

$Where\ C\ is\ speed\ of\ light\ in\ vacuum\ and\ \varepsilon_r$
$is\ permittivity\ of\ dielectric\ material.$

The frequency determined by this formula [13]:

$$f_c = \frac{c}{2a} \tag{4}$$

The equivalent SIW width "ae" is determined in [13].

$$a_e = \frac{a}{\sqrt{\varepsilon_r}} \tag{5}$$

$Where\ a\ is\ a\ broadside\ dimension\ of\ an$
$dielectric\ filled\ rectangular\ waveguide$

From (4), integrated waveguide width a_r can be found by [14]:

$$a_r = a_e + \frac{d^2}{0.95p} \tag{6}$$

Slot is etched at the back of the antenna which is ground plane the parasitic radiation generated by feeding network can be effectively isolated. The microstrip feeding line had been replacing by 50Ω GCPW as feeding element with distance of d_{cpw} is tuned to achieve antenna performance and GCPW technique more simply to design and fabrication process.

TABLE II: DIMENSION OF SIW ANTENNA

Parameters	**CBSA with SIW**	**Square Patch Cavity Backed Antenna**
	Dimension[mm]	
W_p	30	28.508
L_p	30	28.508
a_e	27	-
a_r	26	-
d	1	1
p	2	2
W_{gcpw}	2.671	2.671
d_{cpw}	3.5	3.5
L_{cav}	17.28	17.28

III. RESULT AND DISCUSSION

Slot at the back antenna as a radiation element. Length of the slot effects the cut-off frequency and radiation efficiency while the high of slot able to improve bandwidth as well as substrate thickness has been realized in [8]. From Fig. 5 show how the length of slot effects the S_{11}. When the value of slot is short, the S_{11} is slightly decrease by shifting the cut-off frequency to left. However, S_{11} increase by the cut-off frequency shifting to right simultaneously when the increment of length slot.

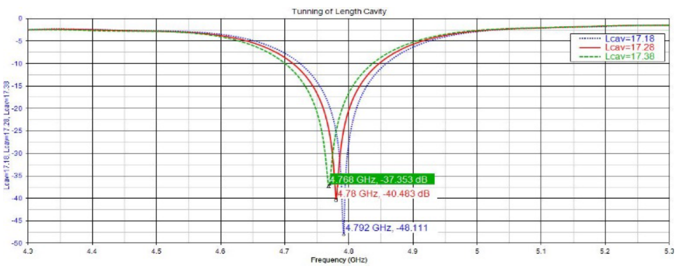


Fig. 5. Investigation on S11 of the proposed antenna by tuning length of slot

A square patch cavity backed antenna and CBSA with SIW had been designed and simulated using CST Microwave Studio software. All parameters result be compared and analyzed to determine the effects of SIW on antenna. Both S parameter of the antenna in Fig.6.

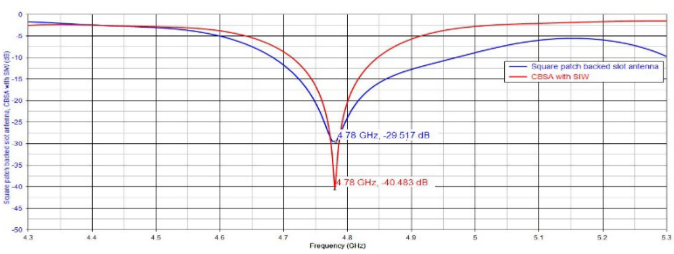


Fig. 6. S_{11} simulation result of CBSA with SIW and square patch cavity backed antenna

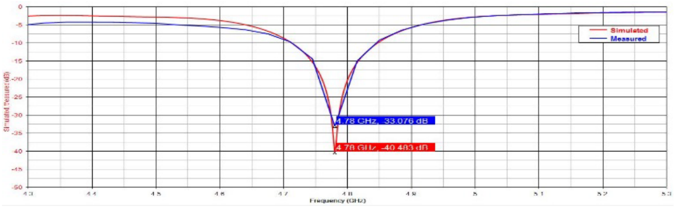


Fig. 7. Simulated and measured S_{11} of the proposed antenna

From Fig.6 show the return loss, S_{11} of the proposed antenna is a -40.483dB while the square patch cavity backed antenna is a -29.517dB. S_{11} of the proposed antenna is higher about 36.8% than the square patch cavity backed antenna. Fig.7 show the simulated and measured S_{11} of the proposed antenna at 4.78GHz. S_{11} of the simulated is slightly high than measured by -40.483dB and -33.076dB respectively. The difference result is caused by PCB fabrication process, riveting of the metallic rod and drilling of the rod on FR4. Bandwidth of the both simulated and measured is quite equal by 136.4MHz. Nevertheless, in term of bandwidth compare in Fig. 6 show the square patch cavity backed antenna is wider than CBSA with SIW which 290.12MHz and 136.39MHz respectively. Return loss can be described as amount of reflected power form the antenna and if S_{11} equal to 0dB mean there are fully power reflected by antenna and nothing is radiated [15]. The value of S_{11} obtain inversely proportion with the value of Voltage Standing Wave Ratio (VSWR). When the antenna meet the high value of S_{11}, the value of VSWR approaching to 1. The good value of VSWR is approximately to 1 by mean the power reaches the load with minimal losses.

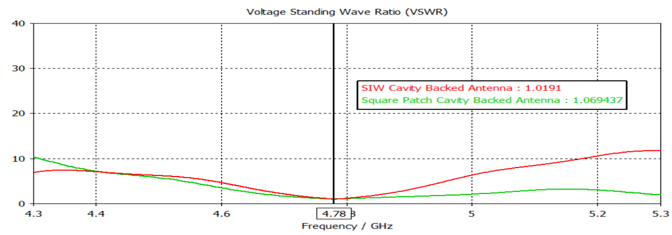
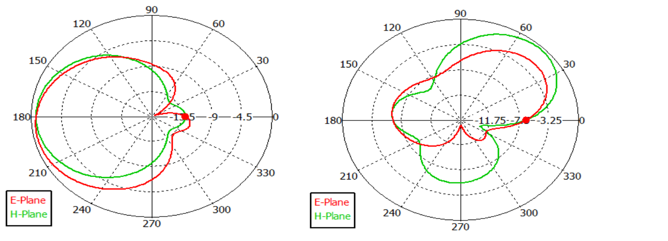


Fig. 8. VSWR simulation result of CBSA with SIW and square patch cavity backed antenna

Fig.8 show the simulation result of VSWR for the both antenna. The result has been obtained proving the theory that is discussed above. VSWR of CBSA with SIW approaching to the 1 by S_{11} approximately to -40.483dB while VSWR of square patch cavity backed antenna is slightly higher than 1 and S_{11} is -29.517dB.



(a) (b)

Fig. 9. Simulated radiation pattern at 4.78GHz in E-Plane and H-Plane (a) 2D CBSA with SIW (b) 2D square patch cavity backed antenna

The radiation pattern in Fig. 9 shows the simulated result between CBSA with SIW and square patch cavity backed antenna. The different phase and directivity were obtained, result form (a) shows the maximum radiating direction between 90° to 270° while result on (b) in range of 0° to 90°. The gain of a proposed antenna better than a square patch cavity antenna increasing by 0.3923dB at 4.78GHz with directivity is 5.731dBi. From the result, the proposed antenna keep promise the good performance radiation.

The whole results of CBSA with SIW and square patch cavity backed antenna are tabulated in Table III.

TABLE III: OVERVIEW RESULT OF THE PROPOSED SIW ANTENNA

Parameters	**CBSA with SIW**	**Square Patch Cavity Backed Antenna**
Fc	4.78GHz	4.78GHz
S_{11}	-40.483dB	-29.517dB
BW	136.39MHz	290.12MHz
$VSWR$	1.0191	1.0694
$Gain$	5.735dBi	4.783dBi

IV. Conclusion

This papers presents the design of CBSA with SIW. The whole antenna design has been fabricated over a single substrate of FR4. A 50Ω GCPW feeding method is used to replace the microstrip line feeding and it's stimulate the SIW cavity. A slot at the back is implemented to provide the good radiation performance. A square patch antenna cavity backed without SIW technique has been simulated and compared with proposed antenna. Comparison of S11, VSWR, radiation pattern and gain show the combination of SIW technique with slot at the back is better performance. The only drawback of the proposed antenna is narrow bandwidth. A proposed antenna is easily for fabricated on single substrate and its low cost.

V. Acknowledgments

The author thank to Mrs. Suhaila Subahir from University Teknologi MARA, Shah Alam for the guiding and insightful suggestion to complete this final year project about CBSA with SIW. Special thanks to my parents who fully support my study also to my entire friend who involved directly or indirectly to accomplish this project.

VI. Recommendations

To improve gain of an antenna, the method of array antenna can be implemented. There are some method of array antenna such as T-junction quarter wavelength and Wilkinson power divider. Besides, to increasing performance of radiation, others slot of shape can be etched at the back of antenna such as cross slot, square slot, ring slot and H-slot. Besides, numerous researchers have been using slot array to increase the radiation performance. The 50Ω feeding method that is used can be replaced by microstrip to SIW transition.

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