A Novel HMSIW Technique Cavity Backed Dual Semi-Circular Slot Antenna

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***Abstract*: In this paper, a half-mode substrate integrated waveguide antenna is designed, fabricated and tested for the frequency of 5.8 GHz. The half-mode substrate integrated waveguide design is used to reduce the overall size of antenna by 50% whilst preserving the similar performance of the full mode substrate integrated antenna. The size of proposed antenna is $0.44\lambda \times 0.59\lambda$ mm^2 and fabricated on material glass-reinforced epoxy with relative permittivity (dielectric constant) 4.4.The semi-circular slot on top layer excites the fundamental mode of magnetic cavity at 5.8 GHz. Despite of compression, the proposed geometry provides gain of 4.66 dB and return loss -23.63 dB at 5.8 GHz. The fabricated design is tested and measured return loss is -21.94 dB at 5.78 GHz which is slightly shifted from 5.8 GHz.**

Keywords: Microstrip Patch Antenna (MPA), Cavity-backed Antenna, High gain, slot antenna, HMSIW.

I. INTRODUCTION

Substrate integrated waveguide (SIW) is an attractive platform for implementing microwave planar components. Non-planar 3D structures can be implemented on single circuit by using the SIW [1]. Different integrated microwave and millimetre wave components have been realised on SIW for various applications at different frequencies. Several kinds of antennas [2] and filters [3– 5] based on SIW have been reported in literature. SIW is basically a planar implementation of a cavity resonator. The field and frequency expressions describing the conventional rectangular waveguide resonator can also be applied for the SIW resonator. SIW-based resonator antennas can operate similar to conventional patch antennas while being able to provide the advantage of uniplanar implementation [6]. These antenna structures can be reduced in size by bisecting it along a fictitious quasi-magnetic wall. This bisecting does not affect the field distribution of the miniaturised structures as compared to the original structure. Half mode SIW (HMSIW) is obtained when SIW resonator is cut along its centre symmetrical plane [7]. These resonator antennas can be used for both linear and circularly polarised antenna designs. In [8] HMSIW technology is used to realiselowprofile, single-fed circularly polarised cavity-backed antennas operating between 5.6 and 8.7 GHz. A wearable antenna based on the aperture field distribution of a half-mode substrate-integrated resonant cavity has been proposed which operates at 4.45 GHz [9]. Owing to its applicability in wearable technology, the design requires silver coated fabric to form the ground and the top planes. In [10] a HMSIW topology has been implemented in textile materials for a dual band on body application. It uses shorting pins on the top metal layer. In [8] introduce the HMSIW technique to reduce the 50% size of antenna without affecting the antenna performance over conventional antenna.

SIW technology, which works as a bridge between planar and non-planar technology, which makes SIW, a very favorable candidate for the design of components operating at microwave and millimeter wave band. Due to this, SIW antennas and array take the advantages of both classical metallic waveguide, which includes high gain, high power capacity, low cross polarization, and high selectivity, and that of planar antennas which comprises low profile, light weight, low fabrication cost, conformability to planar or bent surfaces, and easy integration with planar circuits [18]. Inspired by SIW technology, in this article, HMSIW antenna is introduced with a half circular slit to make a compact SIW antenna which use in WBAN applications. The area of the magnetic cavity is reduced by 50%, by utilizing the symmetric electric field distribution characteristic of SIW technique. The shorting holes act as shield across the edges of antenna, which work as conducting walls. These PEC walls avert radiation losses from the sides; because of this, the antenna’s performance is slightly distressed by the medium [19].

In this article, work is organized as follow: after introduction, section 2 shows the design configuration of SIW antenna followed by HMSIW antenna design. The fabricated and comparison of simulated and measured results shows in section 3 with simulated SAR calculation. Section 4 represents conclusion and future scope of the design.

II. DESIGN AND ANTENNA CONFIGURATION

The resonator cavity is designed such way that which operates in dominant mode of G-band (3.95 GHz -5.85 GHz) for FMSIW. The parameters of cavity like resonant frequency, width and length are calculated from following equation [10]:

$$f_{mnp} = \frac{c}{2\sqrt{\mu_r \varepsilon_r}} \sqrt{\left(\frac{m}{L}\right)^2 + \left(\frac{n}{h}\right)^2 + \left(\frac{p}{W}\right)^2} \quad (1)$$

$$L_{eff} = L - \frac{(d_{via})^2}{0.95\, S_{via}} \quad (2)$$

$$W_{eff} = W - \frac{(d_{via})^2}{0.95\, S_{via}} \quad (3)$$

Where, for the fundamental mode TE_{101}, values of m, n, p is 1, 0 and 1 respectively. L_{eff} is the actual effectual length of the cavity, W_{eff} is the actual effectual width of the cavity, C is the speed of light in vacuum, and μ_r and ε_r are the relative permeability and relative permittivity of the dielectric substrate, respectively.

Parameter	Value(mm)	Parameter	Value(mm)
W	26	W_{HMSIW}	14.4
L_s	43	P_L	30.6
r_o	7.5	h	1.6
w1	1.5	L_2	16
d_{via}	0.8	L_1	2
S_{via}	1.6	W_f	1.5

Figure 1: Antenna without a circular ring slit geometry with equivalent rectangular cavity model

Above Figure 1 shows the geometry of proposed antenna without circular ring slot and equivalent rectangular cavity model of an antenna. From the figure we can directly relate magnetic cavity generate in antenna with rectangular cavity model. To design FMSIW antenna, on the substrate rectangular patch is created having same parameters of standard rectangular waveguide WR187 (47.5788 mm × 22.1488 mm) for G-band (3.94 GHz to 5.99 GHz). Then magnetic cavity is generated by putting arrays of vias with diameter d_{via} and spacing between the consecutive via is S_{via}. This antenna resonates at nearly 4.2 GHz. The dimensions of antenna are shown in Table 1.

Further to improve performance of antenna circular ring slot is generated on the patch which made antenna to resonant at 5.8 GHz. The following equation shows relation between the resonating frequency of the antenna and the radius of the circular ring [10].

$$f_{ring} = \frac{1.8\,C}{2\pi r\sqrt{\varepsilon_{eff}}} \qquad (4)$$

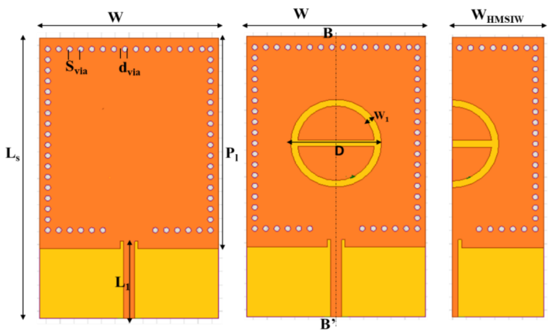
Where, r is the radius of circular ring and $\varepsilon_{eff} = (\varepsilon_r + 1)/2$.

The circular ring slot is made antenna to resonate at 5.8 GHz which also makes antenna radiate. But the proposed antenna has multiple beams in radiation pattern which are reduced by adding horizontal slot in circular ring.

To fabricate proposed design FR_4 material with dielectric constant, ε_r = 4.4, loss tangent, $\tan\delta = 0.02$ is used and the size of the proposed antenna is $0.55\lambda_g \times 1.1\lambda_g \times 0.05\lambda_g$ (where λ_g is the guided wave length at 5.8 GHz). The topmost and bottommost layers of copper claddings are shielded with the vias having the thickness of the substrate is 1.6 mm. To reduce leakage of energy coming out from the PEC walls, guidelines for SIW cavity that are $d_{via}/S_{via} \geq 0.5$ and d_{via}/λ_o are strictly followed. To achieve 50 Ω characteristic, the width of feed line is optimized at 1.5 mm, which is calculated from equation (5). The prototype of antenna is manufactured by PCB technique and vias are drilled and coated with copper by PTH (plated through hole) technique.

$$Z_o = \begin{cases} \dfrac{60}{\sqrt{\epsilon_e}} \ln\left(\dfrac{8d}{W} + \dfrac{W}{4d}\right) & \dfrac{W}{d} \leq 1 \\ \dfrac{120\pi}{\sqrt{\epsilon_e}\left[\frac{W}{d} + 1.393 + 0.667\ln\left(\frac{W}{d} + 1.444\right)\right]} & \dfrac{W}{d} \geq 1 \end{cases} \qquad (5)$$

Table 1: Dimensions of Proposed Geometry [3]



(a) (b) (c)

Figure 2: (a) Antenna with Full-Mode SIW cavity, (b) Antenna with FMSIW cavity with two semi-circular slots, (c) Proposed antenna with Half-Mode SIW cavity with semi-circular slots

Figure 2 shows design of proposed antenna. Initially antenna designed with Full-Mode SIW magnetic cavity with inset fed technique as shown in Figure 2(a). Afterward in the FMSIW structure semi-circular slots are etched on patch with radius of r_o = 7.5 mm which made antenna to resonate at 5.8 GHz, shown in Figure 2(b). Finally, Half-Mode SIW is erected by bisecting FMSIW antenna with slot in two parts from wall B-B', the final HMSIW antenna geometry is shown in Figure 2(c). The Figure 2 shows antenna with evolution through FMSIW to HMSIW cavity. Here, when we go for design of HMSIW, feed line is also cut in half which cause degradation in impedance that is the impedance is change to 53 Ω as per the equation (5), which still gives SWR value between 1 to 2 which is acceptable.

III. FABRICATED ANTENNA AND MEASURED RESULTS

The Figure 3 shows comparison plot of reflection coefficient vs. frequency for three different designing modes of antenna. In first case that is FMSIW design without ring slot, antenna radiates at frequency 4.1 GHz. The FMSIW antenna without circular slot resonates at 4.1 GHz with -17.22 dB return loss. To make antenna radiates at 5.8 GHz circular ring slot is added in top layer of antenna, the radius of the ring is calculated from the equation (4). For the second case, that is FMSIW antenna with circular ring slit resonates at 5.8 GHz with -10.71 dB return loss. Lastly, to achieve compression in size of antenna, antenna is divided in half in xz plane, without changing its characteristics, HMSIW antenna resonates at 5.8 GHz with -17.81 dB return loss. By comparing all three designs, we have fabricated HMSIW antenna which gives same performance response as FMSIW antenna by reducing the antenna size by 50%.

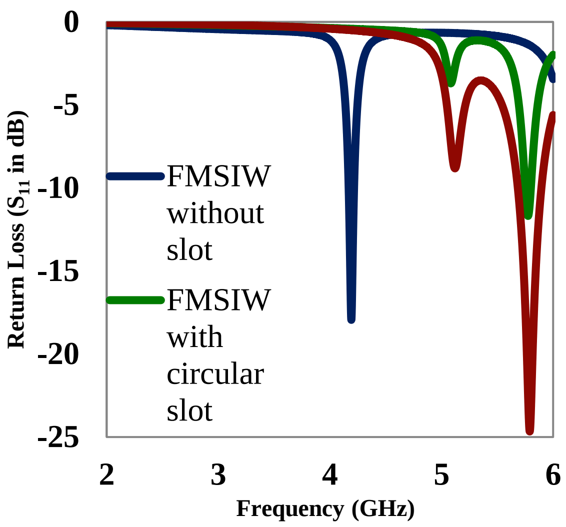


Figure 3: Simulated Return Loss vs. Frequency plot for FMSIW, FMSIW with semi-circular slots and HMSIW

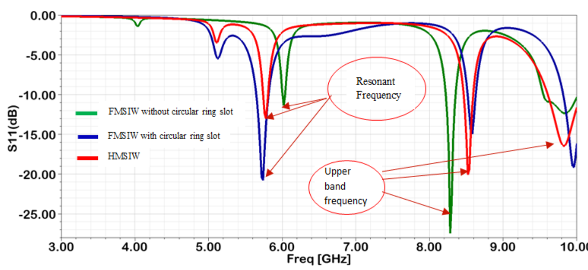


Figure 4: Simulated Reflection coefficient vs Frequency plot for upper band frequency

Figure 4 shows the graph of reflection coefficient for resonant frequency and the upper band frequencies. When we excited antenna with higher mode, it resonates at upper band frequencies.

In Figure 5 (a,b,c), the E-field distribution has been demonstrated for FMSIW antenna, FMSIW antenna with semi-circular slots and FMSIW antenna. It clearly shows that dominant mode TE_{101} is available in all structures.

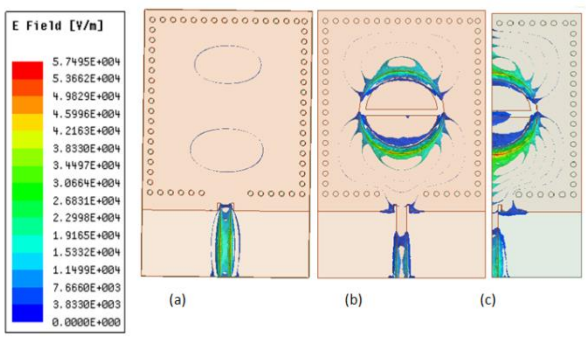


Figure 5: E-field distribution at dominant mode TE101 (a) FMSIW at 4.2 GHz, (b) FMSIW with circular slot at 5.8 GHz, (c) HMSIW with slot at 5.8 GHz

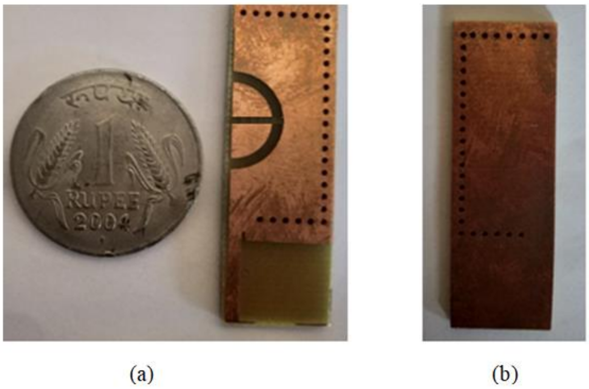


Figure 6: Fabricated HMSIW antenna (a) Top view (b) Bottom view

Figure 6 shows fabricated HMSIW antenna on FR_4 material. On the top layer of antenna is rectangular patch with half circular ring slot and bottom layer is ground plane. The three rows of vias are generated by drilling and then fill up with copper coating by PTH technique.

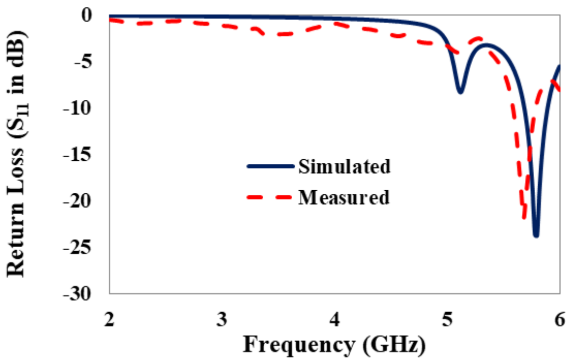


Figure 7: Comparison of Reflection coefficient vs. Frequency between Si

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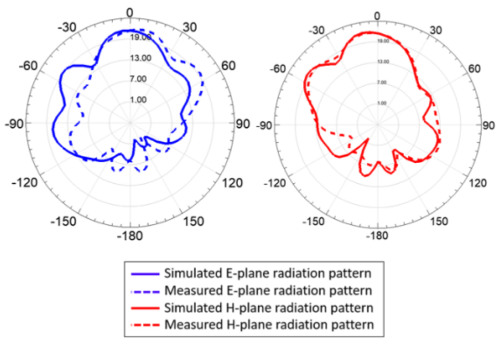

Figure 8: Measured and simulated Radiation Pattern (2D-in dB)

The Figure 7 shows comparison of simulated and measured return loss vs. frequency for HMSIW antenna. The measured result is slightly shifted from the simulated result as shown in Figure 7. From the Figure 6, the simulated return loss is -23.63dB at 5.8 GHz whilst -21. 94dB at 5.78GHz for measured. Here, simulated fractional bandwidth is 1.73% covering from 5.78 GHz to 5.88GHz, while for measured result it is 3.16% covering 5.6 GHz to 5.88 GHz for measured result. Figure 8 (a) shows simulated antenna gain in dB, the simulated peak gain is 4.66 dB at 5.8 GHz. Figure 8(b) shows far field radiation pattern of simulated antenna.

IV. CONCLUSION

A reduced SIW antenna is represented and diminishes is apprehended by HMSIW technique. A circular slot is generated to tune the fundamental mode of cavity at 5.8 GHz. The FMSIW antenna is fabricated and tested. The proposed antenna has return loss of -21.94 dB at 5.8 GHz and 180 MHz bandwidth. The antenna is also tested for SAR value on three layer human tissue model in HFSS. The simulated and measured results indicate that HMSIW antenna have technical potential to be used for WBAN applications where the antenna can easily configure with planer devices.

4. FUTURE SCOPE

It is mandatory.

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Conflict of Interest: Compulsory

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