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# Dual-Band Quarter Mode SIW Cavity Back Slot Antenna

**Jagadeesh Dokuparthi, Sudhakar Alapati**

***Abstract:*** ***A miniaturized quadrant slot antenna backed by the cavity using QMSIW technique is developed for dual-frequency applications. The design process is begun with FMSIW circular cavity which has been cut along magnetic wall twice to get quadrant sector of a circular cavity that is said to be a QMSIW cavity. The QMSIW cavity excited in $TM_{210}$ and $TM_{020}$ modes is loaded by quadrant slot which helps to decrease the resonant frequencies. The CST microwave studio is used to study the operating mechanism of various modes in the cavity. The antenna has been fabricated and measured the $S_{11}$ and principle pattern and also compared with simulated results. The experimental results prove that the antenna $S_{11}$ in dB is low at dual-frequency. One of the resonant frequencies is at 8.05 GHz and other 9.95 GHz with peak gains are around 6.25 dBi and 6.45 dBi respectively.***

***Keywords:*** ***Dual-band, Substrate Integrated Waveguide (SIW), Half Mode Substrate Integrated Waveguide (HMSIW), Quarter Mode Substrate Integrated Waveguide (QMSIW).***

## I. INTRODUCTION

Rapid growth in the area of advanced wireless communication systems demands the design of miniaturized antennas which can be fabricated on single printed circuit board. SIW is the planar form of conventional metallic waveguides which retains characteristics like high-quality factor and high power handling capability. With the advancement in substrate integrated waveguide technology, the antennas can be bisected along a magnetic wall to get Half Mode SIW. The HMSIW can be further divided into two parts along the magnetic wall to get Quarter mode SIW.

A dual-band quarter mode SIW antenna [1] is proposed in which the wave radiates from two cross dielectric apertures. A miniaturized antenna using QMSIW technique [2] is presented in which two stages of Sierpinski Fractal Geometry is incorporated on top of the cavity to decrease the resonant frequency. A top-loaded Sierpinski fractal geometry and bottom-loaded Complementary Split Ring Resonator (CSSR) QMSIW antenna [3] is proposed for size miniaturization. Here, fine-tuning of frequency from 4.96 to 5.88 GHz is achieved by rotating CSSR structure from $0^0$ to $315^0$. A dual-band QMSIW antenna with stub matching circuit [4] is proposed for Wi-Fi applications. A miniaturized CSRR loaded QMSIW antenna [5] for navigation system applications is proposed. Antennas proposed [1-5] are excited by simple line feeding technique and QMSIW is realized from rectangular cavity resonators.

A co-axial fed QMSIW triangular antenna [6] with compact slot using $TE_{101}$ mode is presented to radiate at 2.54 GHz frequency. A compact QMSIW antenna with L-shaped slot using $TM_{101}$ mode [7] is proposed. Shunt metallic via loaded QMSIW antenna [8] is proposed for WBAN applications. Here, fine-tuning of frequency is achieved by increasing the number of shunt-metalized via. A QMSIW textile antenna with two rectangular slits [9] is proposed. Antennas proposed [7-9] are excited by co-axial feeding technique and QMSIW is realized from circular cavity resonators.

In order to reduce the number of antennas in a hand-held device, dual-band antennas are the highest demand. A miniaturized, co-axial fed QMSIW cavity-backed slot antenna is developed using low loss tangent RT Duroid 5880 substrate.

## II. ANTENNA GEOMETRY

A QMSIW slot antenna is shown in Fig 1. Two-sided copper-coated RT Duroid 5880 substrate with relative permittivity of 2.2 and loss tangent of 0.0009 is used to fabricate the resulted antenna. Some portion of the top copper layer is etched for quadrant ring slot and dielectric aperture as shown in Fig1 (a). Later, the substrate is drilled to form several holes which are to be filled with a conductor. The holes that are filled by the conductor are called as metallized via. This process makes the structure behaves like a cavity. However, there are conditions to be satisfied by the distance between the adjacent via (s), the diameter of each via (d) i.e. $d/s \geq 0.5$ and $\lambda_0/d \geq 10$, where $\lambda_0$ is the free-space wavelength. Table I gives the values of the geometrical parameters of the proposed antenna including 's' and 'd' which satisfy the above conditions. Thus the proposed structure behaves like QMSIW cavity. The coaxial feed location is optimized using CST microwave studio for achieving dual-band operation.

**TABLE I: Dimensions of the proposed QMSIW slot antenna**

| Parameter | L | W | S1 | r | $r_1$ |
|---|---|---|---|---|---|
| **Value (mm)** | 16.5 | 16.5 | 1.15 | 13.8 | 15.5 |

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| Parameter | $g_{ext}$ | s | d | fx | fy |
|---|---|---|---|---|---|
| Value (mm) | 3.5 | 1.5 | 1 | 5 | 2.5 |

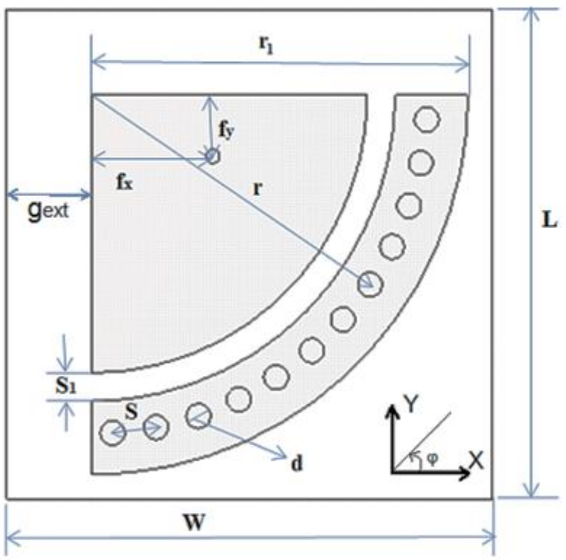



**Fig 1: (a) Top view of proposed QMSIW slot antenna with geometrical parameters**

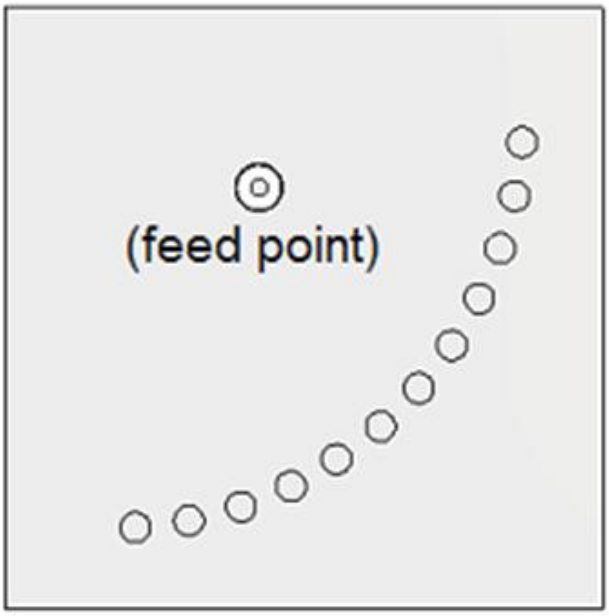


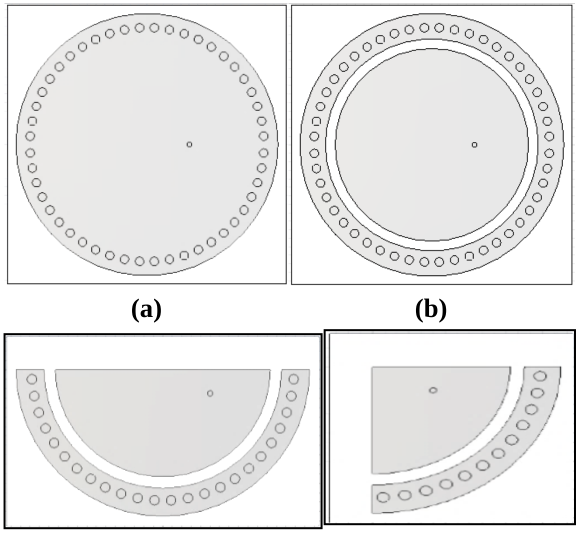

**Fig1: (b) Bottom view of proposed QMSIW slot antenna with indicating feed location**

## III. ANTENNA ELEMENT DESIGN

Fig.2 shows the design evolution of the proposed antenna. The design evolution is started with FMSIW circular cavity whose radius is selected from equation 1. This FMSIW circular cavity resonates with frequencies 5.94 GHz, 9.22 GHz, 12.2 GHz, and 13.4 GHz whose resonant modes are $TM_{010}$, $TM_{110}$, $TM_{210}$, and $TM_{020}$ respectively. The simulated E-field distributions of the above modes are shown in Fig. 3.

$$f_{nmp} = \frac{X_{nm}}{2\pi r\sqrt{\mu_0 \epsilon_r \epsilon_0}} \qquad (1)$$

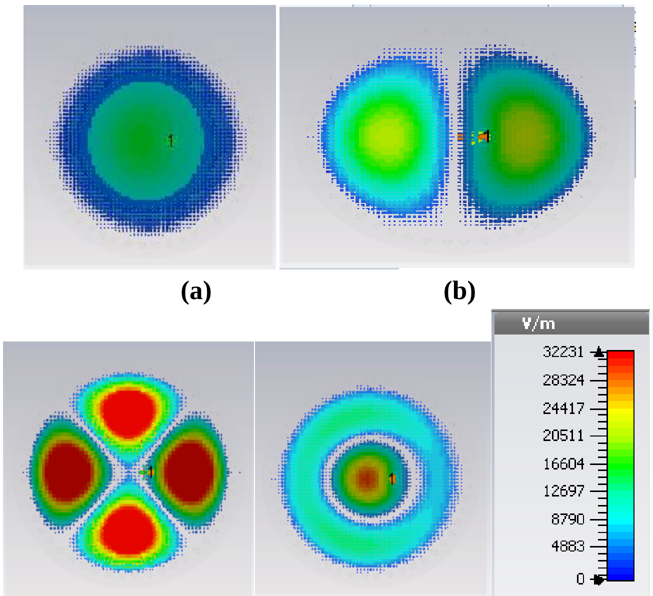
Where $\epsilon_r$, $\epsilon_0$, $\mu_0$ represent the dielectric constant of the substrate, free space permittivity, free space permeability respectively. 'r' is the cavity radius and $X_{nm}$ is the Bessel function of the corresponding mode. Here n, m and p are the integers that indicate changes along the circumferential, radial and longitudinal directions respectively.



(a) (b)

(c) (d)

**Fig 2: Design evolution: a) Full Mode SIW cavity b) Ring slot-loaded Full Mode SIW c) Half Mode SIW version of ring slot-loaded SIW d) Quarter Mode SIW slot antenna (Proposed design)**

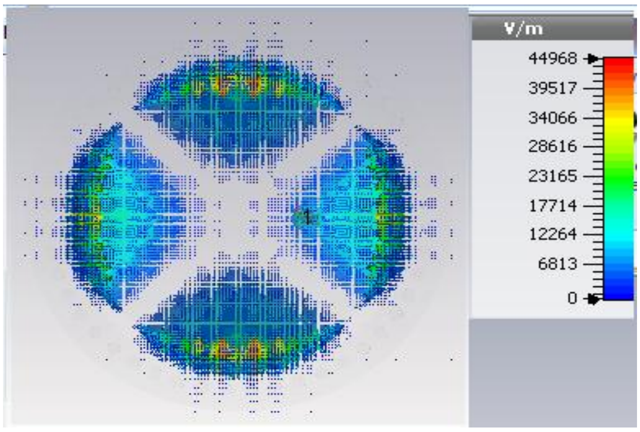



(a) (b)

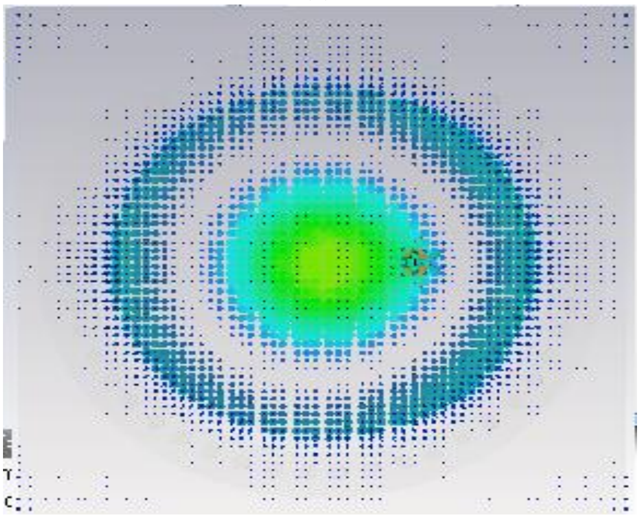
(c) (d)

**Fig 3: Full Mode SIW cavity E-field distributions at a) $TM_{010}$ mode: 5.94 GHz b) $TM_{110}$ mode: 9.22 GHz c) $TM_{210}$ mode: 12.2GHz d) $TM_{020}$: 13.4GHz**

In the second step, the top of FMSIW circular cavity is loaded by a ring slot which increases the effective capacitance and also reduces the resonant frequency. Hence, the resonant frequencies are shifted down to 3.8 GHz, 5 GHz, 8.3 GHz, and 10.1 GHz. Fig. 4 shows the E-field distributions of the ring slot-loaded FMSIW cavity at $TM_{210}$, and $TM_{020}$ modes.

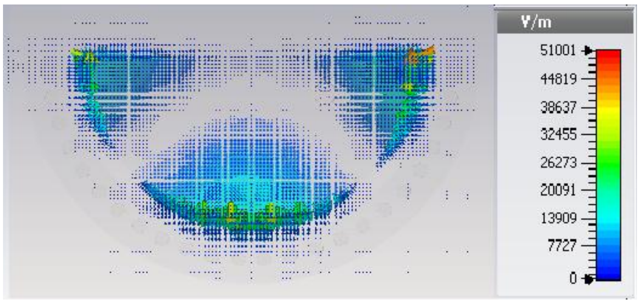



**(a)**

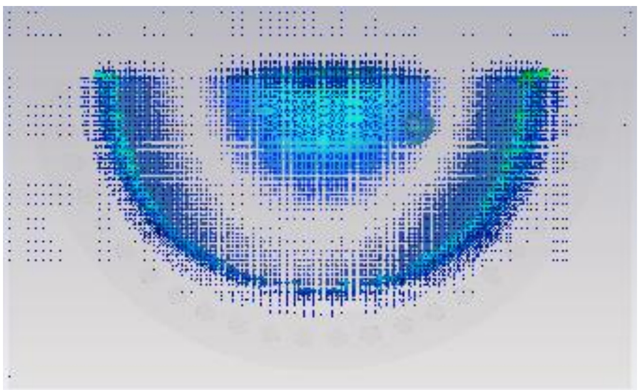


**(b)**

**Fig4: Ring slot-loaded Full Mode SIW cavity E-Field distribution at a) 8.3 GHz: $TM_{210}$ b) 10.1 GHz: $TM_{020}$**




**(a)**



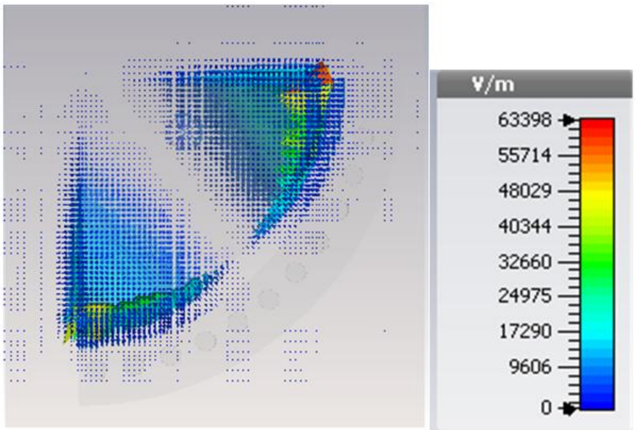
**(b)**

**Fig 5: Half Mode SIW cavity with ring slot E-Field distributions at a) 8.1GHz: $TM_{210}$ b) 10.1 GHz: $TM_{020}$**

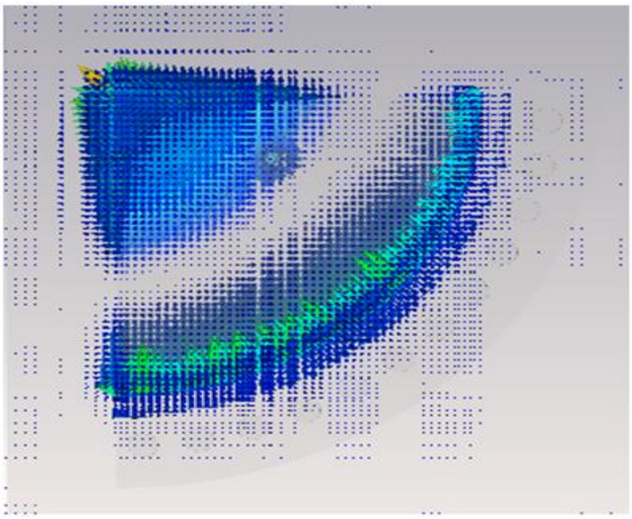
In the next step, this slot-loaded FMSIW circular cavity is divided along a symmetric plane i.e. along a horizontal axis. The half part of the cavity can preserve field distributions of $TM_{210}$, and $TM_{020}$ modes which are shown in Fig. 5.

This half part of SIW cavity is said to be HMSIW cavity. The HMSIW cavity resonates with frequencies 3.7 GHz, 5.2 GHz, 8.18 GHz and 10.08 GHz whose resonant modes are $TM_{010}$, $TM_{110}$, $TM_{210}$ and $TM_{020}$ respectively.

Finally, the HMSIW cavity is cut along a vertical axis which preserves all the above modes except $TM_{110}$ mode as this axis doesn't pass through maximum E-field. Now, the quadrant sector of the circular cavity is left whose E-field distributions of $TM_{210}$, and $TM_{020}$ are shown in Fig. 6. The position of the feed is optimized to get return loss -10 dB below at two-higher order modes i.e. $TM_{210}$, $TM_{020}$.




**(a)**



**(b)**

**Fig 6: E-Field distribution of Proposed design at a) 8.1 GHz: $TM_{210}$ b) 10.1 GHz: $TM_{020}$**

## IV. RESULTS AND DISCUSSION

Fig. 7 shows simulated $S_{11}$ in dB vs. frequency for variation in slot widths of the antenna. Both the center frequencies of the cavity increase with increasing slot width (ws). As the width of the slot increases, equivalent capacitance of the cavity decreases which increases in resonant frequencies. For smaller slot widths, return loss is very low at first resonant frequency when compared with second resonant frequency and for larger slot widths; return loss is very low at the second resonant frequency when compared with a first resonant frequency. The slot width is chosen such that the return loss is approximately the same at both the bands. For the slot width of 1.15 mm, the return loss is approximately equal to -25 dB at the frequencies of 8.15 GHz and 10.05 GHz. The fractional impedance bandwidth at 8.15 GHz and 10.05 GHz are 2.5% and 4% respectively.

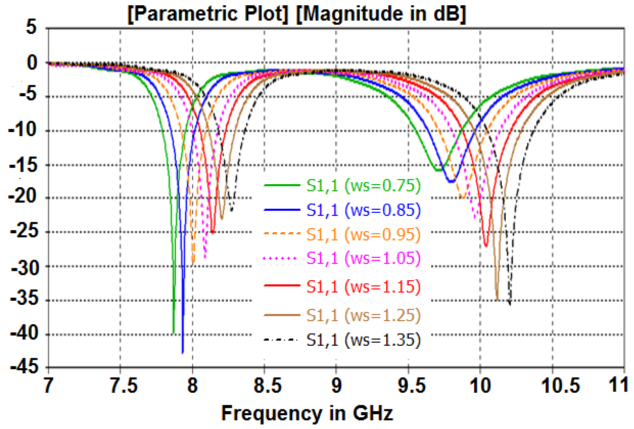
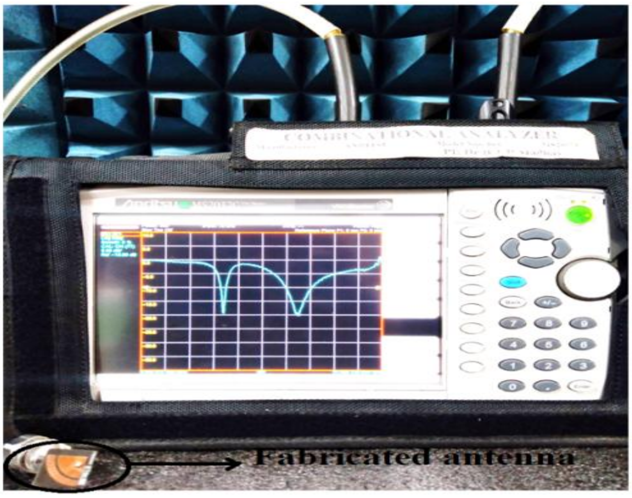



**Fig 7: Simulated $S_{11}$ in dB for different slot width in QMSIW**




**(a)**


**(b)**

**Fig 8: Fabricated QMSIW slot antenna with the experiment setup**

The measurement of $S_{11}$ in dB of the proposed QMSIW slot antenna is performed using the Anritsu MS2037C Vector Network Analyzer (VNA) which is shown in Fig. 8. The measured $S_{11}$ proves that the proposed QMSIW slot antenna is resonating at dual-frequency in which the band1 resonant frequency is 8.05 GHz and band2 resonant frequency is 9.95 GHz. The measured fractional impedance bandwidth at band1 and band2 are 2% and 4.1% respectively. The QMSIW antenna measured peak gain in boresight direction at first and second bands are 6.25 dBi and 6.45 dBi respectively. The comparison between measured and simulated return losses and gain at boresight direction are plotted in Fig 9. It shows that the measured $S_{11}$ at both the bands is in good agreement with the simulated results. However, there exists a deviation in center frequencies is about 0.1 GHz. Moreover, the deviation in gain at boresight direction is about 0.25 ~ 0.75 dB. The fabrication tolerances such as drill tolerance, PCB thickness tolerance, and SMA connector loss cause deviations in the return loss and gain.

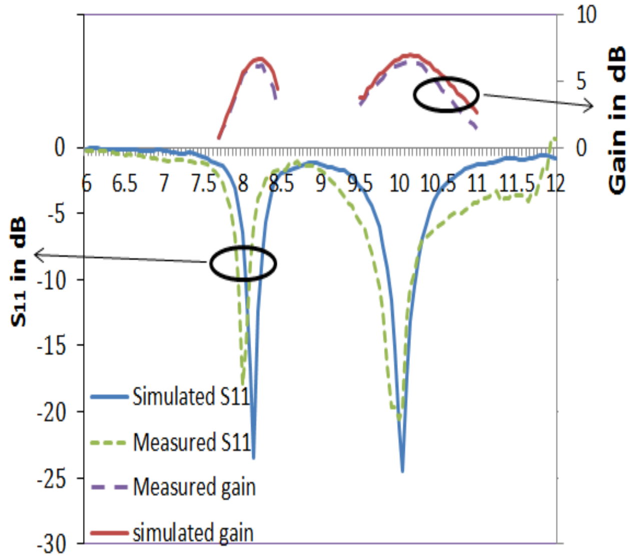



**Fig 9: Return loss and gain**

Fig. 10 shows the normalized radiation patterns at 8.05 GHz and 9.95 GHz. The energy comes from the QMSIW cavity into free space through the magnetic wall and slot. As the energy is radiated from all directions of the antenna the peak gain is obtained in the boresight direction.

The peak gain has slightly deviated from the boresight direction in QMSIW antennas which were discussed in [1-8] as most of the energy is coupled from the dielectric aperture. The planes x-o-z and y-o-z are the E- and H-plane radiation patterns respectively at 8.05 GHz. Fig. 10 (a) and (b) show that the peak cross-polarization gain is -18 dB away from the desired polarization gain at 8.05 GHz. Moreover, the 3-dB beamwidth is more than $75^0$ in both planes. The planes y-o-z and x-o-z are the E- and H-plane radiation patterns respectively at 9.95 GHz. Fig. 10 (c) and (d) show that the peak cross-polarization gain is -16 dB away from the desired polarization gain at 9.95 GHz. Moreover, the 3-dB beamwidth is more than $80^0$ in both planes.

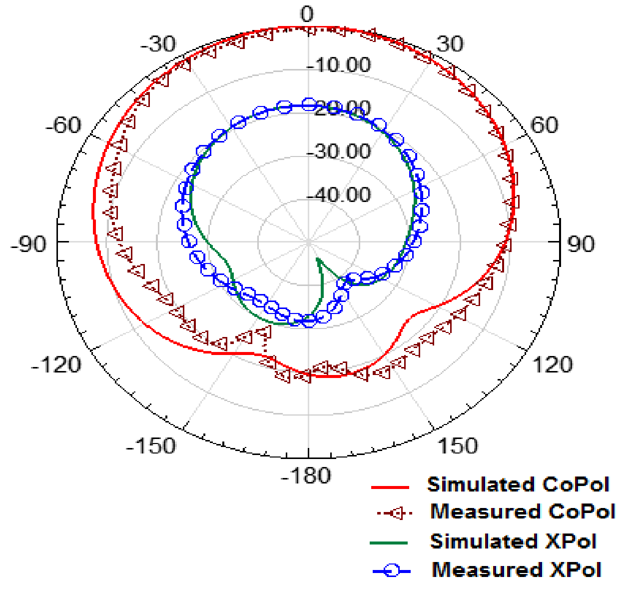



Fig 10(a): E-plane pattern at 8.05 GHz

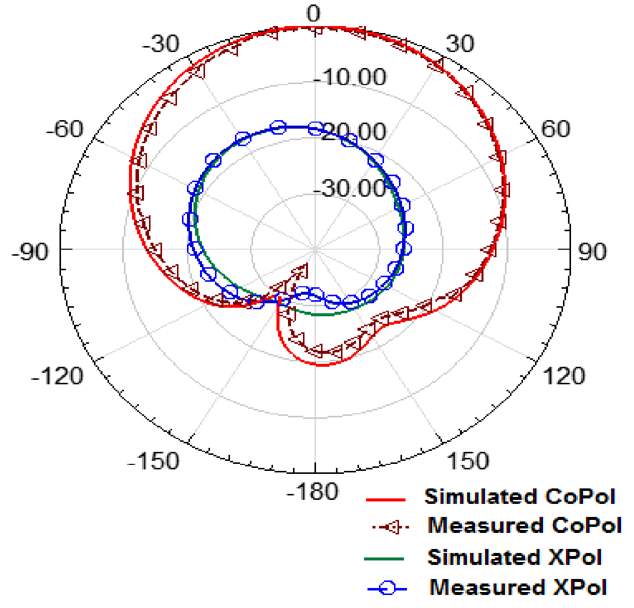



Fig 10(b): H-plane pattern at 8.05 GHz

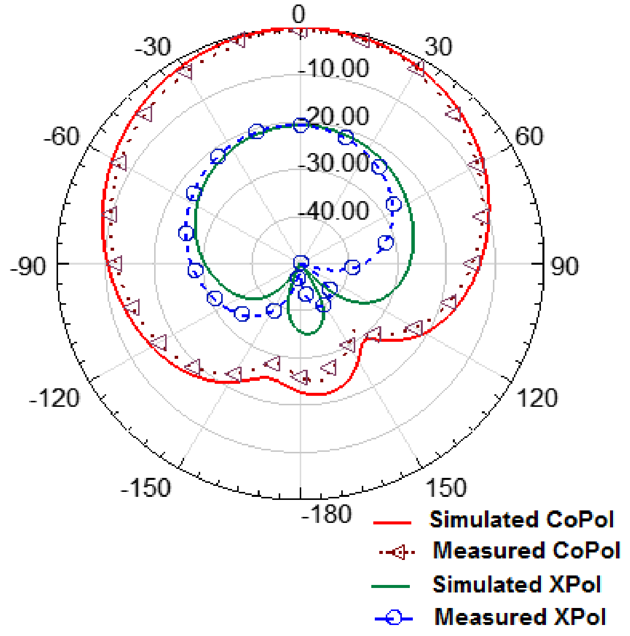



Fig 10(c): E-plane pattern at 9.95 GHz

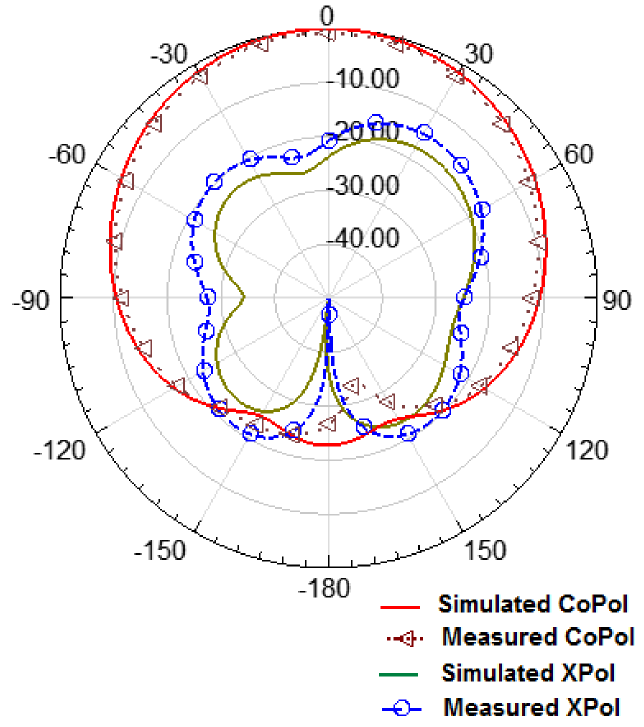



Fig 10(d): H-plane pattern at 9.95 GHz

The $\lambda_l$ in Table II represents the free-space wavelength of the lowest operating frequency. Here the specifications of QMSIW slot antenna are compared with reference dual-band antennas [10-13]. It is proved that the proposed QMSIW antenna size has been reduced with improvement gain when compared with reference antennas. This is achieved due to the excitation of the antenna in higher-order modes. However, a slight decrement in band1 percentage of fractional impedance BW than [12] and [13] and band2 percentage of fractional impedance bandwidth is also less than [11]. This decrement is due to a reduction in the size of the cavity as there is an inverse relationship between bandwidth and volume of the cavity.

**Table- II: Comparison of the proposed QMSIW slot antenna parameters with the reference antennas**

| Ref | | *Center Frequency (GHz)* | *PeakGain (dBi)* | *Fractional Impedance BW (%)* | *Substrate height (mm)* | *Dielectric constant* | *Size* |
|---|---|---|---|---|---|---|---|
| [10] | Band1 | 9.5 | 5 | 1.8 | 0.5 | 2.2 | $1 \lambda_l \times 0.75 \lambda_l$ |
| | Band2 | 10.5 | 5 | 2 | | | |
| [11] | Band1 | 9.3 | 4.86 | 1.4 | 1.6 | 2.2 | $1.06 \lambda_l \times 0.62 \lambda_l$ |
| | Band2 | 16.4 | 6.15 | 5.9 | | | |
| [12] | Band1 | 5 | 5.6 | 3.5 | 1.6 | 2.2 | $1.09 \lambda_l \times 0.82 \lambda_l$ |
| | Band2 | 5.8 | 5.15 | 3.1 | | | |
| [13] | Band1 | 8.5 | 7.5 | 2.75 | 0.8 | 2.2 | $0.83 \lambda_l \times 0.47 \lambda_l$ |
| | Band2 | 10.6 | 6 | 3.35 | | | |
| Proposed work | Band1 | 8.05 | 6.25 | 2 | 0.8 | 2.2 | $0.52 \lambda_l \times 0.52 \lambda_l$ |
| | Band2 | 9.95 | 6.45 | 4.1 | | | |

## V. CONCLUSION

In this paper, a low-profile miniaturized dual-band cavity-backed slot antenna using QMSIW with improvement in gain is proposed. High gain is achieved in both the bands due to excitation of the antenna in two higher-order modes i.e. $TM_{210}$ and $TM_{020}$ and design of the antenna on a low loss tangent substrate. By using the QMSIW, a size reduction of approximately 25% is achieved in comparison with the conventional antenna. Further, making a slot on the top layer causes more than 25% decrement in resonant frequencies which also helped in reducing the size of the antenna.

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