Abstract - Substrate Integrated Waveguide (SIW) is a special antenna technology which retains reduced copper surface waves and low dielectric loss property of classical rectangular waveguides. The antennas developed on SIW have simple configuration with an ease of fabrication in flame redundant wearable and integration in walls and floors. In this sense a Quarter-mode SIW (QMSIW) antenna has been designed, analyzed and its performance has been compared with Half-mode SIW. QMSIW has been precisely designed to operate efficiently in the range of 40 - 57 GHz. It aims at enhancing the bandwidth for 5G applications with a maximum return loss of -36 dB at 55 GHz. HMSIW structure has triple band resonant frequencies at 20.5 GHz, 24.7 GHz & 27 GHz with the return loss values of -34 dB, -14 dB & -32.5 dB respectively. Both antennas operate in 20 – 72 GHz range of 5G applications.

Keywords - SIW-CB, Half-mode, Quarter-mode, Flame Redundant type 4 (FR4) epoxy substrate

1. Introduction
The Innovations and recent developments in various domains and applications posts different challenges in the Wireless Communication system. Integration of everyday objects into the network is one of the important challenges. The ever-increasing demands in millimeter wave frequency involve several technological requirements like high data rate, low latency, a greater number of connected devices i.e., greater capacity of remote execution, improved performance and reliable communication to support 5G Wireless networks. 5G millimeter wave provides high speed data with operating frequency range of 20 – 72 GHz.

The proposed antenna aims at providing solutions to the above-mentioned requirements with high return loss in the frequency range of 5G networks. High gain, improved stability, increased efficiency and better resonating property are the various parameters that need to be considered for developing different antenna topology. Substrate Integrated Waveguide (SIW) is one of the advanced antenna technologies which answers the above-mentioned challenges and requirements. SIW is mostly used for special applications like structures on textiles and different materials, structures for Internet of Things (IoT) application and structures for 5G trending applications are used in industries.

2. SIW Technology and Cavity Backed Antenna
Introduction

Fig. 1: SIW-CB Antenna Technology

The different antenna technologies like Microstrip, Metamaterials and other dimensional antenna technologies suffer from surface waves and the undesired radiation. In SIW Technology the field is restricted inside the SIW structure and hence the above-mentioned losses are minimized. Substrate Integrated Waveguide Cavity Backed (SIW-CB) antenna is a fascinating technology to realize non-planar (waveguide based) circuits into planar (Microstrip) circuits and systems. Selective filters and power amplifiers are conveniently integrated with the chip-set which illustrates the SIW integrating property. SIW also has high isolation factor which makes it a perfect candidate for low-power applications. The other general features like low cost, conformability and easily mountable device are some of the constructional challenges. These challenges are efficiently handled by the SIW technology involved CB antenna. SIW-CB antenna has different modes of operation, of which Quarter-mode and Half-mode are analyzed. The design of Quarter and Half mode SIW cavity backed antenna involves the arrangement of two rows of cylinders with conducting material embedded in a dielectric substrate.
Radiation pattern and dispersion characteristics are similar to the conventional Rectangular Waveguides with reduced radiation leakage [2]. SIW modes are same as traditional metallic waveguide, namely with the TE\(_{n0}\) modes, with \(n = 1, 2 \ldots\) etc. The gaps between metallic via holes do not support TM modes. The dominant mode of a conventional waveguide is TE\(_{10}\) mode with vertical electric current density on the side walls. For primary dimensioning and structuring of SIW design the relation of cut-off frequency and dielectric loss with substrate thickness is important [3]. Thickness of the substrate does not affect the resonant frequency whereas dielectric loss decreases with the increase in substrate thickness. The equation was derived in

\[
W_{\text{eff}} = W + (d / (0.95) s)
\]

\[
W_{\text{eff}} = W / \sqrt{\varepsilon_r}
\]

where

- \(W_{\text{eff}}\) – Dielectric width
- \(W\) – Spacing between the metal via hole rows
- \(s\) – Via hole interspaces
- \(d\) – Via diameter
- \(\varepsilon_r\) – Substrate’s relative permittivity

### 3. Half-Mode SIW antenna design

HMSIW antenna has two rows of metallic via holes but the via-holes are present only for half of the length of the antenna as shown in the Figure 2. The proposed Half-mode SIW–CB antenna has an overall dimension of 18*18*0.8mm\(^3\). The length of the substrate is 18mm whereas that of the radiating patch is 9mm. The dimension of the patch is almost half of the Full-mode SIW-CB antenna. The effective dimension of HMSIW is 9*18*0.8mm\(^3\). For designing a Half-mode SIW antenna, few parameters which influence the performance are considered [4]. Of the few design parameters dielectric substrate and its thickness, feeding technique and frequency of operation are very important [5]. To operate in the range of 20 – 28 GHz frequency the Half-mode antenna has been designed. The above-mentioned operating range appears in the 5G millimeter wave applications. To reduce the radiation losses coaxial feeding technique has been employed. The length of the feeding port is extended since the patch length is halved. This provides the required impedance matching characteristics. The ground plane is directly connected to the outer conductor. Through the dielectric the inner conductor is soldered to the radiating patch [6].

Selection of dielectric substrate is done carefully to provide the required performance characteristics, to easily fabricate and measure in practical conditions. FR4-epoxy substrate has been chosen with the following specifications of relative permittivity \(\varepsilon_r\) 4.4 and dielectric loss tangents 0.02. Substrate thickness is another important parameter which is to be considered for reducing losses. Thickness has to be optimized, since conductor loss is inversely proportional to substrate thickness and directly proportional to the dielectric losses. 0.8mm is the measured substrate thickness [8].

### 4. Quarter-Mode SIW antenna design

QMSIW antenna has metallic via holes present at the sides of the patch as shown in the Figure 3. The overall proposed Quarter-mode SIW–CB antenna dimension is 18*18*0.8mm\(^3\) (same as Half mode). The length and width of the substrate is 18mm each whereas that of the radiating patch is 9mm each, which is a considerable reduction in patch dimension. The dimension of the patch is almost Quarter of the Full-mode SIW-CB antenna. The effective dimension of QMSIW is 9*9*0.8mm\(^3\). The design specifications of Quarter-mode SIW-CB is similar to Half-mode SIW-CB with the importance being given to working frequency, technique of feeding, dielectric substrate material and substrate thickness [9]. The proposed Quarter-mode antenna has been structured to operate in 40 – 57 GHz frequency range which comes under millimeter wave for 5G applications. Comparing the bandwidth of QMSIW it is nearly double that of HMSIW. The same coaxial or probe feeding technique has been carefully used [10]. The width of the feeding line is halved for proper impedance matching.

FR4-epoxy substrate has been chosen with the same specifications, relative permittivity of \(\varepsilon_r\) 4.4 and dielectric loss tangents of 0.02 to provide the required performance characteristics. The other reasons that support the selection of FR4 are easy to fabricate and measure in practical conditions [11].

This similar substrate used is helpful to compare with Half-mode characteristics. Substrate thickness is another important parameter which is to be considered for reducing losses. Thickness has to be optimized, since conductor loss is inversely proportional to substrate thickness whereas directly proportional to the dielectric losses [12]. Substrate thickness used is measured as 0.8mm.
5. Results and Comparison

The HMSIW and QMSIW antennas have the key feature of large bandwidth based on the mode of operation of antenna in the millimeter wave range for 5G applications. The parameters such as resonant frequency and return loss for the respective modes are effectively compared [13]. Both the Half and Quarter mode antenna have three and four resonant frequencies respectively in different GHz frequency ranges. The detailed comparisons of the results are as follows.

**Half-Mode SIW – CB antenna**

HMSIW-CB antenna is characterized by the rows of metallic via holes along the entire width of the antenna but present only for half of the length of the antenna. It has three resonant frequencies at 20.5 GHz, 24.7 GHz & 27 GHz with the return loss values of -34 db, -14 db and -32.5 db respectively. The HMSIW structure has good enough return loss to operate in the three resonant frequencies (20.5 GHz, 24.7 GHz & 27 GHz). Though the return loss is in the higher side for the above-mentioned frequencies, the antenna has a very small operating bandwidth. The entire radiation energy has been used by the three resonant frequencies with high return loss values instead of producing more resonant frequencies with low return loss values [14]. These frequencies support the operation of different electronic components and gadgets through internet for 5G applications. The simulated and measured return loss characteristics are shown in Figure 4.

**Quarter-Mode SIW – CB antenna**

QMSIW-CB antenna is characterized by the rows of metallic via holes present only for half of the width and length of the antenna. More than the resonant frequencies the antenna has a large bandwidth of 16.5 GHz ranging from 40.5 GHz to 57 GHz. QMSIW produces four resonant frequencies at 45, 49.5, 53 & 55 GHz. The maximum value of return loss is -36 db which occurs at 55 GHz. The other return loss values for the respective frequencies are obtained as follows -21.4 db for 45 GHz, -23.5 db for 49.5 GHz and -25 db for 53 GHz. With increased no. of resonant frequencies and enhanced bandwidth, the performance of QMSIW-CB is comparatively better than HMSIW. It covers most of the mm wave range to operate for 5G applications. Though the two antennas operate in different range it works for the same application. These frequencies which is obvious from the overall VSWR results shown in Figure 5. Ansoft High Frequency Structure Simulator (HFSS) is the simulator used for generating simulated results.

The VSWR measures 1 over the three operating frequency ranges which is an excellent value to achieve. The Standing waves have been reduced considerably which is obvious from the overall VSWR results shown in Figure 5. Ansoft High Frequency Structure Simulator (HFSS) is the simulator used for generating simulated results.

The propagation characteristics of HMSIW antenna is obtained for 20 GHz frequency. The E-plane and the H-plane radiation characteristics are shown in Figure 6. The simulated radiation patterns are almost similar for both E and H planes. In spite of these features the antenna has the drawback of limited bandwidth [15]. From the pattern it is clear that the antenna shows unidirectional radiation characteristics.
support the operation of different electronic components and gadgets through internet. This SIW-CB structure has the ability to work in four various frequencies. The simulated and measured return loss characteristics are compared in Figure 7.

![Figure 7: Quarter-mode return loss characteristics](image1)

**Figure 7:** Quarter-mode return loss characteristics

The VSWR value is well below 1.4 over the mm wave range, which is an excellent value to achieve. The Standing waves have been reduced considerably which is obvious from the overall VSWR characteristics as shown in Figure 8. The radiation pattern of QMSIW antenna is obtained for the frequency of 50GHz. The E-plane and the H-plane radiation characteristics are shown in Figure 9. The simulated radiation patterns are almost similar for both E and H planes. From the pattern it is clear that the antenna shows unidirectional radiation characteristics. Quarter-mode antenna has the advantage of large bandwidth is shown in Figure 10.

![Figure 8: Intensity diagrams of QMSIW](image2)

**Figure 8:** Intensity diagrams of QMSIW

![Figure 9: Quarter-mode VSWR characteristics](image3)

**Figure 9:** Quarter-mode VSWR characteristics

The performance parameters of SIW-CB in Half mode and Quarter mode are analyzed and compared in Table 2 given below.

### Table 1: Comparison of Design Parameters

| Design Parameters | Half-mode | Quarter-mode |
|-------------------|-----------|--------------|
| Substrate         | FR4 epoxy | FR4 epoxy    |
| Substrate Thickness | 0.8 mm   | 0.8 mm       |
| Dielectric constant | 4.4       | 4.4          |
| Patch length      | 9 mm      | 9 mm         |
| Patch width       | 18 mm     | 9 mm         |
| Copper thickness  | 0.017 mm  | 0.017 mm     |
| Substrate centre to via-hole centre distance | 7.885 mm | 7.885 mm |
| Via-hole diameter | 1 mm      | 1 mm         |
| Distance between two via-hole centre | 2 mm     | 2 mm         |

From the experiments conducted and results mentioned in the table it is clear that Half-mode has three resonant

### Table 2: Comparison of Performance Parameters

| Performance Parameters | Half-mode | Quarter-mode |
|------------------------|-----------|--------------|
| Frequency range        | 20 – 21 GHz, 24.25 – 25 GHz, 26.5 – 28 GHz | 40.5 – 57 GHz |
| Band                   | Tripleband | Quadraband   |
| Bandwidth              | 3.25 GHz  | 16.5 GHz     |
| Resonant frequencies   | 20.5, 24.7 & 27 GHz | 45, 49.5, 53 & 55 GHz |
| Return loss            | -34 db, -14 db & -32.5 db | -21.4 db, -23.5 db & -36 db |
| VSWR                   | 1 (for the resonant frequencies) | Less than 1.4 (for the entire range) |
| Radiation pattern      | Unidirectional (at 20 GHz) | Unidirectional (at 50 GHz) |

From the experiments conducted and results mentioned in the table it is clear that Half-mode has three resonant
frequencies with limited band of operation ranging from 20 - 21 GHz, 24.25 – 25 GHz and 26.5 – 28 GHz. The effective bandwidth is 3.25 GHz. Quarter-mode produces an enhanced bandwidth of 16.5 GHz from 40.5 – 57 GHz. Half-mode antenna has acceptable VSWR of 1 (for the resonant frequencies) whereas Quarter-mode antenna has excellent VSWR value of Less than 1.4 (for the entire operating range). The radiation characteristics of both the structures show unidirectional pattern with minor variations in E and H plane pattern. The return loss values are also on the higher side for both the antennas. Hence from the performance parameters it is obvious that for the application where a strong signal (return loss) in a particular resonant frequency is required, Half-mode structured antenna can be utilized. Quarter-mode SIW-CB structured antenna can be perfectly suited for the applications where a range of operating frequency is required.

6. Conclusion

Miniaturizations of SIW technology involved cavity backed antennas are proposed with two modes of operation to generate two different performance characteristics. The advantages of SIW technology are combined with FR4 substrate. A systematic investigation of HMSIW and QMSIW is carried out based on cavity resonator concepts. These antennas exhibit a reduced patch size when compared to a conventional SIW design. Proper comparison of design and performance parameters are reported in Table 1 and Table 2 respectively. The designed, simulated, fabricated, measured, compared and analyzed SIW-CB antennas demonstrate a low-profile characteristic to covers the 5G frequency range of 20 – 72 GHz.

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