

# DESIGN OF CIRCULAR VOLUMETRIC ANTENNA USING SIW TECHNOLOGY FOR WIRELESS APPLICATIONS

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**Abstract** –Single band circular volumetric antenna using Substrate Integrated Waveguide (SIW) technology is introduced. The volumetric antenna is made of FR4 (Flame Retardant) substrate material and antenna’s circular patch has a radius of 4 mm. By placing a rectangular slot on the circular patch with 8 mm length and 0.4 mm width, the HFSS antenna simulation tool analyses the reported antenna properties and harvesting the results such as gain of 3 dB, directivity of 4.21, VSWR of 1.31 and return loss of -17.22 dB at frequency of 10.75 GHz. The proposed circular volumetric SIW antenna structures come up with a bandwidth of 210MHz. It is widely used in radar systems, remote sensing and microwave imaging applications.

**Keywords:** Radio Frequency, SIW Technology, Volumetric antenna, Wireless Communication Systems.

## 1. INTRODUCTION

Antennas are crucial components of wireless communication networks. An antenna is, by definition, a device that converts an electromagnetic wave in free space from an RF signal that is traveling on a conductor [1]. Low-profile antennas are necessary in high-performance aircraft, spacecraft, satellite, and missile applications where aerodynamic profile, size, weight, cost, performance, and ease of installation are constraints. Similar standards are currently found in a wide range of other commercial and government applications, including wireless communications and mobile radio. It is possible to use micro strip antennas to satisfy these needs [2].

Micro strip components require strict fabrication concessions when implementing RF, microwave and millimeter-wave components, yet they work quite well for low frequency applications. At higher frequencies, however, they become ineffective. This is because at higher frequencies, wavelengths are shorter. Conversely, waveguide devices are perfect for higher frequency systems, but they are very expensive, difficult to make and difficult to combine with nearby planar components.

The design of effective circuits and parts that operate in the radio frequency (RF) and microwave frequency spectrum now has more options thanks to this technology. SIW bridges the gap between planar transmission line technologies, such as the micro strip, and traditional air-filled rectangular waveguide [3]. The authors presented a

platform for integrating all the components of a microwave circuit inside a single substrate, with a rectangular cross-section. Using a single substrate guarantees a limited volume and simplicity of manufacture, while the rectangular cross-section of the line provides the advantages of the waveguide topology in terms of losses [4]. One attraction to SIW is that the amount of metal that carries the signal is far greater than it would be in micro strip [5].

## 2. SUBSTRATE INTEGRATED WAVEGUIDE

Using two rows of conducting cylinders and slots implanted in a dielectric substrate to connect two parallel metal plates, SIWs are constructed to resemble integrated waveguides (Fig – 1).

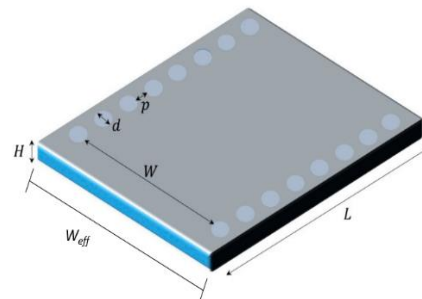
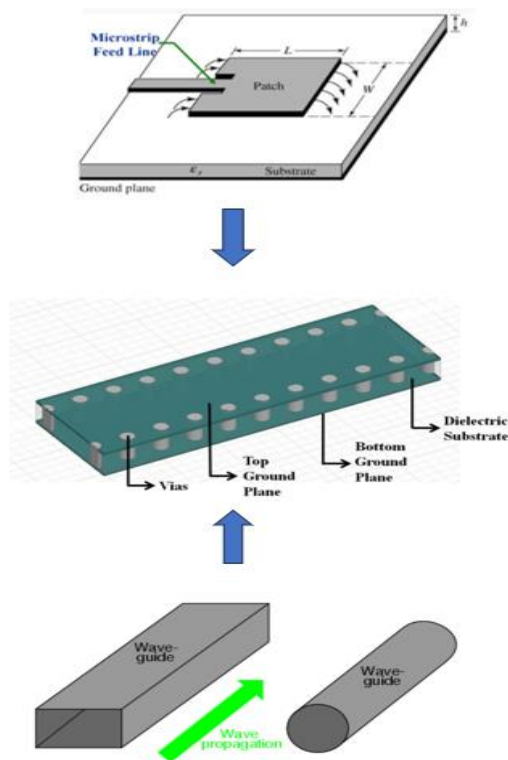


Fig -1: Structure of SIW Antenna

- $w_{eff}$  - Effective width
- $w$  - Width of the cavity
- $L$  - Length of the cavity
- $d$  - Diameter of the metal vias
- $s$  or  $p$  - Spacing between metal vias
- $t$  or  $h$  - Thickness

With the use of a slot antenna, multi-frequency antennas can be created with a low profile, flawless isolation, and easy integration into other planar circuits. The spacing between the vias and the diameter are the key components in the design process also there is some technological gap between them.



**Fig -2:** Technological gap between the micro strip patch and waveguides

The following formula should be used to compute them. The propagation inside a SIW is comparable to that inside a typical hollow waveguide, with a few notable exceptions. The propagating modes resemble the  $TE_{n0}$  mode of the waveguide and are at the  $TE_{10}$  fundamental mode. The size of a SIW and an efficient waveguide with continuous lateral walls are related by several key formulas.

Due to the similarities between the two types of waveguides, it has been discovered that there are empirical correlations between the dimensions of the SIW and the effective width ( $w_{eff}$ ) of the rectangular shape waveguide with the same propagation parameters. These correlations allow for the early design and dimensioning of SIW components without the need for full-wave analysis methods. A relationship found in the design equation is

$$w_{eff} = w - \frac{d^2}{0.95s} \tag{1}$$

where 'd' is the diameter of the metal vias, 'w' signify width of the cavity, ' $w_{eff}$ ' denotes effective width of the SIW and 's' shows spacing between the vias (Fig - 1).

$$w_{eff} = w - 1.08 \frac{d^2}{s} + 0.1 \frac{d^2}{w} \tag{2}$$

Radiation losses are minimized when the vias diameters are large enough and their separations from one another

are small enough. It is possible to empirically determine the vias spacing (s) as a function of diameter (d).

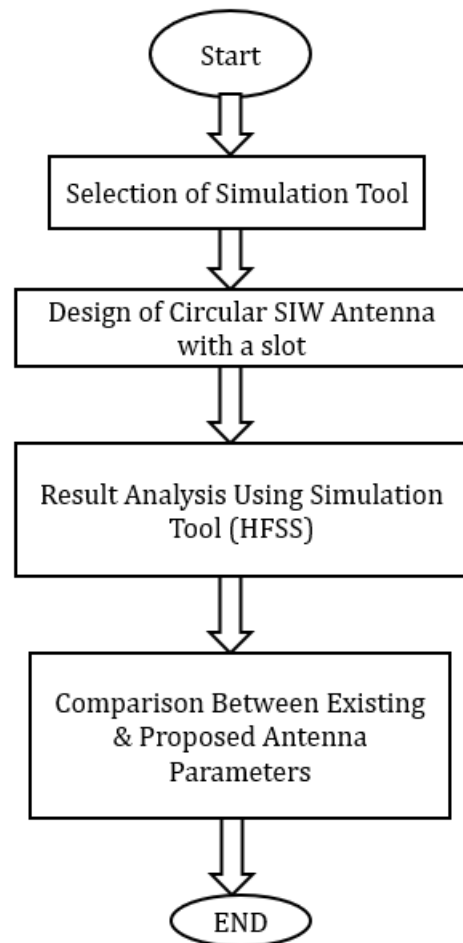
$$\frac{s}{d} < 2.5 \tag{3}$$

The modes of propagation can be calculated using the empirical equation (4)

$$f_{mn0} = \frac{c}{\sqrt{\epsilon_r}} \sqrt{\left(\frac{m}{L}\right)^2 + \left(\frac{n}{w}\right)^2 + \left(\frac{s}{h}\right)^2} \tag{4}$$

Where c is the light velocity in free space, L and W are the cavity's length and width,  $m = 1$ ,  $n = 1$  and  $s = 0$  for the fundamental mode ( $TE_{110}$ ), and  $\epsilon_r$  is the dielectric substrate's relative permittivity. Consequently, SIW design structures show propagation characteristics similar to rectangular waveguides when the metal vias are closely spaced apart and radiation losses are considered.

### 2.1 Antenna Design Flow Chart



**Fig -3:** Pictorial Representation of Antenna Design

The above flow chart represents the pictorial representation of proposed antenna.

## 2.2 Antenna Design Procedure using HFSS

### Step 1

- Adding the substrate (3D plane) in the Editor window.
- Align the substrate using the position.
- Assign the dimensions of the substrate.

### Step 2

- Adding the ground (2D plane) to the substrate in the Editor window.
- Align the ground using the position.
- Assign the dimensions of the ground.

### Step 3

- Adding the patch (2D plane) to the substrate in the Editor window.
- Align the patch using the position.
- Assign the dimensions of the patch.
- Design the specific shapes by using unite or subtract options in the menu bar.

### Step 4

- Add Port material to the substrate.
- Align the material such that it should contain X and Z axis only.
- Assign the dimensions and position.

### Step 5

- Now add the boundaries for the patch and ground.
- Right click on the patch in editor window >> Go to Assign Boundary >> Select Perfect E >> Click ok.
- Repeat same for the ground material.

### Step 6

- Now add the Excitation to the port.
- Right click on the port in editor window >> Go to Assign Excitation >> Select Lumped Port >> Click on Next >> Set the Integration line to New Line >> Now draw a line from ground to patch.

### Step 7

- Now go to the project manager and right click on the Analysis.
- Add Solution Setup >> Click on Auto >> Set the Distribution to Linear Step >> Assign the Start, End and Step Size Frequency >> Click Ok.

### Step 8

- Now from the menu bar go to simulation option.
- Click on validate, If all the steps in the validation shows green mark then go to next step otherwise correct the mistakes in the particular section.
- After the Validation step click on Analyse All.

### Step 9

- Then will notice some messages in the progress and Message Manager Window.
- After noticing "Normal completion of simulation on server: Local machine" message in the message manager window you can generate the reports from the results section in project manager window.

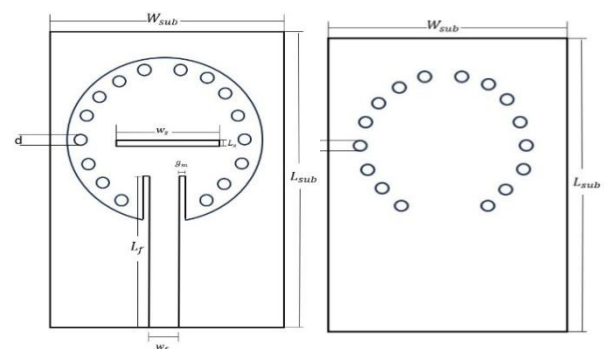
### Step 10

- To generate the results.
- Right click on Results >> Create Modal Solution Data Report >> Rectangular Plot >> Select the Required Parameter >> Click on the New Report.
- After insertion of Infinite sphere, we can simulate the gain and directivity.
- Right click on Results >> Create Far Field Report >> Rectangular Plot >> Select the Required Parameter >> Click on the New Report.

## 3. DESIGN OF PROPOSED ANTENNA

This design consists of bottom as ground plane with substrate and top of circular patch. Which are in common having some cylindrical holes along the patch with some specified measurements called as vias or holes. Vias play the vital role in the radiation of the signal for an SIW antenna.

### 3.1 Antenna Configuration



(i) Top View (ii) Bottom View

Fig -4: Geometry of the proposed antenna

**Table -1:** Dimensions of the proposed antenna

Parameters	Values (in mm)
Length of the substrate ( $L_{sub}$ )	20
Width of the substrate ( $W_{sub}$ )	25
Feed length ( $l_f$ )	11
Feed width ( $w_f$ )	2
Gap between feed to patch ( $g_m$ )	3
Radius of circular patch ( $r$ )	7.5
Diameter of vias ( $d$ )	0.5
Length of the Slot ( $L_s$ )	8
Width of the Slot ( $W_s$ )	0.4
Height of the substrate	1.6

### 3.2 Significance of Circular SIW Antenna with slot

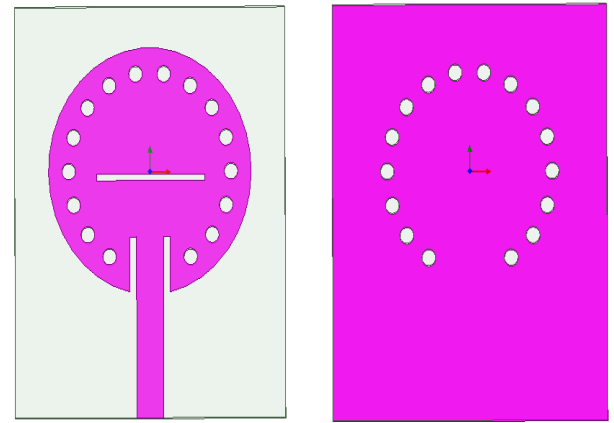
To obtain the best results transverse slot cut is from the circular patch of the antenna, due to this slot the single frequency is radiated by exciting the feed through the port. This can be seen through the field distribution pattern. To obtain the most accurate results is obtained by with and slot consideration. Slot length of 8mm and width of 0.4mm has harvest the radiating frequency 10.75GHz with return loss of -17.22dB, gain is 3dB and VSWR is also in the range between 1-2 only.

**Table -2:** Parametric Analysis based on with and without slot

Parameters	Without Slot	With Slot
S11(dB)	-1	-17.22
VSWR	15.4	1.31
Gain(dB)	-3	3
Bandwidth (GHz)	0	210

## 4. RESULTS

The presented circular volumetric antenna with subtracted slot has been simulated using SIW technology by FR4 substrate. Accordingly observed the parameters using simulation tool Ansys HFSS. The simulated antenna top and bottom view represented in the Fig-5.

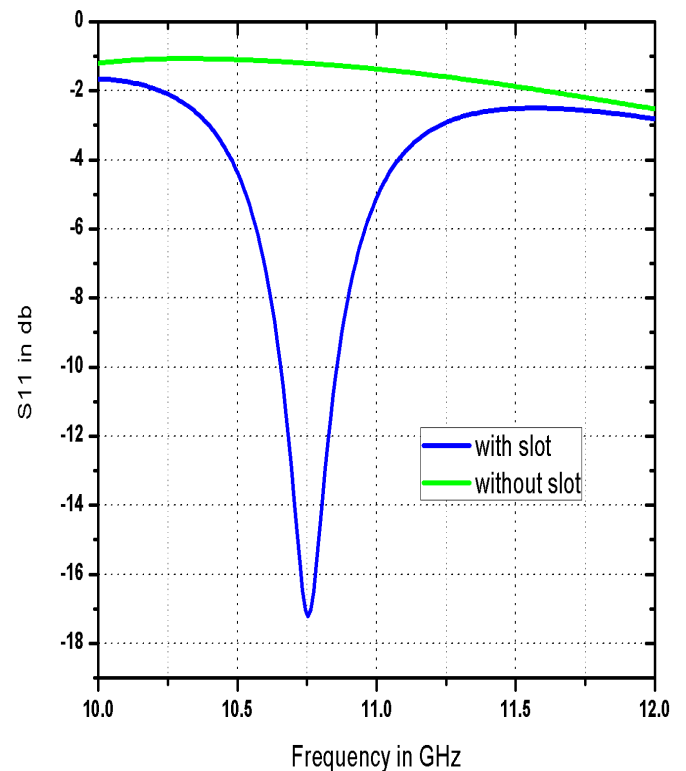


(i) Top View

(ii) Bottom View

**Fig -5:** Simulated antenna

### 4.1 Return Loss



**Fig -6:** Return Loss

From the above graph is clearly noticed that with slot circular SIW antenna obtained at 10.75GHz with -17.22dB return loss. Whereas without slot consideration it's not radiating below -10dB. Accordingly more radiation losses are present.

### 4.2 Voltage Standing Wave Ratio

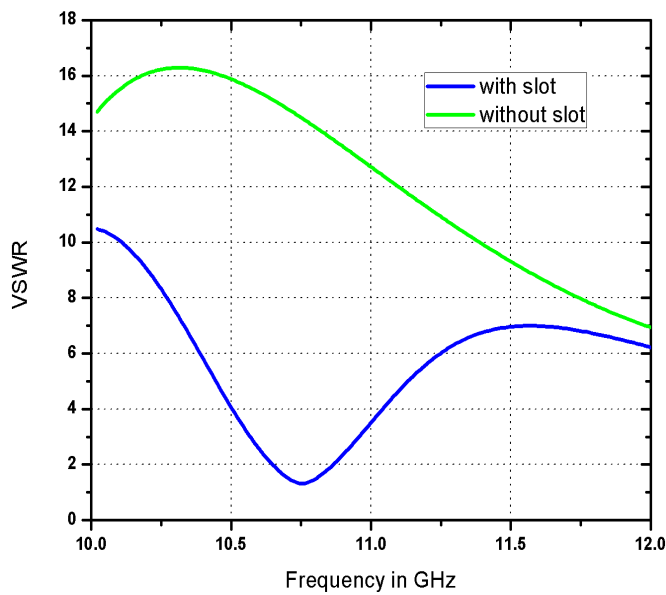


Fig -7: Voltage Standing Wave Ratio

The acceptable VSWR value is above 1 and below 2. From the above plot VSWR value is 1.31 at 10.75GHz without slot of circular SIW antenna. But with slot consideration VSWR is greater than 2, therefore more reflections are takes place.

### 4.3 Bandwidth

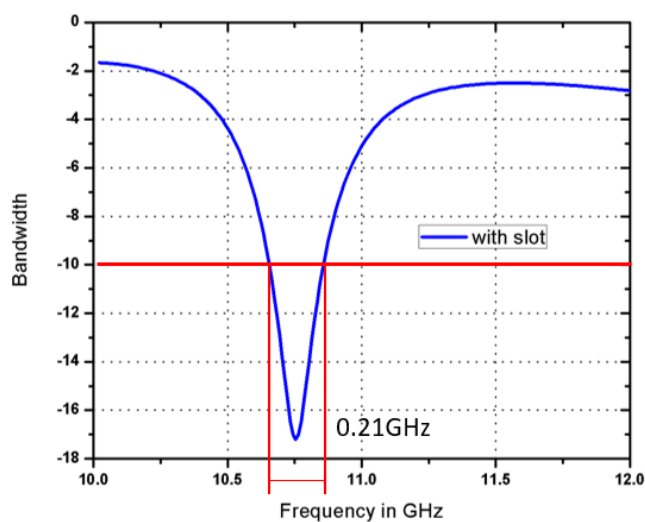


Fig -8: Bandwidth

The bandwidth of an antenna refers to the range of frequencies over which the antenna can operate the bandwidth for this antenna is about 210MHz (10.86GHz-10.65GHz).which is obtained the f1 at 10.65GHz and f2 at 10.86GHz.

### 4.4 Three Dimensional Gain without slot

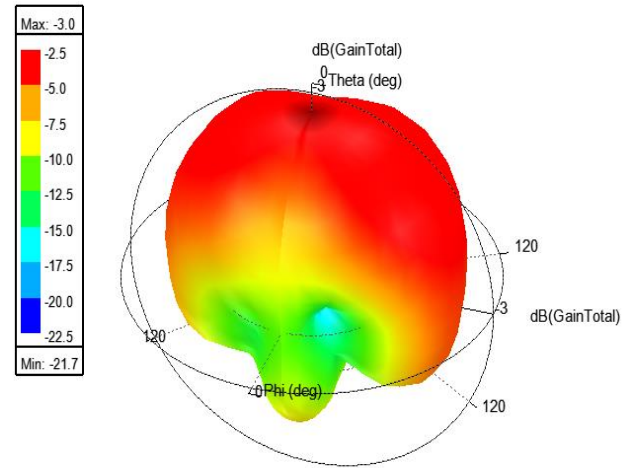


Fig -9: Gain without slot

The acceptable range of gain for an antenna is from 3 dB, and for this simulated antenna obtained the gain of -3dB initially without slot. This is not considerable for practical applications.

### 4.5 Three Dimensional Gain Plot

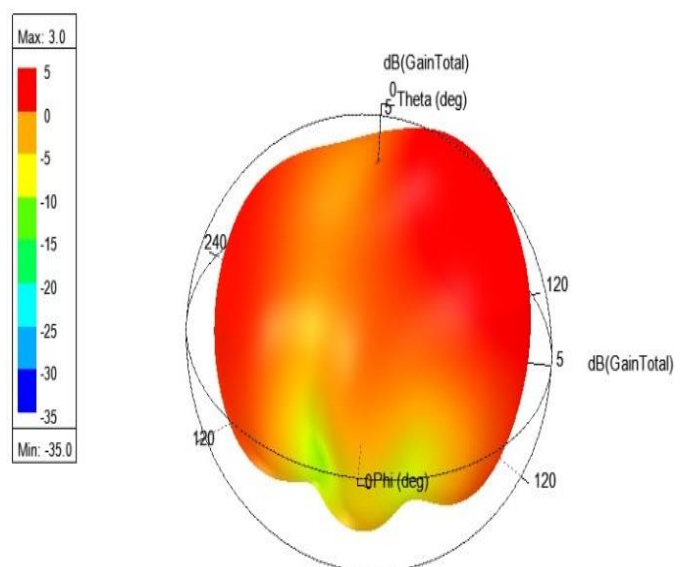


Fig -10: Gain with slot

The gain obtained after placing a slot for the antenna with specific dimensions is 3dB, which is the required gain for any practical antenna.

### 4.6 Electric Field Distribution

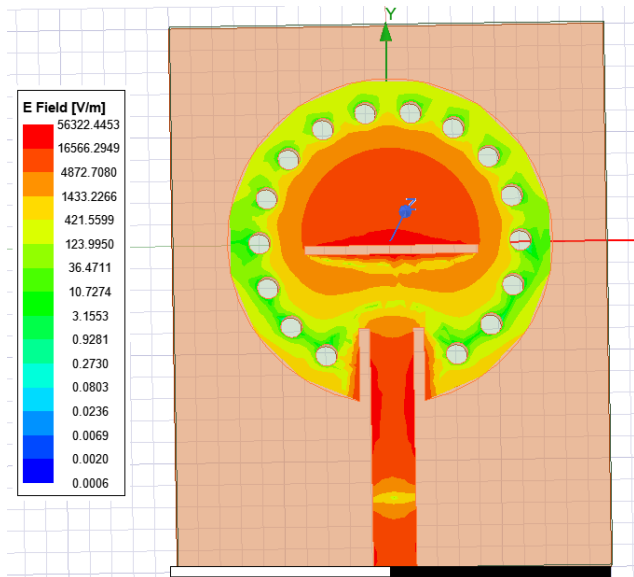


Fig -11: Electric Field Distribution plot

This diagram shows the Electric Field Distribution of the simulated antenna particularly on circular SIW antenna with slot section. The majority of the E-Field can be observed at slot and edges of the patch.

### 4.7 Current Distribution

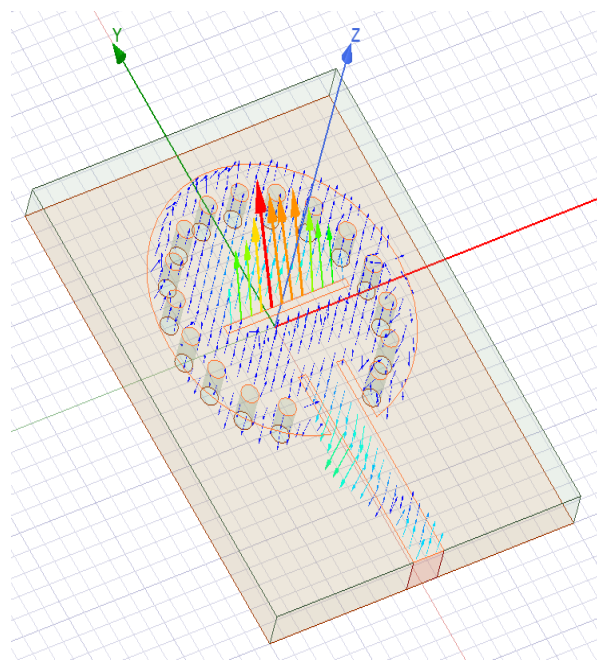


Fig -12: Current Distribution plot

The Current Distribution is also high around the slot and the edges of the patch and it is low around the vias region.

### 4.8 Three Dimensional Directivity plot

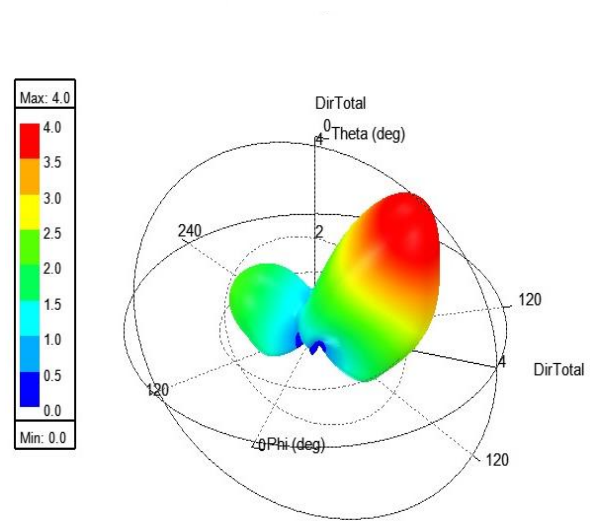


Fig -13: Directivity plot

The Directivity of the simulated antenna is around 4 at the resonating frequency of 10.75GHz.

Table -3: Comparison with existing works with Proposed work

Ref	Radius of Circular patch (mm)	Feed	$f_r$ (GHz)	G (dB)	Band width
6	8	Micro strip Line	5.2	1.7	4%
7	16	Micro strip Line	4.9	1.4	2.1%
8	2.2	Micro strip Line	10	3	2.3%
9	19.75	Micro strip Line	1.7	2	38.3%
10	40	Micro strip Line	2.4	2.2	9.1%
<b>Proposed work</b>	<b>7.5</b>	<b>Micro strip Line</b>	<b>10.75</b>	<b>3</b>	<b>21.0%</b>

The proposed circular volumetric antenna with subtracted slot provides better results. Significantly gain produced 3dB at respective resonating frequency 10.75GHz comparing with ref [6-10].

### 5. CONCLUSION

Initially designed the circular volumetric antenna without slot and then placed a slot with length of 8mm & width of 0.4mm. The acquired results are best for the volumetric antenna with slot and the results are taken out at 10.75GHz with a return loss of -17.22dB. VSWR of 1.31 at 10.75GHz. Gain of 3 dB at 10.75GHz. Obtained bandwidth of 210MHz (10.86GHz-10.65GHz). This proposed antenna design can be used in Radar systems for target detection, Remote sensing applications such as weather monitoring, for 5G networks as SIW antennas can play a role in supporting high-frequency bands, and Microwave imaging for medical imaging systems such as microwave breast imaging for early detection of breast cancer.

### ACKNOWLEDGEMENT






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### REFERENCES

- [1] Constantine A. Balanis, "antenna theory analysis and design", 4th ed. Wiley 2016.
- [2] Ramesh Garg, Prakash Bartia, Inder Bahl, Apisak Ittipiboon, "Microstrip Antenna Design Handbook", Artech House Inc 2001.
- [3] Wael Ali, Ehab Hamad, Mohamed Bassiuny, Mohamed Hamdallah, "Complementary Split Ring Resonator Based Triple Band Microstrip Antenna for WLAN/WiMAX Applications", Radio engineering, Vol.26, No.1, pp. 78-84, Apr.2017.
- [4] Navneet Kumar, Neeraj Julka, "Star Shaped Multiband Antenna for Wireless Application", International Journal of Advancement in Engineering Technology, Management and Applied Science (IJAETMAS), Vol. 04, pp. 29-33, February.2017.
- [5] Razin Ahmed and M. Fokhrul Islam, "Slotted Microstrip Patch Antenna for Multiband Application", International Electrical Engineering Journal (IEEj), Vol. 5, No. 3, pp. 1293-1299, 2014.
- [6] Shalina Garg, Ratish Kumar, "Multiband Microstrip Patch Antenna for Wireless Applications using Metamaterial", International Journal of Advanced Research in Electronics and Communication Engineering (IJARECE), Vol.4, Issue 6, June 2015.
- [7] Ke Wu et.al, "Substrate Integrated Transmission Lines: Review and Applications", IEEE Journal of Microwaves, vol. 1, no. 1, pp. 345- 363, January 2021.

- [8] Daniels et.al, "60 GHz wireless communications: emerging requirements and design recommendations", IEEE Vehicle Technology Magazine, pp. 41-50, 2007.
- [9] Gupta et. al, "Analysis and design of integrated circuit antenna modules", (Wiley, New York, 2000).
- [10] Cassivi et.al, "Dispersion characteristics of substrate integrated rectangular waveguide", IEEE Microwave Wireless Components Letters, vol. 12, pp. 333-335, 2002. Propagation & USNC/URSI National Radio Science Meeting, 2018.

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