DESIGN OF DUAL BAND VOLUMETRIC ANTENNA USING SIW TECHNOLOGY FOR SUB-6GHz APPLICATIONS

V Durga Satish N[1], Jaswanth Varma P[2], Meghana D K[3], Sunil K[4], Sharukh S[5], Ramprasad Ravula[6]

[12345]Graduate Student,[6]Senior Assistant Professor Department of Electronics and Communication Engineering, Sri Vasavi Engineering College, Tadepalligudem, West Godavari, Andhra Pradesh, India.

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Abstract *–Dual band volumetric antenna using SIW (Substrate Integrated Waveguide) technology is presented in this paper. The volumetric size of the antenna is60 mm× 60 mm× 1.6 mm with rectangular patch and ground plane and fed by a micro strip feed line. A rectangular slot is subtracted from the rectangular patch, design and analyzes the characteristics of the volumetric antenna with varying slot length and width using Ansys HFSS simulation tool. The presented antenna achieves dual bands (VSWR ≤2) 5.7GHz and 5.9GHz with gain of 3.41 dB and 4.96 dB at respective frequencies. The projected antenna is low cost and modeled to be used in Sub-6GHz applications.*

Keywords: SIW Technology, Volumetric antenna and Wireless mobile communication.

1. INTRODUCTION

An antenna is the interface between electric currents flowing through metal conductors and radio waves propagating across space. Every radio transmitter and receiver needs to couple their electrical connection to the electromagnetic field.One example of an antenna design with dual functions is the micro strip antenna, which operates in two frequency bands. This is a result of the growing demand to improve the capabilities of wireless systems [1]. The slot patch will, however, modify the emission patterns of the antenna. Switchable slots can also be incorporated into the metal patch to create single-feed dual-band dual-polarized strip antennas [2].

The benefits of substrate integrated waveguide (SIW), including its low cost, low loss, and ease of integration with planar circuits, have been studied [3]–[8]. For integrated microwave and millimeter-wave components and antennas, the SIW has been extensively developed. The dielectric resonator becomes a highly efficient radiator, especially at higher frequencies, when SIW is used to feed it, eliminating the radiation losses of the feeding network [9]. With this method, rows of closely spaced metallic vias between two planes replicate the surrounding walls of a thin rectangular-type waveguide filled with dielectric [10].Many technological challenges arise when using SIW in arrays and antenna structures at lower frequencies. These challenges include reduced dimensions, losses, accurate production of SIW structures, fabrication constraints, and substrate selection. It appears that the creation of extremely compact and integrated systems is made possible by SIW-based antennas and arrays in wireless systems [11].The Internet of Things (IoT) and Fifth Generation (5G) connectivity have been explored. Among the near-future sub-6GHz applications are smart grid, smart cities and telemedicine [12].

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).

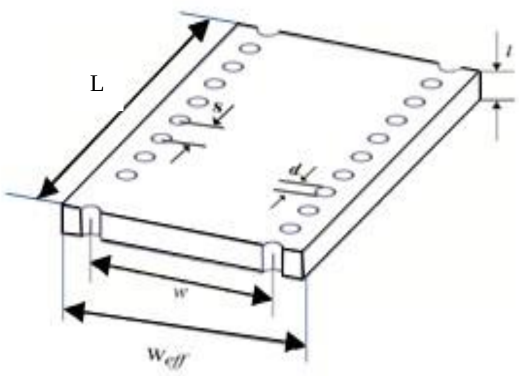


Fig -1: Structure of SIW Antenna

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	- Height of the substrate

With the use of a slot antenna, multi-frequency antennas can be created with a low profile, isolation, and easy integration into other planar circuits. The diameter and the via spacing are important design factors, albeit there is a technological difference between them.

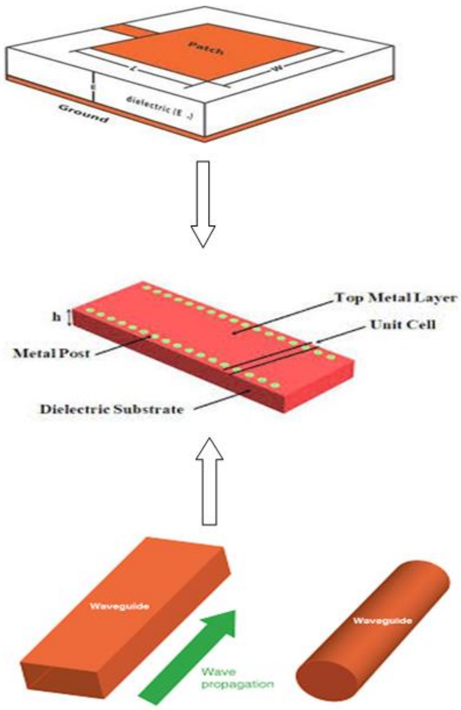


Fig -2: Technological gap between the micro strip patch and waveguides

The propagation inside a SIW is comparable to that inside a typical hollow waveguide, with a few notable exceptions. The propagating modes resemble the TEn0 mode of the waveguide and are at the TE10 fundamental mode. The size of a SIW and an efficient waveguide with continuous lateral walls are related by several key formulas.

It has been discovered that there are empirical correlations between the SIW dimensions and the effective width (‘ w_{eff} ’) of the rectangular shape waveguide with the same propagation parameters. These relationships emerge from the similarities between the two types of waveguides. Without using full-wave analysis techniques, these connections allow for the early design and dimensioning of SIW components. Among the correlations in the design equations is

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

Where ‘d’ is the diameter of the metal vias, ‘w’ signify width of the cavity, ‘w_{eff}’ denote effective width of the SIW and ‘s’ represents spacing between the vias (Fig - 1).

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

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 ascertain the vias spacing(s) as a function of diameter (d).

$$\frac{s}{d} < 2.5 \quad (3)$$

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

$$fmn0 = \frac{c}{2\sqrt{\varepsilon r}}\sqrt{\left(\frac{m}{L}\right)^2 + \left(\frac{n}{w}\right)^2 + \left(\frac{s}{h}\right)^2} \quad (4)$$

Where L and W are the cavity's length and width, c is the light velocity in free space, and ε_r is the dielectric substrate's relative permittivity. For the fundamental mode (TE_{110}), m = 1, n = 1 and s = 0. 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 Flow Chart of Proposed Antenna

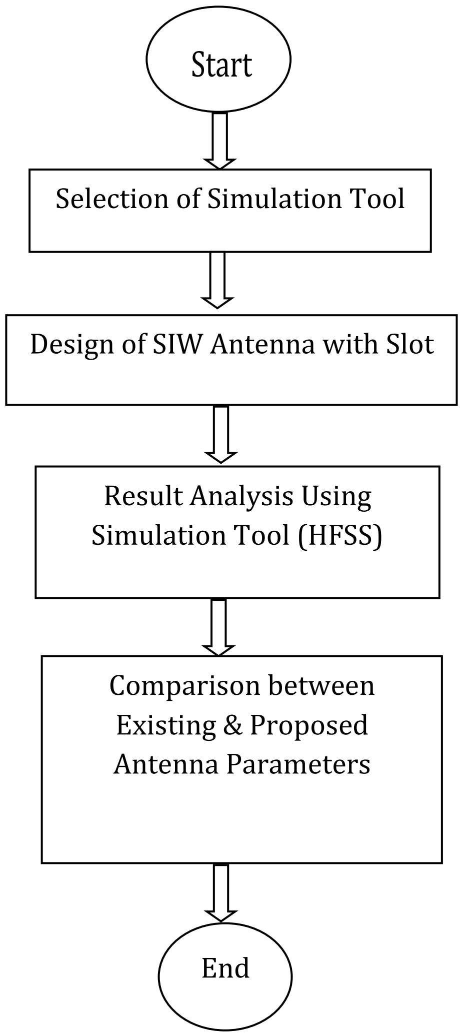


Fig -3: Pictorial Representation of Antenna Design

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 goto simulation option.
- Click on Validate,if all the steps in the validation shows green mark,then go to nextstep 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 a ground plane with substrate and patch which are in common having some cylindrical holes from top to bottom with some specified measurements called as vias. Vias plays the vital role in the radiation of the signal for an SIW antenna. For obtaining the dual bands introducing a transversal slot in the middle of the antenna (Fig – 3).

3.1 Mathematical Analysis

Width $=Vo/2f_r\sqrt{(2/\varepsilon_r)}$
ε_{reff} $=((\varepsilon_r+1)/2+(\varepsilon_r-1)/2[1+12h/w])\ \hat{}\ (-1/2)$
ΔL $=0.412*h((\varepsilon_{reff}+0.3)$
$(w/h+0.264))/((\varepsilon_{reff}-0.258)(w/h+0.8))$
Length = $Vo/(2f_r\sqrt{\varepsilon_{reff}})-2\Delta L$
Effective Width: $w_{eff}=w-d\hat{}2/0.95s$
Ratio of s/d: $s/d< 2.5$
Modes of Propagation:
$f_{mn0}=c/\sqrt{(2\varepsilon_r)}\sqrt{((m/L)\ \hat{}\ 2+(n/w)\ \hat{}\ 2+(s/h)\ \hat{}\ 2)}$
Let V_o = 3×10^8
f_r = 2.4GHz
ε_r = 4.4
h = 1.6 mm
Width = $Vo/2f_r\sqrt{(2/\varepsilon_r)}$
= (3×10^8)/ (2×2.4×10^9) √ (2/ (4.4+1))
Width = 38.036 mm
ε_{reff} $=((\varepsilon_r+1)/2+(\varepsilon_r-1)/2[1+12\ h/w])\ \hat{}\ (-1/2)$
= ((4.4+1)/2+(4.4−1)/2[1+12×1.6/16.015]) ^ (−1/2)

ε_{reff} = 3.586

$\Delta L = 0.412*h((\varepsilon_{reff}+0.3)(w/h+0.264))/((\varepsilon_{reff}-0.258)(w/h+0.8))$

$= 0.412*1.6\ ((3.586+0.3)\ (38.036/1.6+0.264))/((3.586-0.258)\ (38.036/1.6+0.8))$

$\Delta L = 0.7528$

Length $= Vo/(2f_r\sqrt{\varepsilon_{reff}}) - 2\Delta L$

$= (3\times10^8)/(2\times2.4\times10^9\times\sqrt{3.586}) - 2\times0.7528$

$= 31.00436 - 1.5056$

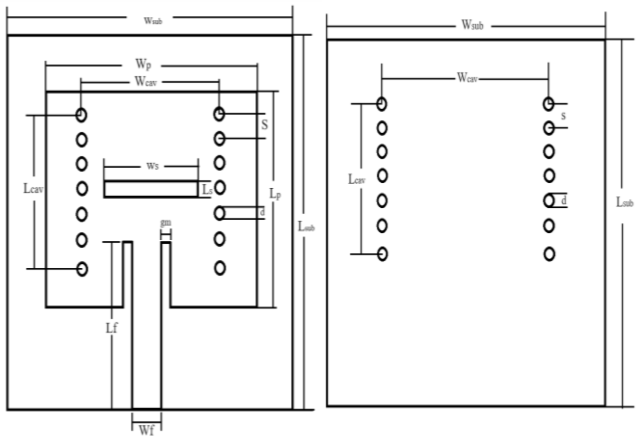
Length = 29.49903 mm

The required width and length of volumetric antenna for specific Parameters are:

Width = 38.036 mm

Length = 29.49903 mm.

3.2 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 (Lsub)	60
Width of the substrate (Wsub)	60
Length of the cavity (Lcav)	24
Width of the cavity (Wcav)	23
Feed length (lf)	15.3
Feed width (wf)	3
Length of the patch (Lp)	29.4
Width of the patch (wp)	38
Gap between feed to patch (gm)	3.25
Spacing between vias (s)	4
Diameter of vias (d)	2.6
Length of the Slot (Ls)	1.6
Width of the Slot (Ws)	16
Height of the substrate	1.6

3.3 Significance of Dual Band SIW Antenna with slot

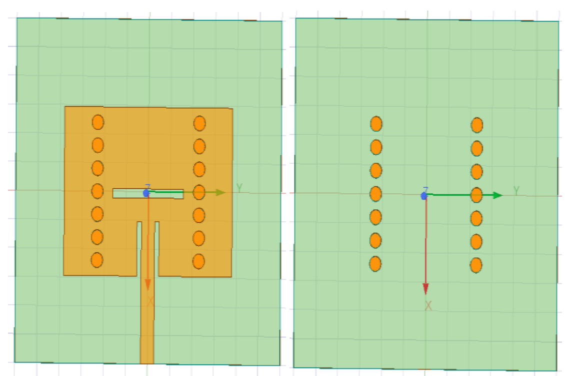
To obtain the dual band frequency the short transverse slot cut is included into the top plane of the antenna, due to this slot the frequency which is applied through the port will be divided in to two frequencies which can be seen through the field distribution pattern. To obtain the most accurate results the length and width of the transverse slot is varied in steps of 0.2mm and the graphs where plotted for the visual comparison, among all the results the one with slot length of 1.6mm and width of 16mm has produce the better results. For both the band of frequencies at this slot the gain is above 3dB and VSWR is also in the range of 1-2 and the return loss has above -16 dB.

Table -2: Parametric Analysis based on slot dimensions

DIMENSIONS OF SLOT		FREQUENCY (f1) = 5.7 GHz			FREQUENCY (f2) = 5.9 GHz		
W	L	S11 (dB)	G (dB)	D	S11 (dB)	G (dB)	D
16	1.6	-17.3	3.41	6.35	-26.7	4.96	7.47
16.2	1.8	-14.6	2.77	5.88	-18.7	4.81	7.32
16.4	2.0	-11.9	2.81	5.92	-15.2	4.69	7.20
16.6	2.2	-10.4	3.36	6.38	12.8	4.64	7.13
16.8	2.4	-8.8	3.37	6.37	-11.0	4.62	7.10
17	2.6	-7.9	3.59	6.59	-9.81	4.53	7.03
17.2	2.8	-5.7	3.49	6.53	-8.73	4.30	6.86

4. RESULTS

The presented volumetric antenna with subtracted slot has been simulated and changing slot dimensions with 0.2mm progressive increment using SIW technology by FR4 substrate. Accordingly observe 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

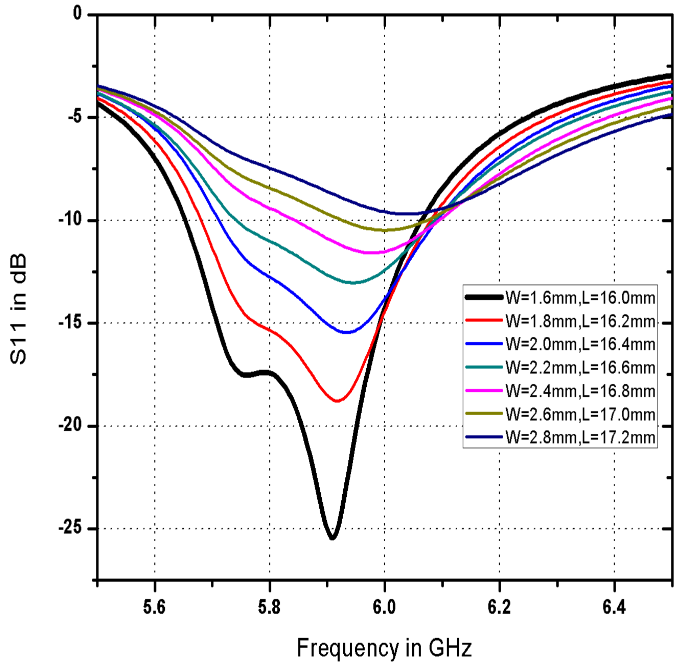


Fig -6: Return Loss

By adjusting the slot width and length the results are compared (Table 2) in steps of 0.2mm and plotted and considering the best ones represented with black color for the return loss obtained dual bands at 5.7GHzand 5.9GHz with -17.3dB and -26.7 dB respectively.

4.2 Voltage Standing Wave Ratio

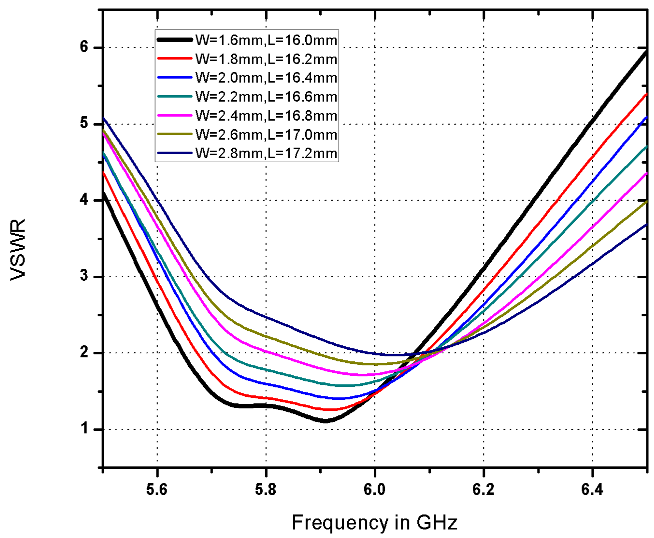


Fig -7: Voltage Standing Wave Ratio

The acceptable VSWR value is in the range of 1-2, from the VSWR graph plot it is clearly noticed that 1.31 and 1.09 are the values of VSWR at respective radiating frequencies.

4.3 Directivity

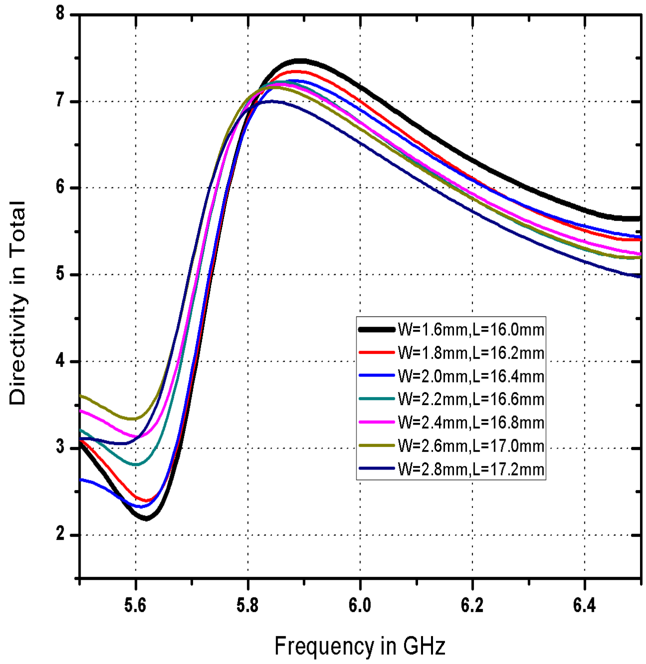


Fig -8: Directivity

The directivity in general should be more than the gain of the antenna and observed directivity of proposed antenna is 6.53 at 5.7GHz and 7.47 at 5.9GHz.

4.4 Gain

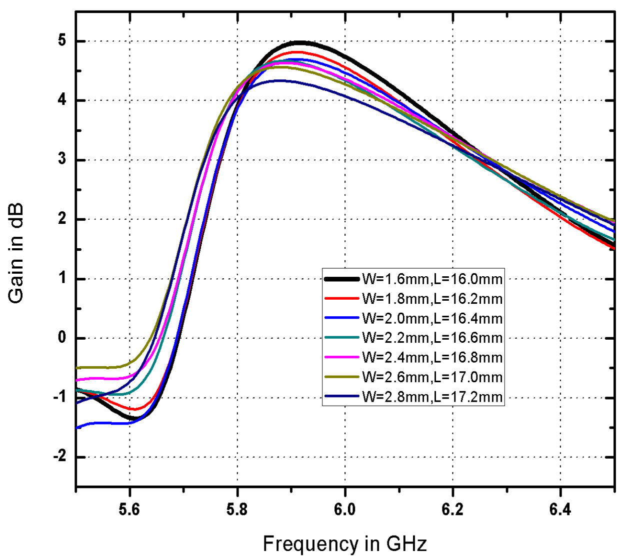


Fig -9: Gain

The acceptable range of gain for an antenna is from above 3 dB and for this simulated antenna obtained the gain of 3.41dB at 5.7GHz and 4.96 dB at 5.9GHz.

4.5 Bandwidth

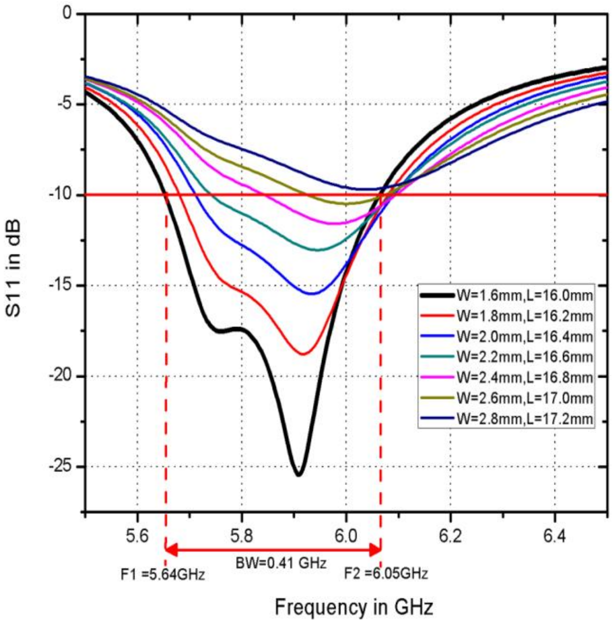


Fig -10: Bandwidth

The bandwidth of an antenna refers to the range of frequencies over which the antenna can operate. The bandwidth for this antenna is about 410MHz which is considerably more we have obtained the F1 at 5.6GHz and F2 at 6.05GHz and after the calculation BW =410MHz [F2 – F1].

4.6 E-Field Distribution

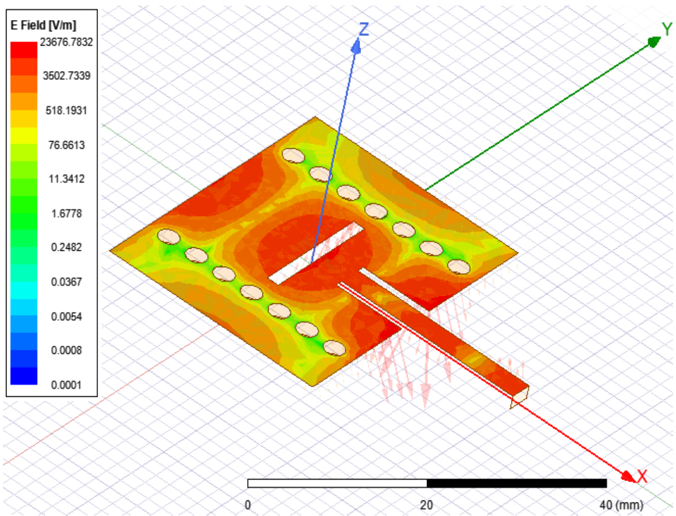


Fig -11: Field Distribution

The above diagram shows the Electric Field Distribution of the simulated antenna particularly on patch section, majority of the E-Field distribution can be observed at slot and edges of the patch.

4.7 Current Distribution

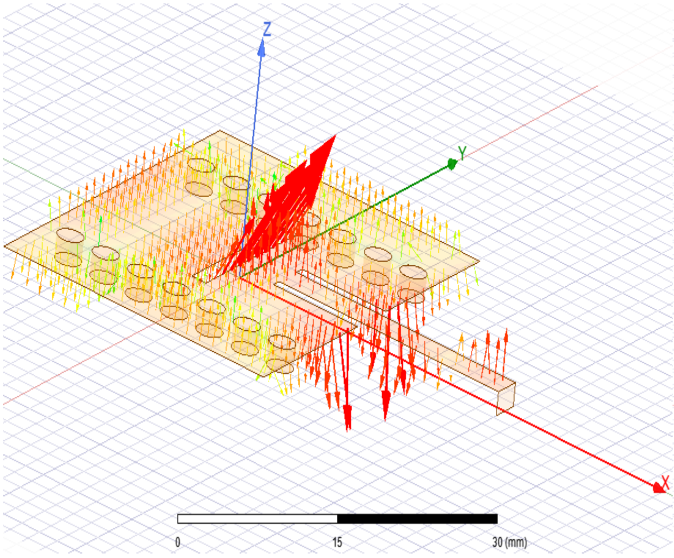


Fig -12: Current Distribution

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

4.8 Three Dimensional Gain Plots

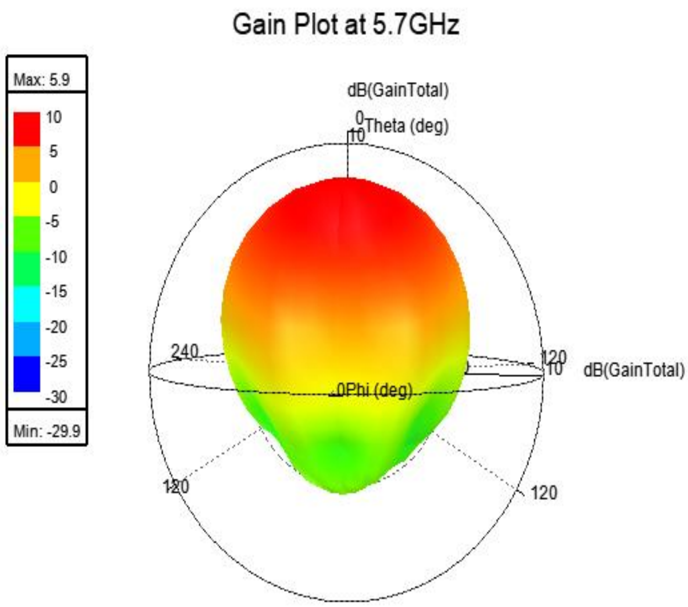


Fig -13: Gain Plot at 5.7GHz

The above diagram represents 3-dimmensional gain plot which harvesting 5.9dB at radiating frequency of 5.7GHz.

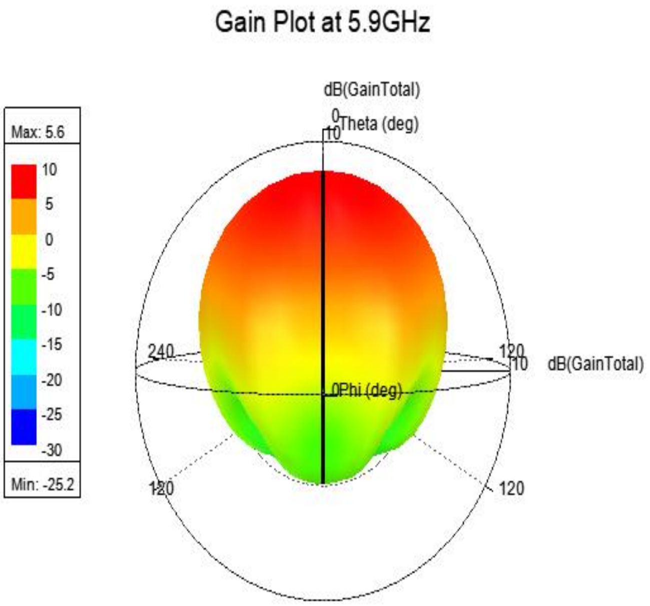


Fig -14: Gain Plot at 5.9GHz

The Figure-14 shows diagram 3-dimmensional gain plot which produce 5.6dB gain at resonating frequency of 5.9GHz.

4.9 Three Dimensional Directivity Plots

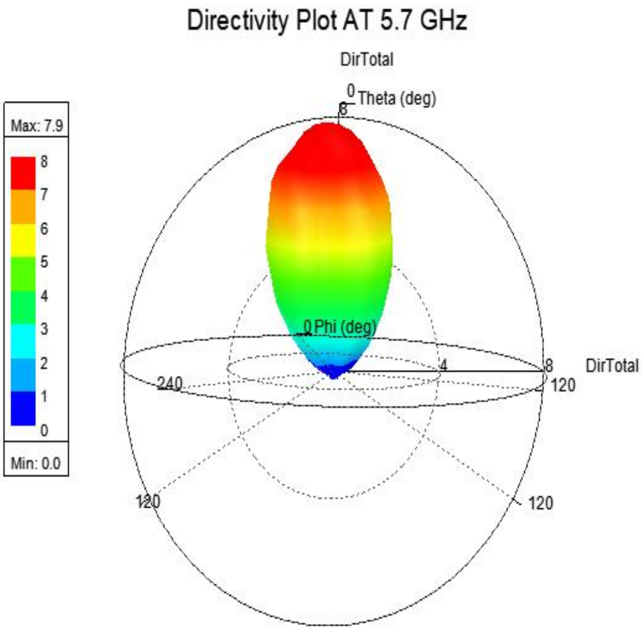


Fig -15: Directivity Plot at 5.7GHz

The above diagram shows 3-dimmensional directivity plot which obtained directivity of 7.9 at resonating frequency of 5.7GHz.

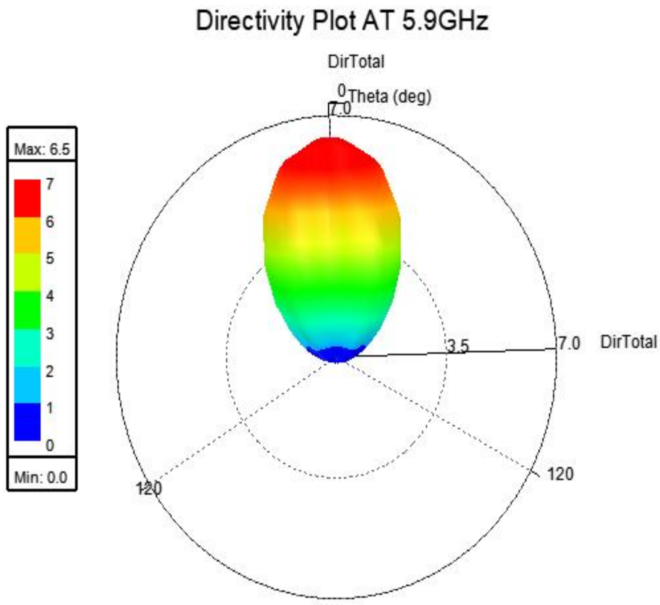


Fig -16: Directivity Plot at 5.9GHz

The Figure-16 represents 3-dimmensionaldirectivity plot which generates directivity of 6.5 at resonating frequency of 5.9GHz.

Table -3: Comparison with existing works with proposed work

Ref	(L*W*h)	Dielectric	Feed	fr (GHz)	Gain (dB)	Bandwidth (MHz)
13	43.8x43.8x2	1.2	Micro strip Line	3.5 & 5.8	2.8 & 3.5	50 & 350
14	42.5x31.9x3	1.17	Micro strip Line	5.26 & 5.85	4.3	300
15	32.3x41.9x3	1.3	Micro strip Line	2.5 & 5.5	2.9 & 5.0	157 & 667
16	33×43×5.23	2.2	Micro strip Line	2.6 & 5.9	3.11 & 6.09	40 & 160
17	8.2x5.2x1.57	2.2	Micro strip Line	3.04 & 5.08	2.1 & 1.9	77 & 213
Proposed Work	**29.4x38x1.6(Patch)**	**4.4**	**Micro strip Line**	**5.7 & 5.9**	**3.41 & 4.96**	**410**

The proposed volumetric antenna with subtracted slot provides better results as compared to reference [13 -17]. Significantly gain produced above 3dB at respective resonating frequencies 5.7GHz and 5.9GHz.

5. CONCLUSION

Designed the Volumetric Antenna for Dual band frequencies using the SIW Technology and Placed a slot with length of 1.6mm & width of 16mm and obtained the bands at 5.7GHz and 5.9GHz with a return loss of -17.3 dB and -26.7 dB respectively.VSWR of 1.3 at 5.7GHz & 1.0 at 5.9GHz. Gain of 3.4 dB at 5.7GHz & 4.9 dB at 5.9GHz.

Obtained bandwidth of 410MHz (6.05GHz-5.64GHz).This proposed antenna design can be used in Sub-6GHz applications [5G applications] significantly like RF Transceiver, Drone Operations at 5.7GHz and Automatic toll collection, Spot weather-impact warnings, Traffic light control at 5.9GHz(Safety Band).

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BIOGRAPHIES

	**Mr. V Durga Satish N** Final Year B.Tech student in the Electronics & Communication Engineering Department at Sri Vasavi Engineering College(A),Tadepalligudem, West Godavari,Andhra Pradesh and India.
	**Mr. Jaswanth Varma P** Final Year B.Tech student in the Electronics & Communication Engineering Department at Sri Vasavi Engineering College(A) Tadepalligudem, West Godavari, Andhra Pradesh and India.
	**Ms. Meghana D K** Final Year B.Tech student in the Electronics & Communication Engineering Department at Sri Vasavi Engineering College(A) Tadepalligudem, West Godavari, Andhra Pradesh and India.
	**Mr. Sunil K** Final Year B.Tech student in the Electronics & Communication Engineering Department at Sri Vasavi Engineering College(A) Tadepalligudem, West Godavari, Andhra Pradesh and India.
	**Mr. Sharukh S** Final Year B.Tech student in the Electronics & Communication Engineering Department at Sri Vasavi Engineering College(A) Tadepalligudem, West Godavari, Andhra Pradesh and India.
	**Ramprasad Ravula** Completed his M.Tech in 2009 from JNTUK, Kakinada, Andhra Pradesh. He has totally 15 Years of teaching experience. Presently he is working as Sr. Assistant Professor in the Department of Electronics and Communication Engineering of Sri Vasavi Engineering College (A), Tadepalligudem, West Godavari, Andhra Pradesh and India. His interested areas of Research are Antennas significantly SIW antenna.