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NOVEL DESIGN OF VOLUMETRIC ANTENNA FOR WIDEBAND APPLICATIONS

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ABSTRACT

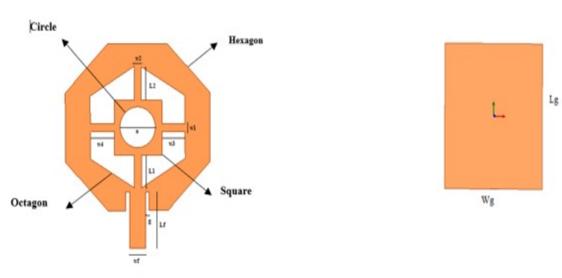
This paper focused on designing a volumetric antenna to achieve high gain and high band width. For ground penetrating radars, medical microwave imaging to detect breast cancer, wideband antennas are significant. This paper focused on designing a volumetric wideband antenna to achieve high directivity high gain and high band width to address the challenges of both radar and medical imaging applications. The width of the antenna, effective dielectric constant, defective length, extension length, and micro strip patch length are meticulously tuned to achieve high directivity, high gain, and bandwidth. The proposed antenna is designed until the return losses, directivity, VSWR, gain and bandwidth values meet the requirements of volumetric wideband applications. The top layer is a hexagon patch. Octagonal is subtracted from hexagonal patch. And then circle is subtracted from the square. FR 4 is used as a dielectric substrate. Return loss (S_{11}) parameter value is analysed at each stage of the antenna. The antenna Resonates at14.22GHz and15.33GHz, Voltage standing wave ratio (VSWR) is estimated, maximum peak gain (G) is achieved at 4.59dB. The band width achieved is 1.88. Input impedance is at 50Ω, current distribution and electric field distribution are evaluated. The VSWR and gain values, return losses, bandwidth are analysed at each stage of the design. The results achieved with the proposed antenna are matched with wide range of wireless sensor applications including Ku band and in specifically in medical era.

Keywords: *Bandwidth, Gain, Voltage Standing Wave Ratio (VSWR) And Volumetric Antenna, Return Losses.*

1. INTRODUCTION

Volumetric antenna is nothing, but micro strip patch antenna is significant for wireless transmission[1]. The proposed antenna is designed for a wide range of applications. Mounting the volumetric antenna at the host device makes it easy to radiate the signal. Dielectric substrate is used to isolate the metal patch and ground plane[1][2]. The proposed volumetric antenna comprising of hexagon shaped patch as a top layer within a square integrating slot considered in four directions i.e., front, back, left side and right side. Octagonal is subtracted from hexagonal patch (as a copper) accordingly circle is subtracted from the square patch (as a copper) with micro strip line feeding technique.

The middle layer is a frame retardant substrate.FR4 is considered as a dielectric substrate material with dielectric constant of ε_r = 4.4 and thickness of the substrate (h) is 1.6mm. The bottom layer is a copper ground plane. Antenna parameters are analysed using micro strip line feed technique [4][5][6].



(i) Top View (ii) Bottom view

Figure 1.1: Designed volumetric antenna Top and Bottom view

The RF power is fed directly to the hexagon shaped radiating patch using a micro strip line that acts as a connecting element. Integrating slots are used to distribute the power to hexagon patch and square shaped patch. These two patches are radiating energy over a total top area of the patch and more energy will be concentrating on edges of the patches [7][8][9][10]. The design view of antenna is shown in Figure1.1

2. METHODOLOGY

In order to implement the novel design of volumetric antenna, various design iterations are implemented. Proposed antenna or design iteration FR4 gives better performance in parametric analysis. Various design iterations are shown in the figures below Fig 2.1. (i) to (iv). In order to design and implement proposed novel structure of volumetric antenna, the basic methodology follows as an algorithm.

Step I. The width (W) of the micro strip patch

$$:w = \frac{c_0}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}}$$

Where

c_o = Light velocity.

ε_r = Dielectric constant

f_r = Radiating frequency

Step II. Effective dielectric constant (ε_{eff})

$$:\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1+12\frac{h}{w}\right]^{-\frac{1}{2}}, \frac{h}{w} > 1$$

Where

ε_{reff} = Effective dielectric constant

ε_r = Dielectric constant of substrate

H = Height of dielectric substrate

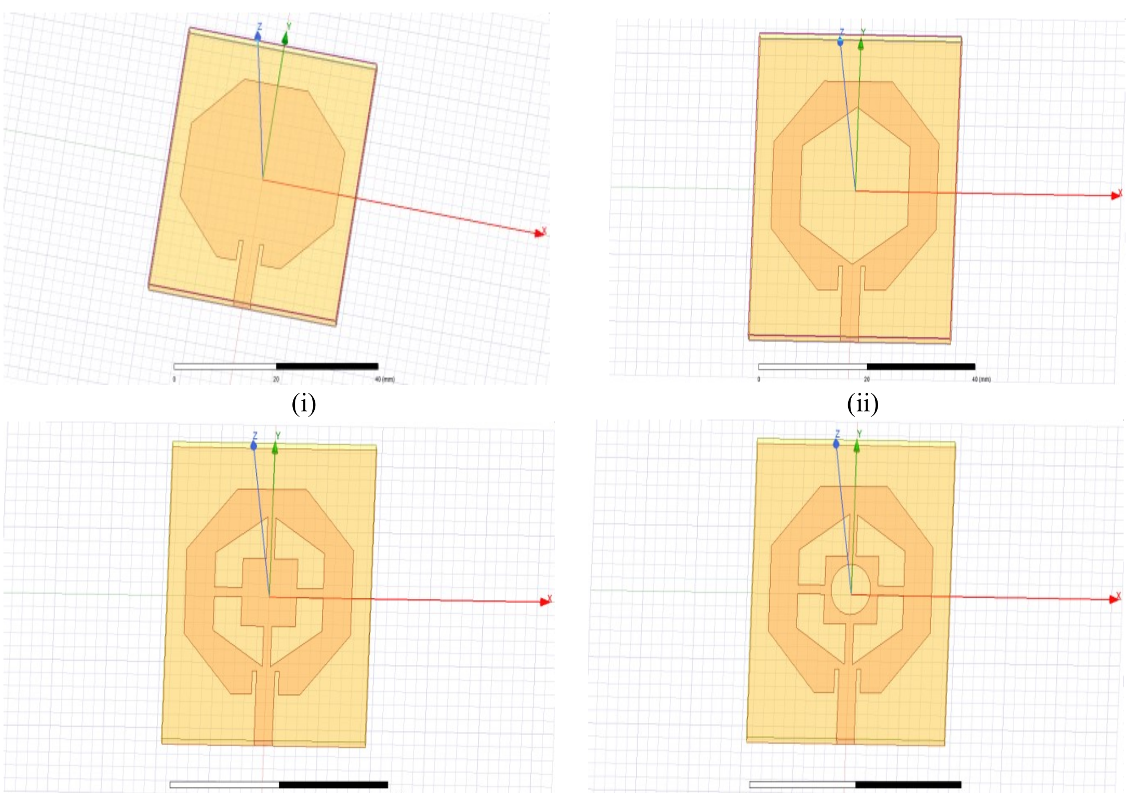
W = Width of the patch

The length of the antenna increases electrically because of fringing [11], so the increase in length is:

Step III. Effective length (L_{eff}): $L_{eff} = \frac{c}{2f_0\sqrt{\varepsilon_{eff}}}$

Step IV. Extension length (ΔL):

$$\frac{\Delta L}{h} = 0.412\frac{(\varepsilon_{reff}+0.3)\left(\frac{W}{h}+0.264\right)}{(\varepsilon_{reff}-0.258)\left(\frac{W}{h}+0.8\right)}$$



(i) (ii) (iii) (iv)

Figure 2.1. (I) To (Iv) Various Design Iterations Of Micro Strip Patch Antenna

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The length 'L' is considered to determine the resonant frequency of the proposed patch antenna. Owing to the fringing field the actual length is bit large and L is considered less than half the dielectric wavelength [12][13]. The antenna performance characteristics are analyzed with the proposed design and fringing effect. Parametric dimensions (in mm) of the antenna are shown in table 2.1.

3. RESULTS AND DISCUSSION

The simulated results are obtained using HFSS (High Frequency Structured Simulator)

Design Iteration-1:

Design iteration-1 considered as hexagonal shaped patch antenna.

The Return loss plot represents the quantity of a reflected signal considered as a S11.It radiate multiple frequencies i.e.,8.05GHz,8.8GHz,9.3GHz,10.67GHz,11.17GHz,13.15GHz,15.35GHz and 15.9GHz with reflection coefficients of -18.8,-13.19,-29.27,-33.95,-24.22,-30.16,-23.7 and -13.75 respectively.

Table.2.1: . Parametric Dimensions (In Mm) Of The Antenna

Parameter	Lsub=Lg	Wsub=Wg	H	ε_r	Wf	Lf	G	L1	L2	W1	W2	W3	W4	A
Dimension (mm)	45	38	1.6	4.4	3.4	10.5	0.8	6.8	6.8	1.6	1.6	5.18	5.18	3.8

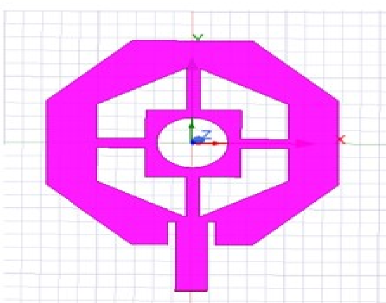

Fig.2.1 Simulated Antenna Top View

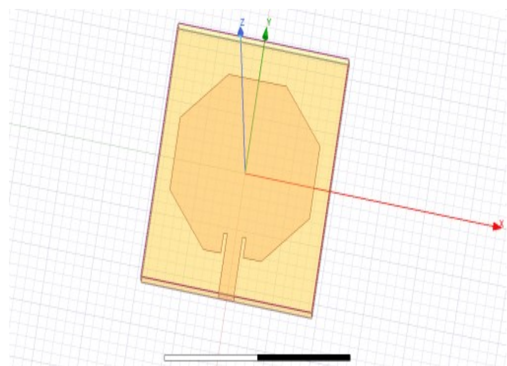

Fig. 3.1: Hexagon Shaped Patch Antenna

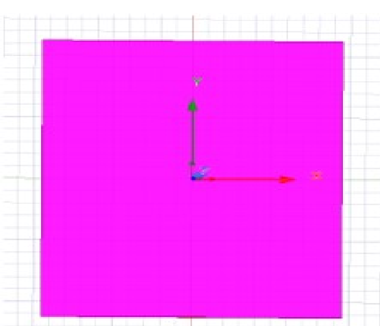

Fig.2.2 Simulated Antenna Bottom View

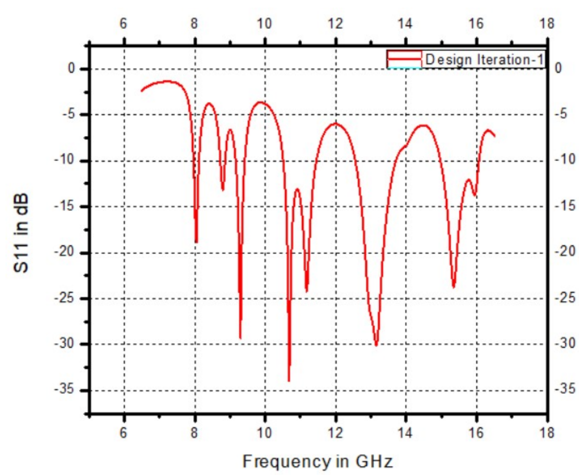

Fig. 3.2: Return Loss Plot

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The voltage standing wave ratio (VSWR) is 1.29, 1.56, 1.07, 1.04, 1.13, 1.09, 1.13 and 1.54 at respective frequency bands. This represents the impedance matching between the field and the load and is approximately close to'1'. But in ideal case the VSWR is '1'. practically the VSWR is considered a good value which is below '2'. The obtained VSWR shows that the antenna is operating significantly well. The characteristic impedance Z_0 is 50 Ω. And the load applied is also 50 Hz. The VSWR is approximately equal to value '1' with decreased VSWR values. The variation of VSWR from 1.56 to 1.07is due to reflections [14][15]. Hexagonal patch antenna is observed with the simulated gains of -6.6dB, -4.4dB, -8.06dB, 0.0dB, 2.7dB, -0.7dB, -1.4dB and 10.27dB at respective frequencies. It is clearly noticed at frequencies 11.17GHz and 15.9GHz, the gain is considerable. For remaining all frequencies, the gain is undesirable because gain values are negative with respective frequencies [16]18].

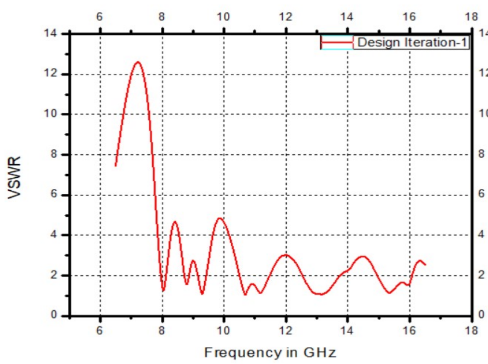

Fig. 3.3: VSWR Plot

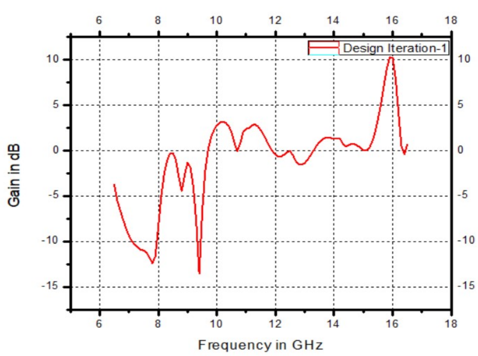

Fig 3.4: Gain Plot

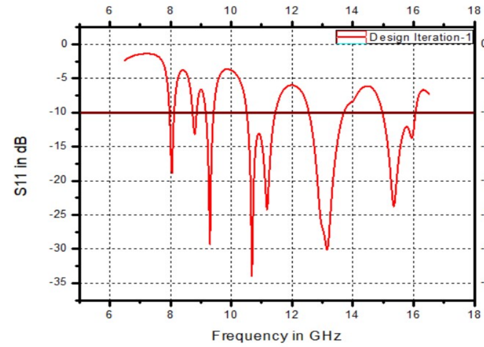

Fig. 3.5: Bandwidth plot

Design Iteration-2:

In design iteration-2 octagon subtracted from hexagonal patch antenna.

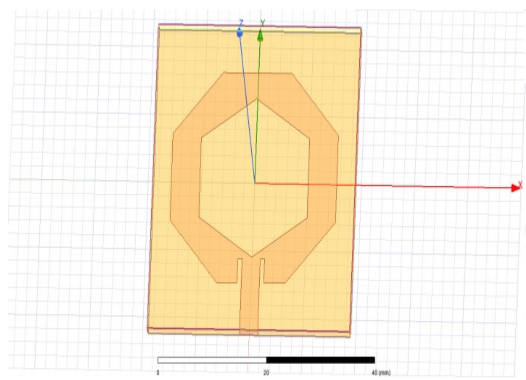

Fig. 3.6: Octagon Subtracted From Hexagon Patch Antenna

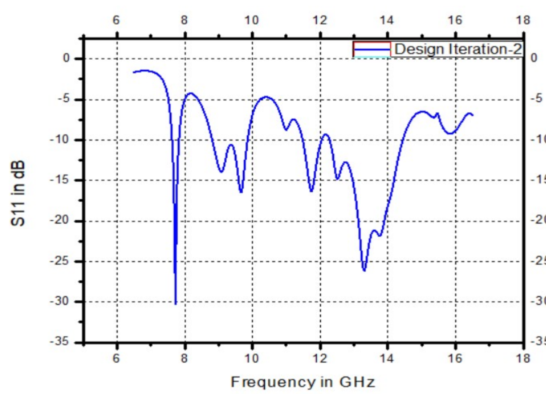

Fig. 3.7: Return Loss Plot

The Return loss plot represents the quantity of a reflected signal considered as a S11. It radiates multiple frequencies i.e.,7.72GHz,9.1GHz,9.6GHz,11.72GHz,12.52GHz,13.3GHz and 13.7GHz with reflection coefficients of -30.2, -

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13.97,-16.42,-16.29,-14.80,-26.18 and -21.81 respectively

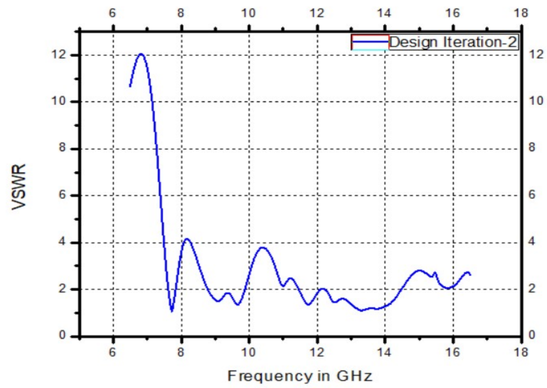

Fig. 3.8: VSWR Plot

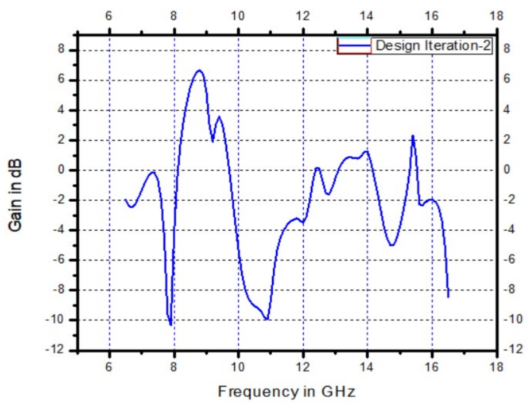

Fig. 3.9: Gain Plot

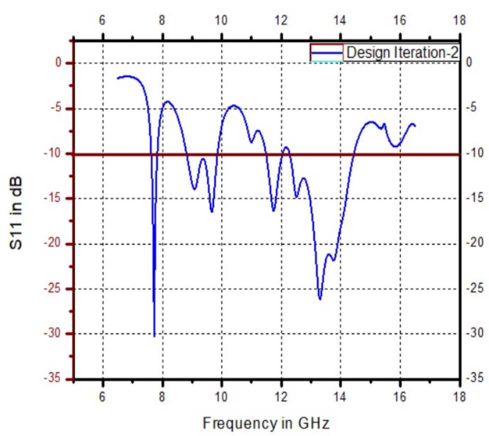

Fig. 3.10: Bandwidth Plot

The voltage standing wave ratio (VSWR) is 1.18, 1.5, 1.35, 1.36, 1.44, 1.18 and 1.10 at respective frequency bands. The obtained VSWR shows that the antenna is operating significantly well. The characteristic impedance Z_0 is 50 Ω. And the load applied is also 50 Hz. The VSWR is approximately equal to value '1' with decreased VSWR values.

Octagon subtracted with hexagon the maximum gain obtained is 3.1 dB with resonating frequency of 9.1 GHz. The remaining gain values are below 3dB which are undesirable for wireless applications. The gain is decreased with octagon subtracted from hexagon

Design Iteration-3:

In design iteration-3 Square patch antenna is integrated to hexagonal patch antenna using slots.

The Return loss plot represents the quantity of a reflected signal considered as a S11. It radiate multiple frequencies i.e.,7.72GHz,8.75G Hz,9.02GHz,10.80GHz,12.40GHz,13.90GHz and 15.15GHz with reflection coefficients of -23.42,-37.82,-23.14,-14.43,-15.74,-29.12 and -26.82 respectively.

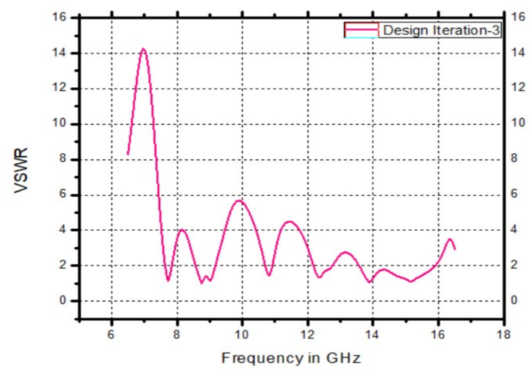

Fig. 4.2: VSWR Plot

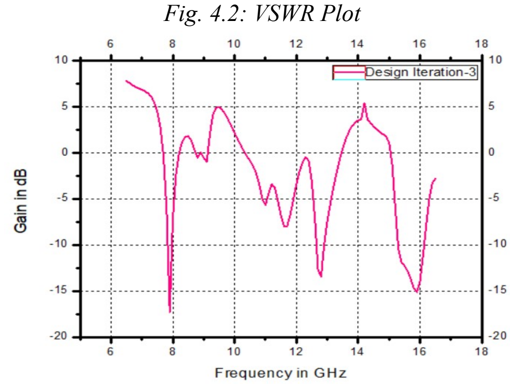

Fig. 4.3: Gain Plot

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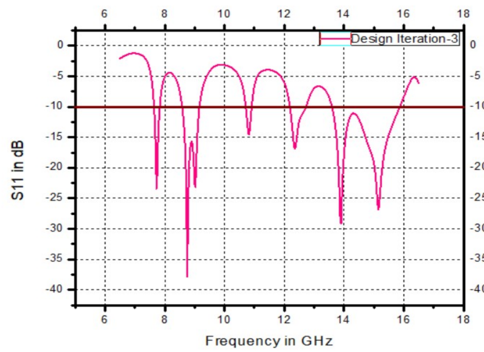

Fig. 4.4: Bandwidth Plot

The voltage standing wave ratio (VSWR) is 1.20, 1.02, 1.23, 1.36, 1.54, 1.34, 1.07 and 1.10 at respective frequency bands. The obtained VSWR shows that the antenna is operating significantly well. The characteristic impedance Z_0 is 50 Ω. And the load applied is also 50 Hz. The VSWR is approximately equal to value '1' with decreased VSWR values.

The maximum peak gain is achieved 3.2 dB with resonating frequency of 13.90 GHz. The remaining gain values are below 3dB which are undesirable for wireless applications.

4. PROPOSED ANTENNA

Proposed antenna structure is best suitable for wideband applications, because all parameters having better results as compared with the remaining design iterations

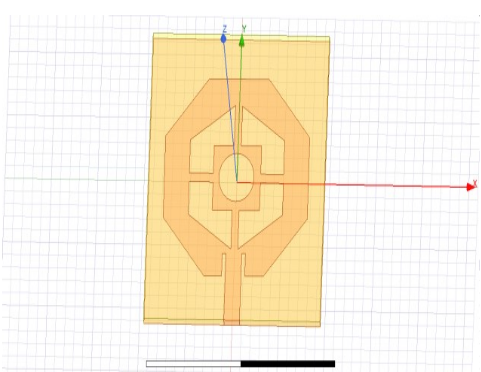

Fig. 4.5: Proposed Antenna Design

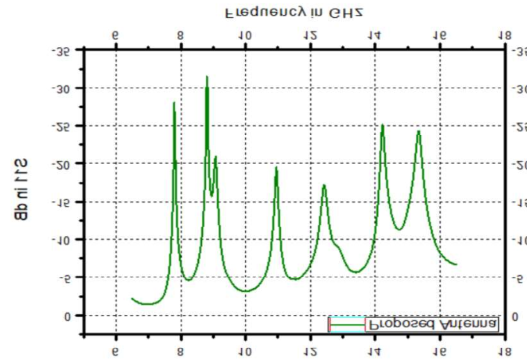

Fig. 4.6: Return Loss Plot

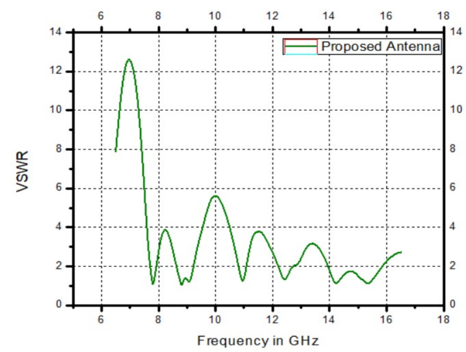

Fig. 4.7: VSWR Plot

Return Loss (S11)

The Return loss plot represents the quantity of a reflected signal considered as a S11. It radiate multiple frequencies i.e.,7.8GHz,8.8 GHz,9.07GHz,10.95GHz,12.42GHz,14.22GHz and 15.33GHz with reflection coefficients of -28.08,-31.53,-20.97,-19.53,-17.24,-25.09 and -24.30 respectively. Figure 4.6 shows the frequency versus reflection coefficient of the proposed antenna. The results of the designed antenna significantly shows two resonating frequencies at 14.2 GHz with-25.09dB reflection coefficient and 15.35 GHz with -24.30dB reflection coefficient which combine to give broader bandwidth.

The voltage standing wave ratio (VSWR) is 1.08, 1.05, 1.19, 1.23, 1.31, 1.1 and 1.2 at respective frequency bands. The obtained VSWR shows that the antenna is operating significantly well. This indicates the impedance matching between the field and the load and, the value should be equal to1 in an ideal situation but not realizable practically.

Practically it should be less than 2 but greater than

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1for good operation of the antenna.This antenna ha s achieved the desired values

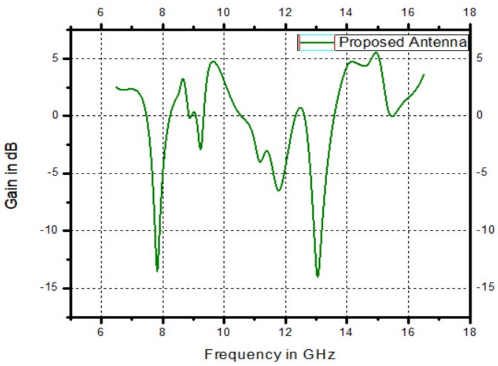

Fig 4.8: Gain Plot

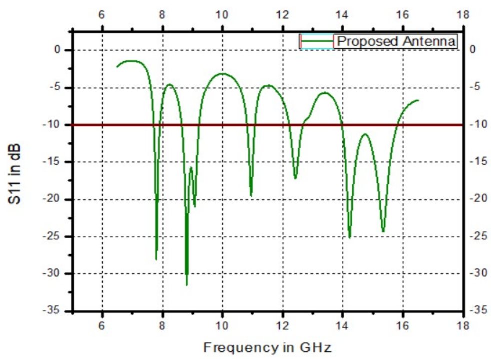

Fig 4.9: Bandwidth Plot

The maximum peak gain of the proposed antenna achieved 4.69 dB with resonating frequency of 14.22 GHz. To achieve reasonably good bandwidth, input impedance matching is deliberated. The efficiency is significantly good with better bandwidth. The band width achieved with the proposed patch antenna is 1.88 GHz. The bandwidth has increased to 54.8 percent. The gain increased 73.70 % with proposed antenna over hexagon shaped patch antenna.

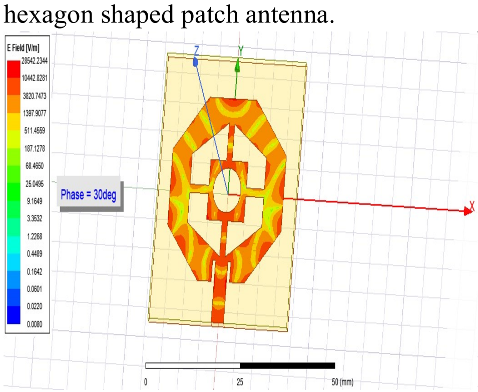

Fig 5: Electric Field Distribution Plot

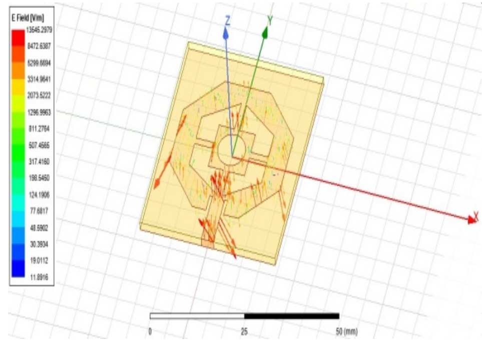

Fig. 5.1: Current Distribution Plot

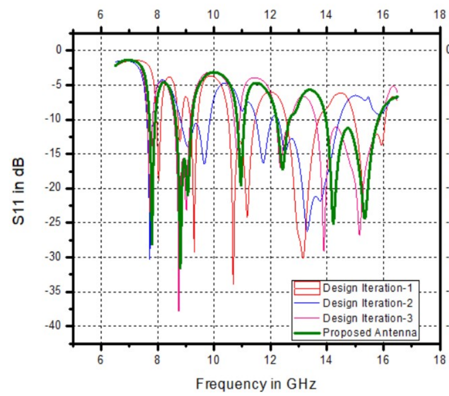

Fig 5.2: S11 Plot Of Design Iterations

The electric field distribution of the projected antenna is shown in Fig 5. From Fig 5. It is observed that the maximum field distribution is obtained in the octagon and inside square of the radiating patch

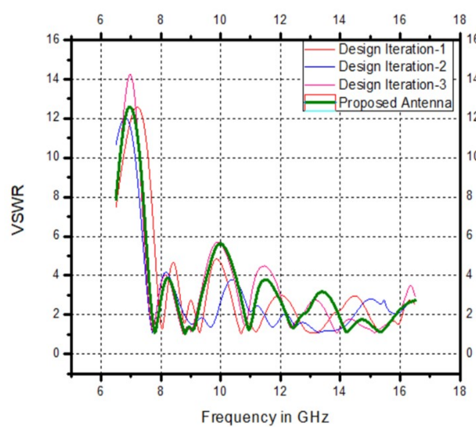

Fig.5.3: VSWR Plot Of Design Iterations

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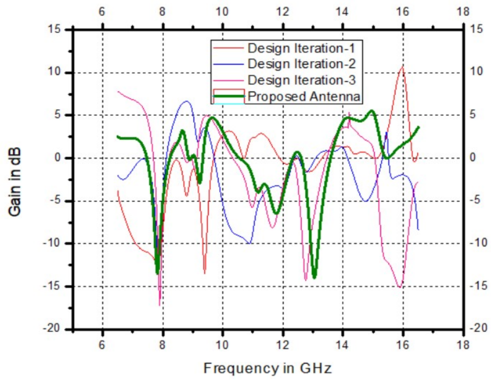

Fig. 5.4: Gain Plot Of Design Iterations

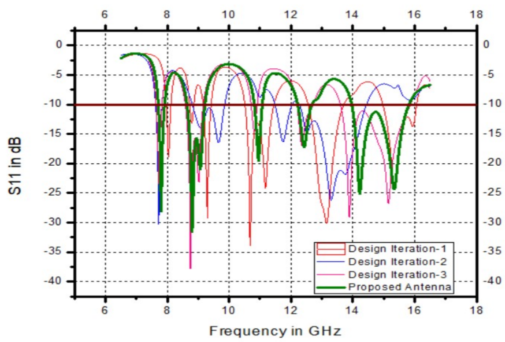

Fig. 5.5: Bandwidth Plot Of Design Iterations

The current distribution of the proposed antenna at center frequency is shown in Fig 5.1. From Fig5.1 it is observed that the maximum current strength is obtained in the edges of the octagon and inside square of the radiating patch which follows longer path in around. The directions of current flowing on the radiating patch are responsible for generation of lower and higher order modes[20]. These nearly excited modes are combined and produce wider bandwidth.

Table 5.1. Comparative Parametric Analysis Between The Design Iterations

Design Iteration	**Radiating Frequency (GHz)**	**Return loss (dB)**	**VSWR**	**Peak Gain (dB)**	**Bandwidth (GHz)**
1	8.05,8.8,9.3,10.67,11.17,13.15,15.35 & 15.9	-18.8,-13.19,-29.27,-33.95,-24.22,-30.16,-23.7 & -13.75	1.18, 1.5, 1.35, 1.36, 1.44, 1.18 & 1.10	2.7	(13.71-12.59) 1.13
2	7.72,9.1,9.6,11.72,12.52,13.3 & 13.7	-30.2,-13.97,-16.42,-16.29,-14.80,-26.18 & -21.81	1.18,1.5,1.35,1.36,1.44,1.18 &1.10	3.1	(9.85-8.81) 1.04
3	7.72,8.75,9.02,10.80,12.40,13.90 &15.15	-23.42,-37.82,-23.14,-14.43,-15.74,-29.12 & -26.82	1.20,1.02,1.23,1.54,1.34,1.07 & 1.10	3.2	0.48
4 (Proposed Antenna)	7.8,8.8,9.07,10.95,12.42,14.22 & 15.35	-25.09,-24.29,-28.08,-31.53,-20.97,-19.53 & 17.24	1.08,1.05,1.19,1.23,1.31,1.11&1.12	**4.69**	(15.80-13.97) **1.88**

Table 5.2. Comparative Analysis: Proposed Antenna With Various Existing Structures

Ref No	Dimensions of Antenna (L×W) mm2	Resonant Frequency (GHz)	VSWR	Peak Gain (dB)	Band width (GHz)
[8]	35×35	12.2	< 2	7.6	0.95
[10]	110x110	5.18	< 2	5.85	0.72
[11]	24.8x30	5.7	< 2	1.13	0.32
[12]	28.02x23.44	4.90	< 2	5.49	0.27
[13]	24x24	3.7	NM	4.3	0.21
[14]	40x28	3.65	NM	2.5	0.7
[15]	28.03x23.45	5.8	< 2	6.21	0.86
Proposed antenna	45x38	14.22 & 15.35	1.11 & 1.2	4.69	1.88

5. CONCLUSION:

For ground penetrating radars, medical microwave imaging to detect breast cancer, wideband antennas are significant. For long distance wireless applications and specifically node to node communication, volumetric antennas are imperative [16] [17] [18]. This paper focused on designing a volumetric wideband antenna to achieve high directivity to address the challenges of both radar and medical imaging applications. The 1.88GHz bandwidth is achieved. i.e. the proposed volumetric antenna operates at a wide range of frequencies. This antenna exhibits VSWR below 2:1. i.e. 1.11 and 1.2. With increasing the frequency, observed that the centre lobes are narrower owing to significant amount of phase cancellation for plane waves of the volumetric antenna. The simulated results of volumetric antenna with hexagon shaped patch combined with square patch produced significant dual band characteristic results. By subtracting octagon from hexagon patch and circle form square patch, dual resonant bands observed one is at 14.22GHz and second one is at 15.35GHz. the return losses for hexagon shaped patch radiates at multiple frequencies.

Maximum return loss -13.75 is observed at 15.9 GHz. And 10.27 dB gain is observed at 11.17 GHz. After octagon is subtracted, the return loss -21.81 is observed at 13.7 GHz and the maximum gain is 3.1dB at 9.1GHz. once the square patch is integrated the return loss is -26.82 at 15.15 GHz

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