Analyzing the Design of the Octagonal Patch Antenna at 67 GHz with Altering Dimensions

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ABSTRACT: This paper presents the optimal design concepts of octagonal patch antenna at 67 GHz with altering substrate and patch dimensions. It is found that the antenna performance is affected with change in antenna dimensions and with dielectric constant. To design an efficient antenna at millimeter wave (MMW) frequencies it is required to have a proper selection of antenna dimensions. It is a challenging task to optimize the antenna constraints such as patch length, patch width, substrate thickness and dielectric constant to get maximum gain. It is necessary to understand how the patch antenna performance is depending on the antenna constraints for efficient design and optimization of the patch antenna and this is effectively addressed in this paper. The proposed work establishes the analysis of patch antenna with a change in antenna dimensions, substrate material dielectric constant and ground structures. The design analysis is done, and simulated results are obtained using licensed HFSS. The proposed work investigates the performance of octagonal patch antenna with different antenna dimensions.

I. INTRODUCTION

Microstrip patch antenna at millimeter wave (MMW) frequency has its applications in remote virtual sign monitoring, military, short-distance communication with high data rates and satellite constellation [1]. H-shaped defect on the ground plane reduces the harmonics. Rectangular MPA with Slit-Slot reduces the size of the antenna which is desirable for MPA design [2].

A lot of research work is already done, and many different types of antennas were designed in L, S, C, X bands (1 GHz–12 GHz) for serving applications for public, private, government and military, like wi-fi, WiMAX, RADAR, navigation, railway signaling, etc. MMW frequencies have wide spectrum bandwidth, therefore, can be used for future mobile networks such as wireless wide area cellular, wireless PAN, wireless MAN which require high data rates and large communication capacity [3]. By optimal selection of antenna dimensions, the design complexity can be minimized [4]. An improvement of impedance bandwidth is obtained from 2.06% to 15.2% with Pentagonal square slotted MPA [5]. Defected ground structures in the patch antenna design can reduce the size of the antenna and suppress the harmonics [6].

The benefits of microstrip patch antenna are less weight, low profile, low cost these benefits make them a good choice for communication networks. Ultrawideband antennas have a wide range of applications such as sensor data collection, tracking application and medical engineering [7]. One of the advantages of microstrip antenna is reduced size however proper choosing of structure size is a major concern to get the best performance of patch antenna [8]. The effective area of patch can be reduced by

introducing the slots in the patch but this can lead to impedance mismatch [9]. A surrogate assisted cost-efficient design optimization procedure can make design fast and improve bandwidth [10]. Power transmission efficiency is maximized with the optimum design of patch antenna arrays [11]. Double slotted swastika antenna design produces circular polarization and circularly polarized antennas are widely used [12]. Dielectric properties are estimated using an in-touch superstrate techniques [13]. Using linearly polarized horn antenna strain can be measured up to the distance of 5cm. Wireless interrogation of circular microstrip antenna is studied beyond 5 cm [14]. By capturing with parylen c, an antenna can be protected against harsh environment [15]. Gap proximity fed microstrip antennas overcomes the alignment difficulties arising from the proximity and aperture feeding structures [16]. Frequency spectrum from 30 GHz to 300 GHz belongs to millimeter waves (MMW), Millimeter waves are finding new uses in short distance communication because of their support to high data rates.

By arranging the antennas in arrays which will be embedded with solar cell can be used for satellite communication at 10 GHz [17]. Better omnidirectional characteristics can be obtained with the horizontally polarized antenna [18]. The antenna with different shapes of patches and slots have different applications and an antenna with rectangular slots can be used for WPAN, Wi-fi applications at 5-6 GHz [19]. U-shaped slots can be used for Bluetooth and WLAN applications [20]. Various design possibilities of monopole antennas which can be considered for UWB applications are presented and discussed [21]. The methodology of introducing slots in patch antenna design is found to improve the bandwidth of antenna [22].

Present communication technologies WiMAX, WLAN and X-band uplink satellite services are having chances to interfere with the present UWB system and 5G technology needs higher data rates.

These issues are better solved by communication systems developed to work at MMW frequencies and these systems need efficient patch antennas. Present proposed orthogonal patch antenna design can be used at MMW frequency (67 GHz) and also presents how antenna dimensions affect its performance.

Microstrip patch antenna optimization using Hybrid Genetic algorithm improves bandwidth of a single patch antenna to 17.8% when compared to an unoptimized antenna of 6% bandwidth [23].

The organization of the paper is as follows, section II depicts antenna design with initial values and results, section III depicts the analysis of change in substrate length and results, section IV depicts analysis of change in all antenna parameters and results, section V portrays analysis of change in antenna dimensions with Defective Ground Structure (DGS), section VI portrays comparison of results and section VII concludes the paper.

II. ANTENNA DESIGN ANALYSIS WITH INITIAL PROPOSED DIMENSIONS

The antenna design parameters are obtained from the fallowing equations

Patch Dimensions:

Patch width (W) can be obtained from

$$W = \frac{u_0}{2f_{rc}} \sqrt{\frac{2}{\varepsilon_r + 1}} \qquad (1)$$

Patch length can be calculated from fallowing

$$f_r = \frac{u_o}{2L\sqrt{\varepsilon_r}} \qquad (2)$$

$$f_{(rc)} = \frac{u_o}{2L_{eff}\sqrt{\varepsilon_{reff}}} \qquad (3)$$

$$L_{eff} = L + 2\Delta L \qquad (4)$$

where
W - Width of the patch.
μ_o - Speed of light.
f_{rc} - Resonant frequency.
ε_r - Dielectric constant of the substrate used.
f_r-Resonant frequency without considering fringing effects.
L - Length of the patch.
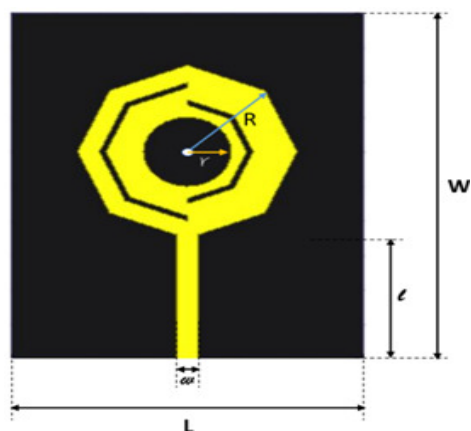$F_{(rc)}$ - Resonant frequency with considering fringing effects.
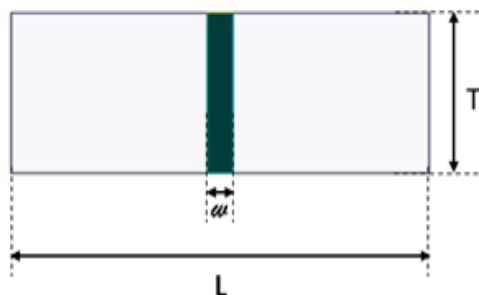L_{eff} - Effective length of the patch.
ε_{reff} - Effective dielectric constant of the substrate used.
The designing schematics of micro strip antenna with octagonal patch is shown in Fig. 1.

The antenna is designed as shown in Fig. 1. and the substrate used is Rogers RT/duronium 6002 (tm) with Ɛr=2.94, the main reason to choose the Rogers RT/duronium 6002 (tm) as the substrate material instead of FR4 is the FR4 has more losses at high frequencies greater than 4 GHz, the material used for patch is gold because the gold material has low losses, and the material used for ground is silver.

(a)

(b)

Fig. 1. Proposed antenna (a) Top view (b) Front view.

Table 1: Antenna dimensions.

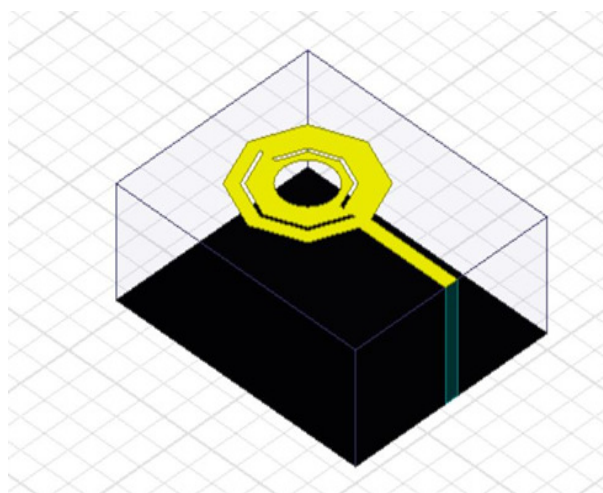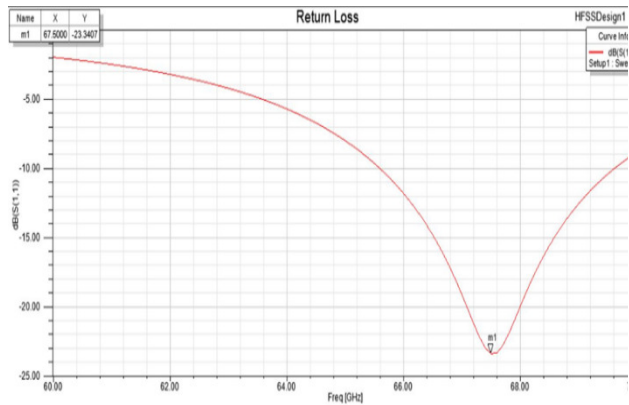| S.No	Name of the parameters	Value (mm)
1.	Substrate dimensions (L*W*T)	2*1.6*0.7
2.	Octagonal patch radius (R)	0.5
	Circular slot (r)	0.2
3.	Patch length (l)	0.72
4.	Patch width (w)	0.1

The 3D view of the designed antenna is shown below
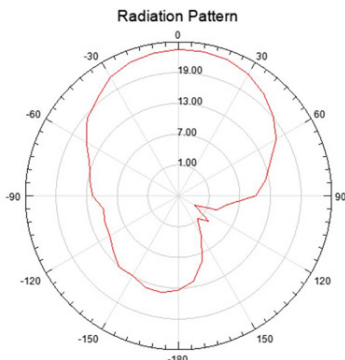

Fig. 2. 3D view of designed antenna.

(a)

(b)

(c)

(d)

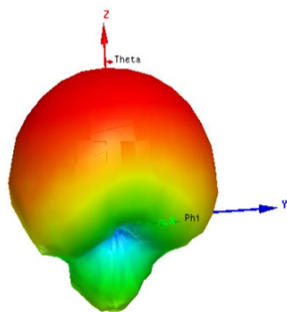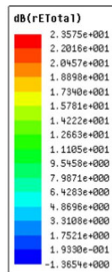**Fig. 3.** Simulated Results (a) Return Losses (b) VSWR (c) Radiation pattern (d) 3D radiation pattern.

The simulated results are shown above. The antenna is resonated at 67.5 GHz and the obtained values are Return loss = -23.34 dB, VSWR = 1.14, Radiation gain = 23.57 dB. The radiation pattern shows major lobe with maximum size and side lobes with minimum size, which is desirable in any antenna design. The antenna is having acceptable return loss and VSWR.
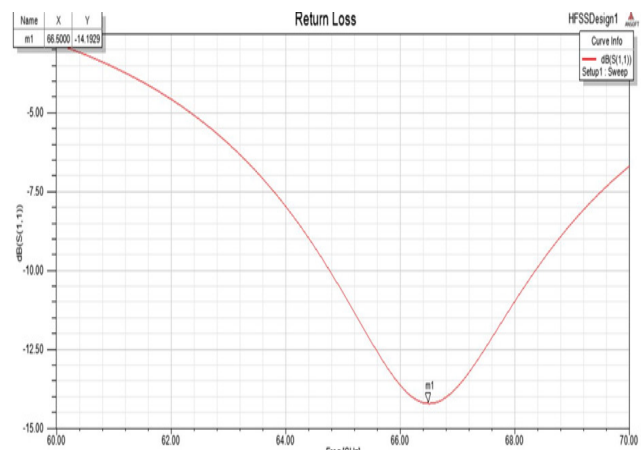
III. ANTENNA DESIGN ANALYSIS WITH CHANGE IN SUBSTRATE LENGTH

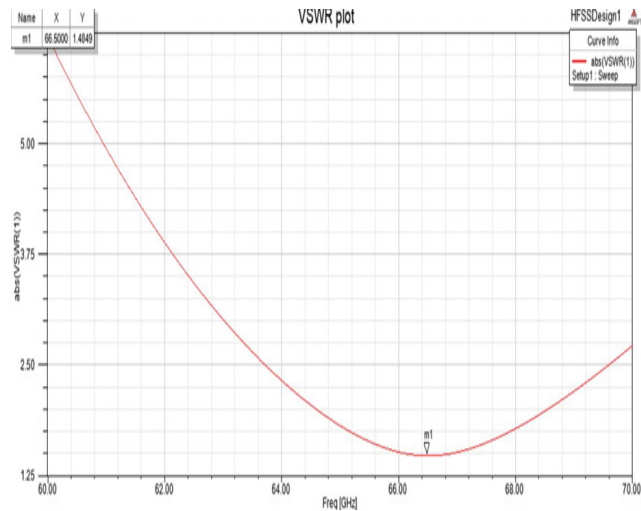Now the antenna is designed as shown in Fig. (1), with a small change in substrate length.

Table 2: Antenna dimensions with small change in substrate length.

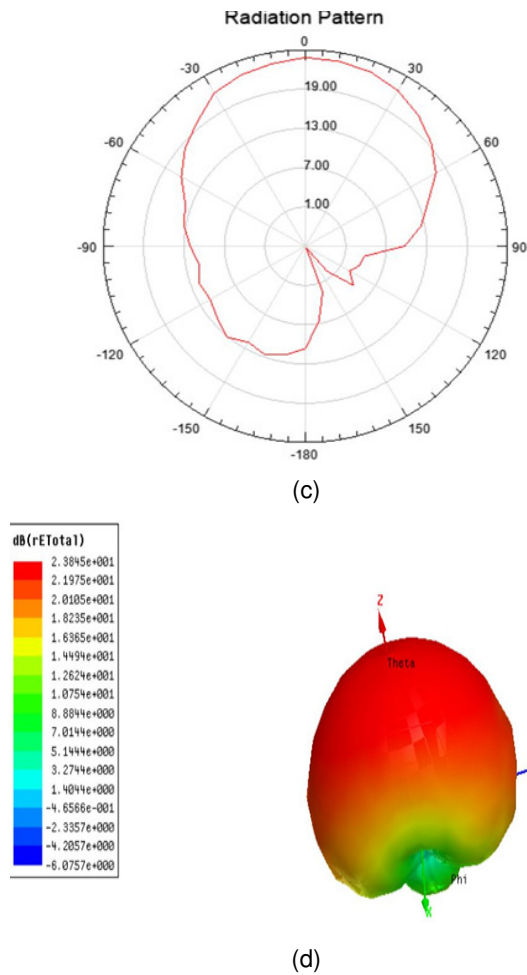| S. No.	Name of the parameters	Value (mm)
1.	Substrate dimensions (L*W*T)	2.2*1.6*0.7
2.	Octagonal patch radius (R)	0.5
	Circular slot (r)	0.2
3.	Patch length (I)	0.72
4.	Patch width (w)	0.1

Results:

(a)

(b)

(c)

(d)

Fig. 4. Simulated Results (a) Return Losses (b) VSWR (c) Radiation pattern (d) 3D radiation pattern.

The simulation results are shown in fig., the antenna is resonated at 66.5GHz and the obtained values are Return loss = -14.19 dB, VSWR = 1.48, Radiation gain = 23.48 dB. Here observed, changes in the values of return loss, VSWR and small fraction of gain with change in substrate length.

IV. ANTENNA DESIGN ANALYSIS WITH CHANGE IN ANTENNA PARAMETERS AND SUBSTRATE MATERIAL

Now the antenna is designed as shown in Fig. (1), the substrate is made up of FR4 material with $\varepsilon r = 4.4$

Table 3: Antenna dimensions.

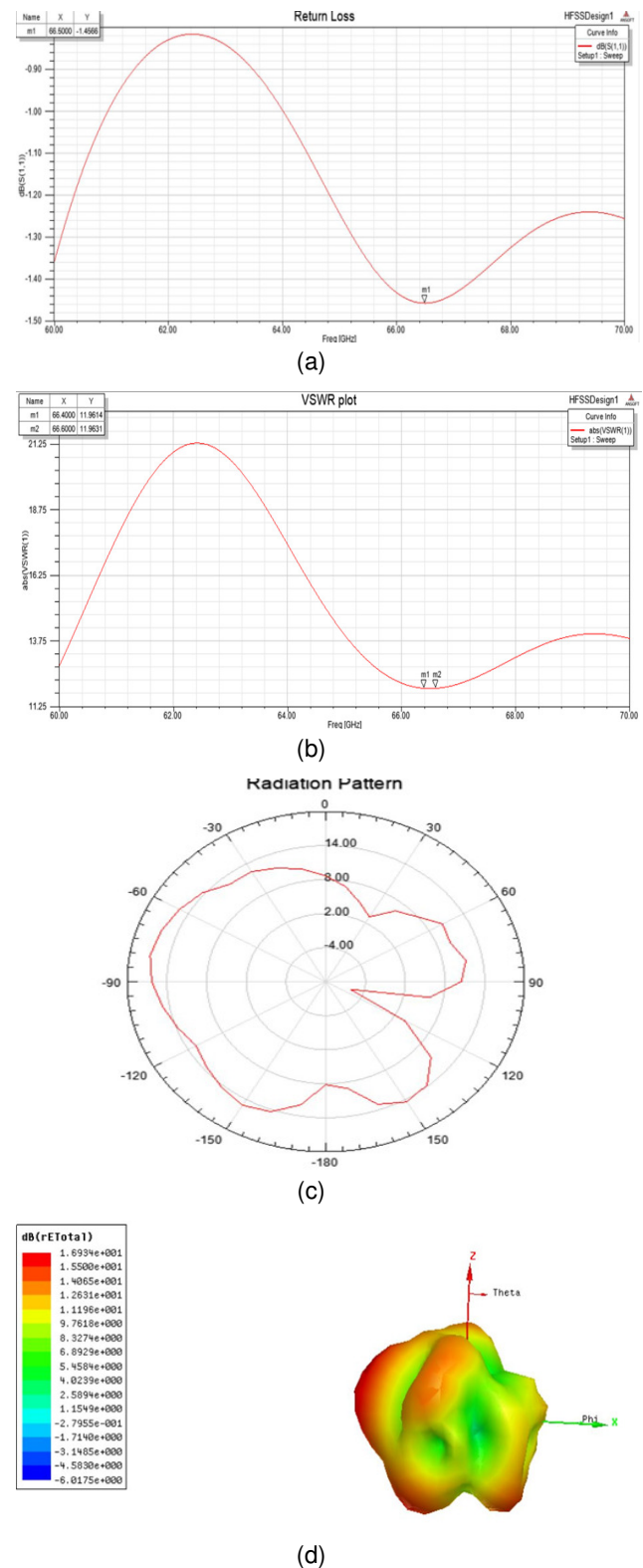| S. No	Name of the parameters	Value (mm)
1.	Substrate dimensions (L*W*T)	4.16*3.5*1.6
2.	Octagonal patch radius (R)	0.8
	Circular slot (r)	0.3
3.	Patch length (l)	1.88
4.	Patch width (w)	0.088

(a)

(b)

(c)

(d)

Fig. 5. Simulated Results (a) Return Losses (b) VSWR (c) Radiation pattern (d) 3D radiation pattern.

The simulation results are shown above, the antenna is resonated at 66.5 GHz and the obtained values are Return loss = -1.45 dB, VSWR = 11.96, Radiation gain = 16.93 dB. Here the poor performance of antenna is observed.

V. ANTENNA DESIGN ANALYSIS WITH CHANGE IN ANTENNA DIMENSIONS WITH DEFECTIVE GROUND STRUCTURE (DGS)

Here instead of normal ground structures which covers the entire substrate, a defective ground is taken which partially covers the substrate. The structure of proposed antenna with defective ground is shown below, the Rogers RT/duronium 6002 (tm) with Ɛr = 2.94 is used as substrate.

(a)

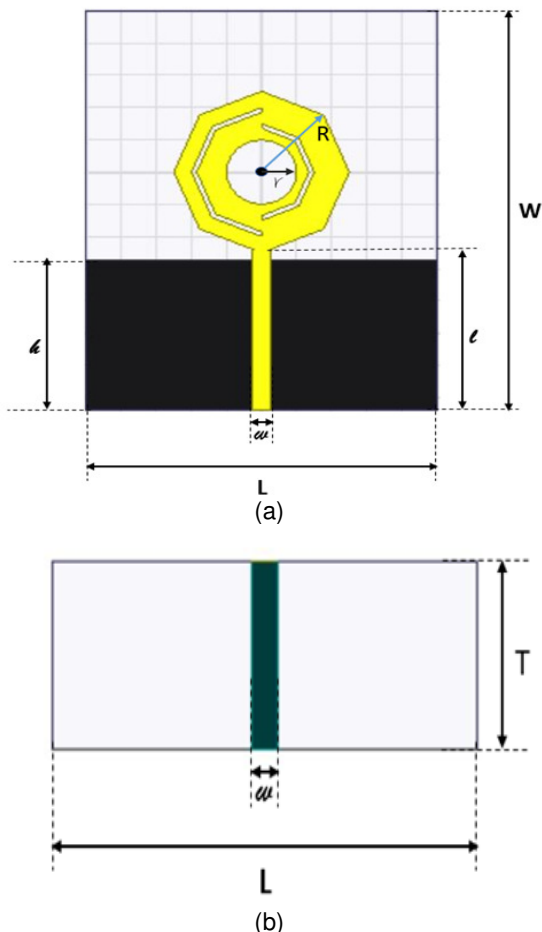(b)

Fig. 6. Proposed antenna (a) Top view (b) Front view.

Table 4: Antenna dimensions with DGS.

S.No	Name of the parameters	Value (mm)
1.	Substrate dimensions (L*W*T)	2.48*2*0.7
2.	Octagonal patch radius (R)	0.5
	Circular slot (r)	0.2
3.	Patch length (l)	1
4.	Patch width (w)	0.1
5.	Ground height (h)	0.93

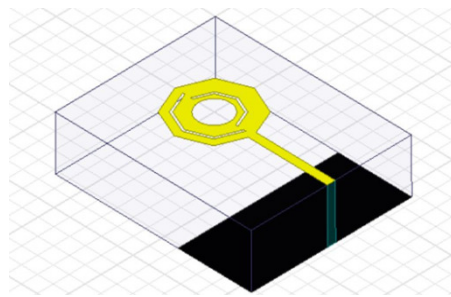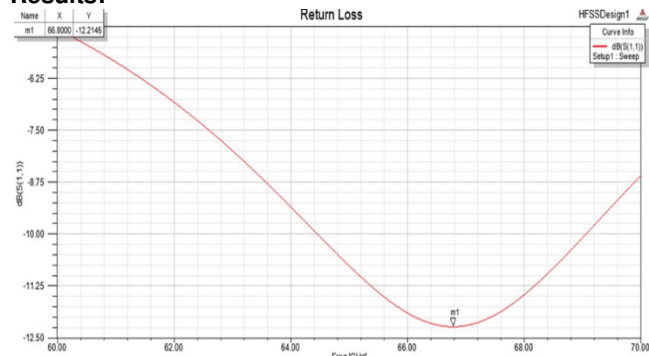The 3D view of the designed antenna is shown below
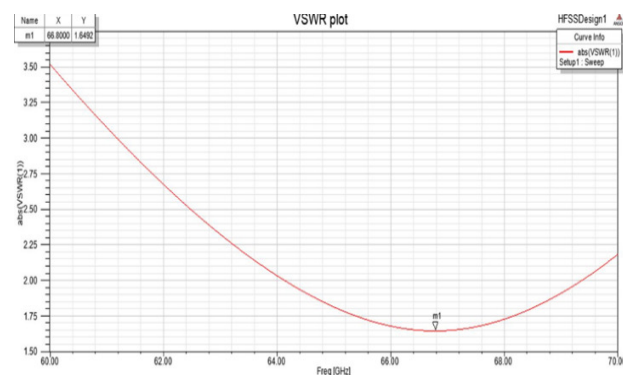

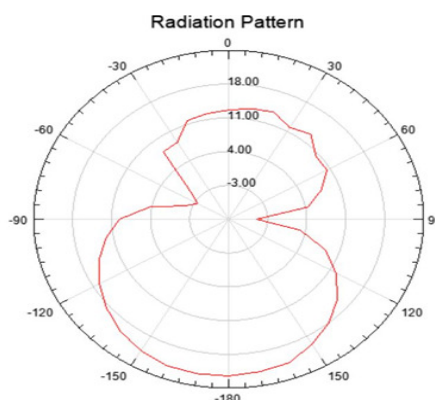**Fig. 7.** 3D view of designed antenna with DGS.
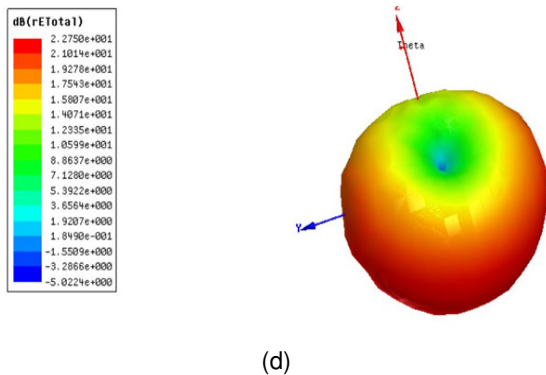
Results:

(a)

(b)

(c)

(d)

Fig. 8. Simulated Results (a) Return Losses (b) VSWR (c) Radiation pattern (d) 3D radiation pattern.

The simulation results are shown above, the antenna is resonated at 66.8 GHz and the obtained values are Return loss = -12.21 dB, VSWR = 1.64, Radiation gain = 22.75 dB. Fairly good results are observed with DGS.

VI. COMPARISON OF RESULTS

Various patch antenna design methodologies proposed in the present work are, design analysis with initial proposed dimensions, with change in the length of the substrate, with variation in both antenna dimensions and substrate and with variation in antenna dimension along with DGS. The results are presented in the Table 5.

From the above table, when the antenna simulated with initial dimensions, the obtained values of return losses, VSWR and gain are -23.34dB, 1.14 and 23.57 dB by seeing these results the antenna will work efficiently at the desired frequency.

When the antenna simulated with a small change in substrate length, the obtained values of return losses, VSWR and gain are -14.19dB, 1.48 and 23.48 dB by seeing these results the antenna have return losses greater than -20dB and VSWR is less than 2 but it was greater than antenna with initial dimensions and gain is around 23 dB so antenna will work at desired frequency but not that much efficient than the first one.

When the antenna simulated with change in antenna dimensions and substrate material, the obtained values of return losses, VSWR and gain are -1.45dB, 11.96 and 16.93dB by seeing these results the antenna have very high return losses i.e., around -1.45 dB and VSWR also a very high value around 11.96 these values indicates that the all the supplied power will returns back and radiation will be less so that the antenna doesn't work at the desired frequency.

When the antenna simulated with change in antenna dimensions and with DGS, the obtained values of return losses, VSWR and gain are -12.21dB, 1.64 and 23.75 dB by seeing these results the antenna have return losses greater than -20dB and VSWR is less than 2 but it was greater than antenna with initial dimensions and gain is around 23 dB, so antenna will work at desired frequency but not that much efficient than the first one.

Here an efficient antenna design is possible only through proper selection of antenna dimensions.

Table 5: Comparative study of Results.

Parameter	With initial dimensions	With change in substrate length	With change in antenna dimensions and substrate material	With change in antenna dimensions with DGS
Return Loss (dB)	-23.34	-14.19	-1.45	-12.21
VSWR	1.14	1.48	11.96	1.64
Gain (dB)	23.57	23.48	16.93	22.75

VII. CONCLUSION

Orthogonal patch antenna design analysis is done by considering different antenna constraints such as substrate thickness, patch size, substrate material and ground structure. Comparative study of results shows that orthogonal patch antenna with initial dimensions provides best results for Return losses, VSWR and gain which are -23.34 dB, 1.14 and 23.57dB respectively. The observations through simulated results conclude that an efficient patch antenna design is possible through only optimal selection of antenna parameters.

VIII. FUTURE SCOPE

The proposed work can be used for design and optimization of Microstrip patch antennas against different constraints mentioned in this paper using nature inspired metaheuristic algorithms such as Grey wolf optimization and Mutation based lion algorithm at MMW frequencies.

ACKNOWLEDGEMENT

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