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DESIGN AND PERFORMANCE ANALYSIS OF MULTIBAND CIRCULAR PATCH ANTENNA AND ANTENNA ARRAY FOR MILLIMETER WAVE APPLICATIONS

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ABSTRACT: This paper presents the circular microstrip patch antenna and antenna array, using defective slots in the ground plane, to generate multiband characteristics used for millimeter wave applications. It is formulated by using cavity model and simulated by an electromagnetic simulator, based on finite element method that is HFSSv15 (High Frequency Structure Simulator). The proposed antenna incorporates 'I' shaped slot and 'U' shaped slots on the ground plane and the radiation parameters such as Gain, VSWR , Return loss and Bandwidth are evaluated .In this work, the feeding techniques namely Edge feed, Inset feed and Coaxial feed are used and comparative analysis is also done. The resulting antenna got four frequency bands; the first resonant frequency is obtained in the Ka band, at about 27 GHz, the second resonant frequency at nearly 38GHz, the third at 43GHz, and the last one at 62GHz. These resonant frequencies could be shifted by tuning the slot dimensions introduced in the ground plane of the proposed antennas. The parametric analysis is also done and the corresponding performance characteristics are evaluated. At the end 1 x 2 circular antenna array using inset feed technique with DGS is also designed for millimeter wave applications.

Index Terms: **Circular Microstrip Patch Antenna, Antenna Array, DGS technique, Edge Feed, Inset Feed, and Coaxial Feed**.

1. INTRODUCTION:

The concept of the Microstrip antenna (MSA) was first proposed in 1953 by Deschamps. However, practical antennas were developed by Munson and Howell in the 1970s. Often micro strip antennas are also referred to as micro strip patch antennas, or simply patch antennas. The unique property of the micro strip patch antenna is its two- dimensional structure. Micro strip antennas have several advantages over conventional microwave antenna and are used in many applications and fields due to its various advantageous such as mechanical robustness and fluency of manufacture [1], low weight and profile [2]. Common shapes of microstrip patch elements are square, rectangular, circular, triangular, circular ring, elliptical and dipole. In this paper, circular microstrip patch antennas and antenna array are discussed.

1.1 FEEDING TECHNIQUES:

Microstrip patch antennas can be fed by a variety of methods namely Edge feed, Inset feed and Coaxial feed.

MICROSTRIP EDGE FEED

In this type of feed technique, a conducting strip is connected directly to the edge of the microstrip patch as shown in Figure 1. The conducting strip is smaller in width as compared to the patch and this kind of feed arrangement has the advantage that the feed can be etched on the same substrate to provide a planar structure

MICROSTRIP INSET FEED

In this type of feed technique the purpose of the inset cut in the patch is to match the impedance of the feed line to the patch without the need for any additional matching element. This is achieved by properly controlling the inset position. Hence this is an easy feeding scheme, since it provides ease of fabrication and simplicity in modeling as well as impedance matching.

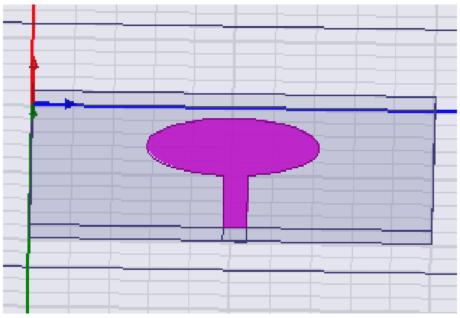

Figure 1.Microstrip edge feed

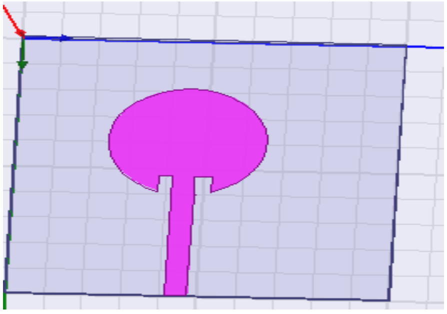

Figure 2.Microstrip inset feed

COAXIAL FEED:

The Coaxial feed or probe feed is a very common technique used for feeding Microstrip patch antennas. As seen from Figure 3, the inner conductor of the coaxial connector extends through the dielectric and is soldered to the radiating patch, while the outer conductor is connected to the ground plane.

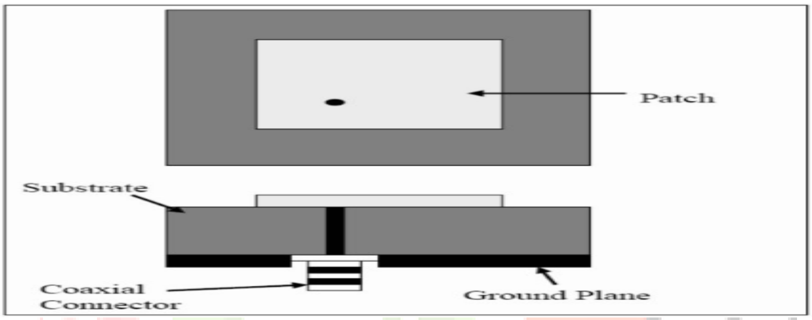

Figure 3. Coaxial feed

1.2 DGS TECHNIQUE:

In this technique the compact geometrical slots embedded on the ground plane of microwave circuits are referred to as Defected Ground Structure (DGS). A single defect (unit cell) or a number of periodic and aperiodic defects configurations may be comprised in DGS. Thus, periodic and/or aperiodic defects etched on the ground plane of planar microwave circuits are referred to as DGS.

DGS has been integrated on the ground plane with planar transmission line, that is, microstrip line, coplanar waveguide, and conductor backed coplanar wave guide. The defects on the ground plane disturb the current distribution of the ground plane; this disturbance changes the characteristics of a transmission line (or any structure) by including some parameters (slot resistance, slot capacitance, and slot inductance) to the line parameters (line resistance, line capacitance, and line inductance). In other words, any defect etched in the ground plane under the microstrip line changes the effective capacitance and inductance of microstrip line by adding slot resistance, capacitance, and inductance. In this paper, we discuss two types of slots in the DGS technique i.e I slot and U slots.

The proposed model is improved using DGS technique in order to reach multiple frequency bands. A parametric study for the slots dimensions and position are carried out in this paper. Also, a comparison between with DGS and without DGS model is presented for different feeding techniques.

2. RELATED WORK:

Now a day‘s Compact microstrip antennas are getting much more attention due to the increase in demands of small size antennas used in personal and commercial purposes. In order to design a compact microstrip antenna at a fixed operating frequency higher dielectric constant of substrate must be used. In In view of the above facts K.K.Parashar [4] performed a study on the design and Analysis of ISlotted Rectangular Microstrip Patch Antenna for Wireless Applications. The proposed Microstrip patch antenna has high gain up to 5 dBi with bandwidth of 49.6% and good radiation efficiency of about 99%.

Mohammad Aneesh, Mohd GulmanSiddiqui, J.A Ansari, Ashish Singh and Kamakshi [5] performed a study on the Inset Feed Toppled H-Shaped Microstrip Patch Antenna for PCS/WiMAX Application. The proposed antenna is expected to be a good candidate for PCS/WiMAX applications due to its higher gain, better efficiency, and good radiation characteristics and the patch antenna is operating at three different resonant frequencies which offer at 1.8GHz, 3.5GHz, 5.5 GHz for triple band operation with the center frequency ratios of Fc2/Fc1=1.94, and Fc3/Fc2=1.57 which provides less interference with other coexisting application bands.

N.T.Markad, R.D.Kanphade and D.G Wakade [6] have proposed the design on the design of cavity model microstrip patch antenna. In this work a design and realization of linearly polarized and dual frequency rectangular microstrip patch antenna in S band at 2.42 GHz is reported. From the results, it is observed that the designed Microstrip patch antenna exhibits a narrow bandwidth and resonates at a frequency of 2.42 GHZ with return loss of -27.0 dB and VSWR is 1.1.

S. Elajoumi, A. Tajmouati, A. Errkik, Am. Sanchez and M. Latrach [7] performed a study on the Microstrip Rectangular Monopole Antennas with Defected Ground for UWB Applications. In this work two compact UWB monopole antennas have been designed and each antenna consists of a rectangular patch fed by 50Ω microstrip transmission line with DGS. From the results, it is observed that the proposed patch antennas exhibits a bandwidth covering the range 16 from 3-14.5GHz for antenna I and 3.2-14.5GHz for antenna II and these final antenna structures offer excellent performances for UWB system applications

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Sushant Sharma, Gurpreet Kumar [8] performed a study on a dual wideband stair shape microstrip patch antenna for c & x band. In this work a compact microstrip patch antenna with reduced size and improved wider bandwidth coverage has been designed. The designed antenna has been used for satellite communication and radar applications in C band (4 - 8 GHz) & X band (8 - 12 GHz).

Dawit Fistum, Dilip Mali and Mohammed Ismail [9] have proposed the Bandwidth Enhancement of Rectangular Microstrip Patch Antenna using Defected Ground Structure - an inverted SHA shaped slot on the ground plane. A comparison is also shown for the proposed Microstrip patch antenna with the antenna structure without DGS. From the results, it is observed that the bandwidth of the Microstrip patch antenna without DGS is 171 MHz with return loss of -45.9128 dB at resonant frequency of 2.4GHz while Microstrip patch antenna with an inverted SHA‘ shaped DGS provides bandwidth of 180 MHz and the return loss reaches up to -47.9223 dB. The proposed antenna is useful for different wireless applications in the S-band, like IMT, WLAN, ISM, RFID and Bluetooth applications.

Adamu Halilu Jabire, Anas Abdu, Salisu Sani, Sani Saminu, Aliyu Uba Taura and Mohammed Olatunji Obalowu [10] performed a study on the Modal Analysis of a Circular Slot Monopole Antenna for UWB application. In this work a wideband double slot antenna is introduced and the proposed monopole antenna is designed using the theory of characteristic mode for slot monopoles. Four modes have been excited to gain a physical insight and to find out which mode is dominant. The proposed patch antenna is designed on multilayer solver analysis in CST version 2017, without considering the feeding port. From the results, it is observed that the mode 1 is the dominant mode and the proposed patch has been used for UWB communication systems applications and it is giving wide impedance width with good radiation characteristics.

Sundeep Ranga, Theodore S. Rappaport and Elza Erkip [11] performed a study on the Millimeter Wave Cellular Wireless Networks: Potentials and Challenges. In this work it surveys measurements and capacity studies to assess Millimeter Wave Cellular Wireless Networks with a focus on small cell deployments in urban environments and various technologies are discussed. From the results, it is observed the measurements in New York City at 28 GHz and 73 GHz demonstrate that, even in an urban canyon environment, significant non-line-of-sight (NLOS) outdoor, street level coverage is possible up to approximately 200 meters from a potential low power microor pico cell base station. On the other hand, technologies such as carrier aggregation and multihop relaying that have had only modest benefits in current cellular networks may play a very prominent role in the mmW space.

3. ANTENNA DESIGN:

Circular microstrip patch antennas are investigated using cavity model and the radius of the circular microstrip patch antenna is computed using the following equation

$$a_p = \frac{F}{[1 + \frac{2h}{\pi \varepsilon_r F}\left(ln\left(\frac{\pi F}{2h}\right) + 1.7729\right)]^{1/2}} \quad \text{----------------------------- (1)}$$

and F is caculated using the formula

$$F = \frac{8.791 \times 10^9}{f_r \sqrt{\epsilon_r}} \quad \text{-------------------------------------- (2)}$$

Where h= height of substrate in mm, ϵ_r= substrate dielectric constant, f_r= resonant frequency the related work is dedicated to operate in the millimeter wave band, more specifically at 30GHz, made with Duroid (tm) substrate. Table 1 presents physical dimensions of the circular microstrip patch antenna for inset feed, edge feed, and coaxial feed techniques.

parameters	Value	Parameters	value
frequency of operation (f_r)	30 GHz	length of the feed in mm	2.5
relative dielectric constant (ϵ_r)	2.2	outer radius in mm	0.15
radius of the patch in mm	1.97	inner radius in mm	0.51
geometry of notch in mm (d x g)	0.6 x 1.2	substrate thickness in mm	0.31
width of feed line in mm	0.6	substrate dimensions in mm (h)	10 x 10

Table 1. Physical dimensions of the circular patch antenna

In order to achieve useful multiband patch antennas, we started from a basic circular microstrip antenna, enhanced using a single DGS placed in the ground plane center with dimensions of 1.8mm x 1.1mm (i.e I slot) which is shown in the figure 5.

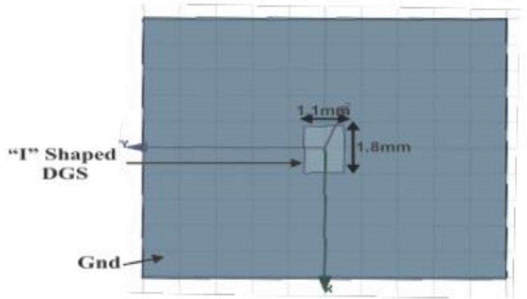
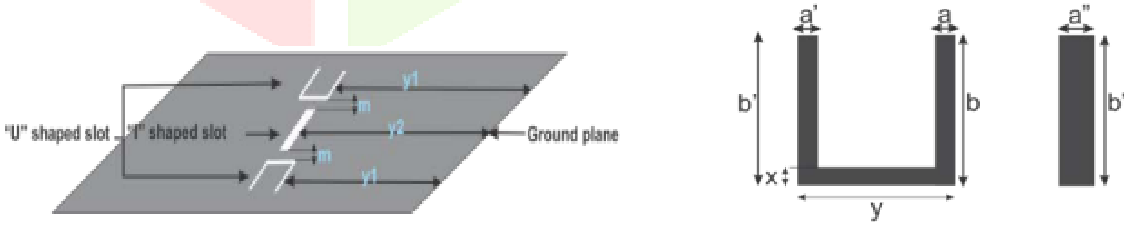


Figure 5. Geometry of I slot DGS

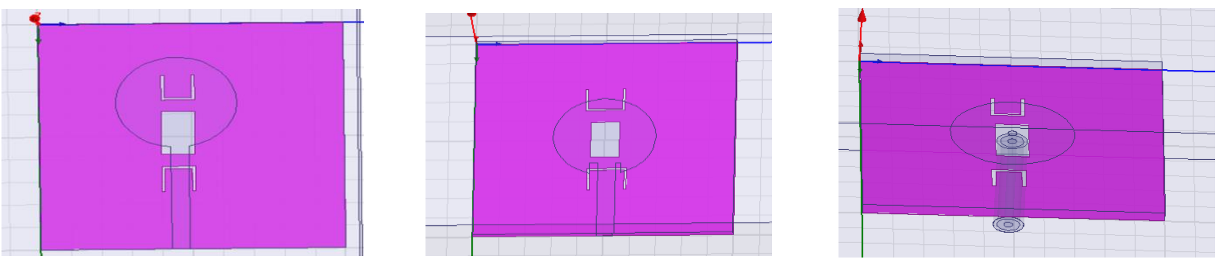
This work is extended by adding more slots in the ground plane in order to achieve more useful multiband characterized by wide bandwidths, improved return loss and greater gain, suitable. To do so, double U shape slots are being cut beside the rectangular slot from antenna ground plane which is shown in the figure 6.



(a) (b)

Figure 6. (a) 2 U slots and I slot (b) geometry of DGS slots

Design model of DGS (U slots & I slot) for different feeding techniques is shown in the figure 7**.**



(a) (b) (c)

Figure 7. DGS with (a) Edge feed (b) Inset feed (c) Coaxial feed

Fractional bandwidth of an antenna is computed by the following equation:

$$FBW = (f_2 - f_1) / f_c \text{ -- } (3)$$

Where f_2 is the upper frequency, f_1 is the lower band frequency and f_c is the center frequency, Fractional bandwidth of wideband antenna is mainly 20% or more.

4. RESULTS AND ANALYSIS

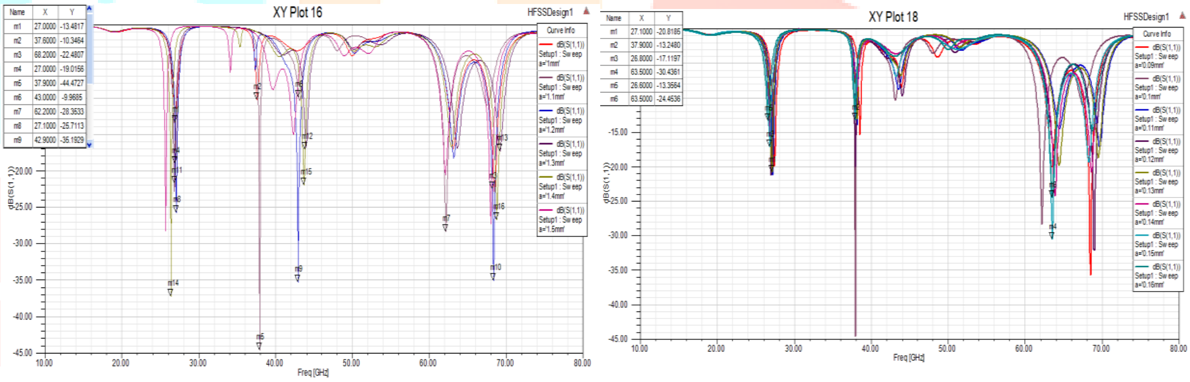
4.1 Simulation results of the work with and without DGS for different feeding techniques are summarized in table 2.

Table 2. Comparison Of Feeding Techniques without and with DGS (Islot) Technique

	Edge feed		**Inset feed**		**Coaxial feed**	
Parameter	**without DGS**	**with DGS**	**without DGS**	**with DGS**	**Without DGS**	**with DGS**
Resonating frequency	30 GHz	31.9 GHz	30 GHz	30.2 GHz	30 GHz	31.6 GHz
Return loss	-16.18 dB	-25.23dB	-29.45 dB	-48.50dB	-16.80 dB	-18.24 dB
Bandwidth	0.55 GHz	0.55 GHz	2 GHz	2 GHz	2.02 GHz	2.02 GHz
VSWR	1.33	1.11	1.06	1.12	1.33	1.22
Gain	7.05 dB	8.19 dB	7.94 dB	8.09 dB	3.54 dB	4.1 dB

4.2 A parametric study for the "U shaped slot dimensions and position is carried out for different feeding techniques in the following.

EDGE FEED WITH DGS



(a) (b)

Figure 8. Return loss plot of different values of (a) b and (b) a

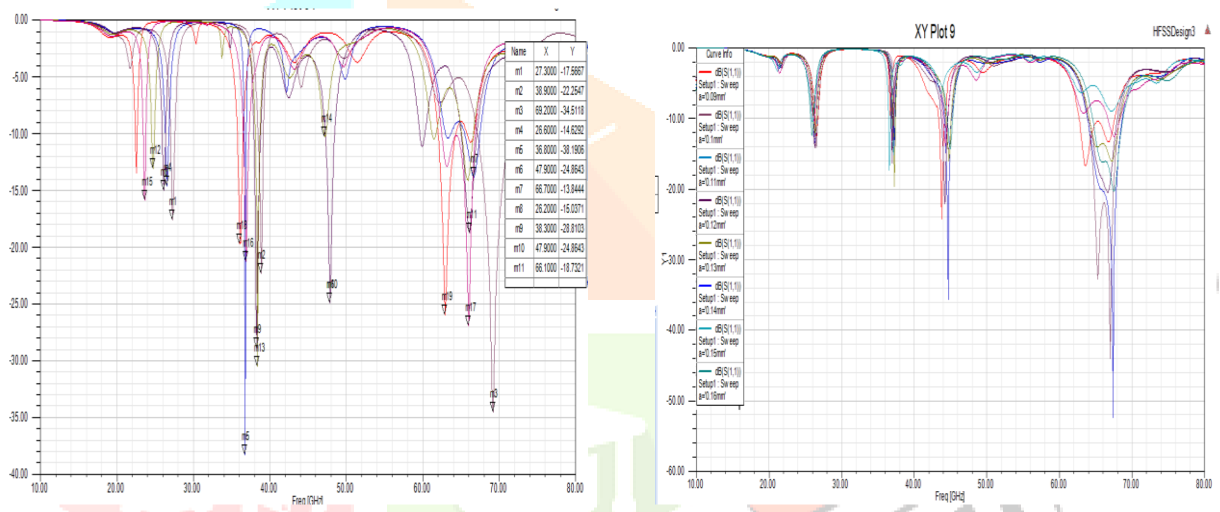
Table 3.simulation results of the antenna as a function of tuning parameter "b"

Value of b	**Operation frequencies (GHz)**	**S11 (dB)**	**Bandwidth (GHz)**	**Value of b**	**Operation frequencies (GHz)**	**S11 (dB)**	**Bandwidth (GHz)**
1mm	27.3 37.6 68.5	-13.48 -10.34 **-23.1**	1.4 - 6.8	**1.3mm**	26.8 44.0 69.2	-22.82 -16.51 -17.35	0.48 0.7 1.6
1.1mm	27.0 37.9 43.1 62.2	-19.01 **-44.47** -10.39 -28.35	1.03 0.34 0.21 1.52	**1.4mm**	26.4 43.7 68.8	-37.16 -21.98 -26.70	0.6 0.72 7.26
1.2mm	27.10 42.90 68.40	-25.71 -35.19 -34.98	0.53 0.95 7.2	**1.5mm**	25.7 42.3 68.0	-28.26 -15.0 -27.21	0.3 1.2 2.1

Table 4. Simulation results of the antenna as a function of tuning parameter of "a"

Value of a (b=1.1mm)	Operation frequencies in GHz	S11 in dB	BW in GHz	Value of a (b=1.1mm)	Operation frequencies in GHz	S11 in dB	BW in GHz
0.09mm	27.4 38.5 63.4 68.5	-19.89 -15.45 -19.96 -35.61	0.3 0.2 1.1 0.9	**0.13mm**	27.1 37.9 41.2 65.2	-20.81 -13.24 -10.10 -19.10	0.5 0.2 - 7.2
0.1mm	27.0 37.9 43.1 62.2	-19.01 **-44.90** -10.39 -28.35	1.03 0.34 0.2 1.5	**0.14mm**	26.8 37.9 63.5	-17.22 -13.93 -30.4	0.5 0.4 2.1
0.11mm	27.2 38.1 69.7	-21.18 -13.96 -16.99	0.64 0.2 0.7	**0.15mm**	26.6 37.9 66.4	-13.35 -11.20 -24.40	0.6 0.1 2.3
0.12mm	27.0 37.9 69.0	-21.17 -20.02 -32.10	0.4 0.5 1.9	**0.16mm**	26.3 37.3 44.2 67.6	-12.47 -13.01 -21.5 -11.0	0.1 0.5 0.92 6.3

INSET FEED WITH DGS



(a) (b)

Figure 9. Return loss plot of different values of (a) b and (b) a

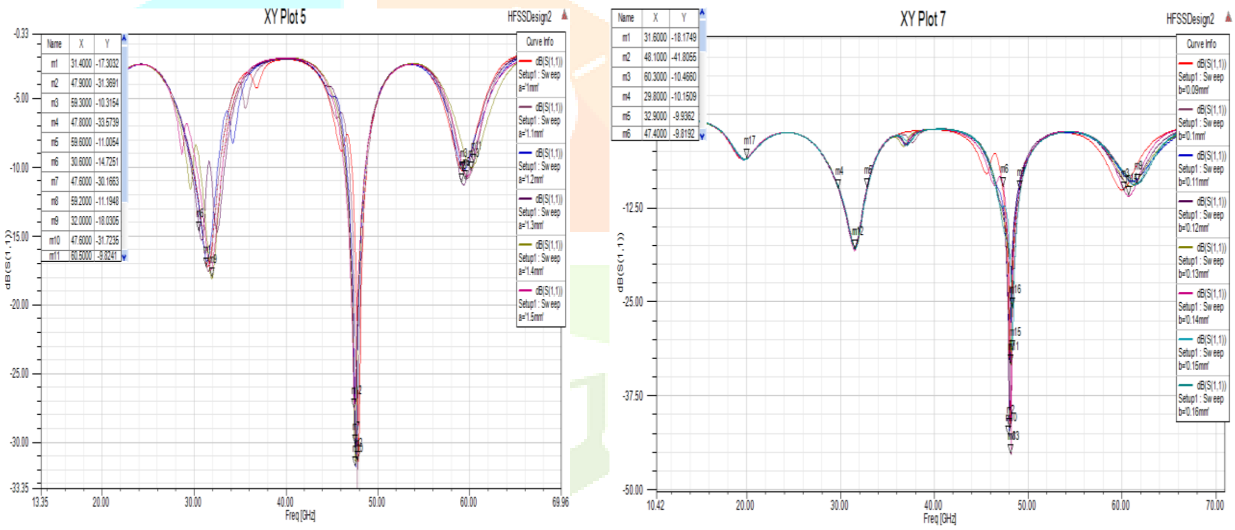
Table 5. Simulation results of antenna as a function of tuning parameter "b"

Value of b	Operation frequencies (GHz)	S11 (dB)	Bandwidth (GHz)	Value of b	Operation frequencies (GHz)	S11 (dB)	Bandwidth (GHz)
1mm	27.3 38.9 69.2	-17.56 -22.25 -34.56	0.57 1.18 1.3	**1.3mm**	24.8 38.4 47.2	-13.05 -30.43 -10.27	0.75 0.68 1.27
1.1mm	26.6 36.8 47.9 66.7	-14.62 **-38.19** -24.86 -13.84	0.5 0.93 1.83 4.5	**1.4mm**	23.7 36.9 66.0	-15.85 -21.22 -26.88	0.2 - 0.9
1.2mm	26.2 38.3 47.9 66.1	-15.03 -28.81 -24.86 -18.78	0.85 0.57 0.92 1.32	**1.5mm**	36.1 62.9	-19.72 -25.95	0.82 11.5

Table 6. Simulation results of antenna as a function of tuning parameter of "a"

Value of a (b=1.1mm)	Operation frequencies in GHz	S11 in dB	Bandwidth in GHz	Value of a (b=1.1mm)	Operation frequencies in GHz	S11 in dB	Bandwidth in GHz
0.09mm	26.6 36.8 43.6 63.6	-12.07 -10.37 -24.28 -16.75	0.5 - 1.7 4.9	**0.13mm**	26.5 37.3 44.8 67.3	-11.99 -19.6 -16.02 -15.91	0.2 0.3 0.7 3.8
0.1mm	26.5 37.4 44.9 67.0	-14.22 -11.31 -16.87 -44.01	0.2 0.7 1.4 4.2	**0.14mm**	26.5 37.3 44.7 67.4	-14.22 -23.93 -35.60 -52.30	0.5 0.2 0.1 5.2
0.11mm	26 37.2 45 67.6	-12.44 -18.35 -14.37 -20.25	0.3 0.1 0.7 4.1	**0.15mm**	26 36.6 42.7 66.4	-11.2 -17.37 -10.9 -13.4	0.3 0.7 - 1.3
0.12mm	26.3 37 44.2 66.6	-14.22 -16.28 -22.06 -20.44	0.5 0.2 0.9 5.1	**0.16mm**	26.3 37.3 44.2 67.6	-12.47 -13.01 -21.5 -11.0	0.1 0.5 0.92 6.3

COAXIAL FEED WITH DGS



(a) (b)

Figure 10. Return loss plot of different values of (a) b and (b) a

Table 7. Simulation results of the antenna as a function of tuning parameter of "b"

Value of b	Operation frequencies (GHz)	S11 (dB)	Bandwidth (GHz)	Value of b	Operation frequencies (GHz)	S11 (dB)	Bandwidth (GHz)
1mm	31.5 47.9 59.5	-17.2 -31.3 -10.1	3.4 2.3 0.01	**1.3mm**	32.5 47.6 59.6	-14.72 -30.16 -11.26	4 2.2 6
1.1mm	31.5 47.8 59.9	-17.52 -33.57 -10.71	3.2 2 4.8	**1.4mm**	31.9 47.6 60.2	-18.13 -31.35 -10.02	3.8 2.4 0.03
1.2mm	31.4 47.6 59.4	-16.81 -31.72 -10.23		**1.5mm**	31.8 47.5 59.7	-17.48 -27.50 -10.67	2.8 2.3 8

Table 8. Simulation results of the antenna as a function of tuning parameter of "a"

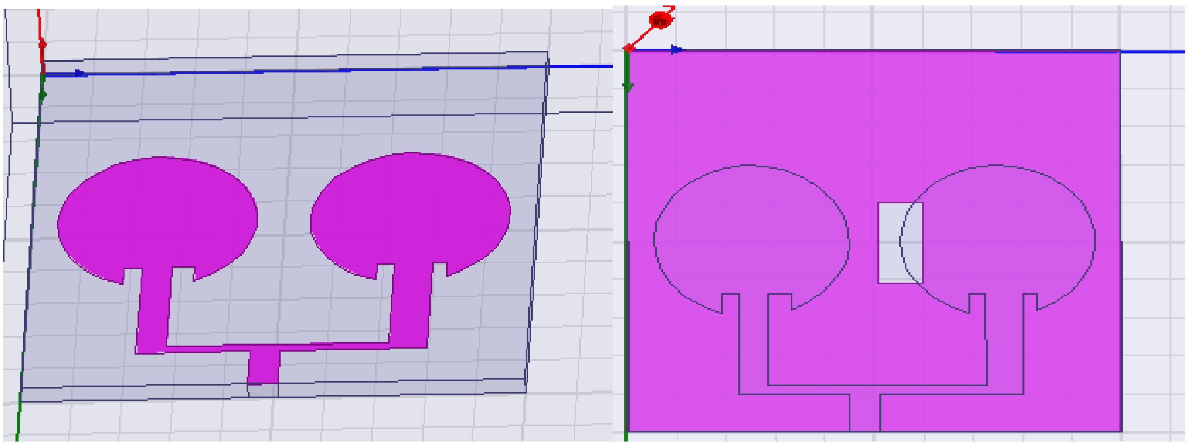
Value of a (b=1.1mm)	Operation frequencies in GHz	S11 in dB	BW in GHz	Value of a (b=1.1mm)	Operation frequencies in GHz	S11 in dB	BW in GHz
0.09mm	31.6 48.1 60.3	-18.17 -41.80 -10.46	0.22 0.42 0.01	**0.13mm**	31.6 48.2 61.7	-18.17 -33.34 -10	0.22 0.4 -
0.1mm	20.2 31.6 48.2 61.7	-7.3 -18.18 **-45.31** -9.35	- 0.22 0.3 -	**0.14mm**	20.1 31.6 48.2 60.8	-6.2 -18.18 -45.31 -10.93	- 0.22 1.2 0.5
0.11mm	31.6 45.5 60.9	-18.2 -35.77 -10.46	0.22 0.5 0.08	**0.15mm**	31.5 48.4 61.7	-18.3 -31.41 -10.11	0.23 2 0.3
0.12mm	31.6 48 60.7	18.2 -42.77 -11.46	0.22 0.5 0.02	**0.16mm**	31.3 48.4 62	-17.25 -25.85 -10.25	0.18 1.9 0.12

From summarized results listed in the table 3- table 8, we can observe that the good performance is at position a=1.1mm and b= 0.14mm for U slots and Comparison of feeding techniques with DGS (I slot and 2 U slots) technique at a=1.1mm and b=0.14mm is shown in the table

Table 9. Comparison Of Feeding Techniques with DGS (I slot and 2 U slots) technique

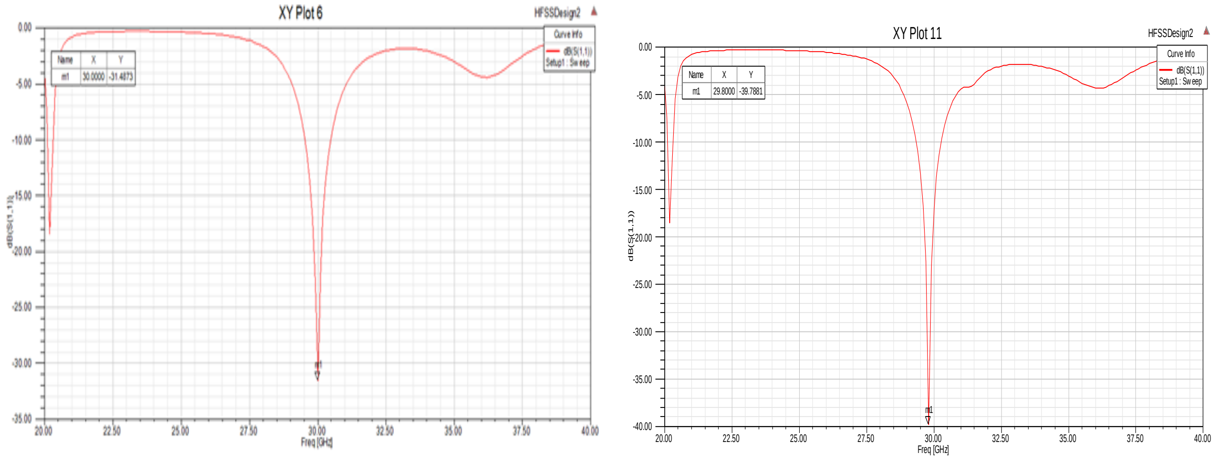
Techniques	Operating frequency in GHz	Return loss in dB	VSWR	Bandwith in GHz
Coaxial feed	20.1 31.6 48.2 60.8	-6.2 -18.18 **-45.31** -10.93	3.05 1.28 1.01 1.79	- 0.22 1.2 0.5
Microstrip edge feed	27.0 37.9 43.1 62.2	-19.01 **-44.90** -10.39 -28.35	2.5 1.08 1.25 1.11	1.03 0.34 0.2 1.5
Microstrip inset feed	26.5 37.3 44.7 67.4	-14.22 -23.93 -35.60 -52.30	1.60 1.08 1.09 1.006	0.5 0.2 0.1 5.2

From the comparison of feeding techniques it is observed, inset feed technique has good performance in terms of gain, return loss, VSWR and bandwidth. Now we design ,the 1x 2 Circular patch antenna array using inset feed technique without DGS and with DGS (I slot) for millimeter wave applications .



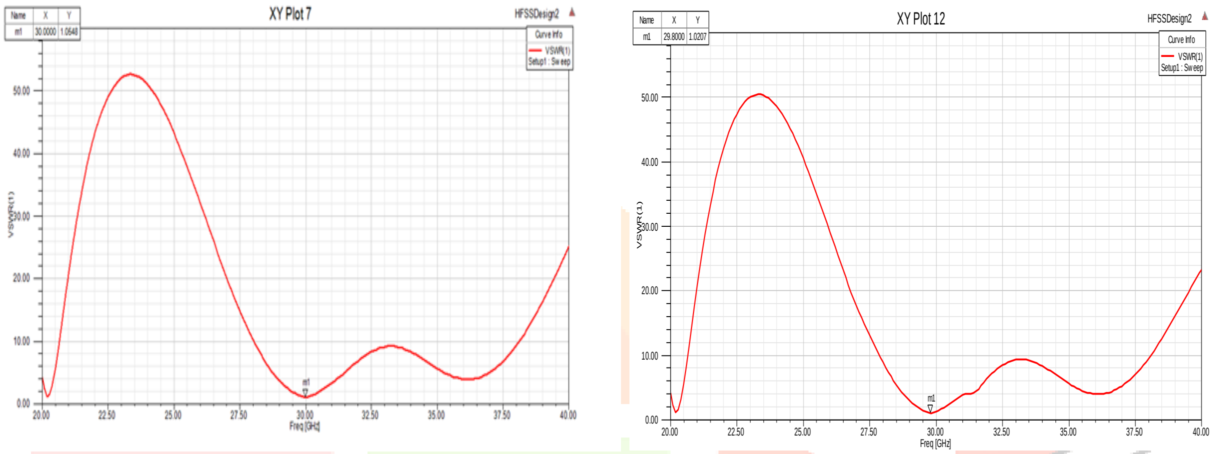
(a) (b)

Figure 11. Design model (a) without and (b) with DGS



(a) (b)

Figure 12. Return loss (a) without and (b) with DGS



(a) (b)

Figure 13. Return loss (a) without and (b) with DGS

Table 10. Comparison of 1x2 circular patch antenna arrays with and without DGS

parameter	without DGS	with DGS
Resonant frequency	30 GHz	29.8 GHz
Return loss	-31.48 Db	-39.78 dB
VSWR	1.054	1.02
Bandwidth	1 GHz	1 GHz
Gain	9.125 dB	9.23 dB

Thus it is observed that circular patch antenna array with I slot DGS technique has good performance than the circular patch antenna array without DGS.

5. CONCLUSION:

From the results, it is observed that the circular patch antenna using inset feed has good performance in terms of gain, return loss, VSWR and bandwidth. The proposed patch antenna is well matched, characterized by a wide bandwidth (5.2 GHz), enhanced return loss(-52.3dB at 62 GHz), VSWR (1.006) and the design of multiband patch antenna that operates mainly around the frequencies 27GHz, 38GHz, 43GHz and 62GHz.

The 1x2 circular patch antenna array with defective ground structure using inset feeding technique is also designed in this project. The return loss of circular patch antenna array without DGS is -31.48dB at resonant frequency of 30 GHz with the gain of 9.125dB.While the circular patch antenna array with I slot DGS achieved the return loss of -39.78 dB with the gain of 9.23dB.Thus it is observed that circular patch antenna array with I slot DGS technique has good performance than the circular patch antenna array without DGS. Thus, the proposed antennas are useful in Satellite Communication, Automotive Applications, Body scanners, Radar Communication applications.

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