DGS BASED SLOTTED MICROSTRIP PATCH ANTENNA FOR MM-WAVE AND 5G APPLICATIONS

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ABSTRACT

This paper aims to propose a defected ground structure (DGS) based slotted microstrip patch antenna (MPA) for mm-Wave (mmW) and 5G applications. RT-Duroid having dielectric constant 2.2 and height 0.408 mm is used as a substrate for the proposed antenna. Inset feed has been used for better impedance matching. The antenna structure comprises three rectangle-shaped slots at the top and a rectangular DGS at the bottom. The purpose of using DGS is to enhance the desired antenna performances. 34 GHz has been used as an operating as well as resonating frequency for the antenna. This frequency lies in Ka-band which goes well with mmW and next-generation 5G communication networks. The design results show that the proposed antenna is suitable for the said applications. HFSS software has been used for antenna design and simulation.

Keywords: *DGS, mmW, inset feed, MPA, 5G.*

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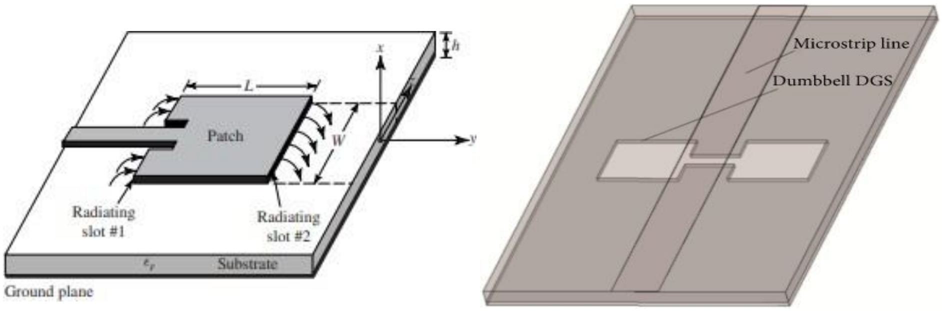
1 INTRODUCTION

The Ka band ranges from 26 GHz to 40 GHz. It is mainly used in satellite communication. Due to short wavelength, it can also be used for close range radars. Ka band frequency allows high speed data communication. It also allows the usage of small dish antennas. Because of small antenna size, the production, installation and maintenance becomes very inexpensive and also easier.

The microstrip patch antenna (MPA) [1], as depicted in fig. 1, is an arrangement wherein top surface of the dielectric substrate contains a radiating patch and bottom surface contains a ground plane. Among various feeding techniques for MPA, we have used inset feed as it provides better impedance matching. It, therefore, eliminates the need of any other matching elements, which helps in overall antenna size reduction.

MPAs are mostly used at microwave frequencies and are easy to fabricate. These are extensively used in mobile, satellite communication system, WLANs and GPS system. These antennas are easily integrated with microwave integrated circuits (MICs) and support both linear and circular polarizations. MPAs are low cost, light weight and low size antennas. Despite these advantages, MPAs have disadvantages like low gain and low impedance bandwidth.

Defects (or slots) created in the ground plane are called defected ground structure (DGS) [2]. These defects, as depicted in fig. 1, can be single or multiple. It suppresses mutual coupling between elements and thereby reduces harmonics. So, DGS has filter characteristics. Moreover, it reduces antenna size, boosts bandwidth and enhances the overall antenna gain.



(i) MPA (ii) DGS model

Fig 1 – Microstrip patch antenna and a model of DGS

2 LITERATURE SURVEY

There have been many researches taking place in the field of antennas aimed at achieving higher bandwidth and gain. DGS is one of such techniques for improving these parameters. In [1, 2], an introduction and overview of MPA have been presented along with features, advantages, limitations and different types of feeding techniques.

[3] gives information about DGS wherein it says that DGS has band-gap characteristic in some frequency bands. It also provides an equivalent model of DGS using 3-D field analysis method. Finally, it designs and implements a low pass filter using DGS. In [4], DGS for harmonic control of MPA has been designed. After modeling and analyzing the DGS based on ABCD formulation a simple DGS with N=2 has been designed for harmonic control. Transmission line theory model has been used. In [5], proposed DGS reduces cross polarized radiation of the antenna. It also examines the performance of circular patch with and without DGS. In [6-8], a review on microstrip antenna with DGS has been given which concludes that there is a growing and significant development in the area of DGS. It is still open for the researchers to research on the field of antennas using DGS. In [9], linearly polarized bi- directional microstrip array antenna with DGS is presented. Corporate feed network has been used to feed the array elements. Two DGS models have been proposed in the paper. [10] deals with the use of DGS on flexible substrate for wireless body area network applications.

[11] throws light on the use of slots in different patch geometries and gives the performance evaluations in each case. [12] talks about C-slot for textile material based MPA whereas [13] takes elliptical slots into consideration for wireless communication applications. [14] seeks to talk about hexagonal rings for satellite applications.

[15] emphasizes on the use of mmW for mobile communication. [16] tells about various factors that influence mmW antenna performance w.r.t mobile phones viz. path loss between radio frequency integrated circuits (RFIC) and mmW antenna arrays, mmW antenna materials, problems with round edges, screen-to-body ratio, etc.

[17] uses slot and DGS for 15-34 GHz antenna and finally uses array method to increase the overall gain. It seeks to use the antenna for wireless systems and aerospace platforms. [18] talks about antenna for Ka- and X- bands applications.

3 Antenna Design Calculations

The proposed antenna with inset feed is designed to work in Ka-band (26-40 GHz). RT-Duroid with dielectric constant of 2.2, loss tangent of 0.0009 and at a height of 0.408mm is used as substrate for the proposed design. The dimensions of the patch are taken as 2.62 3.22 0.416 mm. The operating frequency is 34 GHz which lies in the Ka-band.

Width of the patch, $w = \frac{c}{2f} \times \sqrt{\frac{2}{\varepsilon_r + 1}}$ = 3.48mm

where, c = speed of the light, ε_r= dielectric constant, and f =

frequency.

Effective dielectric constant, $\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} +$

$\frac{\varepsilon_r-1}{2}\left(1+\left(\frac{12h}{w}\right)\right)^{-1/2}$ = 1.984

Effective length of the patch, $L_{eff} = \frac{c}{2f\sqrt{\varepsilon_{reff}}}$ = 3.13mm

Fringing length of the patch on two sides, $\Delta L = \frac{0.412\times h(\varepsilon_{reff}+0.3)(\frac{w}{h}+0.264)}{(\varepsilon_{reff}-0.258)(\frac{w}{h}+0.8)}$ = 0.19mm

Length of the patch, $L = L_{eff} - 2\Delta L$ = 2.75mm

Length of the substrate, $L_g = 6h + L$=5.246mm

Width of the substrate, $w_g = 6h + w$ = 5.976mm

DGS has been placed in the ground plane by trial and error method. Also, the slots on the patch are of double the size of the feed width and the slot that is straight to feed line is same size as the feed line. The gap used for the inset feed is 0.06 mm and width of the feed is 0.25 mm.

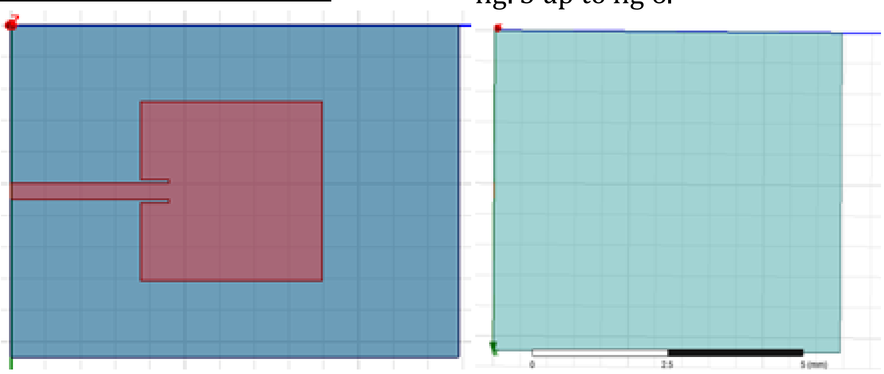
Table 1- Antenna Design Parameters

Parameter	Dimension (mm)
W_g	5.97
L_g	5. 24
W	3.48
L	2.75
W_f	0.25
L_f	1.4
Gap of the inset feed	0.06
DGS	1.7 3.22
Corner slots on the patch	0.64 2.48
Central slot on the patch	0.25 2

4 RESULTS AND DISCUSSIONS

Basic Antenna

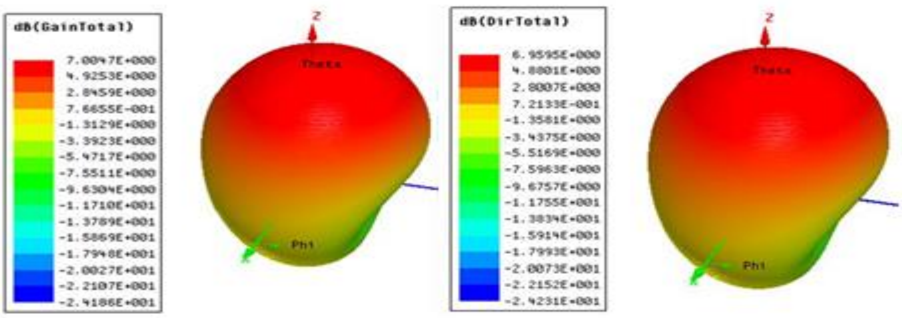
An inset-fed MPA, resonating in Ka band, is taken as a basic antenna, as shown in fig 2. Various parameters are also shown subsequently from fig. 3 up to fig 6.



(i) Front View **(ii) Rear View**

Fig 2 – Front and rear views of basic antenna

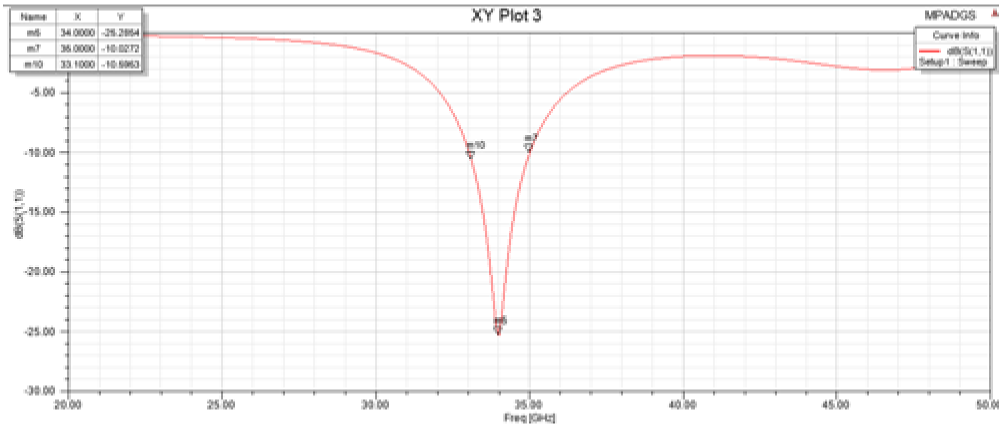
Basic antenna (on XY plane) does not use DGS as depicted from the rear view in fig. 2. Inset has been used at the centre.



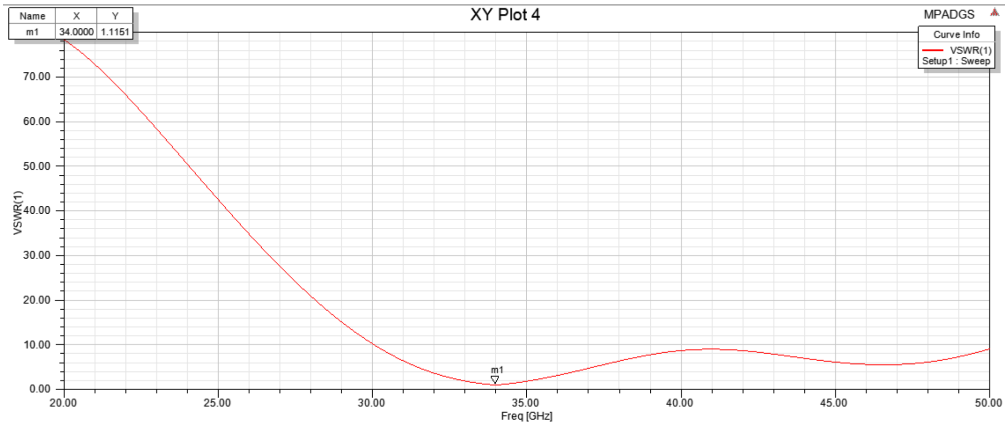
(i) Gain (ii) Directivity

Fig 3 – Gain and Directivity of the basic antenna

From fig.3, it is shown that the basic antenna achieves a total gain of around 7dB and directivity of around 6.9595 dB in the broadside direction (i.e. along z-direction).



(i) Return loss

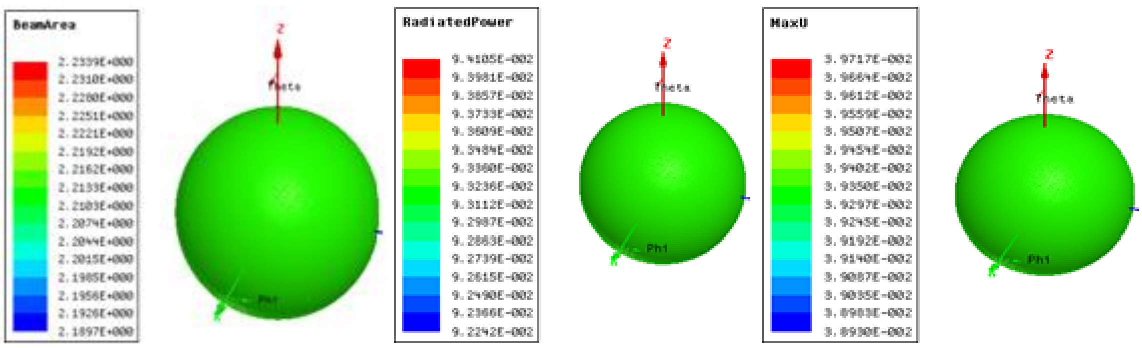


(ii) VSWR

Fig 4 – Return loss and VSWR of the basic antenna

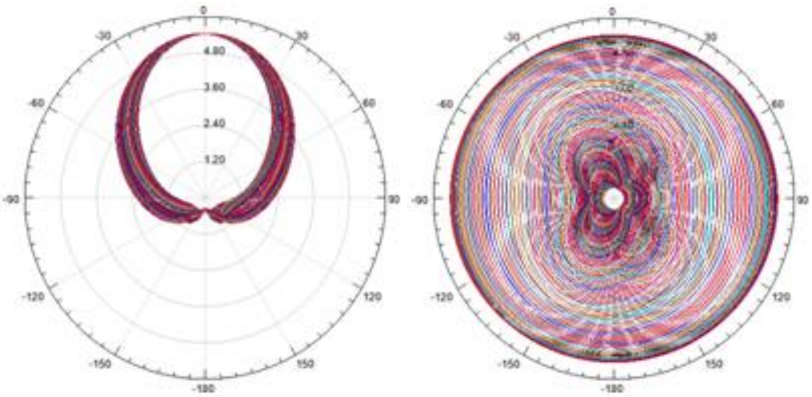
From fig 4, it is shown that the antenna resonates exactly at the operating frequency i.e. 34 GHz giving return loss of

-25.28 dB and VSWR of 1.11, which are pretty much under tolerable limits. The obtained bandwidth at 34 GHz is around 1.9 GHz.



(i) Beam Area (ii) Radiated Power (iii) U_{max}

Fig 5 – Beam area, Radiated power and Max. Radiation intensity (Umax) of the basic antenna



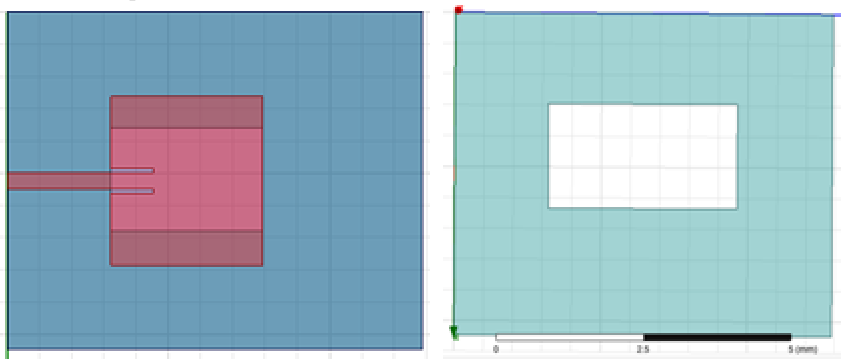
(i) E-Plane (ii) H-Plane

Fig 6 – 2D radiation patterns of the basic antenna

Fig 5 and 6 give details about other parameters like beam area, power, radiation intensity and 2D radiation pattern of the basic antenna.

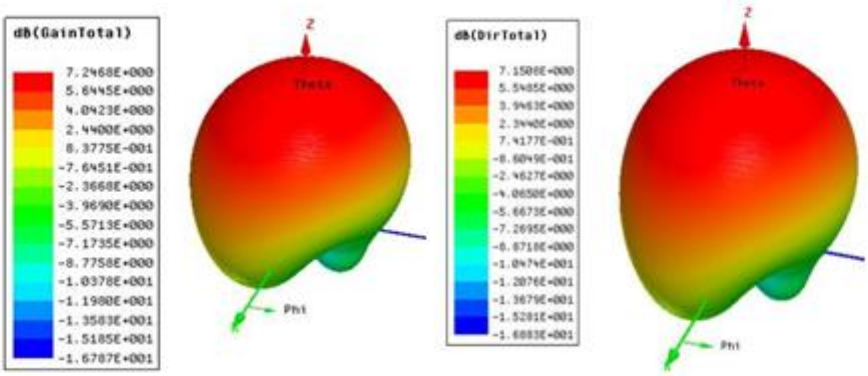
Basic Antenna with DGS

A rectangular DGS has been introduced, as discussed earlier and depicted in fig. 7, with an aim to increase the overall performance of the basic antenna. The dimensional features of DGS have been purposefully taken to resemble the rectangular patch. Trial and error method is used to finalize its position in the ground plane.



(ii) Front View (ii) Rear View

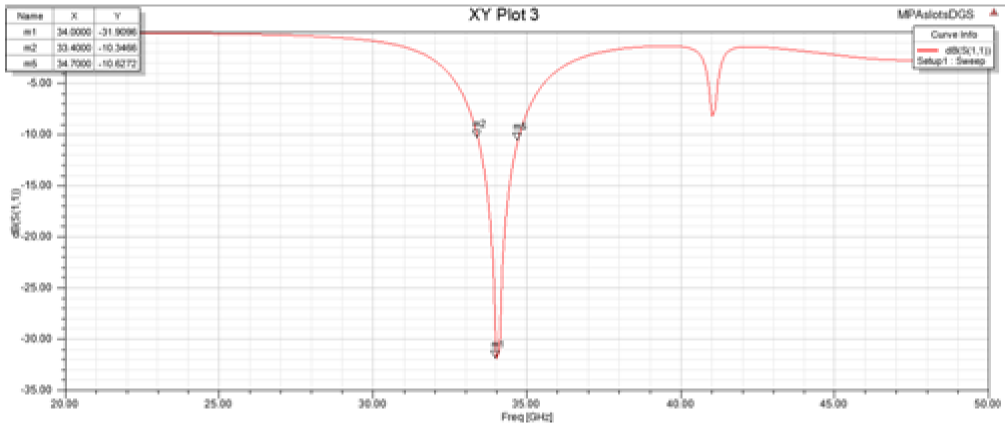
Fig 7 – Front and rear views of basic antenna with DGS



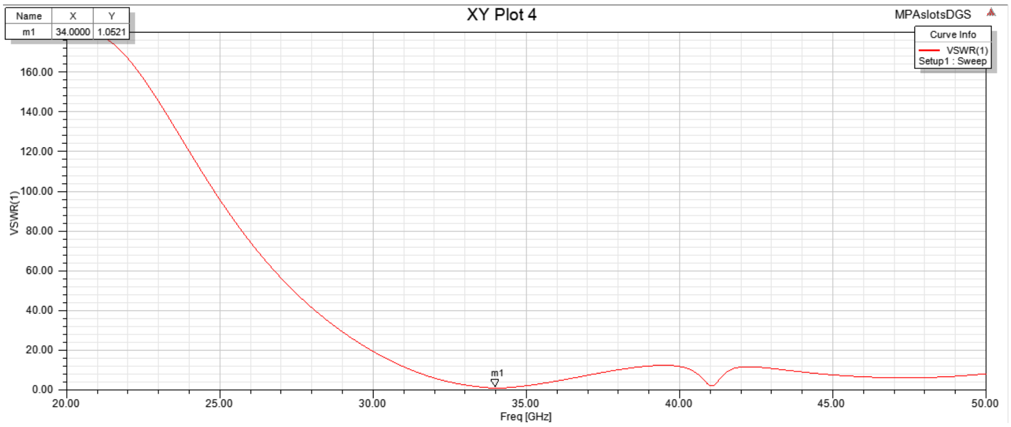
(i) Gain (ii) Directivity

Fig 8 – Gain and Directivity of the basic antenna with DGS

From fig.8, it is shown that gain and directivity are increased to 7.2468 dB and 7.15 dB respectively, once DGS is introduced.



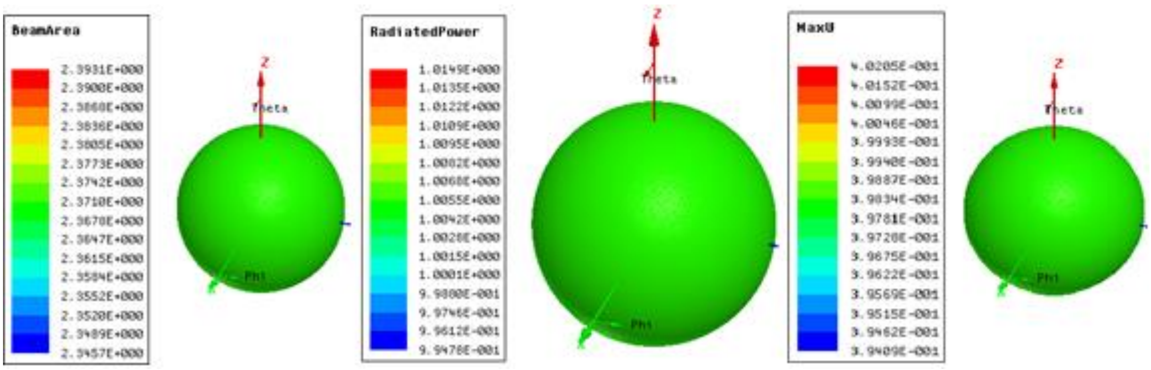
(i) Return loss



(ii) VSWR

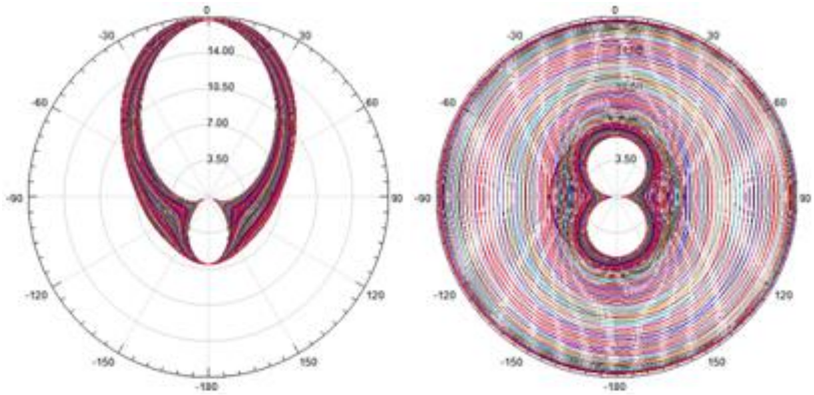
Fig 9 - Return loss and VSWR of the basic antenna with DGS

From fig 9, it is shown that resonance occurs again at 34 GHz giving return loss of -31.9 dB and VSWR of 1.06, which show considerable improvements. The obtained bandwidth with DGS is around 1.3 GHz.



(i) Beam area (ii) Radiated power (iii) Max. Radiation Intensity (U_{max})

Fig 10 – Beam area, Radiated power and Max. Radiation intensity (Umax) of the basic antenna with DGS



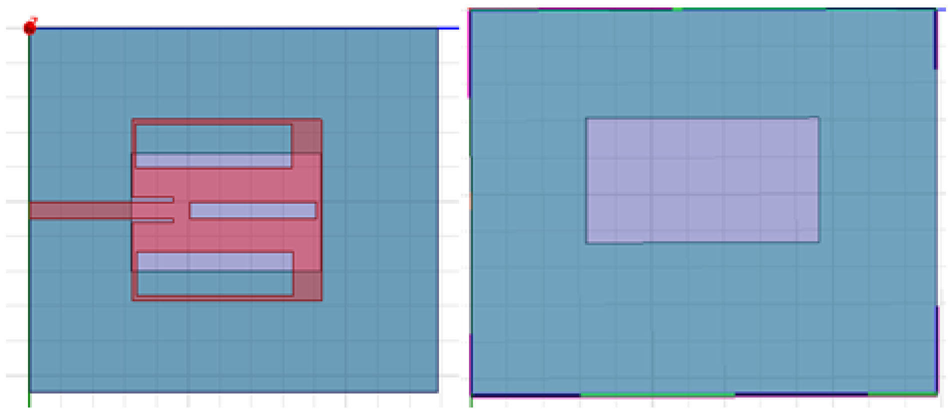
(i) E-Plane (ii) H-Plane

Fig 11 – 2D radiation patterns of the basic antenna with DGS

Fig 10 and 11 give details about other parameters like beam area, power, radiation intensity and 2D radiation pattern of the basic antenna with DGS.

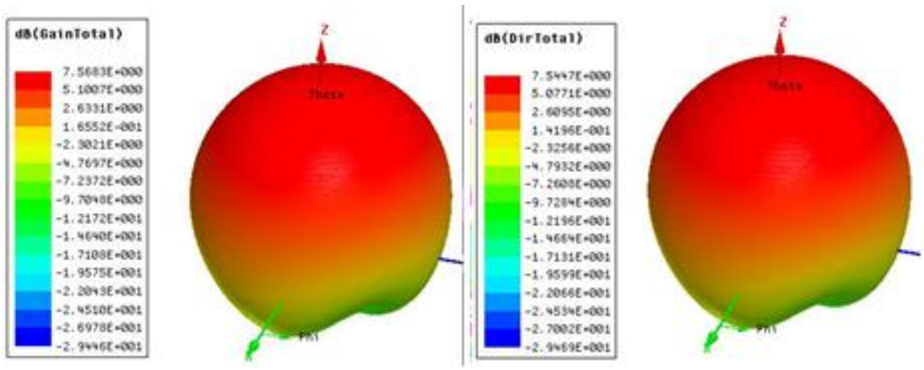
Proposed Antenna

Finally three rectangular slots have been placed on to the patch as shown in fig 12, which resonates remarkably in Ka band with enhanced gain and other performance parameters as shown in subsequent figures.



(iii) Front view (ii) Rear view

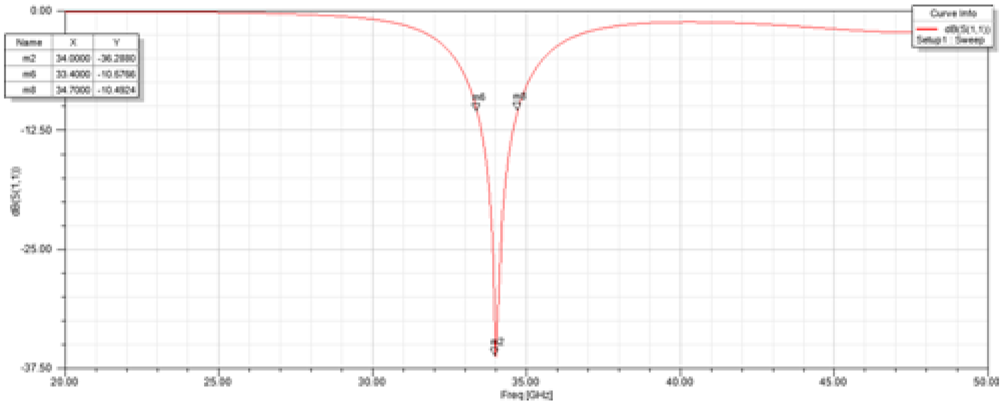
Fig 12 – Front and Rear views of proposed antenna



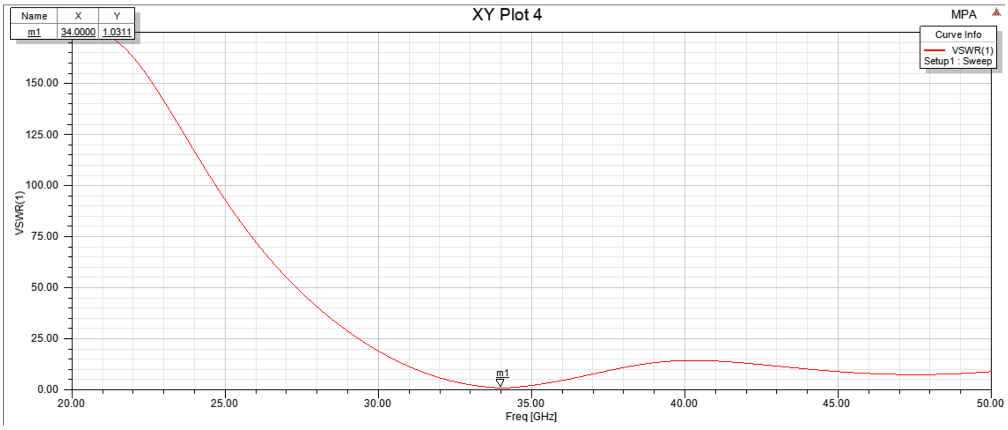
(i) Gain (ii) Directivity

Fig 13 – Gain and Directivity of proposed antenna

Fig.13 shows an increase in gain and directivity to 7.5683 dB and 7.54 dB respectively, once the slots are introduced.



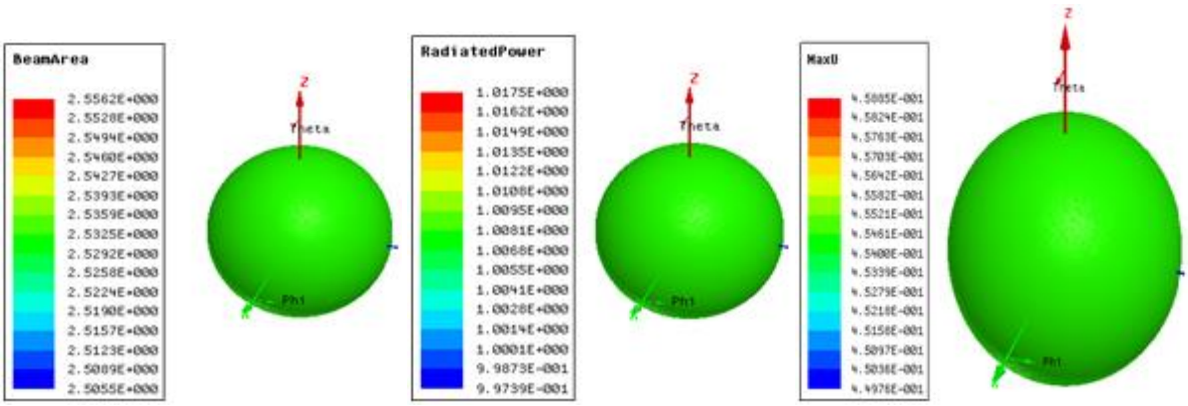
(i) Return loss



(ii) VSWR

Fig 14 – Return loss and VSWR plot for the proposed antenna

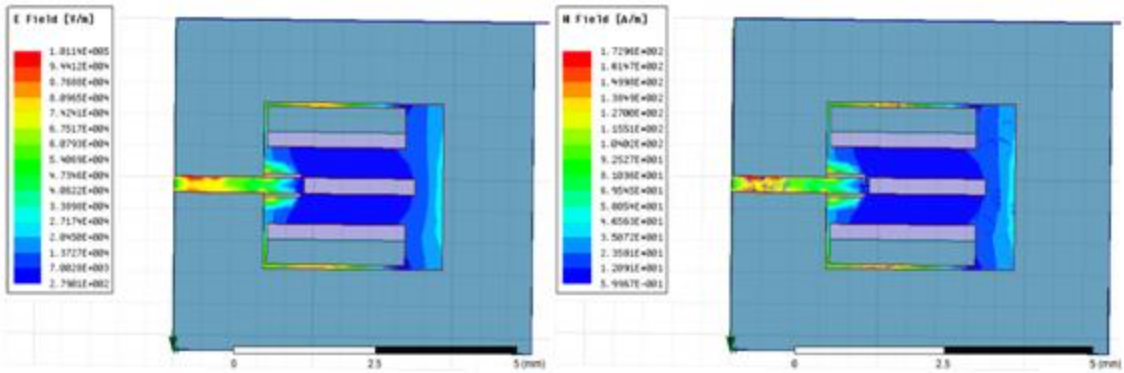
Fig. 14 shows that proposed antenna is resonating at 34 GHz with return loss of -36.288 dB and VSWR of 1.03. The obtained bandwidth is around 1.3 GHz.



(i) Beam area (ii) Radiated Power (iii) Max. Radiation Intensity (U_{max})

Fig 15 – Beam area, Radiated power and Max. Radiation intensity (Umax) of the proposed antenna

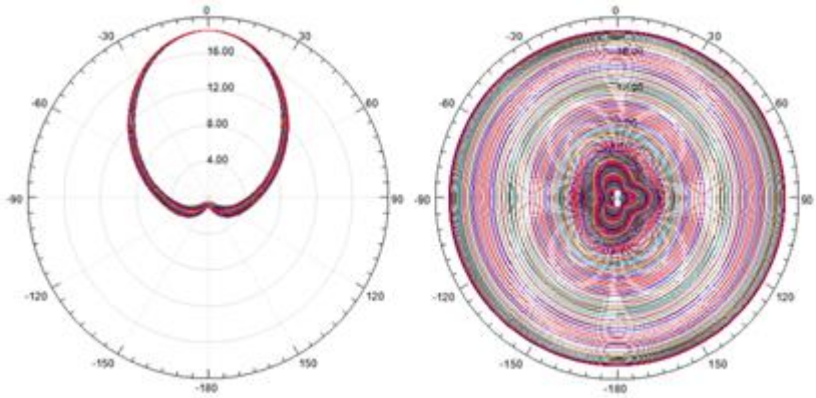
Fig 15 shows an improvement in terms of beam area, power radiated by the proposed antenna and max. radiation intensity along broadside direction.



(i) E-Field (ii) H-Field

Fig 16 – Field overlays of the proposed antenna

Fig 16 gives the electric and magnetic field distributions which shows that fields are highly concentrated along the two opposite edges, one at the feed and the other being the opposite side.



(i) E-Plane (ii) H-Plane

Fig 17 – 2D radiation patterns of the proposed antenna

Fig 17 gives the 2D radiation patterns for electric and magnetic fields, which again show an improvement over the previous two designs.

Finally, table 2 gives an overall comparison of the three designs.

Table 2 – Comparison of antenna parameters

Parameters	Basic antenna	Basic antenna with DGS	Proposed antenna
Gain(dB)	7.0047	7.2468	**7.5683**
Directivity(dB)	6.9595	7.15	**7.5447**
Return loss(dB)	-25.28	-31.9	**-36.288**
VSWR	1.11	1.06	**1.03**
Bandwidth (GHz)	1.9	1.3	1.3
Max. E-field (Emax)	4.8	14	**16**
Max. Beam Area	2.2339	2.393	**2.5562**
Max. Radiated Power	0.0941	1.0149	**1.0175**
Max. Radiation Intensity	0.0397	0.402	**0.45885**

From table 2, it is clear that the proposed antenna works supremely well at the resonating frequency and fulfils all the necessary requirements to be needed for its possible use in mmW and 5G applications.

5 CONCLUSION

In this paper, slotted MPA with DGS has been proposed. The proposed antenna at resonating frequency gives higher gain of 7.57 dB, directivity of 7.54 dB and improved parameters such as return loss of -36.29 dB and VSWR of 1.03, along with a wide bandwidth of 1.3 GHz. As 5G needs a wide bandwidth along with considerably good performances like gain, return loss, etc., the proposed antenna augers well with the demands of millimeter wave and 5G applications.

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