Design, Simulation and Experimental Validation of Wideband DGS Circularly Polarized Micro Strip Patch Antenna For C-Band Satellite Communication Applications

Karedla Chitambara Rao

Abstract: ***Satellites are very prominent for current and future communication applications like broadcasting, 5G and Military Communications. Most of the Satellites are used for radio communication. For communicating purpose, the satellite antenna must have unique characteristics such as circular polarization, broad beam width and good axial ratio. In order to have such type of unique characteristics, the micro strip patch antenna is the suitable antenna for Satellite applications because of its advantages. In this paper, a Wide band DGS circularly polarized micro strip patch antenna has been proposed for C-Band Satellite Communication Applications. Two defects or slots are introduced in the ground plane and those are orthogonally overlapped to get the circular polarization characteristics. In addition to this, these two slots enhance the bandwidth of the patch antenna by tuned to different frequencies. Moreover, the patch with defective ground structure is simulated and fabricated. Also measurements are carried out and obtained results are compared with the simulated results. It is noted that all the simulated and measured radiation patterns of the antenna have been carried out for all the frequencies and data has been compiled. However, some of the simulated and measured radiation patterns are included in this paper due to space constraint.***

Keywords:Micro strip patch antenna, Defective Ground structure and C-Band Satellite Communication.

I. INTRODUCTION

The drawbacks of the ordinary micro strip patch antenna are low gain and low bandwidth. The low gain and low bandwidth can be improved by using so many techniques. Out of them, defective ground structure is the familiar technique to improve the gain and bandwidth. Defective ground structure technique is nothing but a creating a defect or slot on the ground plane. This defect will acts as a parallel tuned circuit which resonate at a required frequency by modifying the slot based on the proper measurements.

Two slots are required in overlap manner to get a circular polarization which is essential for satellite communication applications. Based on the DGS technique, the antenna can be operated at a multiple frequencies which lead to the enhancement of bandwidth of the antenna. The frequency for the C-Band is allocated in the electromagnetic spectrum from 4GHz to 8 GHz. C-Band is mostly used for the communication applications like Wi-Fi, Wi-Max and 4G Communications. C-Band frequencies are used for both downlink and up link purpose. The frequency range of downlink is from 3.7GHz to 4.2 GHz and 5.925GHz to 6.425 GHz for uplink. Nakano, et al. [1-7] had explained about circular polarization and how it obtained from the patch antenna. Circular polarization may also be achieved by feeding the two orthogonal lines in TM_{01} and TM_{10} modes. Horizontal polarized wave can be obtained in TM_{01} mode and vertical polarized wave in TM_{10} mode respectively. Moreover, these two waves can be achieved simultaneously from a square patch antenna. A. Iwasaki, et al. [8] had designed a micro strip patch antenna with circular polarization characteristics. The circular polarization characteristics were obtained by using the crossed slots and their lengths are different. The designed antenna has been resonated at a frequency of 1575.42MHz. The fundamental mode (TM_{11} mode) of circular patch antenna was obtained by

selecting the proper lengths of the slots. Moreover, the circular polarization was achieved by using equal amplitudes and 90^0 phase difference. The patch and feed lines are fabricated on 1.6mm substrate and its dielectric constant is 2.6. Right hand circular radiation was achieved by making the

length of slot 1 greater than the length of slot 2.Similarly, left hand circular polarization was achieved by making the length of slot 1 smaller than the length of slot 2. 36% size reduction was achieved when compared to ordinary patch. Better measurement values are achieved like VSWR is 2:1 and axial ratio less than 3dB. Z.N.Nasimuddin, et al. [9] had designed a circular polarized micro strip patch antenna for the frequency range of 2.397GHz to 2.512GHz. Circular polarization may also achieved by using the asymmetric slots with different length. The designed antenna has been fabricated on an FR4 substrate with thickness of 1.6mm.When compared to ordinary patch, 12% size reduction was obtained .Moreover, better measurement values are also achieved such as 10-dB return loss and 3-dB axial ratio bandwidth.

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II. DESIGN EQUATIONS

For an efficient antenna, the width (W) is given by the formulae

$$W = \frac{c}{2f_r}\sqrt{\frac{2}{\epsilon_r + 1}} \quad (1)$$

Where c is the free space velocity

ϵ_r = dielectric constant

The effective dielectric constant (ϵ_{reff}) of the micro strip patch antenna is

$$\epsilon_{reff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2}\left(1 + 12\frac{h}{w}\right)^{-\frac{1}{2}} \quad \frac{w}{h} > 1 \quad (2)$$

The extension length (ΔL) is given by the following formulae

$$\Delta L = 0.412h\frac{(\epsilon_r + 0.3)\left(\frac{W}{h} + 0.264\right)}{(\epsilon_r - 0.258)\left(\frac{W}{h} + 0.8\right)} \quad (3)$$

Effective length (L_{eff}) is calculated by using the formulae

$$L_{eff} = \frac{c}{2f_r\sqrt{\epsilon_{reff}}} \quad (4)$$

The actual length of the patch is calculated by using the formulae.

$$L = L_{eff} - 2\,\Delta L. \quad (5)$$

III. DESIGN SPECIFICATIONS

The specifications in the Table I are considered for the C-Band patch antenna.

Table-I:Design Specifications Of C-Band Patch Antenna

S.No	Design parameter	Specification
1	Receiving frequency range	3700MHz-4200MHz
2	Transmitting frequency range	5900MHz-6400MHz
3	VSWR	3:1(Max)
4	Gain	-3dBi(Min) to +3dBi(Max)
5	Polarization	LHCP
6	Beam width	Max(90^0),Min(17.03^0)
7	Axial ratio	≤ 5dB
8	Spatial coverage	Overtop hemisphere
9	Connector	SMA
10	Input impedance	50Ω

IV. DESIGN PARAMETERS

Design parameters of C-Band Micro strip patch antenna are calculated based on the design equations, which are presented in the section II.

Table-II:Design Parameters Of C-Band Micro Strip Patch Antenna With Defective Ground Structure

S.No	Design parameter	Calculated value
1	Resonant frequency	5.05GHz
2	Ground plane (Copper) thickness	0.1mm
3	Ground plane length	23.37mm
4	Ground plane width	27.87mm
5	Substrate (FR4 Lossy) thickness	1.6mm
6	Substrate dielectric constant	4.3
7	Patch (Copper) thickness	0.1mm
8	Patch length	13.77mm
9	Patch width	18.24mm
10	Large slot(Defect) length	2.4mm
11	Large slot(Defect) width	1mm
12	Small slot (Defect) length	1.2mm
13	Small slot (Defect) length	0.5mm

V. SIMULATED MICRO STRIP PATCH ANTENNA WITH DEFECTIVE GROUND STRUCTURE

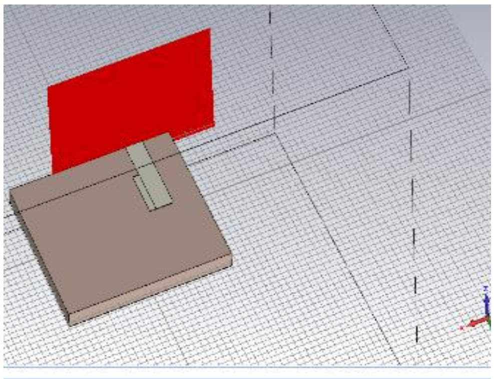


Fig.1.Simulated Micro strip patch antenna with Defective Ground Structure

In the Fig.1, the exciting points of the both the slots (defects) are orthogonal to each other for providing the circular polarization at the resonating frequencies. The co-axial type of feeding technique has been used for this antenna.

VI. SIMULATION RESULTS

The C-Band Micro strip patch antenna is designed at a centre frequency of 5.05GHz.The designed antenna was simulated and analyzed for the various characteristics like VSWR, Gain, axial ratio, 3-dB beam width and Radiation patterns at the various receiving and transmitting frequencies. Gain and axial ratio of the antenna are taken at the different angles of θ (-45^0, 0^0&45^0) by fixing the φ at 0^0 for analysis. Radiation patterns such as 3D and 2D radiation patterns are also taken at the various frequencies for analysing the radiation characteristics.

A. Simulated VSWR

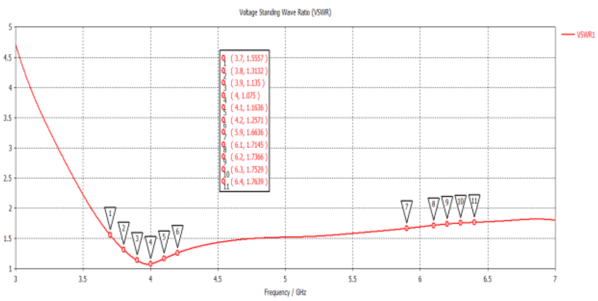


Fig.2.Simulated VSWR versus frequency

Table-III : Simulated VSWR At Various Receiving And Transmitting Frequencies

Frequency (MHz)	VSWR	Frequency (MHz)	VSWR
3700	1.5557	5900	1.6636
3800	1.3122	6000	1.6737
3900	1.135	6100	1.7145
4000	1.075	6200	1.7366
4100	1.1636	6300	1.7529
4200	1.2571	6400	1.7639

The Fig.2 shows that VSWR versus frequency. In the Table 3, the simulated VSWR values are obtained from the Fig.2. From the Table 3, it is noted that the low VSWR values at the receiving and transmitting frequencies are 1.075 at 4000MHz and 1.6636 at 5900MHz respectively. These values are good and suitable for C-Band Satellite Communication applications.

B. Simulated Gain

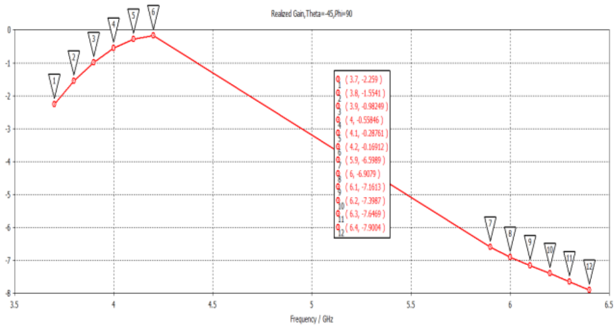


Fig.3.Simulated Gain versus frequency at θ= -45^0

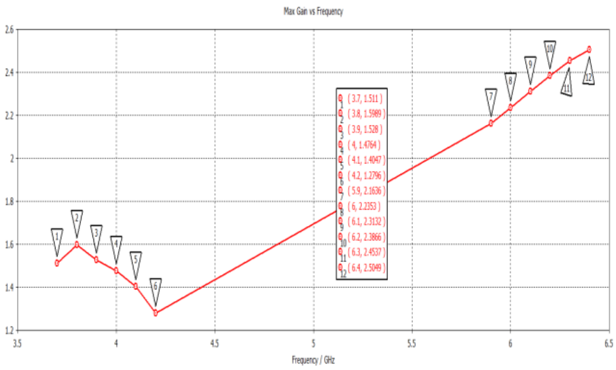


Fig.4.Simulated Gain versus frequency at θ=0^0

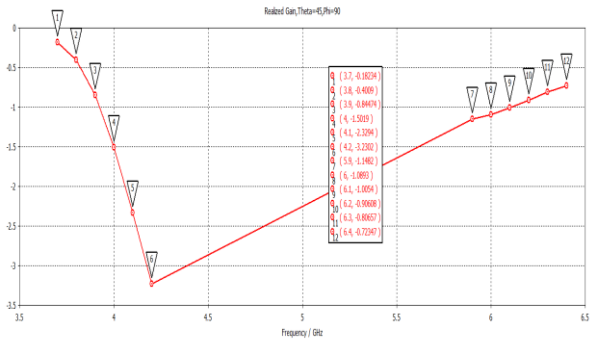


Fig.5.Simulated Gain versus frequency at θ= 45^0

Table-IV: Simulated Gain At Different Angles Of Θ For Various Receiving And Transmitting Frequencies.

Frequency (MHz)	Simulated Gain(dBi)		
	θ = - 45^0	θ=0^0	θ =45^0
3700	-2.259	1.511	-0.1853
3800	-1.5541	1.5989	-0.4009
3900	-0.98249	1.528	-0.8447
4000	-0.55846	1.4764	-1.5019
4100	-0.28761	1.4047	-2.3294
4200	-0.16912	1.2796	-3.2302
5900	-6.5989	2.1636	-1.1482
6000	-6.9079	2.2353	-1.0893
6100	-7.1613	2.3132	-1.0054
6200	-7.3987	2.3866	-0.9060
6300	-7.6469	2.4537	-0.8065
6400	-7.9004	2.5039	-0.7234

The figures 3 to 5 show that Gain versus frequency at the different angles of θ (-45°,0^0&45°). In the TABLE 4, the simulated Gain is obtained at different angles of θ from the figures 3 to 5. From the above Table 4, it is noted that the highest gain values are obtained at 0^0 when compared to the -45° and + 45°. It is also noted that, the higher Gain values at 0° for receiving and transmitting frequencies are 1.5989dBi at 3800MHz and 2.5039dBi at 6400MHz respectively. Similarly at -45° and +45°, the higher Gain values are -0.28761dBi at 4100MHz, -6.5989dBi at 5900MHz, 0.1853dBi at 3700MHz and -0.7234dBi at 6400MHz respectively. These higher Gain values are good and suitable for C-Band Satellite Communication applications.

C. Simulated Axial Ratio

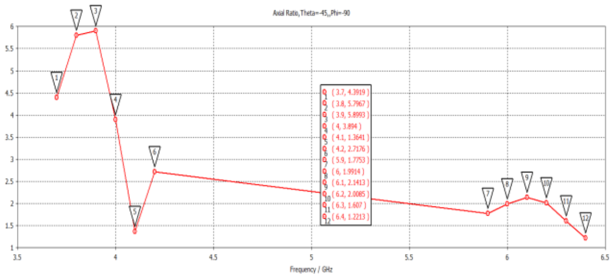


Fig.6.Simulated axial ratio versus frequency at θ=-45^0

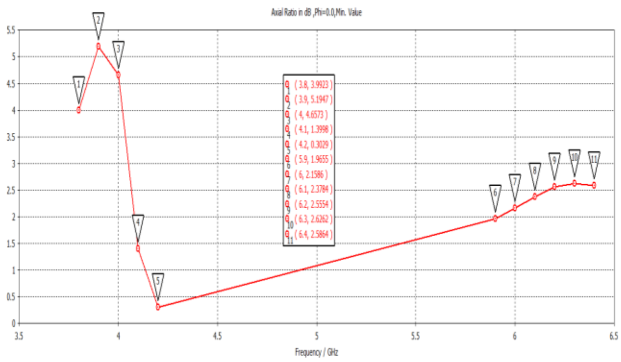


Fig.7.Simulated axial ratio versus frequency at θ=0^0

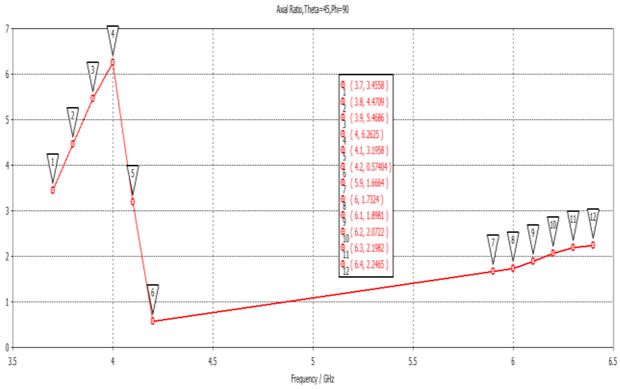


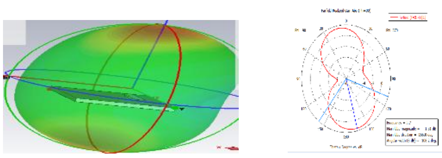
Fig.8.Simulated axial ratio versus frequency at θ=45^0

Table-V:Simulated Axial Ratio At Different Angles Of θ For Various Receiving And Transmitting Frequencies

Frequency (MHz)	Simulated axial ratio (dB)		
	θ = - 45^0	θ= 0^0	θ = 45^0
3700	4.3919	3.9521	3.4558
3800	5.7967	3.9923	4.4709
3900	5.8993	5.1947	5.4686
4000	3.894	4.6573	6.2625
4100	1.3641	1.3998	3.1958
4200	2.7176	0.3029	0.5740
5900	1.7753	1.9655	1.6664
6000	1.9914	2.1586	1.7324
6100	2.1413	2.3784	1.8981
6200	2.0085	2.5554	2.0722
6300	1.607	2.6262	2.1982
6400	1.2213	2.5864	2.2465

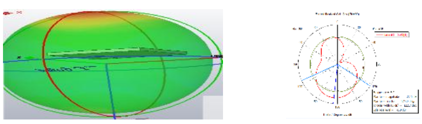
The figures 6 to 8 show that axial ratio versus frequency at the different angles of θ (-45°,0^0&45°). In the TABLE 5, the simulated axial ratio is obtained at different angles from the figures 6 to 8. From the above TABLE 5, it is noted that lower axial ratio values at 0^0 for the receiving and transmitting frequencies are 0.3029dB at 4200MHz and 1.9655dB at 5900MHz respectively. Similarly at -45° and +45°, the lower axial ratio values are 1.3641dB at 4100MHz, 1.2213dB at 6400MHz, 0.574dB at 4200MHz and 1.6664dB at 5900MHz respectively. These lower axial ratio values are good according to the given design specifications and suitable for C-Band Satellite Communication applications.

D. Simulated Radiation Patterns at Receiving and Transmitting Frequencies



(a) 3-D Pattern (b) 2-D Pattern

Fig.9.Simulated radiation pattern at 3700 MHz



(a) 3-D Pattern (b) 2-D Pattern

Fig.10.Simulated radiation pattern at 5900 MHz

Table-VI:Simulated 3-Db Beam Width At Various Receiving And Transmitting Frequencies

Frequency(MHz)	3-dB beamwidth (deg)	Frequency(MHz)	3-dB beamwidth (deg)
3700	108.2	5900	122.7
3800	111.9	6000	119.3
3900	120.2	6100	115.8
4000	256.3	6200	112.7
4100	249.6	6300	110.1
4200	243.6	6400	108.2

The figures 9 to 10 show that simulated 3D and 2D radiation patterns at various receiving and transmitting frequencies. In the Table 6, the simulated 3-dB beam width values are obtained from the 2D radiation patterns. From the above Table 6, it is noted that the higher 3-dB beam width value for the both receiving and transmitting frequencies are 256.3^0 at 4000MHz and 122.7^0 at 5900MHz respectively. The higher 3-dB beam width values are best and suitable for C-Band Satellite Communication applications.

VII. FABRICATION AND MEASUREMENT RESULTS

The Fig.11 shows that fabricated C-Band patch antenna. This antenna is measured for various characteristics such as VSWR, Gain, axial ratio, 3-dB beam width and Radiation patterns at the various receiving and transmitting frequencies

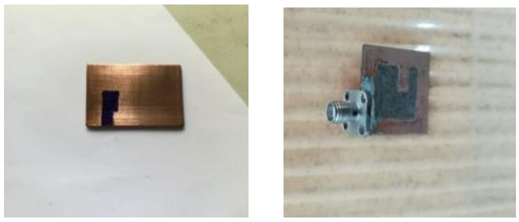


Fig.11.Fabricated C-Band Micro strip patch antenna

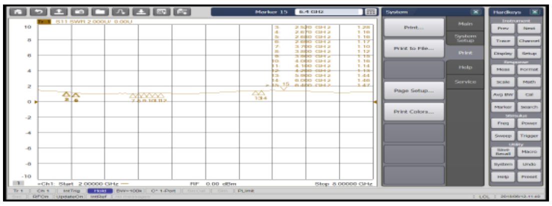


Fig.12.Measured VSWR versus frequency

Table-VII: Measured VSWR At Various Receiving And Transmitting Frequencies

Frequency (MHz)	VSWR	Frequency (MHz)	VSWR
3700	1.1	5900	1.44
3800	1.12	6000	1.46

3900	1.15	6100	1.47
4000	1.16	6200	1.47
4100	1.14	6300	1.47
4200	1.13	6400	1.47

The Fig.12 shows that VSWR versus frequency. In the TABLE 7, the measured VSWR values are obtained from the Fig.12. From the TABLE 7, it is noted that the lower VSWR values at the receiving and transmitting frequencies are 1.1 at 3700MHz and 1.44 at 5900MHz respectively. The lower VSWR values are good and suitable for C-Band Satellite Communication applications.

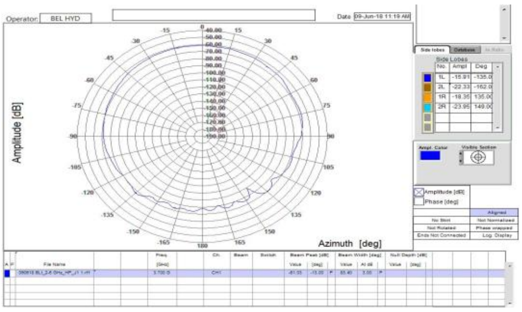


Fig.13. Measured radiation pattern in Horizontal Polarization at 3700MHz

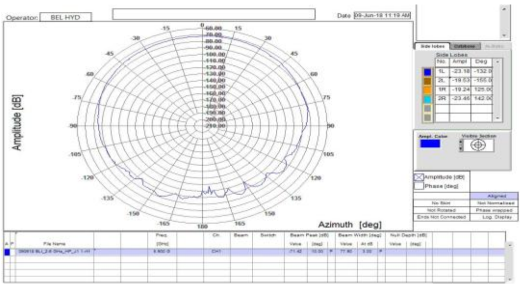


Fig.14. Measured radiation pattern in Horizontal Polarization at 5900MHz

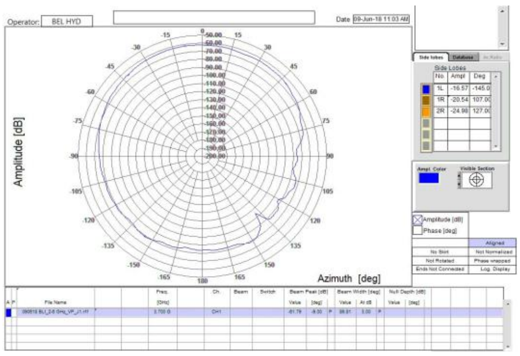


Fig.15.Measured radiation pattern in Vertical Polarization at 3700MHz

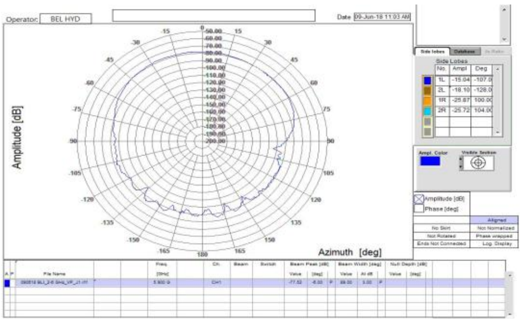


Fig.16. Measured radiation pattern in Vertical Polarization at 5900MHz

The measured 3-dB beam width values are taken from the measured radiation patterns in Horizontal and Vertical Polarizations, which are presented in the sections (b) and (c) of VII

Table-VIII: Measured 3-Db Beam Width Of Antenna Under Test In Horizontal And Vertical Polarizations At Various Receiving And Transmitting Frequencies

Frequency (MHz)	Measured 3-dB beam width (deg)	
	3-dB beam width of AUT in Horizontal Polarization	3-dB beam width of AUT in Vertical Polarization
3700	83.4	89.81
3800	75.5	61.92
3900	93.59	74.93
4000	93.77	81.37
4100	80.37	81.93
4200	99.93	58.47
5900	77.9	89
6000	58.06	77.61
6100	62.36	62.84
6200	74.85	30.92
6300	76.41	45.37
6400	73.28	56.71

From the TABLE 8, it has been observed that the higher 3-dB beam width values in Horizontal and Vertical polarizations are 99.93^0 at 4200MHz, 77.9^0 at 5900MHz, 89.81^0 at 3700MHz and 89^0 at 5900MHz respectively. The higher 3-dB beam widths values are good and suitable for C-Band Satellite Communication applications.

A. Measured Beam Peak and Standard Antenna Gain for Various Receiving and Transmitting Frequencies.

AUT Beam peak values are obtained at different angles from the measured radiation patterns in Horizontal and Vertical polarizations, which are presented in the sections (b) and (c) of VII

B. Measured Gain in Vertical Polarization

Measurement of Gain is carried out in Vertical Polarization. Here AUT gain is calculated based on the AUT beam peak, Standard antenna beam peak, Standard antenna gain, Polarization losses and cable losses. In the TABLE 10, AUT Gain is calculated at different angles for each frequency based on the following equation.

AUT Gain = AUT Beam peak- Standard antenna beam peak + Standard antenna Gain + 3dB polarization loss + 2dB cable losses (6)

In the equation (6), AUT beam peak, Standard antenna beam peak and Standard antenna Gain values are considered from the TABLE 9. From the TABLE 10, it is observed that the highest gain values are obtained at 0^0 when compared to the -45° and + 45° . In Vertical Polarization, the higher Gain values for the receiving and transmitting frequencies at 0^0 are 10.58dBi at 3700MHz and 8.58dBi at 6200MHz respectively. Similarly at -45° and +45°, the highest Gain values are 7.143dBi at 3700MHz, 6.649dBi at 6100MHz, 8.13dBi at

3700MHz and 7.773dBi at 6100MHz respectively. The obtained higher Gain values are good and suitable for C-Band Satellite Communication applications.

Table-IX: Measured AUT Beam Peak In Vertical Polarizations At Different Angles Of θ, Standard Antenna Beam Peak And Standard Antenna Gain For Various Receiving And Transmitting Frequencies

Frequency (MHz)	AUT Beam peak values(dBm) in Vertical Polarization			Standard antenna beam peak(dBm)	Standard antenna Gain (dBi)
	$\theta = -45^0$	$\theta = 0^0$	$\theta = 45^0$		
3700	-65.22	-61.79	-64.239	-48.17	19.2
3800	-70.97	-64.36	-66.017	-46.62	19.3
3900	-72.70	-71.79	-75.386	-48.46	19.4
4000	-69.76	-65.56	-68.704	-48.7	19.5
4100	-68.69	-63.46	-65.986	-49.15	17.4
4200	-69.98	-67.04	-71.841	-51.19	17.6
5900	-79.69	-77.52	-80.296	-52.63	21.72
6000	-84.65	-79.19	-83.86	-53.9	21.8
6100	-85.26	-79.11	-84.137	-65.01	21.9
6200	-88.32	-85.43	-91.793	-67.06	21.95
6300	-94.00	-84.54	-91.934	-64.1	22
6400	-96.02	-87.46	-92.247	-62.96	22.1

Table-X:Measured AUT Gain At Different Angles Of θ In Vertical Polarization For Various Receiving And Transmitting Frequencies

Frequency (MHz)	AUT Gain (dBi) in Vertical Polarization		
	$\theta = -45^0$	$\theta = 0^0$	$\theta = 45^0$
3700	7.143	10.58	8.131
3800	-0.058	6.56	4.903
3900	0.159	1.07	-2.526
4000	3.435	7.64	4.496
4100	2.86	8.09	5.564
4200	3.801	6.75	1.949
5900	-0.344	1.83	-0.946
6000	-3.957	1.51	-3.16
6100	6.649	12.8	7.773
6200	5.686	8.58	2.217
6300	-2.908	6.56	-0.834
6400	-5.966	2.6	-2.187

C. Measured Axial Ratio

Axial ratio is calculated based on the measured AUT beam peak values of radiation patterns in Horizontal and Vertical Polarizations, which are presented in the sections (b) and (c) of VII

Table-XI:Measured Axial Ratio At Different Angles Of Θ For Various Receiving And Transmitting Frequencies

Frequency (MHz)	Measured axial ratio(dB)		
	$\theta = -45^0$	$\theta = 0^0$	$\theta = 45^0$
3700	3.227	0.76	1.739
3800	1.478	0.24	3.983
3900	3.201	5.41	5.386
4000	1.735	3.95	2.296
4100	0.31	0.92	3.014
4200	0.489	0	1.841
5900	4.694	6.1	5.296
6000	0.657	1.62	1.86
6100	9.739	9.27	10.863
6200	1.676	3.59	2.207
6300	10.008	5.27	6.934
6400	14.026	9.45	7.247

In the TABLE 11, the axial ratio value at different angles is calculated based on the following equation.

Axial ratio = | Maximum beam peak of AUT in HP pattern - Maximum beam peak of AUT in VP pattern | (7)

From the TABLE 11, it has been observed that the lower axial ratio values at 0^0 are 0dB at 4200MHz and 1.62dB at 6000MHz respectively. Similarly at -45° and +45°, the lower axial ratio values are 0.31dB at 4100MHz, 0.657dB at 6000MHz, 1.739dB at 3700MHz and 1.86dB at 6000MHz respectively. The obtained lower axial ratio values are good according to design specifications and suitable for C-Band Satellite Communication applications.

VIII. CONCLUSION

Micro strip patch antenna with DGS has been proposed for C-Band Satellite Communication Applications. The patch with defective ground structure is simulated and fabricated. Also measurements are carried out and obtained results are presented. The enhancement of bandwidth of patch antenna is achieved by using defective ground structure. In addition to this, all the simulated and measured values are obtained by using the DGS technique for the C-Band Satellite Communication applications. Moreover, the experimentally measured values are better when compared to simulated values.

From the measured results, the lower VSWR values are obtained at the receiving and transmitting frequencies as 1.1 at 3700MHz and 1.44 at 5900MHz respectively. The higher Gain values in Vertical Polarization are achieved at 0^0 for the receiving and transmitting frequencies as 10.58dBi at 3700MHz and 8.58dBi at 6200MHz respectively. Similarly at -45° and +45°, the higher Gain values are achieved as 7.143dBi at 3700MHz, 6.649dBi at 6100MHz, 8.13dBi at 3700MHz and 7.773dBi at 6100MHz respectively. The lower axial ratio values are obtained at 0^0 for the receiving and transmitting frequencies as 0dB at 4200MHz and 1.62dB at 6000MHz respectively. Similarly at -45° and +45°, the lower axial ratio values are obtained as 0.31dB at 4100MHz, 0.657dB at 6000MHz, 1.739dB at 3700MHz and 1.86dB at 6000MHz respectively. The higher 3-dB beam width values in Horizontal and Vertical polarizations are obtained for the receiving and transmitting frequencies as 99.93^0 at 4200MHz, 77.9^0 at 5900MHz, 89.81^0 at 3700MHz and 89^0 at 5900MHz respectively. It is concluded that all the measured values are best and suitable for C-Band Satellite Communication applications. Hence, patch antenna with DGS is accepted for C-Band Satellite Communication applications.

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