Design and Characterization Analysis of Microstrip Patch Array Antenna with Dumbell shaped DGS for ISM Band Applications

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Abstract: To detect the malignant cancer oust issues in the breast, various techniques are used. These are Mammography ,MRI, and Ultrasound etc. These technologies are miserable during examining. The Microwave Breast Imaging technique generates scattered signals and it detects abnormal tissues after transmission and reception of Microwave signals.Therefore,1X4 array antenna is designed. It detect the tumor at early stage. This array antenna is more specific to detect the malignant issues. The array antenna has 1X4 arrays, with Defected Ground Structure (DGS).It will increase efficiency of this model. This model is used in ISM (Industrial, Scientific, and Medical).It is designed for center frequency2.4GHz. The input return loss should be greater than 10. FR4 is used as Substrate. Theoretical modeling and simulation by HFSS Software is done to optimize antenna parameters. Three antennas namely Microstrip patch antenna, 1 x 4 MSP array antenna and 1 x 4 MSP array antenna with DGS are fabricated and the experimental results are verified in an anechoic chamber of millimeter wave and antenna lab. It is found that the experimental results match the simulated results. It is found that array and DGS enhances the antenna parameters like antenna gain, return loss, VSWR and bandwidth at 2.4GHz frequency for ISM band applications.

Keywords: Microstrip Antenna, Defected Ground Structure, ISMB and, Array Antenna, Microwave Breast Imaging Technique

1. Introduction

1.1. Microwave Breast Imaging Techniques

Due to Cancer, large number of human beings surrendered to death in the world. In Woman, Breast Cancer is the main health issue. Early detection will reduce the mortality rate (Çalışkan, R., 2015). The techniques available to detect the malicious tissues are X-ray mammography, MRI, Ultrasound, Microwave breast imaging technique. These techniques have some limitations. It cannot detect small lt issues. X-rays penetrates ionizing radiations in the human body. MRI technique uses the magnet whereas Ultrasound techniques use emission and reception of sound waves. Both uses ionized radiations. Thus, Microwave Breast imagining technique is used to overcome these drawbacks (Banu, S., 2013).

Microwave breast imaging technique uses the antennas to detect malicious tissues. The antennas are placed near the skin of human body (Shrestha, S., 2010). The microwaves are sent into human body and the malicious tissues are detected. The scattering signals are generated during the penetration of the microwave signals. These scattering signals are captured by receiving antennas and analyzed (Afyf, A., 2015). With signal analysis, position and the volume of tumor is detected. Malicious tissues can be found out if the water level of tissue is high or temperature of tissue is high. When microwave energy is absorbed by tissues then the size and conductivity of cancerous tissues gets increased. By receiving the scattered signal from tissues, the conclusion can be drawn that the tissues which have more scattering signals are cancerous tissues. Thus malicious tissues are detected. Microstrip Patch Antenna is used to correct the drawbacks of Microwave breast imaging technique (Nalam, M., 2014). Fig. 1.1 shows the amount of signal scattered by a malicious tissue (breast tumor) is greater than that of normal breast tissues. The scattered signals are analyzed and utilized for the tumor detection (Singh, P. K., 2013).

Fig.1.1–Scattering Signals in the tissues.

1.2 Microstrip Antenna Background

An antenna acts as a transducer that converts radio frequency electrical currents at waveguide into electromagnetic waves in space. It is an important design consideration in any communication system for providing extensive coverage of the newest wireless applications in various fields. Many applications have different requirements for an antenna and its parameters. Conventional antennas that are used in wireless communication systems are large in size and weight. Therefore, the size of the complete transceiver module is large.

In modern communication systems, researchers are looking for antennas that are smaller in size (Ghaloua, A 2017) and weight; consequently, the transceiver size and weight will be reduced. Therefore, the microstrip patch antenna is the one that can fulfill the requirement of the smaller in size, lighter in weight and lower cost solution. Hence, by using this antenna the size and weight of the wireless communication system will be small. So, there are different types of patch antennas which are used in wireless communication systems such as microstrip patch antenna (Jia, L. L., 2005), microstrip slot (Gautam, A. K., 2015) or travelling antenna and printed dipole antenna.

In this paper, the MSPA is proposed for wireless communication applications. To enhance the gain, array antenna is proposed. Similarly, defected Ground Structure will enhance the bandwidth, return loss parameters of the antenna. Since micro strip patch antennas have a low profile, low cost, are mechanically robust and easy to fabricate, they are becoming increasingly popular in demand within a variety of applications. These are the important considerations in such antenna designs. It is basically a metal patch suspended over a ground plane. The limitations of an MSPA are its low bandwidth, low efficiency and low gain. These limitations can be addressed by using a thick substrate, cutting slots in the patch, using different shapes of patches, using different locations of feeds, using a low dielectric constant substrate and making array antennas. Researchers then represent micro strip antenna design technology differently for improvements in its radiation characteristics, size reduction, low cost etc. In the recent years, there have been several new concepts that have been applied to micro strip antenna design. Out of these concepts, the DGS is one that has been used for the design of MSPA differently.

For the purposes of improving the performance parameters of the MSPA, a technique called DGS is used. It is a technique in which the ground is intentionally modified by placing a defect of various shapes and sizes at different locations to improve the antenna performance characteristics. Depending on the shape and size of the defect, the shielded current distribution will be disturbed. This distribution will influence the input impedance and the current flow of the antenna. The excitation and electromagnetic waves propagating through the substrate layer are also controlled by DGS. Thus, with the help of DGS, we can improve and optimize the performance parameters of the antenna. The MSPA with DGS (Jian, X. C., 2005) is used in wireless communication for ISM band applications. Due to the unlicensed frequency band, the ISM band is used for many wireless communication applications in various fields. These are used in modern aerospace, vehicle and man-portable systems, cordless phones, Bluetooth devices, and wireless communication network for the purpose of frequency allocation to the ISM Band (Bharadwaj, R., 2017). The ISM band has received great attention by academicians and industrialists in the field of telecommunications. An MSPA having 1 x 4 array structure with embedded DGS used for wireless communication systems for ISM band applications is proposed in this paper.

2. Design of Microstrip Patch Antenna (MSPA)

2.1 Design of MicroStripPatchantenna - Theoretically

The Microstrip Patch Antenna for 2.4 GHz frequency and FR4 substrate is designed theoretically and then it is simulated by High Frequency Structure Simulator (HFSS) software for optimization of performance parameters (Singh, P. K., 2013).

Steps: DesignofMSPAfor2.4GHz in ISMBand

Step I - Substrate FR4. Dielectric constant: 4.4

Step II –Operative Frequency: 2.4 GHz

Step III - Calculation of Width of Patch (W) is given by equation (1),

Where, C= 3 X 108, ε r = 4.4,

fo= 2.4 GHz,

Width of Patch (Wp) = 38.22 => 38 mm

$$W = \frac{c}{2f_o\sqrt{\frac{\varepsilon_r+1}{2}}}$$ Equation (1)

Step IV - Calculation of the Effective Dielectric Constantis given by equation (2).

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1+12\frac{h}{w}\right]^{-\frac{1}{2}}$$ Equation (2)

The Effective Dielectric Constant =3.99

Step V - Calculation of the Effective lengthis given by equation (3),

Effective length = 30.25mm

$$L_{eff} = \frac{c}{2f_o\sqrt{\epsilon_{eff}}}$$ Equation (3)

Step VI - Calculation of the length extension is given by equation (4)

$$\Delta L = 0.412h\,\frac{(\epsilon_{eff}+0.3)(\frac{W}{h}+0.264)}{(\epsilon_{eff}-0.258)(\frac{W}{h}+0.8)}$$ Equation (4)

(ΔL) = 0.70 mm

Step VII – Calculation of Length and Width of Transmission Line(LT and WT) is given by equation (5) and (6) respectively

$LT = \lambda / (4\sqrt{\varepsilon r})$ = 14.89 mm => 15 mm Equation (5)

$Zo = 377 / [\,[(WT/h)+2]\sqrt{\varepsilon r}\,]$, where Zo = 50 Ω Equation (6)

WT = 2.56 mm=> 3 mm

Step VIII – Calculation of actual length of the patch is given by equation (7),

$Lp = Leff - 2\Delta L$ Equation (7)

(Lp)=28.4mm => 28 mm

Step IX – Calculation of the ground plane dimensions(Lg and Wg)is given by equation (8) and (9) respectively

Ls =Lp + 2 LT = 28 + 2x 15 = 58 mm Equation (8)

Ws = Wp + 2 LT = 38 + 2x 15 = 68 mm Equation (9)

Figure1.2shows,the dimensions of the microstrip patch antenna for the resonant frequency of 2.4 GHz and using FR4 as a substrate. Probe feed is fabricated on the same substrate so that total structure will remain planer. It also eliminates spurious feed network radiation (Kaur, G., 2019).

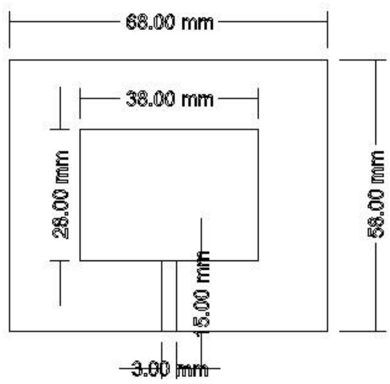


Fig.1.2- Design of MicroStripAntenna (Theoretical)

Table 1.1 shows the dimensions of the single patch Antenna designed theoretically for the resonant frequency of 2.4 GHz with FR4 as a substrate.

Table 1.1- Dimensions of single patch Antenna (Theoretical)

Input Parameters	Value
PatchWidth	38 mm
PatchLength	28 mm
Transmission LineWidth	3 mm
Transmission LineLength	15 mm
GroundPlaneWidth (Wg)	68 mm
GroundPlaneLength (Lg)	58 mm

2.2 Design of MicroStripPatchAntenna (MSPA) – With HFSS Simulation:

The Microstrip Patch Antenna is simulated with High Frequency Structure Simulator software. The parameters such as resonant frequency, VSWR, return loss, bandwidth are so optimized to get the optimized performance parameters (Dharani, K. R., 2014). Figure 1.3 shows the simulated design of the MSPA with optimized performance parameters.

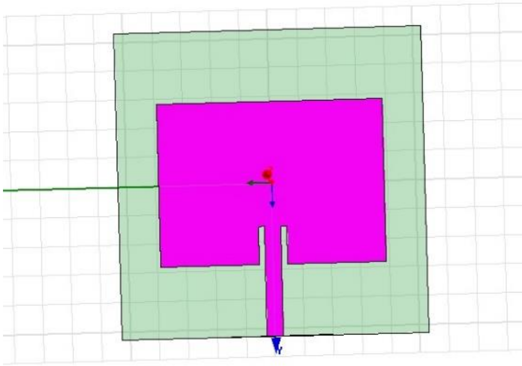


Figure1.3- Simulated design of single MicroStrip Patch Antenna

Table 1.2 shows the dimensions of the simulated design of the single microstrip patch antenna designed with HFSS software for the resonant frequency of 2.4 GHz with FR4 as a substrate.

Table 1.2- Dimensions of single patch Match Antenna (Simulation)

Input Parameters	**Value**
PatchWidth	38.22
PatchLength	30.25
Transmission LineWidth	1.6 mm
Transmission LineLength	15 mm
GroundPlaneWidth (Wg)	66 mm
GroundPlaneLength(Lg)	58 mm

2.3 Simulation Results: Single Patch Antenna

Figure 1.4 shows the return loss of MSPA which is -18.57 dBFigure 1.5 shows the VSWR of MSPA which is 1.26. The figure 1.6 shows the radiation pattern of the MSPA. Figure 1.7 shows the 3 D polar plot indicating the radiation and gain.

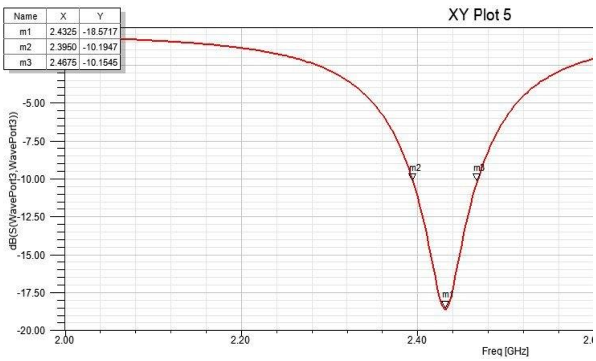


Fig. 1.4 - Return Loss for single patch Antenna**.**

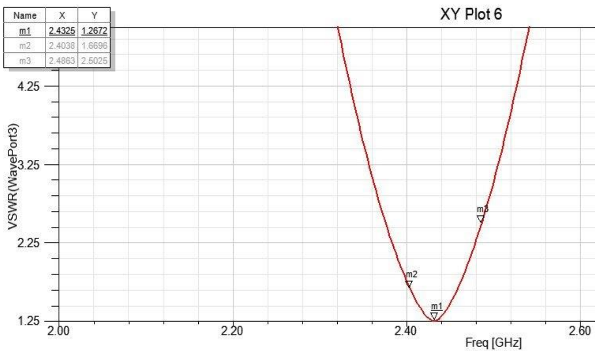
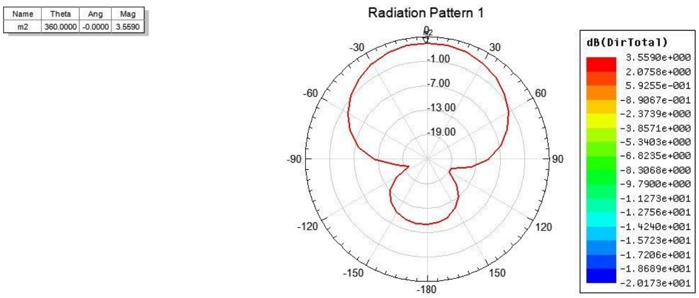


Fig. 1.5- VSWR for single patch Antenna.



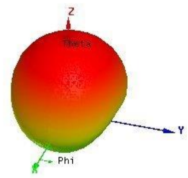


Fig.1.6- Radiation Pattern of for single patch MSPA. **Fig.1.7-** 3-D Polar Plot of Single MSPA

2.4 Defected Ground Structure

The performance parameter soft he antenna can be improved by making a defect in the ground called Defected Ground Structure.It is created intentionally. The basic component is making a resonant gapors lot made in the ground. It is placed directly on the transmission line. By creating the various shapes, DGS is realized. These shapes are used to create defect in a ground structure].Depending on the size and shape of the defect, current distribution is disturbed. This distribution will influence the input impedance and the current flow of the antenna. The excitation and electromagnetic waves propagating through the substrate layer are also controlled by DGS.Thus, with the help of DGS, we can improve and optimize the performance parameters of the antenna.

There are two types of DGS. One is Single and other is Periodic. Periodic DGS is formed by repeating shape of the single DGS. While forming Periodic DGS, its shape, distance between two DGS and the distribution pattern of DGS are considered. DGS changes current distribution in the ground plane of microstrip line. It will change the values of inductance and capacitance. The duplication of single cell in a periodic pattern, gives much better results and better characteristics. DGS acts as L-Cresonator circuit. During the transmission of RF signal through DGS to microstrip line, strong coupling occurs between DGS and line. The Figure 1.8 shows the microstrip patch Antenna with DGS.

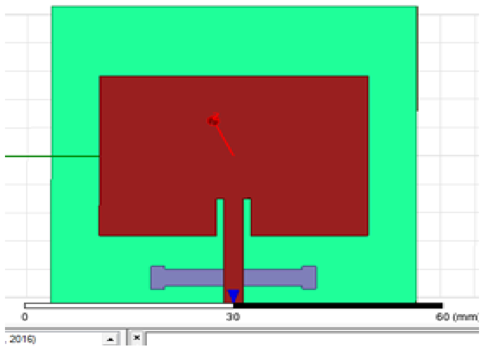


Fig.1.8 –Microstrip antenna with DGS

2.5 1 x 4 Microstrip Patch Array Antenna

A microstrip patch antenna with four-element antenna array employing a defected ground structure is investigated. Microstrip patches constitute a prime candidate for the elements of integrated phased array. Such arrays may include active devices on the same substrate integrated monolithically and operate at ISM Band frequencies. Design of these arrays depends upon understanding the effects of substrate thickness, dielectric constant and grid spacing. The input impedance is calculated so as to feed the input signal to all the elements with minimum attenuation.The figure 1.9 shows the 1 x 4 microstrip array antenna.

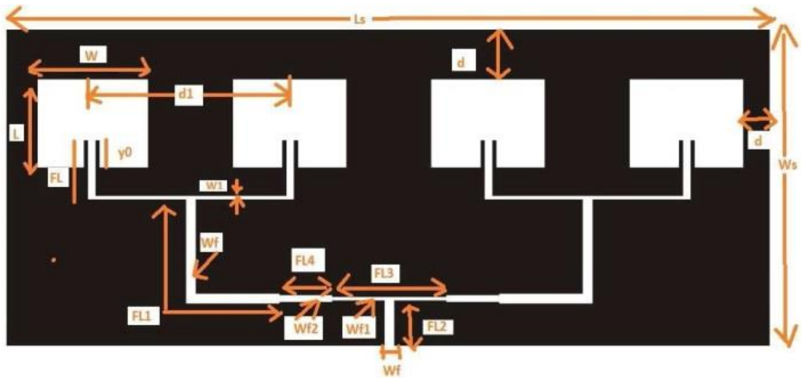


Fig.1.9– 1 x 4 microstrip array antenna

2.6 Simulation of 1x 4 Microstrip Patch Antenna

Figure 1.10 shows the 1 X 4 Micro strip Array Antenna with a single wave port of 50Ω. Quarter Wave Matching Technique is used for equal distribution of current in the array.

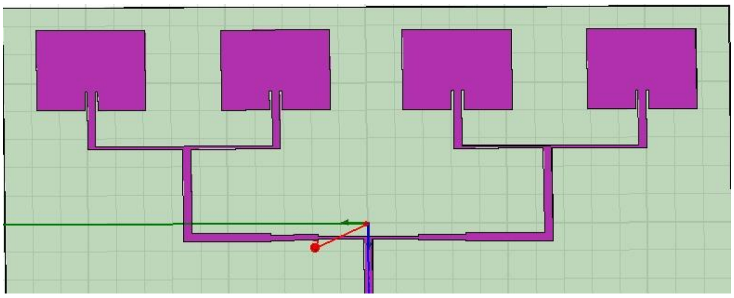


Fig.1.10 Simulation of 1X4 array microstrip antenna with HFSS

2.7 Simulation Results: 1x 4 MSPA Array Antenna

Figure 1.11 shows the return loss of MSPA which is -27.32dBFigure 1.12 shows the VSWR of MSPA which is 1.08. Figure 1.13 shows the radiation pattern of the MSPA. Figure 1.14 shows the 3 D polar plot indicating the radiation and gain.

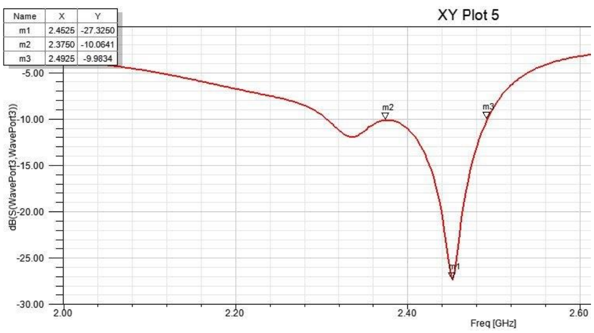


Fig.1.11 - Return Loss of 1 x 4 MSPA Array

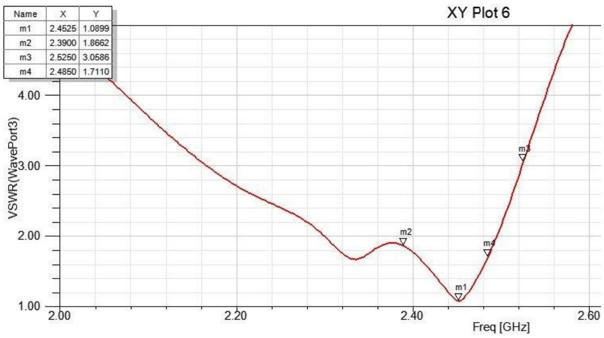
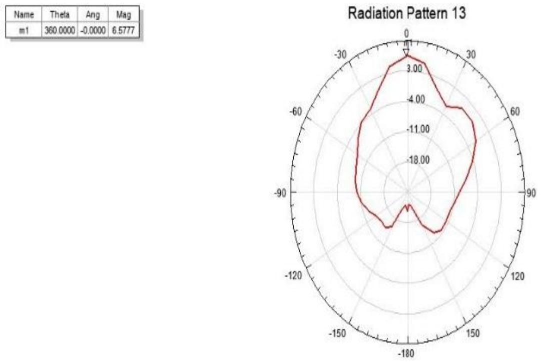


Fig.1.12- VSWR of 1 x 4 MSPA Array



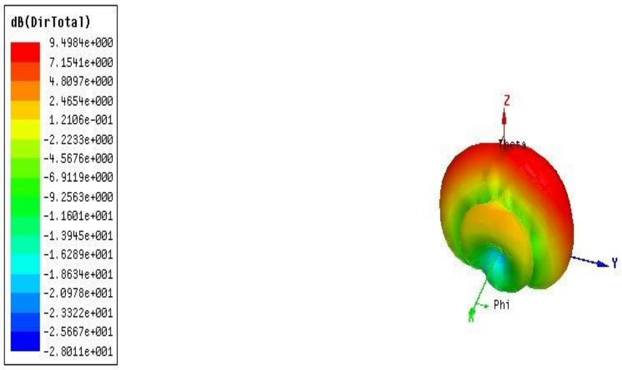


Fig.1.13 - Radiation Pattern of 1 x 4 MSPA Array**.** **Fig.1.14 -** 3 D Polar Plot of 1 x 4 MSPA Array

2.8 Simulation of 1x 4 Microstrip Patch Antenna with DGS

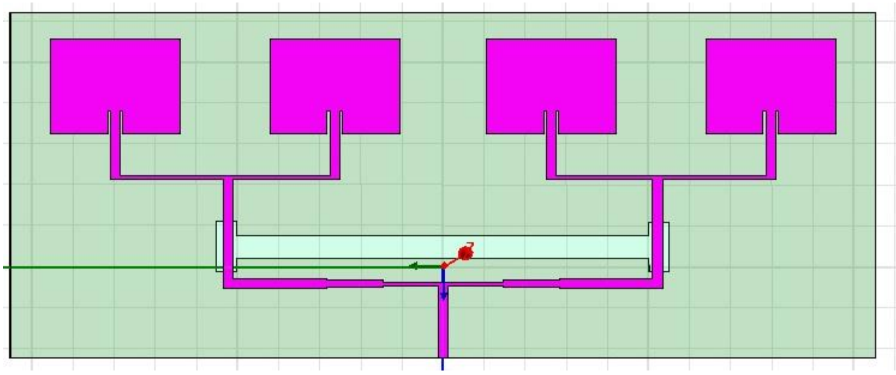
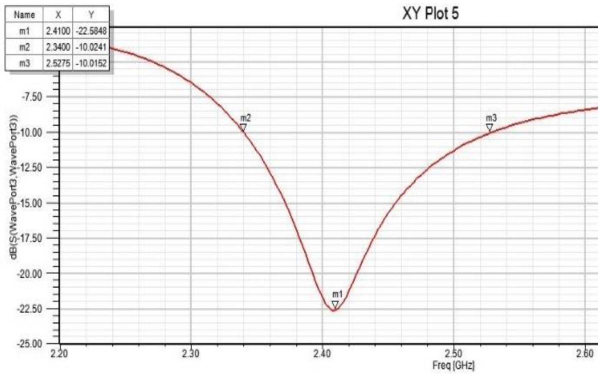


Fig.1.15 -HFSS Simulation of 1X4 Microstrip array antenna with DGS

Figure 1.15 Shows 1 X 4 Micro strip Array Antenna with Defected ground structure. Defected Ground Structure is used above the Wave Port. Defected Ground Structure is Creating Defect in the Ground plane of the antenna. Due to Defected Ground Structure, there is change in the Current Distribution of antenna.

2.9 Simulation Results: 1 x 4 MSPA Array Antenna with DGS

Figure 1.16 shows the return loss of MSPA which is -22.58dBFigure 1.17 shows the VSWR of MSPA which is 1.16. Figure 1.18 shows the radiation pattern of the MSPA. Figure 1.14 shows the 3 D polar plot indicating the radiation and gain.



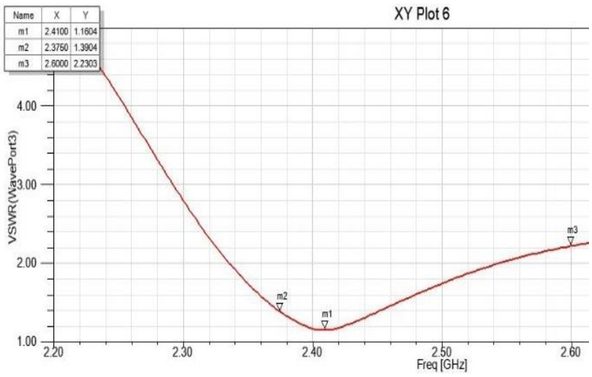


Fig.1.16- Return Loss of 1 x 4 Array with DGS **Fig.1.17-** VSWR of 1 x 4 Array with DGS

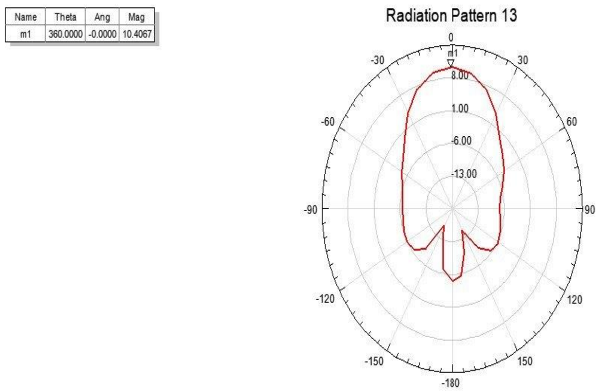


Fig.1.18- Radiation Pattern of 1 x 4 Array with DGS

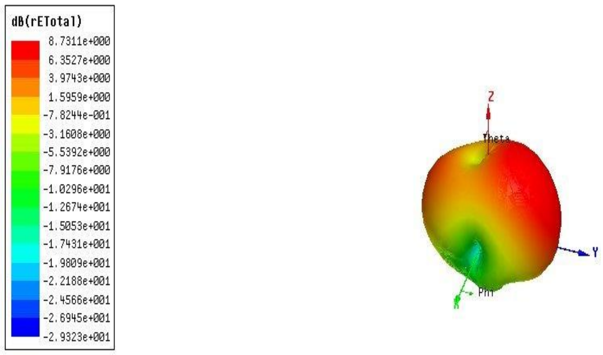


Fig.1.19- 3 D Polar Plot of 1 x 4 Array with DGS

Table 1.3- Comparison between Various Micro strip Array Antenna parameters with simulated results

Type of MSA	Frequency (GHz)	Return loss (dB)	VSWR	Band width (MHz)	Gain (dB)
Single patch	2.43	-18.57	1.26	72.5	3.55
1 x 4 Patch Array	2.45	-27.32	1.08	117..5	9.49
1 x 4 Patch Array DGS	2.41	-22.58	1.16	187.5	8.73

3. Fabrication of Antennas

Figure 1.20 and 1.21 shows the Patch and Ground of single Microstrip patch Antenna respectively. Figure 1.22 and 1.23 shows the Patch and Ground of 1x4 Microstrip Array Antenna respectively. Figure 1.24 and 1.25 shows the Patch and Ground of 1x4 Microstrip Array Antenna with DGS respectively.

Fig 1.20- Single Element MSPA Patch **Fig 1.21-** Single Element MSPA Ground

Fig 1.22- 1 x 4 Element MSPA Array Patch **Fig 1.23-** 1 x 4 Element MSPA Array Ground

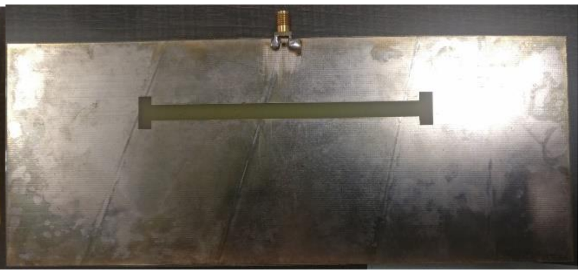



Fig 1.24- 1 x 4 Element MSPA Array Patch with DGS **Fig 1.25-** 1 x 4 Element MSPA Array with DGS Ground

4. Testing of Antennas

The Figure 1.26 shows the testing of MSPA. The Figure 1.27 shows the testing of 1 x 4 Array MSPA. Figure 1.28 and Figure 1.29 shows the testing of 1 x 4 Array MSPAwith DGS


Fig 1.26 - Testing of MSPA **Fig 1.27 –** Testing of 1 x 4 Array MSPA


Fig 1.27 – Testing of 1 x 4 Array MSPA with DGS **Fig 1.28 –** Testing of 1 x 4 Array MSPA with DGS

5. Parametric Results after Fabrication of Antennas

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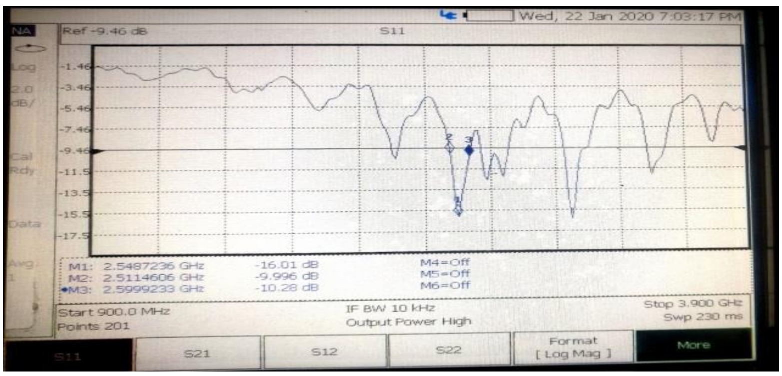

Fig Return Loss of Single Element Microstrip Patch Antenna

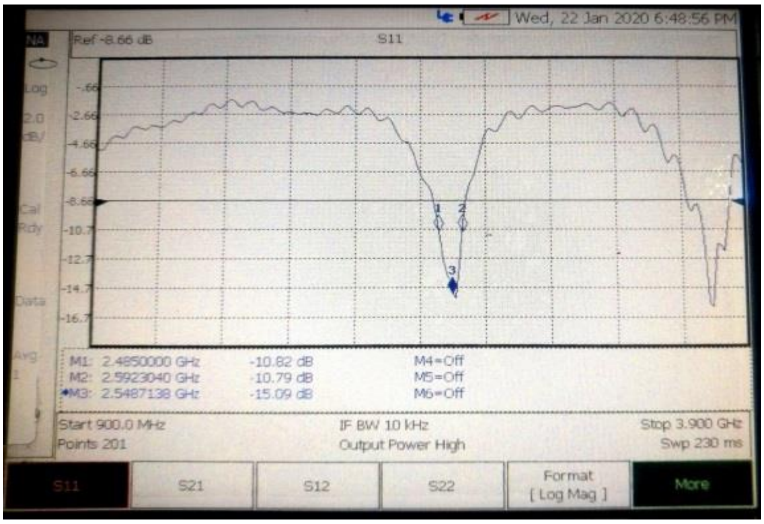

Fig Return Loss of 1 x 4 Microstrip Patch Array Antenna

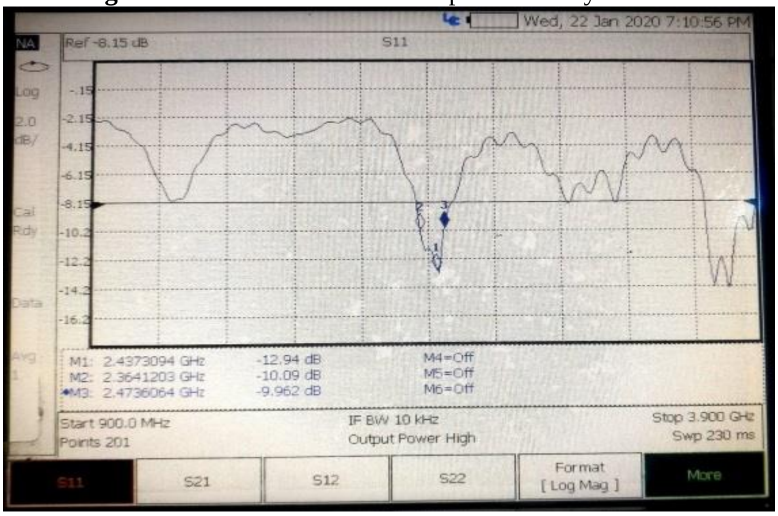

Fig Return Loss of 1 x 4 Microstrip Patch Array Antenna with DGS

Table 1.4- Comparison of Fabricated Antenna Results

MSPA	Freq. (GHz)	Return loss (dB)	VSWR	Band width (MHz)	Gain (dB)
Single	2.54	-16	1.37	88	3.5
1x4 Array	2.54	-15	1.43	107	7.5
1x4 Array DGS	2.43	-13	1.57	110	10

Table 1.4 shows the Comparative study of performanceofMicroStripSinglePatchAntennato1x4 Patch array antenna and 1x4 Patch array antenna with DGS. As the number of patches of antenna increases, bandwidth and gain of antenna increases.

6. Conclusion

The 1 x 4 microstrip array antenna structure with and without DGS has been successfully designed. It is simulated by using HFSS software. The performance parameters include Return loss, VSWR, Bandwidth, Radiation pattern and Gain in the proposed design.The1x4 microstrip array antenna with defected ground structure as low profile, low weight and having thin substrate working in ISMB and .Out of the three configurations of antennas, the Single Patch Antenna provides the average values of antenna performance parameters. Single Patch MSPA has return loss of -16 dB, VSWR of 1.67, bandwidth of 88 MHz and gain of 3.5 dBThe 1 x 4 Patch Array Antenna provides the better values of antenna performance parameters. The 1 x 4 Patch Array MSA has return loss of -15 dB, VSWR of 1.43, bandwidth of 107 MHz and gain of 7.5 dBThe 1 x 4 Patch Array Antenna with DGS provides the improved values of antenna performance parameters. The 1 x 4 Patch Array

MSA with DGS has return loss of -13 dB, VSWR of 1.57, bandwidth of 110 MHz and gain of 10 dB.The bandwidth of 1 x 4 Array Antenna with DGS is improved to 110 MHz with respect to 88 MHz, the bandwidth of Single Patch Antenna. The gain of the 1 x4 Array Antenna with DGS is improved to 10 dB with respect to 3.5 dB, the gain of Single Patch MSA. Thus array antenna with DGS improves the gain as well as bandwidth to some extent.

Therefore, it can be concluded that the performance parameters of the 1 x 4 Microstrip Array Antenna with DGS have improved as compared with the Single Patch Microstrip Antenna. These results are tested and measured at the millimeter wave and antenna lab of DRDO, India. These antennas are used in the ISM band applications.

7. Future Scope

The requirement of today's communication systems is to reduce the size of wireless device. Researchers and scientists in the world are moving towards systems that are smaller and smaller in size and towards the miniaturization (Gautam, C. S., 2012) by optimizing the performance parameters. With the use of fractal techniques, size of the 1 x 4 Microstrip Array Antenna with DGS can be reduced further for wireless communication applications. The array elements can be increased to increase the gain as per requirement of applications. This can be considered in the future scope of 1 x 4 Microstrip Array Antenna with DGS.

8. Acknowledgment

Theresults ofSingle MSPA, 1 x 4 Microstrip Array Antenna - without DGS and with DGSare tested and measured in the millimeter wave and antenna lab of DRDO, India. I am very much thankful to the authority of DRDO for facilitating me to test and measure the experimental results of antennas.

9. References

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