Design and Comparative Characterization Analysis of LSFMA with different DGS for ISM Band Applications

Sujit Dharmpatre*,[1] and Mukul Sutaone[2]

[1 2]Department of Electronics and Telecommunication Engineering, College of Engineering, Pune (COEP), Pune, Maharashtra, India

Abstract- In this paper, a Left Sided Feed Microstrip Antenna (LSFMA) embedded with Defected Ground Structures (DGS) of shapes O, H and U for Industrial Scientific and Medical (ISM) band applications has been proposed. The antenna is designed with an FR4 substrate having a dielectric constant ε_r of 4.4 with a thickness of 1.6 mm, a dielectric loss tangent tan (δ) of 0.02 and a lande G factor of 2. The radiating patch dimensions of 38 mm x 27.6 mm are the same for the microstrip patch antenna (MSPA) without the DGS, the 'O' shaped and the 'H' shaped DGS, whereas dimensions for the U-shaped DGS are 40.5 mm x 27.6 mm. The patch thickness (t) = 0.009 mm, realizes a good impedance matching, improved gain and bandwidth, a steady radiation pattern and a constant group delay at 2.4 GHz. For the LSFMA configuration, a gain of 0.52 dB and bandwidth of 70 MHz have been reported. Three different shapes of DGS such as O, H, and U are used in the ground plane of the MSPA to observe the various effects on radiation characteristics in the ISM band. LSFMAs with different DGS are used to improve the antenna gain, return loss, VSWR and bandwidth at 2.4 GHz frequency for ISM band applications. The proposed LSFMA with different 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.

Keywords-ISM band, LSFMA, MSPA, antenna, DGS.

1. INTRODUCTION

1.1. Microstrip Antenna Background

An antenna is the link between the transmitter and receiver in space. It is 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. Though antennas seem to have an infinite variety, they all operate on the same basic principal of electromagnetic. On the other hand, 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, many researchers and scientists have been known for novelty in research and developments of antenna design techniques. Researchers are looking for antennas that are smaller in size [10] 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 [1], microstrip slot [18] or travelling antenna and printed dipole antenna. In this paper, the MSPA is proposed for wireless communication applications. In applications where thickness and conformability are the main requirements, MSPAs are used. 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 [18], using different shapes of patches, using different locations of feeds and using a low dielectric constant substrate. 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 [1] is one that has been used for the design of MSPA [3] 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.It will disturb the shielded current distribution depending on the shape and size of the defect. The disturbance at the shielded current distribution will influence the input impedance and the current flow of the antenna. It can also control the excitation and electromagnetic waves propagating through the substrate layer. Thus, with the help of DGS, we can improve and optimize the performance parameters of the antenna. The defected ground structure (DGS) [1, 2] applied for strip line or micro strip lines or coplanar waveguide structures has become one of the most popular and interesting areas of research owing to its extensive applicability in antenna designs. The DGS structure designed in many ways can effectively enhance the performance characteristics of the micro strip antenna as per the application demand. The improvement in radiation characteristics of a micro strip antenna by using DGS has been found in the proposed design. The MSPA with DGS [1, 2] 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. The fastest growing applications of these bands have been used for short range and low power communication systems. These are used in cordless phones, Bluetooth devices, and wireless communication network for the purpose of frequency allocation to the ISM Band [8]. The ISM band has received great attention by academicians and industrialists in the field of telecommunications. An MSPA with embedded DGS used for wireless communication systems for ISM band applications is proposed in this paper.

1.2. Microstrip Antenna proposed concepts

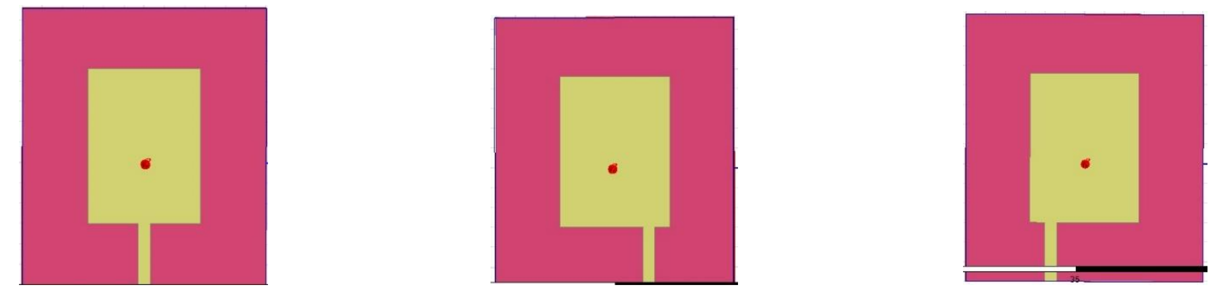
Three different configurations of MSPAs are proposed in this paper based on the antenna feeding locations. The feed locations are, center feed, right sided feed and left sided feed. The feed locations such as center feed, right sided feed and left sided feed are adjusted so as to match the input impedance [23] of the MSPA which enhances the radiation characteristics of the antenna. High Frequency Structure Simulation (HFSS) software is used for simulation of these antennas. With the HFSS simulation, it is found that the Left Sided Feed Microstrip Antenna [5, 13, 16] (LSFMA) gives better results than the Centre Feed and the Right Sided Feed Antennas [3]. The input impedance of the Left Sided Feed Microstrip [16] Antenna (LSFMA) should be matched to the characteristic impedance (Z_0) of the transmission line [23]. Due to this, the feed width and length is so optimistic that the LSFMA antenna impedance is matched to (Z_0) = 50 Ω. The micro strip-feed [16] antenna has advantages such as high gain, wide bandwidth, and a stable radiation pattern. The effective dielectric constant (ε_{reff}) is responsible for the overall stability of the radiation [5] characteristics of the LSFMA. The left sided feed couples the energy continuously to the antenna patch and DGS with the constant phase. This helps to realize optimised gain, bandwidth and a stable radiation pattern of the antenna. The left sided micro strip feed has a dielectric constant $\varepsilon_r = 4.4$, and a length (ℓ) = 15 mm and width (w) = 3.00 mm are proposed for the LSFMA. It achieves a maximum gain of 0.52 dBi and a bandwidth of 72 MHz at 2.4 GHz.

In this paper, using minimum DGS perimeters, the optimized radiation characteristics of antennas have been presented. We have reported recent investigations into microstrip antennas with different shapes of DGS [2] in the ground plane. The LSFMA is another novel technique used along with the DGS, for the purpose of investigation and improvement of the performance characteristics of a microstrip antenna [13]. All the LSFMA [3] based DGS are designed at 2.4 GHz resonant frequency, which gives the designated radiation characteristics of an antenna for the ISM band applications. The O, H, and U shapes are used as DGS [1] for the design of the proposed antenna. The operating frequency of these antennas is in the ISM band [6], which is 2.4 GHz. The comparative parametric studies of these different shapes of DGS have been proposed and presented in this paper. The patch size of all the DGS supported LSFMAs is equal except the patch size of U-shaped DGS [7]. It has been observed that the frequency response of the LSFMA with DGS improves as compared to the LSFMA without DGS structures [3].

2. ANTENNA CONFIGURATION AND DESIGN PARAMETERS

2.1. LSFMA Design – A feeding techniques

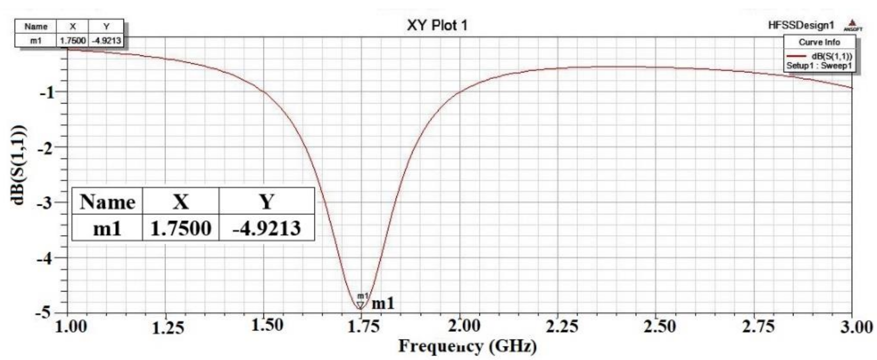
Configuration of the proposed antenna with different feeding positions has been presented in this paper. Three different feeding configurations have been proposed to analyze the radiation characteristics of the desired antenna structure. Feeding techniques such as center feed, left side feed and right side feed are used for the microstrip antenna [13]. Microwave energy is coupled to the antenna with these feeding configurations. Figure 1(a) shows the center feed rectangle patch antenna [4, 14]. In this, the microwave energy is coupled at center of the rectangle patch. The ratio of the E to the H field is proportional to the impedance of the feed location [23]. At the end of the patch, the current is zero and at the center of the patch, it is maximum.



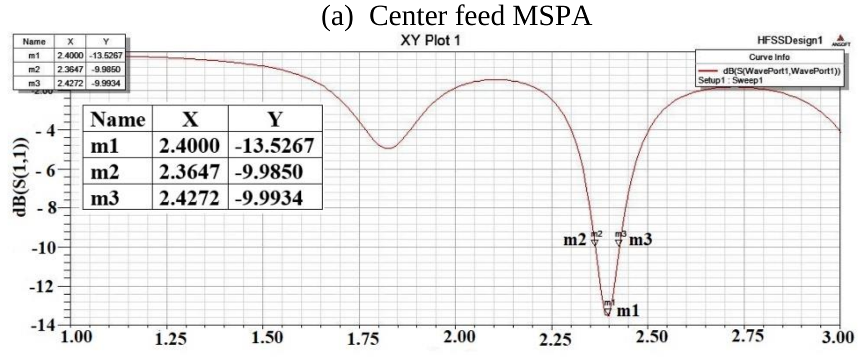
(a) Center feed MSPA (b) Right sided feed MSPA (c) Left sided feed MSPA

Figure 1 Rectangular Patch Antennas with center, right sided and left sided feed.

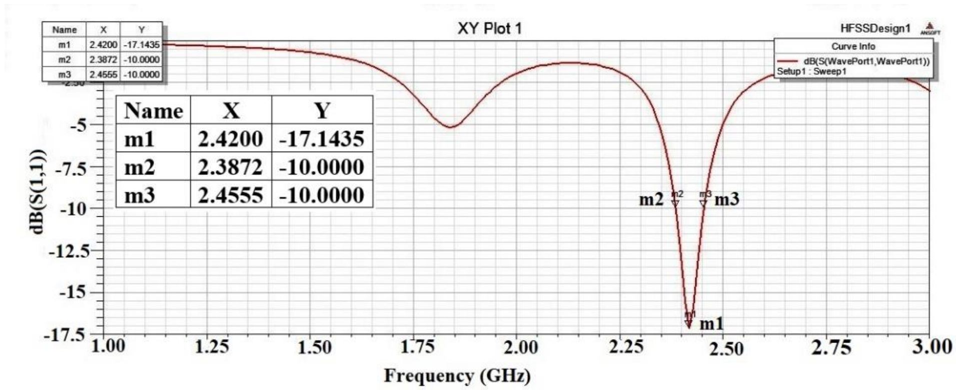
At the end of the patch, the voltage is maximum and at the center, it is minimum. The fringing E-fields [5] between the edges of the rectangle patch and the ground plane add up in phase due to voltage distribution and it produces the radiation. The effect of fringing will depend on the thickness of the substrate and dimensions of patch. Figure 1(b) and Figure 1(c) show the right and left sided feed rectangle patch antennas respectively. Out of these two, the left sided feed configuration provides better results for ISM band applications [6, 15]. Figure 2 shows the return loss characteristics of the three configurations namely (a) center feed, (b) right sided feed and (c) left sided feed. The left sided feed gives better radiation characteristics than the other two configurations. Here the dimensions of all the three patch rectangles [4] are the same, only the feed position of rectangle patch antenna has been changed. The length (ℓ) and width (w) of rectangle patch is 38 mm and 27.6 mm respectively. All the three configurations of rectangle patch are without DGS [1, 2].



(a) Center feed MSPA



(b) Right sided feed MSPA



(c) Left sided feed MSPA

Figure 2. Return loss of rectangular microstrip patch antenna for center, right sided and left sided feed.

Figure 2(a) shows that the return loss is almost -5 dB and the bandwidth is zero at resonant frequency for the center feed antenna. Therefore, it is clear from the graph that the characteristics of the center feed rectangle patch antenna does not satisfy the requirement of a radiating antenna. The return loss characteristics of the right side and left side feed antennas are shown in Figure 2(b) and Figure 2(c) respectively. These characteristics show the improvements in the result. The return loss is almost -13.52 dB with a bandwidth of 60 MHz for the right side feed rectangle patch; whereas, the return loss is -17.14 dB with a bandwidth of 70 MHz for left side feed rectangle patch.

Table 1 shows a comparison of radiation [5] characteristics of different feeding configurations of rectangle patch antennas by keeping the dimensions of the feed length, the feed width, the patch length, and the patch width constant.

Table 1. Comparison of radiation characteristics of different feeding configurations of rectangle patch antenna.

Sr. No.	Parameters/ Descriptions	Centre feed	Right feed	Left feed
1	Higher frequency (GHz)	0.00	2.42	2.45
2	Lower frequency (GHz)	0.00	2.36	2.38
3	Centre frequency (GHz)	1.75	2.4	2.42
4	Bandwidth (GHz)	0.00	0.06	0.07
5	Return loss (dB)	-5	-13.52	-17.14
6	VSWR	3.62	1.59	1.53
7	Gain (dB)	-9.2	0.49	0.52

From these results, it is seen that, the left sided feed antenna has comprehensive results to achieve better radiation characteristics as compared to the center and right sided feed antennas. Hence, it is named as a left sided feed micro strip [16] antenna (LSFMA). The principal operating frequency of the antenna is 2.4 GHz for ISM band applications [8].

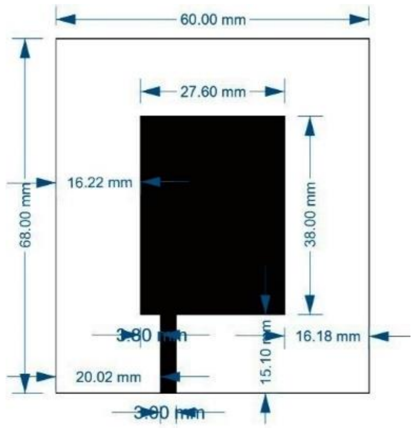


Figure 3. Dimensions of the proposed LSFMA without DGS.

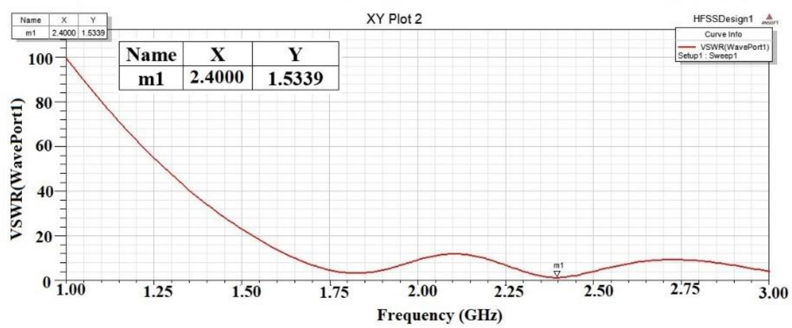
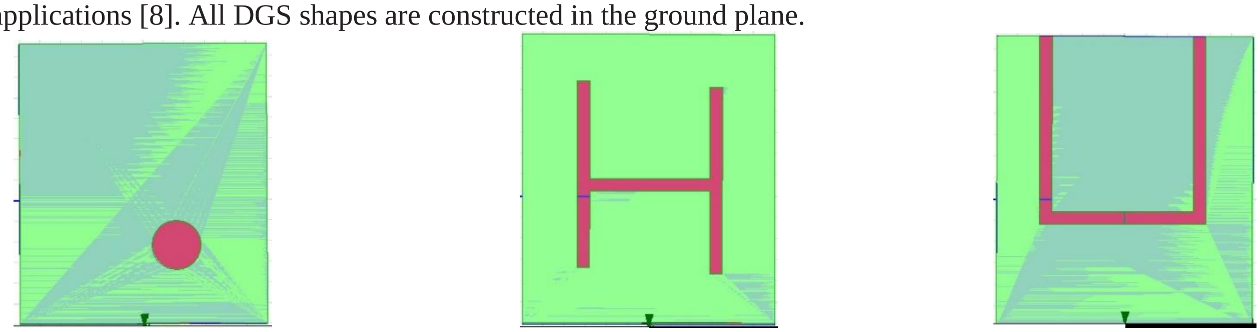


Figure 4. VSWR of the proposed LSFMA antenna, which is less than 2 (VSWR << 2).

Figure 3 shows the dimensions of the proposed LSFMA without DGS. The patch length (*Pl*) = 38 mm, patch width (*Pw*) = 27.6 mm, patch height (*Ph*)= 0.009 mm, feed length (*Fl*) = 15 mm, feed width (*Fw*) = 3 mm, substrate length (*Sl*) = 68 mm, substrate width (*Sw*) = 60 mm and substrate height (*Sh*) = 1.6 mm. The radiating patch used here is a PEC-Perfect Electric Conductor. The substrate used for the LSFMA is an FR4 glassy epoxy having a dielectric constant (εr) = 4.4. Figure 4 shows the VSWR of the LSFMA, which is less than 2 (VSWR << 2). The VSWR given by the proposed LSFMA antenna is 1.53 at 2.4 GHz (i.e. VSWR = 1.53). In the LSFMA antenna, the ground dimensions are equal to the substrate dimensions.

2.2. LSFMA Design –A DGS techniques

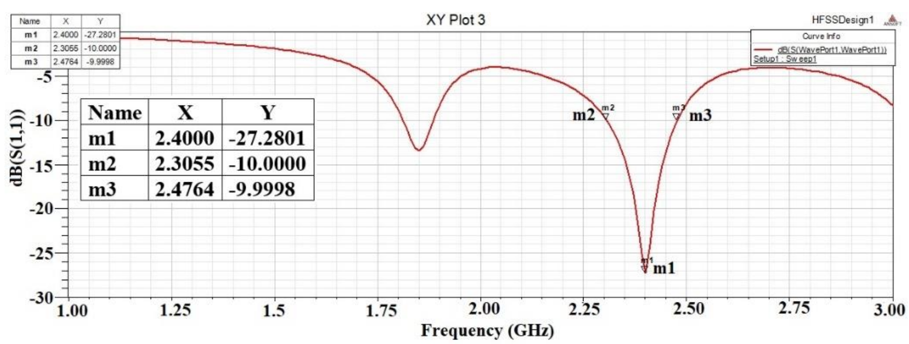
The LSFMA has been used along with DGS for the desired radiation characteristics. Three different shapes used as DGS in the ground plane which are O, H, and U. Figure 5 shows the proposed LSFMA with the three different DGS shapes used in the ground plane namely, (a) 'O' shaped DGS, (b) 'H' shaped DGS (c) 'U' shaped DGS. These three shapes give different radiation characteristics at 2.4 GHz resonant frequency for ISM band applications [8]. All DGS shapes are constructed in the ground plane.



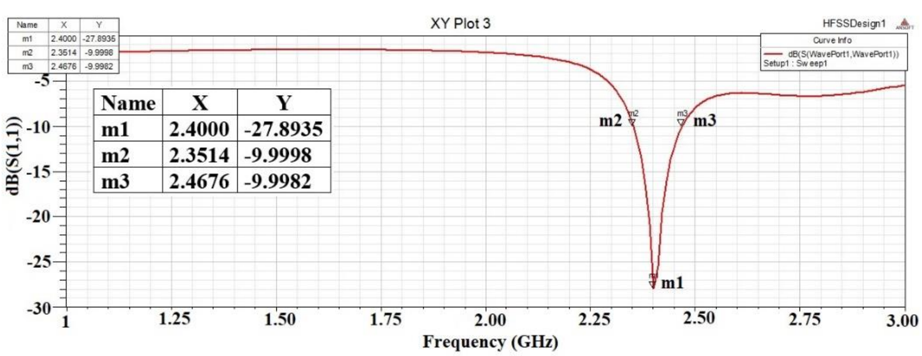
(a) LSFMA with 'O' shaped DGS (b) LSFMA with 'H' shaped DGS (c) LSFMA with 'U' shaped DGS

Figure 5. Proposed LSFMA with three DGS shapes - ‘O’ shaped DGS; ‘H’ shaped DGS and ‘U’ shaped DGS.

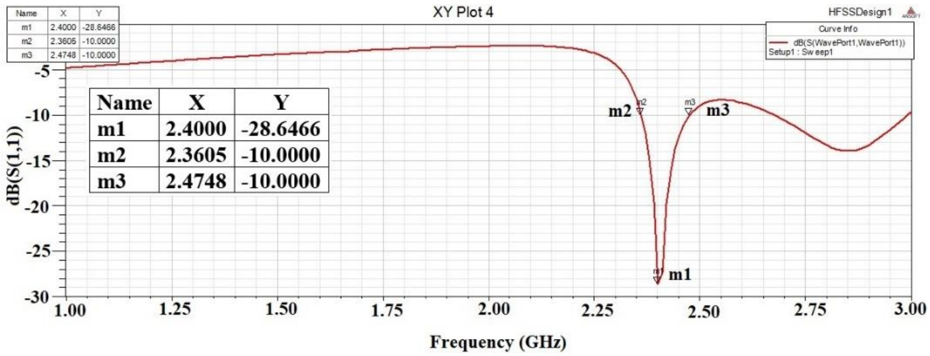
The location of the ‘O’ shaped DGS, embedded in ground is observed near the junction of the feed and antenna patch as shown in Figure 5(a). In this junction, 50 ohm impedance is matched between the feed (transmission line) and antenna patch [14, 23]. The EM energy supplied to the transmission line is coupled to the antenna through the junction. Due to the coupling of the EM energy between the feed-patch and the DGS, the radiation bandwidth of the LSFMA [3] antenna gets increased. In the LSFMA, another DGS shape that is embedded in the ground plane is ‘H’. The two vertical sides of the H shaped DGS [11] overlap with the length of the rectangular patch of antenna. The horizontal side of the ‘H’ shaped DGS covers half the length of the rectangle patch as shown in Figure 5(b). This will help to increase the coupling between the H, the DGS and the radiating patch. Due to this phenomenon, the antenna bandwidth and gain [9] have been increased as shown in Figure 6(a) and Figure 6(b) respectively. The third DGS structure embedded in the ground plane of the LSFMA is the ‘U’ shape [7]. In this, there is a gap between the ‘U’ shape and the rectangle patch antenna, forming the electromagnetic band gap (EBG) [1, 2] structure as shown in Figure 5(c). As a result, the radiation characteristics of the LSFMA antenna are quite improved. Figure 6, shows the return loss characteristics of the LSFMA with DGSs such as ‘O’, ‘H’ and ‘U’ shape. The return loss characteristics of the LSFMA with ‘O’ shaped DGS has been increased to -27.28 dB at 2.4 GHz frequency. Figure 6(a) shows the radiation bandwidth of the LSFMA with the ‘O’ shaped DGS in which the Bandwidth = 171 MHz and the gain is -3.27 dB. As compared to the LSFMA without DGS, the bandwidth of the LSFMA with DGS is higher. The improved bandwidth of the LSFMA with the ‘O’ DGS is almost 101 MHz more than the LSFMA without the DGS. The fractional bandwidth of the ‘O’ shaped LSFMA is almost 253.5%. The second DGS used in the ground plane of the LSFMA is the ‘H’ shape. A Figure 6(b) show that the radiation bandwidth of the ‘H’ shaped LSFMA is 116 MHz and the gain is -2.36 dB. As compared to the LSFMA without DGS, the bandwidth of the LSFMA with ‘H’ DGS is higher. The improved bandwidth of the LSFMA with the ‘H’ DGS is almost 46 MHz more than the bandwidth of the LSFMA without the DGS. The fractional bandwidth of the ‘H’ shaped LSFMA is almost 171%. The return loss characteristic of the LSFMA [3] with the ‘H’ DGS has been increased to -27.89 dB at 2.4 GHz frequency.



(a) LSFMA with ‘O’ shaped DGS



(b) LSFMA with ‘H’ shaped DGS



(c) LSFMA with ‘U’ shaped DGS

Figure 6. Return loss characteristics of the LSFMA with ‘O’ shaped DGS, ‘H’ shaped DGS and ‘U’ shaped DGS.

The third DGS used in the ground plane of the LSFMA is the ‘U’ shape. Figure 6(c) shows the radiation bandwidth of the ‘U’ shaped LSFMA is 114 MHz and gain is -0.9 dB. As compared to the LSFMA without the DGS, the bandwidth of the LSFMA with the DGS is higher. The improved bandwidth of the LSFMA with the ‘U’ DGS is almost 44 MHz more than the LSFMA without the DGS. The fractional bandwidth of the ‘U’ shaped LSFMA is almost 169%. The return loss characteristic of the LSFMA [3] with the ‘U’ shaped DGS [7] has been increased to -28.64 dB at 2.4 GHz frequency. Therefore, it can be concluded that the radiation characteristics of the LSFMA with the DGS have been improved as compared to the LSFMA without the DGS. Table 2 shows a comparative statement of the radiation characteristics of the LSFMA with DGS structures for ‘O’, ‘H’, and ‘U’ shapes [1, 2].

Table 2. Comparative statement of radiation characteristics of LSFMA with DGS structures of ‘O’, ‘H’, and ‘U’ shape.

Sr. No.	Parameters	‘O’ shape DGS	‘H’ shape DGS	‘U’ shape DGS
1	Resonant frequency (GHz)	2.4	2.4	2.4
2	Return loss (dB)	-27.28	-27.89	-28.64
3	VSWR	1.09	1.08	1.07
4	Gain (dB)	-3.27	-2.36	-0.9
5	Bandwidth (GHz)	0.171	0.116	0.114
6	Fractional bandwidth MHz)	71	48	47.5
7	Relative bandwidth (GHz)	1.07	1.05	1.05
8	Group Delay (ns)	0.0068	0.0073	0.0064

2.3. LSFMA Design with and without DGS-A comparative study

The comparative parametric study of the LSFMA with and without DGS is an interesting reading. It has been observed that there is a far better improvement in the radiation characteristics such as bandwidth, gain [9] and VSWR of the LSFMA with the DGS as compared to the LSFMA without the DGS. The LSFMA antenna with the DGS structure is suitable for the ISM band applications [8].

Table 3. Comparative study of LSFMA with and without DGS.

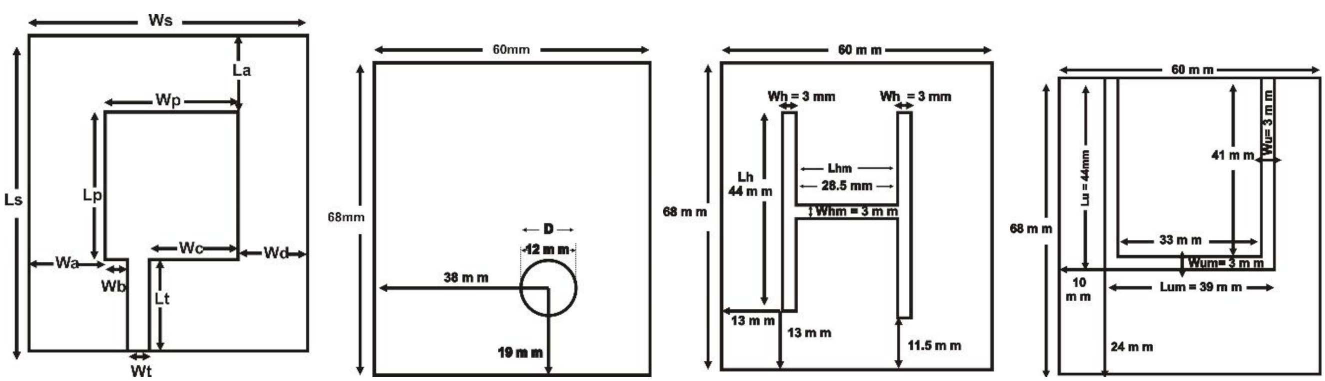
Sr. No.	Parameters	LSFMA without DGS	LSFMA with ‘O’DGS	LSFMA with ‘H’DGS	LSFMA with ‘U’DGS
1	Resonant	2.4	2.4	2.4	2.4

	frequency(GHz)				
2	Return loss (dB)	-17.14	-27.28	-27.89	-28.64
3	VSWR	1.53	1.09	1.08	1.07
4	Gain (dB)	0.52	-3.27	-2.36	-0.9
5	Bandwidth(GHz)	0.0683	0.171	0.116	0.114
6	Fractional bandwidth (MHz)	28	71	48	47.5
7	Relative bandwidth (GHz)	1.02	1.07	1.05	1.05
8	Group Delay (ns)	0.0062	0.0068	0.0073	0.0064

Table 3. shows a comparative study of the LSFMA with and without DGS. The LSFMA without the DGS has a return loss of -17.14 dB and the LSFMAs with DGS have return loss of - 27.28 dB, - 27.89 dB and - 28.64 dB, for ‘O’, ‘H’ and ‘U’ shapes respectively. It is observed that, the antenna bandwidth is very limited for the LSFMA without DGS and it is drastically increased for LSFMAs with DGS. The gain of the LSFMA antenna without DGS is 0.52 dB. The gain of LSFMAs with ‘O’, ‘H’ and ‘U’ DGS shapes been reported as - 3.27 dB, - 2.36 dB and - 0.9 dB respectively at 2.4 GHz as shown in Figure 9. From the results, it is found that the LSFMA with the DGS gives better radiation characteristics than LSFMA [3] without DGS.

3. DESIGN PARAMETERS AND SIMULATION RESULTS

Figure 7(a) and Table 4 shows the dimensions of the substrate, patch, and feed of the proposed LSFMA [3] with and without the DGS. These dimensions give better optimized results at 2.4 GHz frequency. The patch dimensions of the LSFMA without the DGS and the LSFMAs with O, H shaped DGS are same, whereas the patch dimensions of U shaped DGS are different. The dimensions of feed are the same for all the four antennas.



(a) Patch Dimensions (b) Dimensions of ‘O’ DGS (c) Dimensions of ‘H’ DGS (d) Dimensions of ‘U’ DGS

Figure 7. Patch and DGS dimensions of LSFMA without DGS and with DGS.

The antenna patch dimensions of the proposed LSFMA without DGS [1, 2] are as shown in Figure 3. Figure 7(a) shows the patch dimensions of the proposed LSFMA without DGS and LSFMA with ‘O’, ‘H’ and ‘U’ shaped DGS. Table 4 shows the patch dimensions of all the four antennas. It also provides a comparative study of the patch dimensions of all the four antennas. For the O and H shaped DGS, [11] the patch length x width is 38 mm x 27.6 mm. But, for the LSFMA [3] with the ‘U’ shaped DGS, the patch length x width is 40.5 mm x 27.6 mm.

Table 4. Patch Dimensions of the proposed LSFMA with and without DGS.

Dimensions (mm)	LSFMA	O – DGS	H – DGS	U – DGS
Ws	60	60	60	60

Ls	68	68	68	68
Wp	27.6	27.6	27.6	27.6
Lp	38	38	38	40.5
Wt	3	3	3	3
Lt	15	15	15	15
Wa	16.2	16.2	16.2	16.2
Wb	3.8	2.8	4.8	4.8
Wc	20.8	21.8	19.8	19.8
Wd	16.2	16.2	16.2	16.2
La	15	15	15	12.5

Figure 7 (a), Figure 7(b), Figure (c) and Table 5 shows the dimensions of DGS - O, H and U shapes. The ‘O’ shaped DGS in the ground plane has a diameter (D) of 12 mm. The ‘H’ shaped DGS has dimensions i.e. side length (*Lh*) x width (*Wh*) = 44 mm x 3 mm and middle line length dimensions (*Lhm*) x width (*Whm*) = 28.5 mm x 3 mm. In case of the ‘U’ shaped DGS, the dimensions of the side length are (*Lu*) x width (*Wu*) =44 mm x 3 mm and middle line length dimensions are (*Lum*) x width (*Wum*) =39 mm x 3 mm, as shown in Figure 7(b), 7(c), 7(d) and Table 5.The VSWR characteristics for three DGS [1] are as shown in Figure8. The VSWR in all three DGS designs is less than 2 (VSWR < 2) at 2.4 GHz frequency.

Table 5. Dimensions of DGS for proposed LSFMA

DGS Shape	Dimensions (mm)			
O	D = 12			
H	*Lh* = 44	*Wh* = 3	*Lhm* =28.5	*Whm* = 3
U	*Lu* = 44	*Wu* = 3	*Lum* = 39	*Wum* = 3

The gain is -3.27 dB, -2.36 dB and - 0.9 dB for the ‘O’, ‘H’ and ‘U’ shaped LSFMAs with DGS respectively. The graph of gain for the three DGS is as shown in Figure 9. The group delay for the three LSFMSA with DGS is as shown in Figure 10.

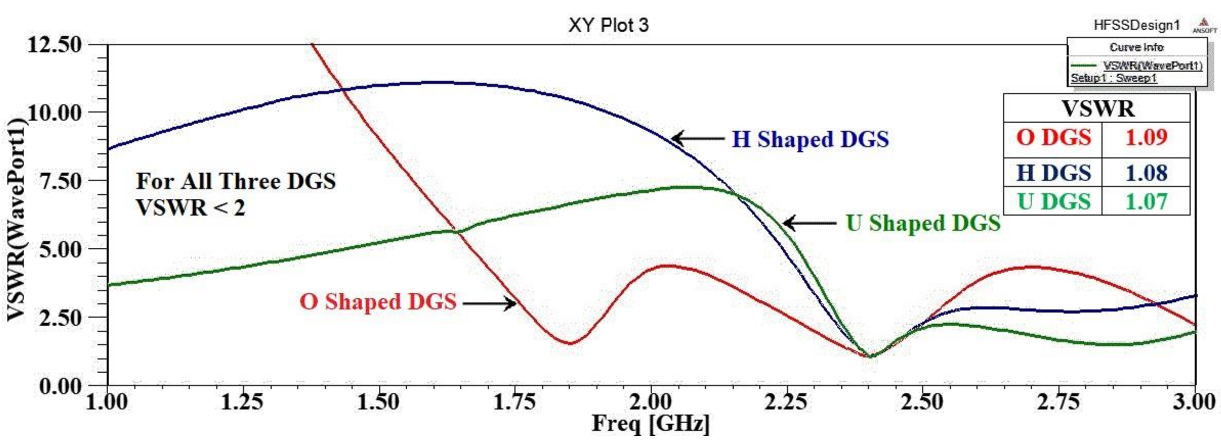
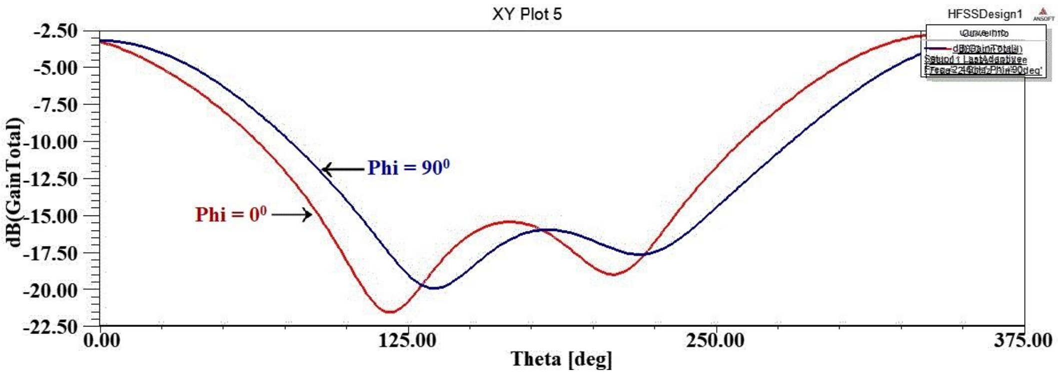
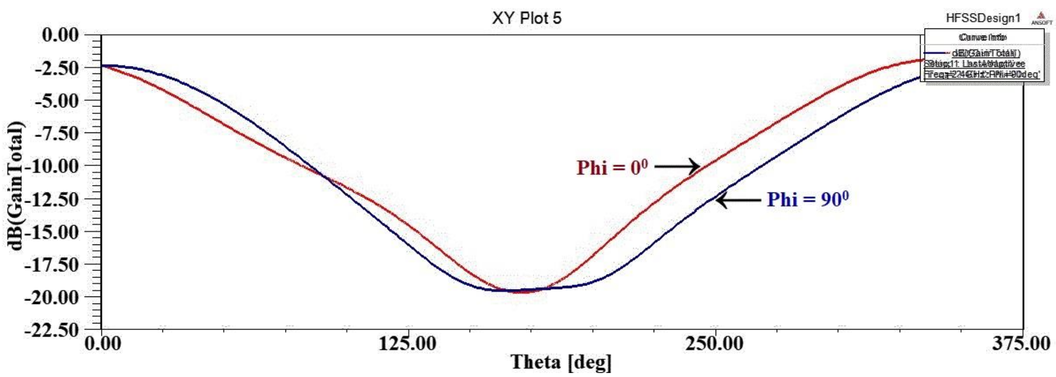


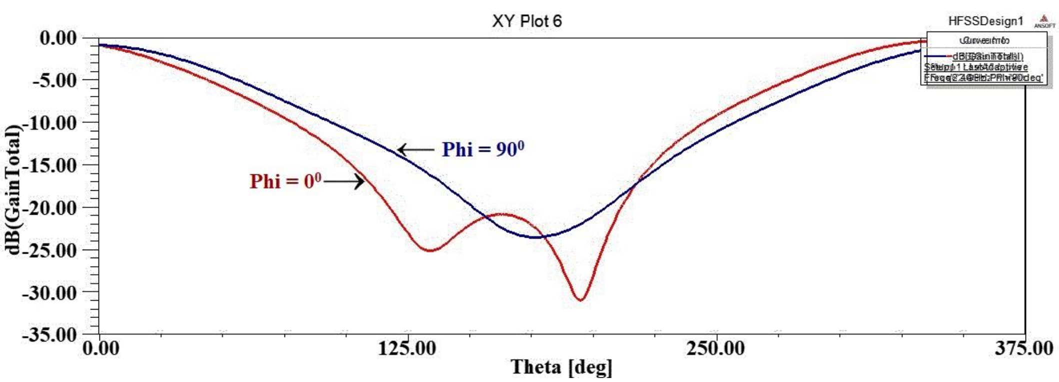
Figure 8. VSWR for three DGS structure ‘O’, ‘H’ and ‘U’ less than 2 (VSWR<2).



(a) Gain for ‘O’ DGS



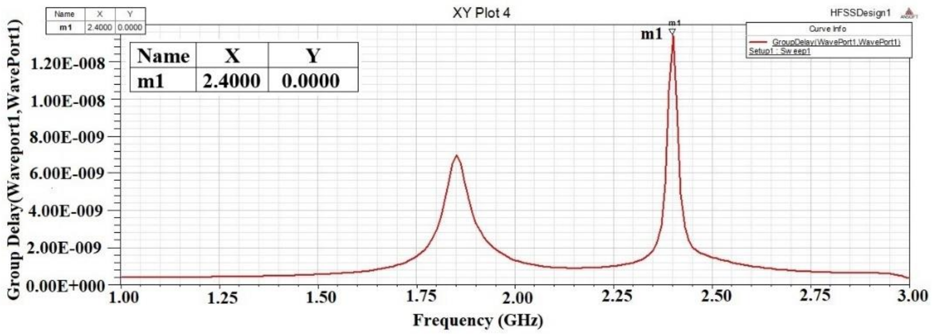
(b) Gain for ‘H’ DGS



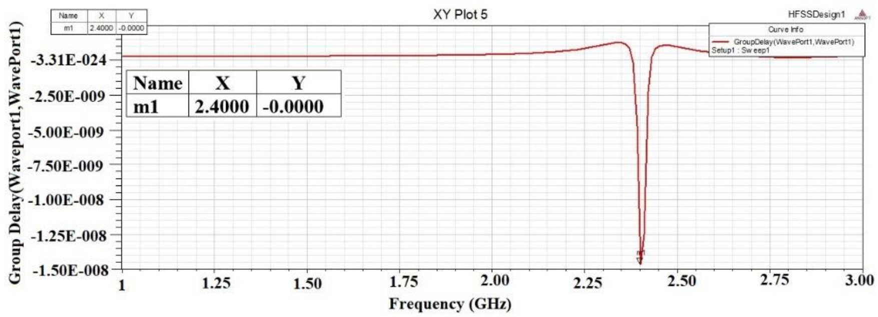
(c) Gain for ‘U’ DGS

Figure 9. Graph of Gain for the ‘O’ shaped DGS, the ‘H’ shaped DGS and the ‘U’ shaped DGS structure at 2.4 GHz at Phi = 0 deg and Phi = 90 deg, with a different value of theta.

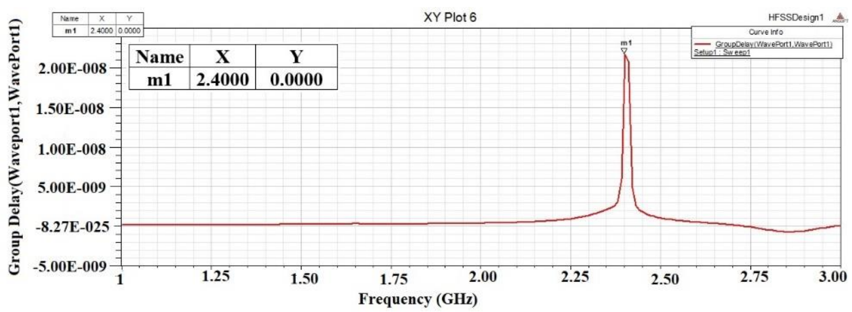
Figure 9 shows the graph of gain [9] for (a) the ‘O’ shaped DGS structure at 2.4 GHz at Phi = 0 deg and Phi = 90 deg, with a different value of theta (b) the ‘H’ shaped DGS structure at 2.4 GHz at Phi = 0 deg and Phi = 90 deg, with a different value of theta, (c) the ‘U’ shaped DGS structure at 2.4 GHz at Phi= 0 deg and Phi = 90 deg with a different value of theta.



(a) Group delay for 'O' shaped DGS



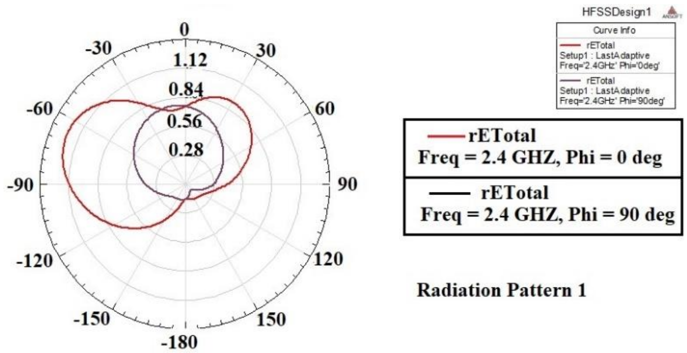
(b) Group delay for 'H' shaped DGS



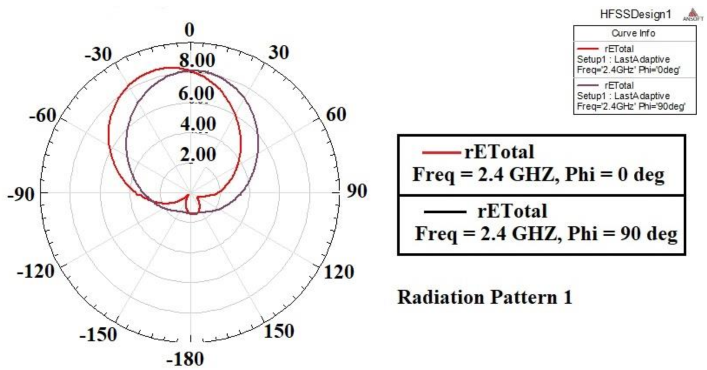
(c) Group delay for 'U' shaped DGS

Figure 10. Graph of the group delay for the 'O' shaped DGS, the 'H' shaped DGS and the 'U' shaped DGS structure.

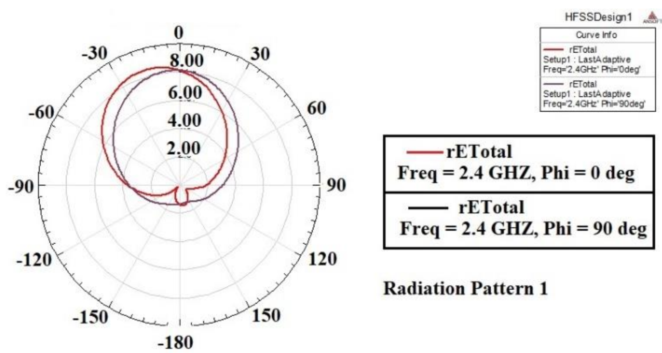
Figure10 shows the graph of the group delay for the three DGS structure (a) 'O' shape, (b) 'H' shape and (c) 'U' shape. The radiation patterns of the three different feeding structures of the rectangle patch antennas without DGS at 2.4 GHz frequency are as shown in Figure11**.** The radiation patterns at Phi = 0 and 90 degrees for all values of theta at 2.4 GHz for the three feeding configurations without the DGS are shown in Figure 11. Figure 11(a), Figure 11(b) and Figure 11(c) show the radiation pattern of the center, right and left feed rectangle patch antennas respectively for E and H planes. The directive gain is -1 dB for the center feed antenna as shown in Figure 11(a).The directive gain has been increased up to 12 dB in the right sided feed rectangle patch antenna. So, the improvement in the directive gain is almost 13 dB for the right sided feed designs shown in Figure 11(b). Finally, the directive gain is increased up to 14 dB in the left sided feed as shown in Figure11(c).



(a) Center feed MSPA



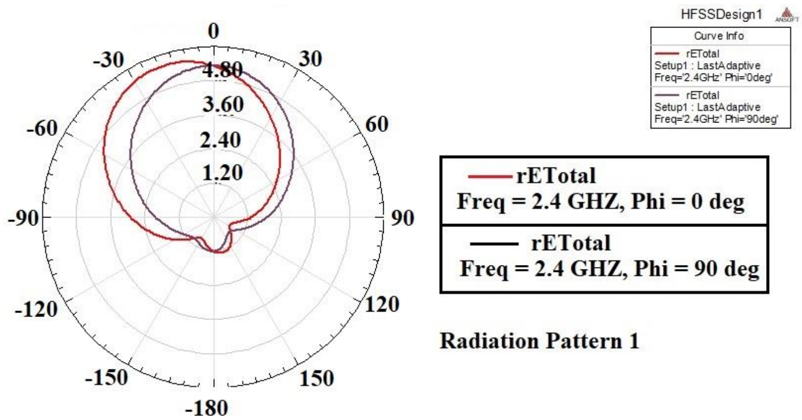
(b) Right sided feed MSPA



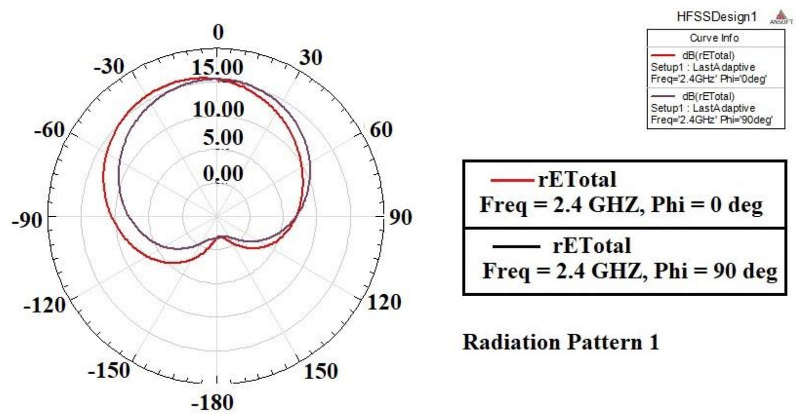
(c) Left sided feed MSPA

Figure 11. Radiation pattern of center feed, right sided feed and left sided feed MSPA with Phi = 0 = 90 degree.

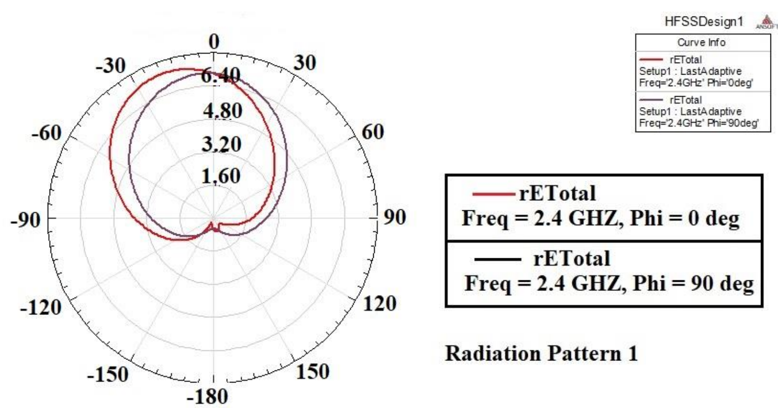
The radiation pattern of the LSFMA with 'O', 'H', and 'U' shaped DGS is as shown in Figure 12. The directive gain is 4.8dB in the LSFMA with embedded the 'O' shaped DGS as shown in Figure 12(a). The gain has been increased up to 5.6 dB in the 'H' shaped LSFMA. The directive gain is improved almost 0.8 dB for the 'H' shaped LSFMA as shown in Figure 12(b). In the 'U' shaped LSFMA, the directive gain is increased up to 6.4 dB as shown in Figure 12(c). The radiation pattern of three DGS [1, 2] structures of the LSFMA is as shown in Figure12for Phi = 0 and 90 degree for all theta values at 2.4 GHz.



(a) ‘O’ shaped DGS



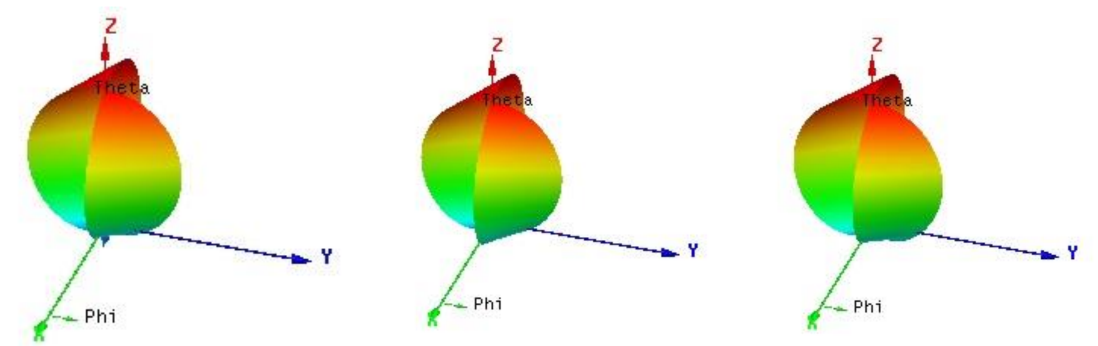
(b) ‘H’ shaped DGS



(c) ‘U’ shaped DGS

Figure 12. Radiation pattern of the LSFMA for ‘O’ shaped, ‘H’ shaped, and ‘U’ shaped DGS.

3D polar plots of the LSFMA antenna for ‘O’, ‘H’, and ‘U’ shaped DGS for all values of theta and phi are as shown in Figure13. It shows the radiation efficiency of the antenna in the E and H plane is maximum.



(a) ‘O’ shaped DGS (b) ‘H’ shaped DGS (c) ‘U’ shaped DGS

Figure 13. 3D polar plots of the LSFMA for ‘O’, ‘H’, and ‘U’ shaped DGS for all values of theta and phi.

4. ANTENNA FABRICATIONS

Figure14 shows the fabricated model of the proposed LSFMA for (a) without DGS, (b) with ‘O’ DGS, (c) with ‘H’ DGS and (d) with ‘U’ DGS. These antennas are fabricated with the help of an electronic etching system facility. Therefore, the antennas are fabricated with fine and sharp resolution.

(a) LSFMA without DGS (b) LSFMA with ‘O’ DGS (c) LSFMA with ‘H’ DGS (d) LSFMA with ‘U’ DGS

Figure 14. Fabricated model of the proposed LSFMA - without DGS, with ‘O’ DGS, with ‘H’ DGS and with ‘U’ DGS.

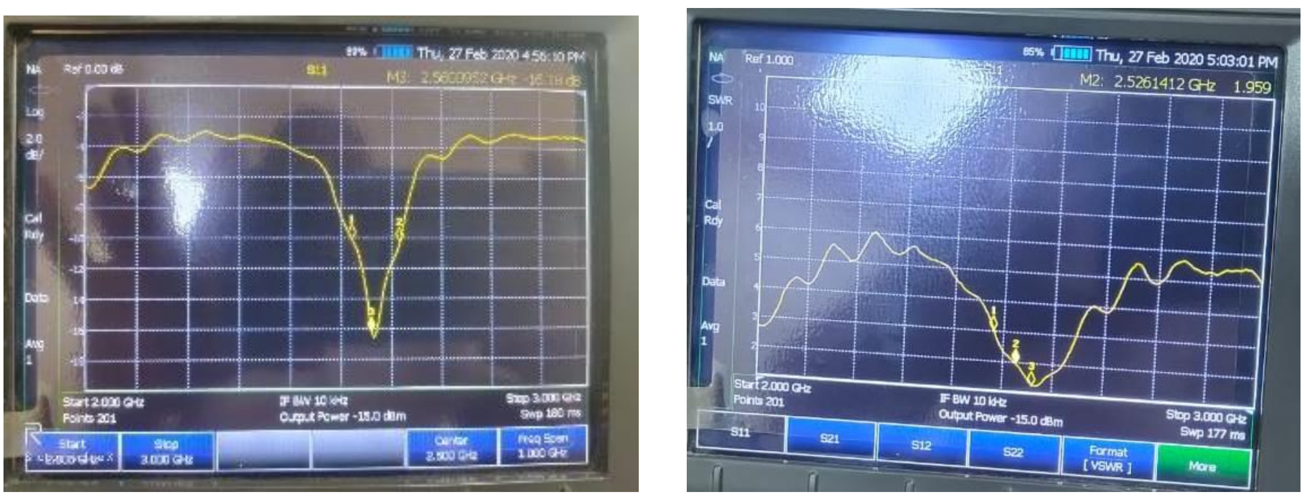
5. ANTENNA MEASUREMENT AND EXPERIMENTAL RESULTS

5.1. Measured and Experimental Results

Figure 15 shows the experimental set up used for the measurement of radiation characteristics of LSFMA with and without DGS. These results are measured in the millimeter wave and antenna lab using the antenna tests and measurement facility. The Key sight Vector Network Analyzer N5916A of frequency range from 30 KHz to 14 GHz is used to test and measure the radiation characteristics of the LSFMA.

Figure15. Experimental set up used for measurement of the radiation characteristics of the LSFMA without DGS and with O, H, and U shaped DGS.

Figure16 shows radiation characteristics of the LSFMA without DGS [1, 2]. Figure 16(a) shows the return loss characteristics of LSFMA. The return loss is almost -16.18dB at 2.5 GHz resonant frequency. The bandwidth achieved with this design is almost 72 MHz. The Figure 16(b) shows VSWR of the proposed LSFMA. The value of VSWR achieved of this design is almost 1.9.

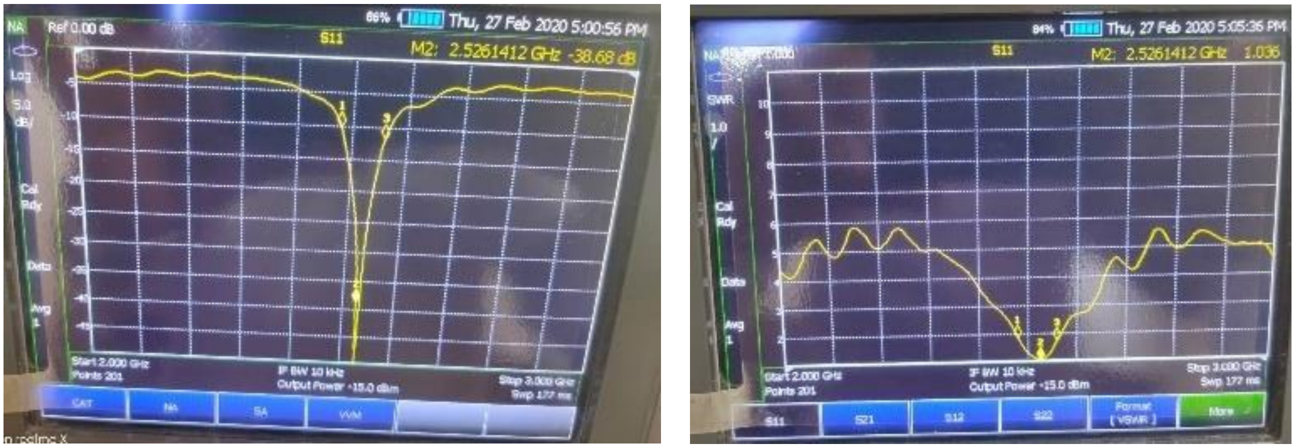


(a) Return Loss

(b) VSWR

Figure 16. Return loss and VSWR of LSFMA without DGS.

Figure 17 shows radiation characteristics of the LSFMA with the O shaped DGS [1, 12, 20]. In this design, the measured return loss value is almost -38.68 dB and the measured bandwidth is approximately 176 MHz, which is greater than the bandwidth of the LSFMA without DGS. In this, the antenna bandwidth is increased by 104 MHz than the LSFMA without DGS. The VSWR is almost 1 (VSWR = 1). Figure 17(a) shows the return loss characteristics and Figure 17(b) shows the VSWR of the LSFMA with the O shaped DGS [12, 20].



(a) Return loss (b) VSWR

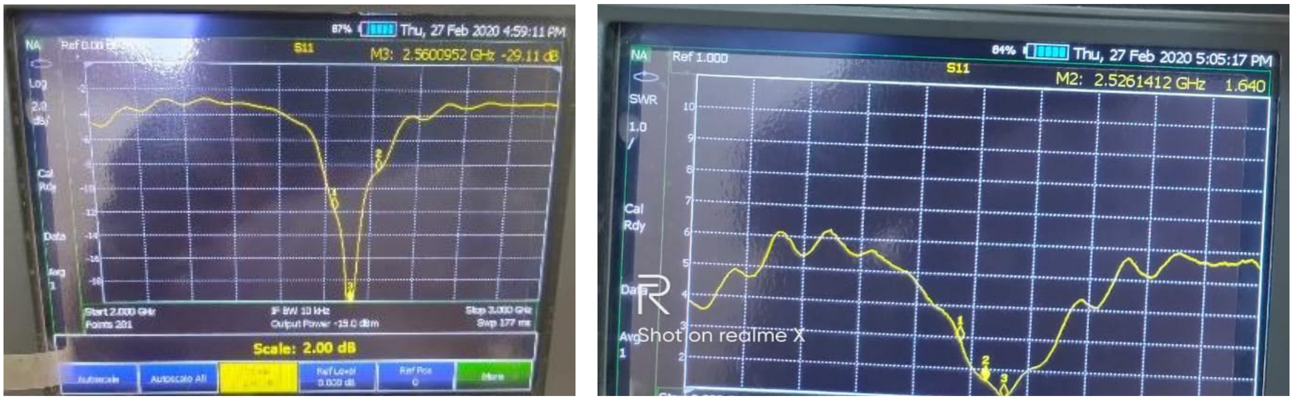
Figure 17. Return loss and VSWR of LSFMA with 'O' shaped DGS.

Figure 18 shows radiation characteristics of the LSFMA with the H shaped DGS [11]. Figure 18(a) shows the measured result of the return loss of the LSFMA with the H shape DGS [2]. The return loss obtained is almost -27.34 dB, the antenna bandwidth almost 126 MHz which is greater than the bandwidth of the LSFMA without the DGS. Therefore, in the LSFMA with the H shaped DGS [11], the bandwidth has increased almost 54 MHz more than the bandwidth of the LSFMA without the DGS as shown in Figure 18(a). The measured value of the VSWR in the LSFMA with the H shaped DGS is almost 1.8 (VSWR = 1.8) as shown in Figure 18(b).

(a) Return loss (b) VSWR

Figure 18. Return loss and VSWR of LSFMA with 'H' shaped DGS.

Figure19 shows radiation characteristics of the LSFMA with the U shaped DGS. The measured value of the return loss characteristics is almost -29.11 dB and the measured bandwidth is approximately 132 MHz, which is greater than the bandwidth of the LSFMA without DGS. In this, the antenna bandwidth is increased by 60 MHz than the LSFMA without DGS. The VSWR is almost 1.6 (VSWR = 1.6). Figure 19(a) shows the return loss characteristics and Figure 19(b) shows the VSWR of the LSFMA with the U shaped DGS.



(a) Return loss (b) VSWR

Figure 19. Return loss and VSWR of LSFMA with ‘U’ shaped DGS.

5.2. Comparison of Experimental Results

The experimental results of the LSFMA without DGS are measured and compared with the results of all the LFSMAs with the DGS structures. It is found that the radiation characteristics of the proposed antenna are quite improved in the LSFMA with the DGS than the ones without DGS.

Table 6. Comparative study of measured results of LSFMA with and without DGS

Sr. No.	Parameters	LSFMA without DGS	LSFMA with ‘O’ DGS	LSFMA with ‘H’ DGS	LSFMA with ‘U’ DGS
1	Resonant frequency(GHz)	2.5	2.5	2.5	2.5
2	Return loss (dB)	-16.18	-38.68	-27.34	-29.11
3	VSWR	1.9	1	1.8	1.6
4	Bandwidth(MHz)	72	176	126	132

With the use of the DGS, the antenna gain [9], the bandwidth, the return loss and other parameters are improved. These antennas are tested and measured in the millimeter wave and antenna lab. These results are measured on the Keysight VNA N5916A of frequency range from 30 KHz to 14 GHz. Table 6 shows the comparative study of measured results of the LSFMA with and without DGS [1, 2].

6. CONCLUSIONS

Out of the three feeding configurations of antennas, the LSFMA provides improved radiation results. Further, a model of the LSFMA with and without DGS is proposed in this paper. The parametric study shows that the LSFMAs with the DGS have better radiation results than the LSFMA without the DGS. The return loss characteristics of the LSFMA with the ‘O’ shaped, ‘H’ shaped and ‘U’ shaped DGS have been increased to -38.68 dB, -27.34 dB, and -29.11 dB respectively at 2.5 GHz frequency from -16.18 dB, which is the return loss characteristic of the LSFMA without the DGS. The improved return loss of the LSFMA with the ‘O’, ‘H’ and ‘U’ DGS is almost -22.50 dB, -11.16 dB and -12.93 dB more than the LSFMA without the DGS respectively. The bandwidth of the LSFMA with the ‘O’ shaped, ‘H’ shaped and ‘U’ shaped DGS has been increased to 176 MHz, 126 MHz and 132 MHz respectively at 2.5 GHz frequency from 72 MHz, which is the bandwidth of the LSFMA without the DGS. The improved bandwidth of the LSFMA with the ‘O’, ‘H’ and ‘U’ DGS is almost 104 MHz, 54 MHz and 60 MHz more than the LSFMA without the DGS respectively.

Therefore, it can be concluded that the performance parameters of the LSFMA with the DGS have improved as compared with the LSFMA without the DGS. 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 [8].

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 [10, 17, 19, 21, 22]. With the use of fractal [12] techniques, size of the LSFMA can be reduced further for wireless communication applications. This can be considered in the future scope of LSFMA.

8. ACKNOWLEDGMENT

The LSFMA antenna results are 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

1 Jia, L. L., Jian, X. C., Quan, X., Jian, P. W., Wei, S., and Liang, J. X., "Compact microstrip low pass filter based on defected ground structure and compensated microstrip line," IEEE Explorer, 0-7803-8846-1/05/ IEEE, pp: 1-4, 2005.
2 Breed, G., "An introduction to defected ground structures in microstrip circuits," *High Frequency Electronics*, 7(11), 50-54, 2008
3 Ajay, V. G., Parvathy, A. R., & Mathew, T., "Microstrip antenna with DGS based on CSRR array for WiMAX applications," *International Journal of Electrical and Computer Engineering*, 9(1), 157, 2019.
4 Sawant, K., & Kumar, R., "Design of UWB novel based gain and bandwidth enhancing CPW fed modified ground curved pentagonal antenna,"*International Journal of Microwave and Optical Technology, IJMOT Publishers*, Vol.7, No.3, IJMOT-2011-12-265 © 2012 ISRAMT, Pp: 160-169, 2012.
5 Hou, Y., Li, Y., Zhang, Z., &Iskander, M. F., "Microstrip-fed surface-wave antenna for end fire radiation," *IEEE Transactions on Antennas and Propagation*, 67(1), 580-584, 2018.
6 Wa'il, A., Shaaban, R. M., & Ahmed, Z. A., "A modified E-shaped microstrip patch antenna for dual band in x-and ku-bands applications," *In Journal of Physics*, Conference Series (Vol. 1234, No. 1, p. 012028). IOP Publishing, 2019.
7 Parui, S. K., & Das, S., "A new defected ground structure for different microstrip circuit applications," *Radioengineering-Prague*, 16(1), 16, 2007.
8 Bharadwaj, R., "Design of micro-strip patch antenna array using DGS for ISM band applications," *Glob J Res Rev*, 4, 1-4, 2017.
9 Raviteja, G. V., Lakshman, I., Sruthi, B. Y. S., Kumar, B. M., &Anuradha, K. S., "Defected ground structured microstrip patch antenna with Quad L–shaped slot for gain enhancement at 4.8 GHz Frequency," *Communications*, 7, 1-5, 2018.
10 Ghaloua, A., Zbitou, J., El Abdellaoui, L., Errkik, A., Tajmouati, A., &Latrach, M., "A miniature circular patch antenna using defected ground structure for ISM band applications," *In Proceedings of the 2nd International Conference on Computing and Wireless Communication Systems* (pp. 1-5), 2017.
11 Boutejdar, A., Elsherbini, A., Omar, A., "Design of a novel ultra-wide stop band low pass filter using H-defected ground structure," *Microwave And Optical Technology Letters* / Vol. 50, No. 3, DOI 10.1002/mop, PP: 771-775, 2008
12 Kushwaha, N., & Kumar, R., "An UWB fractal antenna with defected ground structure and swastika shape electromagnetic band gap," *Progress in Electromagnetics Research*, 52, 383-403, 2013.
13 Abdelgwad, A. H., "Microstrip patch antenna enhancement techniques," *International Journal of Electronics and Communication Engineering*, 12(10), 703-708, 2018.
14 Rani S. S., Naik, K. K., "Analysis of Vivaldi antenna etched with the circular patch and complementary

split ring resonator slot," *International Journal of Innovative Technology and Exploring Engineering (IJITEE)* ISSN: 2278-3075, Volume-8 Issue-7, PP: 2959-2961, 2019.
15 Roopan, Samantaray, D., Bhattacharyya S., "A multiband wearable antenna with defected ground structure," *URSI AP-RASC 2019, New Delhi, India*, 09, PP: 1-4, 2019.
16 Liu, W. C., Wu, C. M., & Dai, Y., "Design of triple-frequency microstrip-fed monopole antenna using defected ground structure," *IEEE transactions on antennas and propagation*, 59(7), 2457-2463, 2011.
17 Pei, J., Wang, A. G., Gao, S., &Leng, W., "Miniaturized triple-band antenna with a defected ground plane for WLAN/WiMAX applications," *IEEE Antennas and Wireless Propagation Letters*, 10, 298-301, 2011.
18 Gautam, A. K., Kumar, L., Kanaujia, B. K., &Rambabu, K., "Design of compact F-shaped slot triple-band antenna for WLAN/WiMAX applications," *IEEE Transactions on Antennas and Propagation*, 64(3), 1101-1105, 2015.
19 Yin, K., &Xu, J. P., "Compact ultra-wideband antenna with dual band stop characteristic," *Electronics Letters*, 44(7), 453-454, 2008.
20 Jaiswal, A., Sarin, R. K., Raj, B., &Sukhija, S., "A novel circular slotted microstrip-fed patch antenna with three triangle shape defected ground structure for multiband applications," *Advanced Electromagnetics*, 7(3), 56-63, 2018.
21 Nouri, A., & Dadashzadeh, G. R., "A compact UWB band-notched printed monopole antenna with defected ground structure," *IEEE antennas and wireless propagation letters*, 10, 1178-1181, 2011.
22 Abdollahvand, M., Dadashzadeh, G., &Mostafa, D., "Compact dual band-notched printed monopole antenna for UWB application," *IEEE Antennas and Wireless Propagation Letters*, 9, 1148-1151, 2010.
23 Acharjee, J., Singh, A. K., Mandal, K., & Mandal, S. K., "Defected ground structure toward cross polarization reduction of microstrip patch antenna with improved impedance matching," *Radioengineering*, 28(1), 33, 2019.