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INVESTIGATION ON DGS BASED LINE FED MULTIBAND PATCH ANTENNA FOR WIRELESS APPLICATIONS

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Abstract

The novel antenna resonating for multiple bands using Defected Ground Structure (DGS) has been presented in this paper. The antenna is designed on FR-4 substrate with the dimensions 35×24×1.6mm³ and Loss tangent (tanδ) of 0.02, dielectric constant ε = 4.4. The patch is rectangular shape forming as the top layer on the substrate and fed with line feeding then the ground plane with multiple notches forming as inverted T-shape linked from tail to tail using rectangular notch and the combination forms as Defected Ground Structure (DGS). The antenna is designed and studied the parameters like return loss, VSWR, Gain, and current distribution. The antenna has achieved a very good response in all aspects and can be used for multiple applications. The effect of change in feedline width with center-fed has also been studied in this paper. The antenna is simulated using the HFSS tool.

Keywords:

Defected Ground Structure, Defected Patch Structure, Ultra-Wideband, Super Wide Band, Gain, VSWR, Return Loss, Current Distribution, Line feed

1. INTRODUCTION

Microstrip Antenna is an integral part of any wireless communication system. No matter for any frequency tuning the antenna for that particular frequency is a challenging task for the engineers. In wireless communications, the microstrip antenna is mostly used. The intention behind is very simple because of its low profile, ease in fabrication. At the same time locating the feeding point is also important for this antenna to gain certain parameters.

The novel idea of designing the compact and multiband antenna is the recent developments happening in communication technology. The miniaturization can be easily achieved in the microstrip antenna without disturbing the other antenna parameters. By inserting slots on the top layer as well on the bottom ground layer after a thorough investigation the 90% of miniaturization has been achieved in the literature. Without disturbing the physical dimensions of the antenna by inserting multiple slots on the patch known as Defected Patch Structure (DPS) and also using the technique of Defected Ground Structure (DGS), the antenna will achieve multiple resonances. And the resonances can also be shifted towards lower or higher frequencies by just tuning the DGS alone. Different shapes of DPS and DGS are contributed in the literature to enhance the parameters of the antenna-like return loss, VSWR, gain, and directivity. After inserting the DGS the antenna started radiating at multiple frequency bands due to the change in the current distribution.

Designing the antenna for UWB or SWB and tuning it for multiple bands is a very important and challenging task. The FCC has prescribed the bandwidth of 7.5GHz from 3.1GHz to 10.6GHz as an Ultra-wideband [1]. And the SWB can be considered as from 1GHz to 20GHz. The different geometrical shapes of compact size entrenched on the ground plane are referred to as Defected Ground Structure (DGS). Before the idea of DGS, it was Photonic Band Gap (PBG) and Electromagnetic Band Gap (EBG) have been in usage. But because of its difficulty in fabrication and large occupying size, DGS has dominated and replaced the EBG and PBG in most of the cases [2]. By etching L-Notch on the ground plane with the feeding technique of coaxial probe has gained 3 resonances in L-band and S-band [3]. The antenna with DGS forming the geometry of U-shape, I-shape, and three PIN diodes reconfigurable antenna has responded multiple resonances over the entire bandwidth of 1GHz to 10GHz [4]. Inserting the DGS below the feed line also achieved the band rejection characteristics [5]. The improvement over the conventional EBG is using the Defected Ground Compact Electromagnetic Band Gap (DG-CEBG) is the new technique used to achieve the band rejection characteristics [6]. Another technique of suppressing the upper band and allowing the lower band as a low pass filter (LPF) has been proposed by inserting the DGS below the feed line of the antenna and achieved a very good response over the UWB region [7]. With the combination of split ring structures, L and U shapes on the ground plane, the antenna resonates for three multiple frequencies [8]. Fork-shaped antenna with U-shape and extended U-shape DGS has also been designed for rejecting few frequencies under UWB spectrum. And the antenna achieved a very good response by resonating at multiple frequencies [9]. The antenna designed for C-band and X-band under UWB spectrum by inserting the DGS has been implemented [10]. The better performance achieved with rectangular DGS and circular patch antenna and by varying the diameter of the disc the antenna efficiency also increased in terms of return loss and gain [11]. Rounding the defective ground is another technique used for UWB antenna to attain better performance of antenna parameters under biomedical applications [12]. The insertion of DGS and multiple-input-multiple-output (MIMO) antenna array has been designed for reducing mutual coupling between the antennas under UWB applications [13].

2. ANTENNA GEOMETRY WITH DGS

The proposed antenna is designed using FR4 substrate with 1.6 mm thickness, dielectric constant ε_r = 4.4, loss tangent tanδ = 0.02, and dimension of 35(L)×24(W) mm^2. The width and length of the conducting patch are defined as W_P=15mm, L_P=14mm, feed line width FL_W=2.5mm, and feed line length FL_L=15mm which makes the antenna resonating at f_r = 5GHz as per mathematical analysis [3]. The bottom side DGS has been integrated on the ground plane with the combination of square slot and back to back linked T-Slot w.r.t square slot. The dimensions of the bottom side DGS are listed in the Table.1. The complete antenna model is shown in Fig.1.

Table.1. Bottom side DGS dimensions with all combinations

Parameter		Dimensions (mm)
Square Sot (Sq) (x,y)		(6,6)
Left bottom Side T-Notch (x,y)	L_1	6, 0.4
	L_2	7,1
	L_3	6, 0.4
	L_4	1,12
Right bottom Side T-Notch (x,y)	R_1	6, 0.4
	R_2	7,1
	R_3	6, 0.4
	R_4	1,12

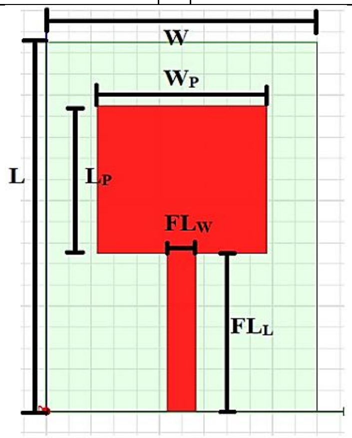


Fig.1(a). Top View

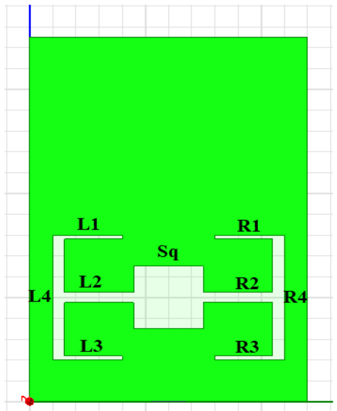


Fig.1(b). Bottom View with DGS

The insertion of bottom side DGS underneath the strip line will change the effective capacitance and inductance of the strip line thereby adding the slot resistance, capacitance and inductance. Therefore the response of the proposed antenna along with the designed resonating frequency will resonate for multiple frequencies as shown in Fig.1(c) and Fig.1(d) for return loss and VSWR.

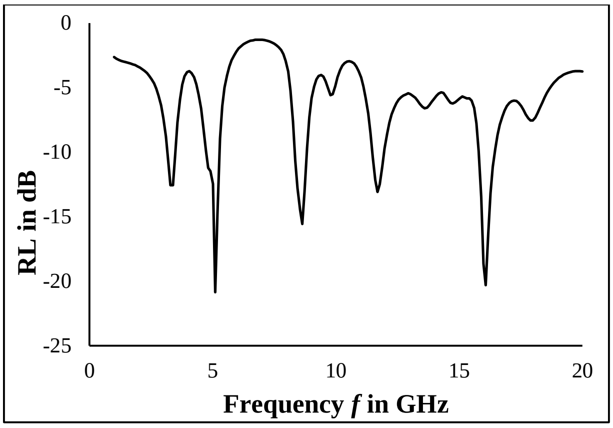


Fig.1(c). Return Loss

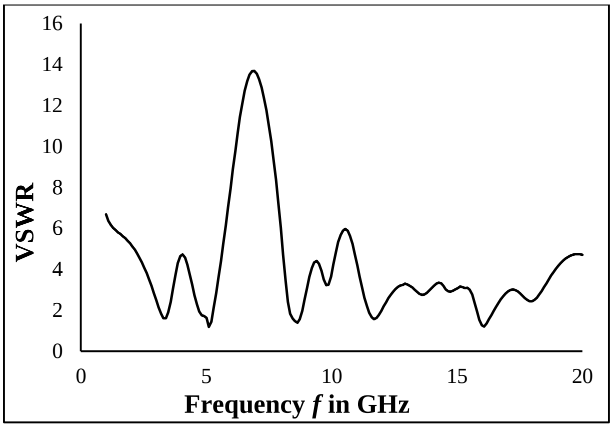


Fig.1(d). VSWR

From the Fig.1(c) and Fig.1(d) inserting one bottom side, DGS as per the specification of the Table.1 achieved five multiple frequencies. The responses are tabulated as in Table.2.

Table.2. Responses

Sl. No.	Responses			
	Parameter	Frequencies in GHz	RL in dB	VSWR
1	Bottom Side DGS	f_1=3.29	-12.55	1.61
2		f_2=5.10	-20.83	1.19
3		f_3=8.63	-15.56	1.40
4		f_4=11.69	-13.07	1.57
5		f_5=16.08	-20.31	1.21

The next investigation is inserting top side DGS along with bottom side DGS. And the top side DGS also follows the same dimensions as per Table.(1) and listed the parameter in Table.(3).

Table.3: Topside DGS dimensions with all combinations

Sl. No.	Parameter		Dimensions (mm)
1	Square Slot (Sq) (x,y)		(6,6)
2	Left top Side T-Notch (x,y)	L_{11}	6, 0.4
		L_{12}	7,1
		L_{13}	6, 0.4
		L_{14}	1,12

3	Right top Side T-Notch (*x*,*y*)	R_{11}	6, 0.4
		R_{12}	7,1
		R_{13}	6, 0.4
		R_{14}	1,12

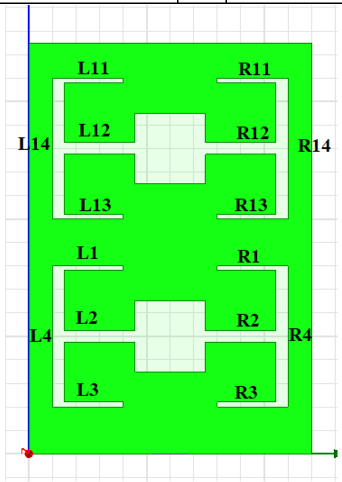


Fig.2. Topside and Bottom side DGS

By inserting the topside DGS along with bottom side DGS the response of the antenna has been enhanced as shown in Fig.2(a) and Fig.2(b) when compared with Fig.1(c) and Fig.1(d).

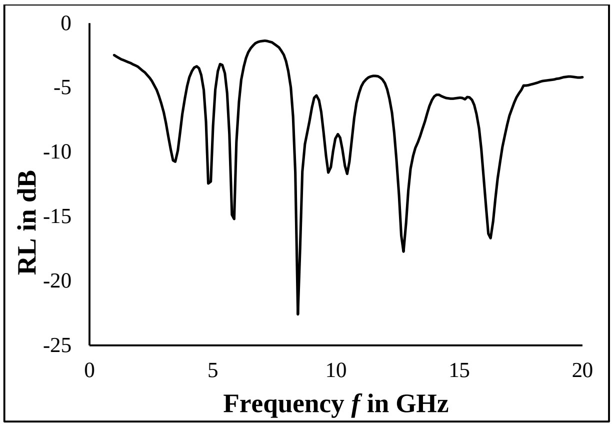


Fig.2(a). Return Loss

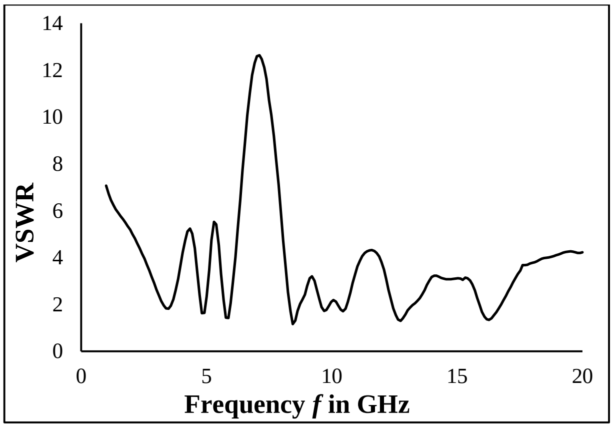


Fig.2(b). VSWR

The responses after inserting the top side and bottom side DGS has been achieved eight multiple bands and tabulated in Table.4.

Table.4. Responses

Sl. No.	Responses			
	Parameter	Frequencies in GHz	RL in dB	VSWR
1	Bottom Side + Tope Side DGS	f_1=3.48	-10.74	1.81
2		f_2=4.81	-12.43	1.64
3		f_3=5.86	-15.19	1.42
4		f_4=8.44	-22.58	1.16
5		f_5=9.68	-11.58	1.71
6		f_6=10.45	-11.69	1.70
7		f_7=12.74	-17.73	1.29
8		f_8=16.27	-16.67	1.34

3. INSERTING DGS FOR MULTIPLE BANDS

The equivalent circuit of DGS can be analyzed by any one of the following methods:

- LC and RLC equivalent circuits.
- π shaped equivalent circuit.
- Quasi-static equivalent circuit.
- Using an ideal transformer.

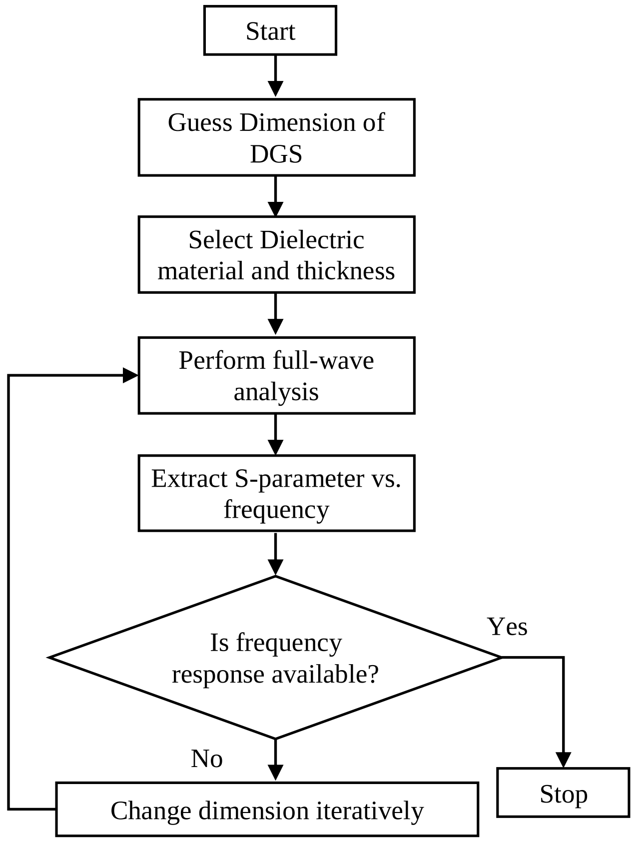


Fig.3(a). Flowchart analysis for DGS

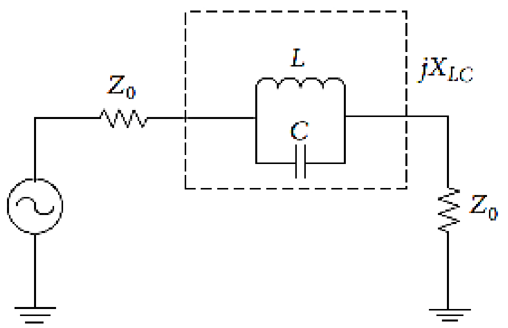


Fig.3(b). Equivalent circuit of DGS

However, the topside and bottom side DGS looks like a heavy dumbbell shape and can be analyzed by LC and RLC equivalent circuit or π shaped equivalent circuit [2]. To gain the multiple resonances for the antenna the flowchart can be followed as in Fig.3(a) and DGS equivalent circuit in Fig.3(b).

The DGS slotted area is related to effective inductance and capacitance. Such that the DGS slotted area is directly proportional to inductance and inversely proportional to the capacitance [14]. Thereby increasing the dimensions of DGS will increase the inductance and mark response on the lower frequencies then decreasing the dimensions of DGS will decrease the capacitance thereby mark response on the higher frequencies. The effective reactance of the LC resonator of Fig.3(b) can be obtained as,

$$X_{LC} = \frac{1}{\omega_0 C}\left\{\frac{\omega_0}{\omega} - \frac{\omega}{\omega_0}\right\} \tag{1}$$

where ω_0 is the angular resonant frequency and the values of L and C can be described as,

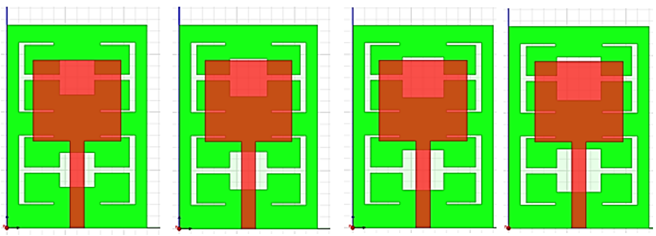
$$C = \frac{\omega_c}{z_0 g_1} \cdot \frac{1}{\omega_0^2 - \omega_c^2} \tag{2}$$

$$L = \frac{1}{4\pi^2 f_0^2 C} \tag{3}$$

where f_o is the resonant frequency and f_c is the cut-off frequency.

3.1 PARAMETRIC ANALYSIS OF SQUARE SLOT OF DGS

The parametric analysis of the square slot on both top side and bottom side DGS is studied as per the variations from (6mm, 6mm), (6.5mm, 6.5mm), (7mm, 7mm) and (7.5mm, 7.5mm) as shown in Fig.4 and the response can be observed in Fig.4(e).



(a) (b) (c) (d)

Fig.4. (a) Sq_Slot (6mm, 6mm), (b) Sq_Slot (6.5mm, 6.5mm), (c) Sq_Slot (7mm, 7mm), (a) Sq_Slot (7.5mm, 7.5mm)

From the responses, it is clear that for the values of the square slot at (6mm, 6mm) the results are acceptable.

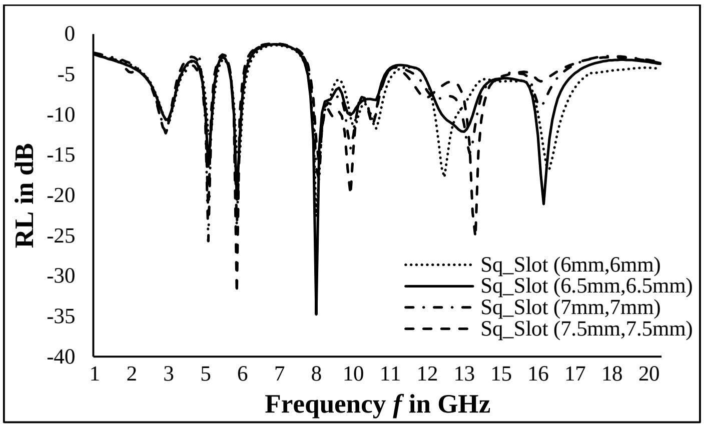


Fig.4(e). Parametric analysis of Square slot for return loss

3.2 PARAMETRIC ANALYSIS OF CENTERED FEEDLINE

The parametric analysis of the central feed line is studied for the values FL_W=2.0mm, FL_W=2.5mm, FL_W=3.0mm. This change in feed line width also shows the effect on resonances due to the insertion of DGS underneath the feedline. The response of return loss can be observed in Fig.4(f). From the response, it is very clear that to achieve sharp responses FL_W=2.5mm, FL_W=3.0mm will suits best as the slot resistance, slot capacitance, and slot inductance will play their role in resonating for multiple frequencies.

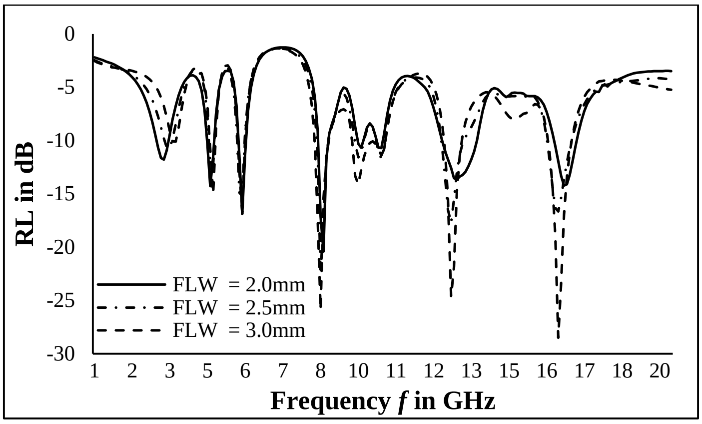


Fig.4(f). Parametric analysis of feed line width for return loss

3.3 PARAMETRIC ANALYSIS OF DGS SLOTS L4 WITH R4 AND L14 WITH R14

The parametric analysis of bottom side DGS slot of L_4 w.r.t. R4 and vice versa then L_{14} w.r.t. R_{14} and vice versa have been studied to obtain the variations in the resonance of antenna w.r.t. Fig.2. The L_4 variation of 1.0mm, 1.5mm, and 2.0mm with constant of R_4 at 1.0mm and R_4 variation of 1.0mm, 1.5mm, and 2.0mm with constant of L_4 at 1.0mm is studied and the responses are shown in Fig.5(a) and Fig.5(b).

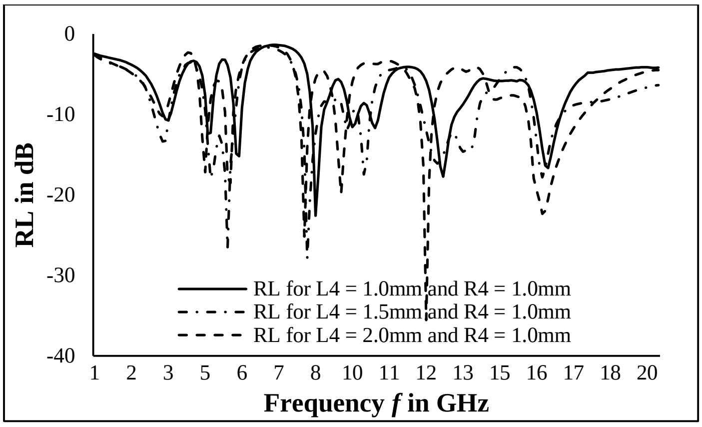


Fig.5(a). Parametric analysis L_4 varied w.r.t. R_4

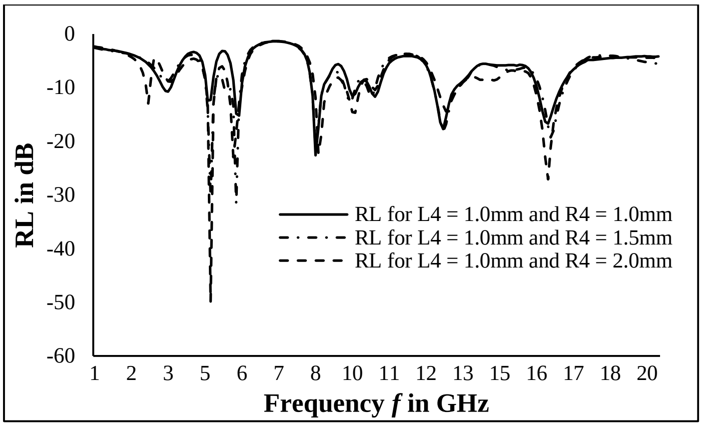


Fig.5(b). Parametric analysis R4 varied w.r.t. L_4

The same variation of L_{14} w.r.t. R_{14} and vice-versa is analyzed; the response of the graph is shown in Fig.5(c) and Fig.5(d).

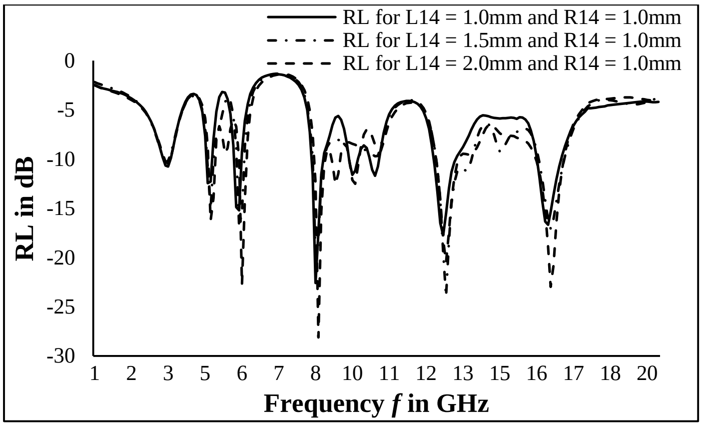


Fig.5(c). Parametric analysis L_{14} varied w.r.t. R_{14}

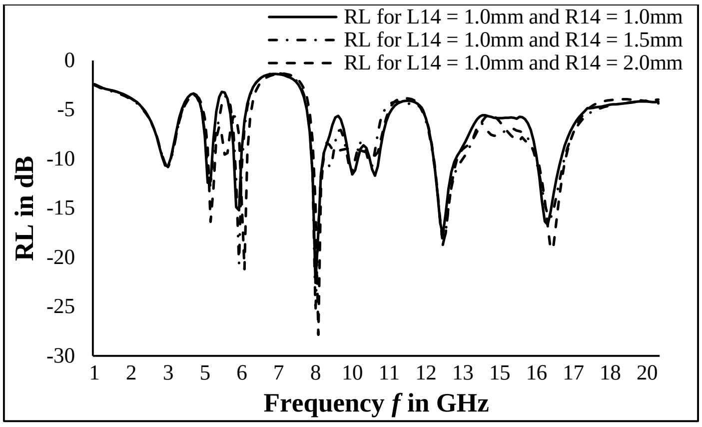


Fig.5(d). Parametric analysis R_{14} varied w.r.t. L_{14}

From the above parametric analysis, it is very clear that to make the antenna for resonating at required different frequencies need to tune the DGS.

4. RESULTS

The antenna gain and current distribution for the proposed multi-band antenna through line feeding are shown in the below Fig.6 and the complete result analysis is tabulated in the Table.5.

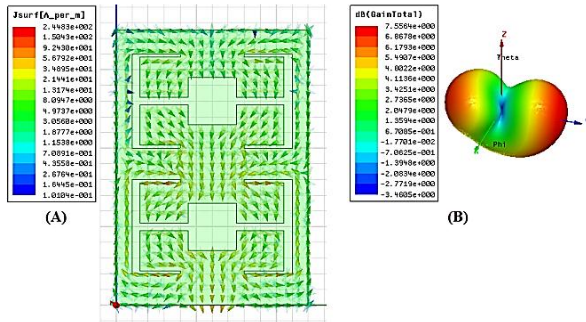


Fig.6(a). Current distribution and (b) 3D Gain at f_1=3.48GHz

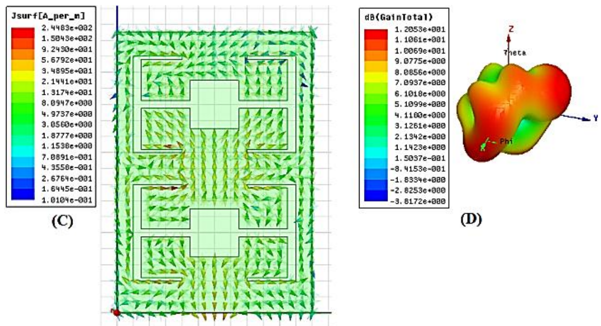


Fig.6(c). Current distribution and (d) 3D Gain at f_2=4.81GHz

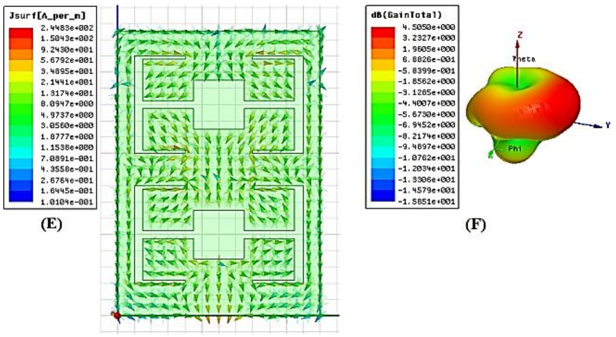


Fig.6(e). Current distribution and (f) 3D Gain at f_3=5.86GHz

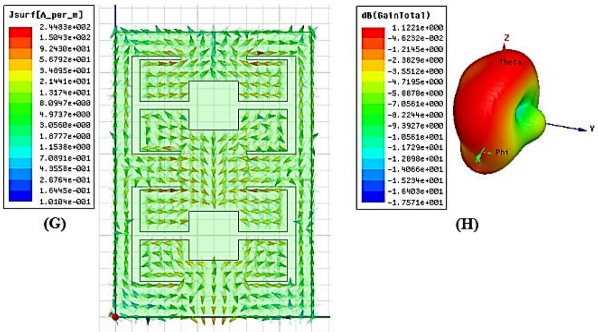


Fig.6(g). Current distribution and (h) 3D Gain at f_4=8.44GHz

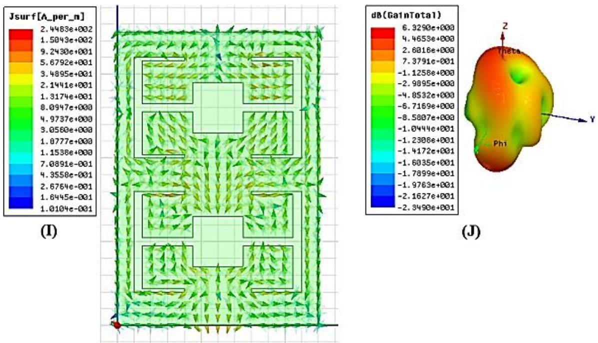


Fig.6. (i) Current distribution and (j) 3D Gain at f_5=9.68GHz

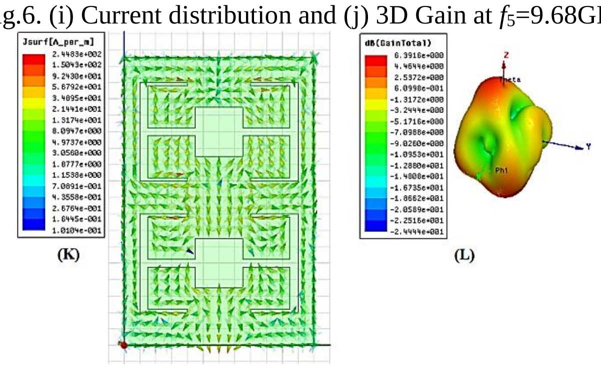


Fig.6(k). Current distribution and (l) 3D Gain at f_6=10.45GHz

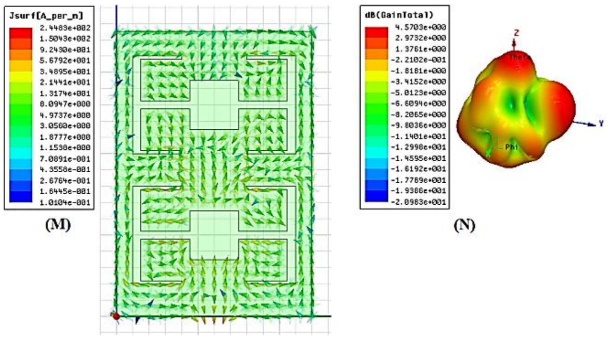


Fig.6(m). Current distribution and (n) 3D Gain at f_7=12.74GHz

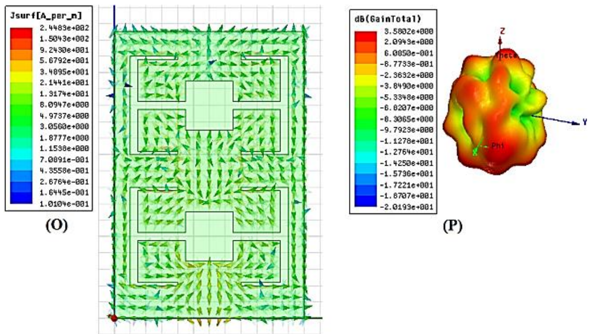


Fig.6(o). Current distribution and (p) 3D Gain at f_8=16.27GHz

Table.5(a). RL and VWSR of Bottom side DGS

Sl. No.	Parameter	Freq. in GHz	RL in dB	VSWR
1	Bottom Side DGS	f_1=3.29	-12.55	1.61
2		f_2=5.10	-20.83	1.19
3		f_3=8.63	-15.56	1.40
4		f_4=11.69	-13.07	1.57
5		f_5=16.08	-20.31	1.21

Table.5(b). Gain and %BW of Bottom side DGS

Sl. No.	Freq. in GHz	Gain in dB	Fractional BW	%BW
1	f_1=3.29	8.70	0.097	9.7
2	f_2=5.10	7.70	0.105	10.5
3	f_3=8.63	3.37	0.055	5.5
4	f_4=11.69	5.76	0.040	4.0
5	f_5=16.08	4.86	0.039	3.9

Table.5(c). RL and VWSR of Bottom side and Top Side DGS

Sl. No.	Parameter	Freq. in GHz	RL in dB	VSWR
1	Bottom Side DGS + Top Side DGS	f_1=3.48	-10.74	1.81
2		f_2=4.81	-12.43	1.64
3		f_3=5.86	-15.19	1.42
4		f_4=8.44	-22.58	1.16
5		f_5=9.68	-11.58	1.71
6		f_6=10.45	-11.69	1.70
7		f_7=12.74	-17.73	1.29
8		f_8=16.27	-16.67	1.34

Table.5(d). Gain and %BW of Bottom side and Top Side DGS

Sl. No.	Freq. in GHz	Gain in dB	Fractional BW	%BW
1	f_1=3.48	7.55	0.071	7.1
2	f_2=4.81	12.05	0.039	3.9
3	f_3=5.86	4.50	0.044	4.4
4	f_4=8.44	1.12	0.046	4.6
5	f_5=9.68	6.32	0.030	3.0
6	f_6=10.45	6.39	0.029	2.9
7	f_7=12.74	4.57	0.058	5.8
8	f_8=16.27	3.58	0.050	5.0

5. CONCLUSION

The proposed antenna is simulated and various parameters are analyzed to achieve different resonances. It has been observed that the antenna-1 with a single bottom side DGS reacted for five resonances under which three frequencies are within UWB region and two are in SWB region, whereas antenna-2 by inserting bottom side and top side DGS on the ground plane the antenna response is quite better and reacted for eight resonances under which six frequencies are within UWB region and two other are under SWB region. The return loss, VSWR, and gain achieved are also acceptable for both antennas. The antenna-2 can be used in S-band for Satellite, Sirius XM Radio, Unlicensed (Wi-Fi, Bluetooth, etc.), Cellular Phones, C-band for Satellite, µWave relay, X-band for RADAR and Ku-band for Satellite TV, Police RADAR applications.

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