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Design of Modified Dumbbell Shaped Slotted Multiband Miniaturized Antenna with Defected Ground for Future Mobile Communications

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Abstract: Modified Dumbbell shaped slotted multiband miniaturized antenna with Rectangular, Circular and Elliptical shaped defected ground structures for future mobile communications is presented in this paper. Patch of rectangular shape operating at 2.4 GHz frequency is designed and eighteen slots of rectangular shape with a dimension 2.5mm x 3.5mm is made on outer boundaries of the patch and a modified dumbbell shaped slot is made on middle of the patch. The ground plate is defected with Rectangle, Circle and Elliptical shapes. The proposed antenna is operated at 6 different N frequency bands of 5G bands including N24 (1.625- 1.660) GHz, N48 (3.550-3.700) GHz, N77 (3.3-4.2) GHz, N70(1.695- 1.710) GHz, N78(3.3-3.8) GHz, and N104(6.425- 7.125) GHz. For rectangular defected ground structure, 4.4dBi gain is obtained. For circular defected ground structure, 4.6dBi gain is obtained. For elliptical defected ground structure, 4.8dBi gain is obtained. Simulated results shows that designed antenna will be utilized for future mobile communication including GPS, VOLTE, Wi-Fi, and 6 5G bands.

Keywords: *Modified Dumbbell shape, Multiband, Miniaturized, Defected ground structure, future mobile communications.*

1. Introduction

Demand for wireless communication devices with smaller and compact sizes are increasing exponentially in recent days. As antennas are important part in wireless communication device, there is another important requirement to have a small antenna operating at multiple frequencies and providing different features to wireless users. Multi frequency operated antennas can be designed using slotted techniques, but they reduce the antenna gain. Hence Defected Ground structures concept were used in antenna design to increase the antenna gain. Previously researchers used many techniques towards improving the gain of the antenna one including them is defected ground structure. Defected ground is nothing removing certain part of ground plane with certain shapes and positions. In a patch antenna, a DGS is made by engraving off a particular shape on the ground plate, depending on the selected measurement and defect shape, the current distribution on the ground plate will be disturbed, foremost to a measured excitation that results in alteration of the S parameter of the antenna and result in gain enhancement.

Slotted part of DGS is directly proportional to effective inductance and inversely proportional to effective capacitance.

Hence increasing or decreasing the DGS area results in shifting the resonant frequency. Increasing slot area of DGS reduces resonant frequency whereas decreasing DGS area decreases effective capacitance and increases resonant frequency.

Several approaches were made in developing DGS, some are discussed here. Sequentially etched four rectangular slots and four open type diagonal slots correspondingly made on the patch and ground plate, Operated at 2.39 − 2.52 GHz Wi-Fi bands with gain of 2.2 dBi [1]. Coplanar waveguide antenna is designed with two reversed L-shaped elements operated at 2.4 GHz obtaining gain of 3.5 dBi [2]. Rectangular shaped patch antenna using DGS is designed, operating at 2.4 GHz frequency with gain of 4.4 dBi[3].Tapered octagonal shaped patch antenna with DGS embedded split ring resonators is designed in [4] operated at 3.31 GHz, 6.5 GHz and 12.1GHz. Gain of the antenna at operated frequency is about 3.76 dBi. Antenna is designed using semi-SRS slots and annular ring slots were made on radiating patch using DGS. Designed antenna operated at 6.95 GHz [5]. The ground plate is altered by inserting U shaped slot with wide open sides and I shaped slots in shorter ends to achieve multi band operation of the antenna and to enhance the antenna parameters in antenna design [6]. A rectangular patch antenna with edge trimmed is designed and optimized with DGS and genetic algorithm. G shaped defected ground is made on ground plate to enhance the band width of UWB antenna [7]. H shaped

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DGS is made on ground plane to a rectangular patch antenna to improve antenna gain. Designed antenna is functioned at 2.4 GHz for WI-FI applications [8]. Square patch is designed and different defected structures like circle, rectangle, hole, rhombic, square and hexagonal are made on the ground plate. Performance of antenna is noted for different defected ground structures [9]-[12].

Kumar, M et all. designed an UWB based monopole antenna, that operated over 2.6GHz - 18 GHz. Triangular shaped patch antenna using rectangular DGS was presented in [15], here DGS is used for improving the bandwidth. X. Lou et al. introduced UWB antenna using DGS operated in 5 GHz - 6 GHz scale with better band rejection feature [16]. The designed antenna consists of two slots of square shape in diagonal and in partial ground plate. The DGS is used to achieve the Wireless LAN band and cover bandwidth from 3.50 - 8.7 GHz. S. F. Jilani et al. designed a T slot MIMO antenna with DGS in [17]. Proposed constructed antenna using DGS with rectangular slot achieved 8.50dBi gain and 88.6% antenna efficiency.

In this research paper, A modified dumbbell-shaped slot is made on center of patch and bordered by 18 rectangular shaped slots for multiband operation. After, to boost the gain further, DGS is considered to the slotted patch antenna. Different defected structures like rectangle, circle and ellipse were made on ground plane and observed the multiband operation and enhancement in the gain of a patch antenna. The simulated results like S-parameter, VSWR, Gain, Directivity and Radiation pattern were observed for the modified dumbbell shaped slotted antenna with and without defected ground structures. As mentioned in previous antenna designs, the proposed antenna is simple in design, smaller with a single layer, eliminates the tradeoff between gain enhancement and s parameter.

1.1 Design Calculations

Mathematical calculations for finding dimensions of rectangular shaped patch antenna is calculated with Transmission line method. Antenna is designed at 2.4GHz frequency, substrate height is made as 1.6 mm and substrate material is selected as FR4.

$$f_r = 2.4GHz$$

$$h = 1.6mm$$

$$\varepsilon_r = 4.4$$

Patch Shape is: Rectangular.

Width of the Patch, $W = \frac{c}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}}$ = 38mm

Effective Dielectric Constant,

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left(\frac{1}{\sqrt{1+\frac{2h}{W}}}\right)$$ = 2.7+1.7*0.96=4.33

Effective Length, $L_{eff} = \frac{c}{2f_r\sqrt{\varepsilon_{reff}}}$ = 0.0625/2.08 = 30mm

$$\Delta L = h \times 0.412 \times \frac{(\varepsilon_{reff}+0.3)\left(\frac{W}{h}+0.264\right)}{(\varepsilon_{reff}-0.258)\left(\frac{W}{h}+0.8\right)}$$ = 0.6592 * (4.63*24.014)/(4.072*24.55) = 0.733

Patch Length, $L = L_{eff} - (2 \times \Delta L)$ = 30-1.466=28.54mm

Ground Plate length, $L_g = 6h + L$ = 38.14mm

Ground Plate Width, $W_g = 6h + W$ = 47.6mm

Slot Dimensions: considered as Length x Width = 2.5 mm x 3.1 mm

1.2 Design of multiband minuaturized antenna with dgs using hfss:

A rectangular patch is designed at 2.4 GHz frequency band a modified dumbbell shaped slot is made on center of the patch. 18 rectangular shape slots of dimension 2.5 mm x 3.5 mm are made around the modified dumbbell shaped slot using HFSS software for design and simulation. Three types of Defected ground structures i.e, Rectangle, circle, and ellipse were designed for slotted antenna.

1.2.1 Design of Dumbbell shaped Multiband Miniaturized Antenna with Rectangular Defected Ground Structure:

Dumbbell shaped slotted antenna is designed with 18 rectangular slots on path and Rectangular shaped slot is made on the ground plane for proper notching of frequencies. Designed rectangular slotted patch antenna is presented in fig. 1. Designed slotted antenna with rectangular DGS is presented in figure 2. From fig. 2, it was examined a rectangular DGS on ground, 18 slots with dumbbell shaped slot on the patch.

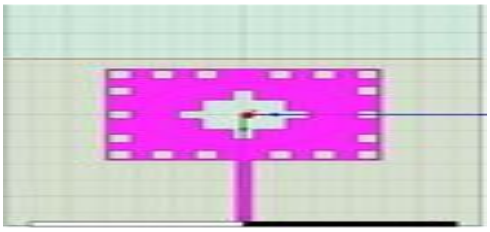

Fig 1.: Designed modified Dumbbell shaped slotted patch antenna.

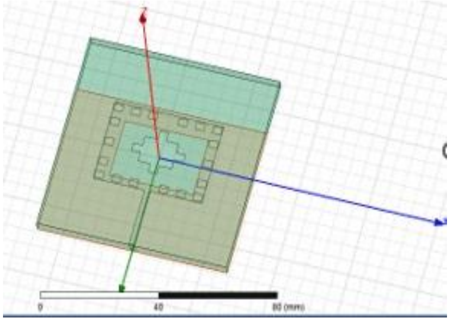

Fig 2: Designed modified Dumbbell shaped slotted antenna with rectangular DGS.

1.2.2 Design of Multiband Miniaturized Antenna using Circular Defected Ground Structure:

Circular shaped slot is made on the ground plane for proper notching of frequencies. Designed slotted patch antenna using rectangular DGS is presented in below figure 3. It was observed that Circular DGS on ground, 18 slots with dumbbell shaped slot on the patch.

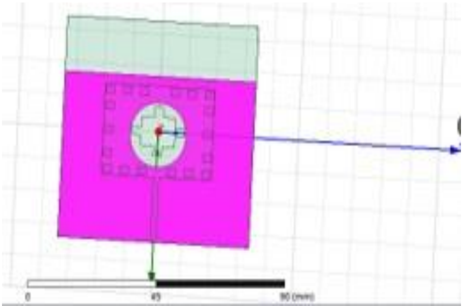

Fig 3: Designed modified Dumbbell shaped slotted antenna using Circular DGS.

1.2.3 Design of Multiband Miniaturized Antenna using Elliptical Defected Ground Structure:

Elliptical shaped slot is made on the ground plane for proper notching of frequencies. Designed slotted patch antenna using Elliptical DGS is presented in below figure 4, it was observed that Elliptical DGS on ground, 18 slots with dumbbell shaped slot on the patch.

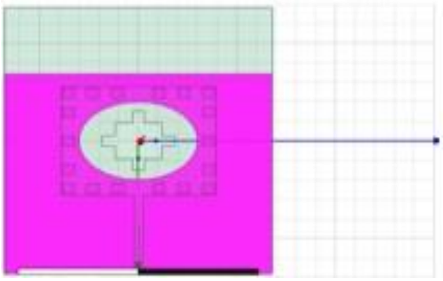

Fig 4: Designed modified Dumbbell shaped slotted antenna using Elliptical DGS.

2. Simulated Results And Analysis

Designed Antenna with rectangular, circular, and elliptical DGS were simulated between 1 to 10 GHz by using HFSS software. Antenna parameters include Return loss, VSWR, 2D & 3D Radiation patterns, Directivity and Gain is observed and plotted in graphs.

2.1 Simulated results for Slotted antenna with Rectangular DGS:

Return loss: From simulated plot, return loss of Dumbbell shaped slotted antenna with Rectangular DGS is shown in fig. 5. From plot, it is noticed that antenna is functioned at 4 frequency bands i.e. 1.50 GHz – 1.70 GHZ, 3.4GHz - 4.3GHz, 6.1GHz - 7.90GHz, 9.40GHz - 10GHz.

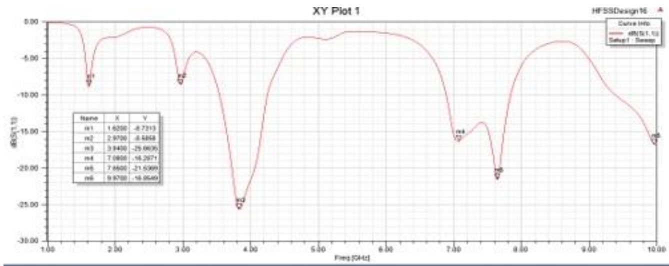

Fig 5: Return Loss plot for modified Dumbbell shaped slotted antenna with rectangular DGS.

VSWR: VSWR plot for Dumbbell shaped slotted antenna with Rectangular DGS is revealed in fig. 6. At 1.50GHz band, attained VSWR is around 1.9, at 3.60 GHz band, attained VSWR is around 1.3, at 4.2 GHz band, attained VSWR is around 1.6, at 7.4 GHz band, attained VSWR is around 1.5 and at 9.4 GHz band, attained VSWR is around 1.8.

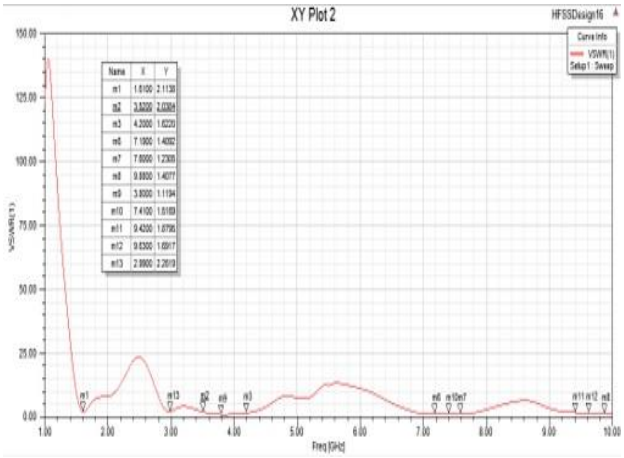

Fig 6: VSWR plot for modified Dumbbell shaped slotted antenna with rectangular DGS.

Radiation Patterns: 2D radiation patterns of Dumbbell shaped slotted antenna with rectangular DGS is shown in fig. 7.

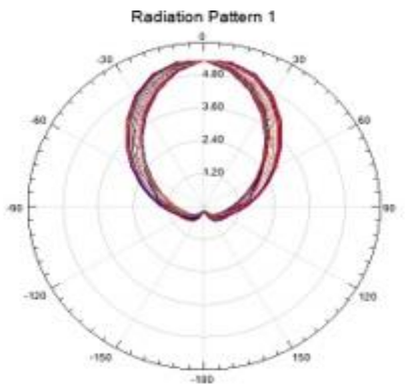

Fig 7: 2D radiation patterns for modified Dumbbell shaped slotted antenna with rectangular DGS.

Gain: Simulated Gain of Dumbbell shaped slotted patch antenna with Rectangular DGS is indicated in fig. 8. From the plot, it was noted that Gain of antenna is around 4.3dBi.

Fig 8: Gain for slotted antenna for modified Dumbbell shaped slotted antenna with rectangular DGS.

Directivity: Simulated Directivity of Dumbbell shaped slotted patch antenna with Rectangular DGS is indicated in figure 9. From the plot, Directivity of the slotted antenna is around 7.5dBi.

Fig 9: Directivity for slotted antenna for modified Dumbbell shaped slotted antenna with rectangular DGS.

2.2 Simulated Results of slotted antenna with Circular DGS:

Return loss: Return loss of Dumbbell shaped slotted patch antenna with Circular DGS is revealed in fig. 10. From plot, it is noted that antenna is functioned at four frequency bands 1.9GHz-2.1GHz, 3.6GHz-4GHz, 6.7GHz-7.3GHz, 9.9GHz-10GHz.

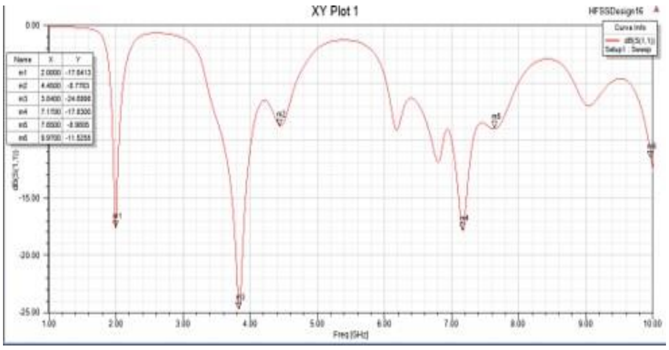

Fig 10: Return Loss plot of modified Dumbbell shaped slotted antenna with Circular DGS.

VSWR: VSWR plot of Dumbbell shaped slotted patch antenna with Circular DGS is indicated in fig. 11. It was noted that at 2GHz band, attained VSWR is around 1.4, at 3.4 GHz band attained VSWR is around 1.3, at 7.1 GHz band attained VSWR is around 1.3, at 8.2 GHz band attained VSWR is around 1.5 and at 9.2 GHz band attained VSWR is around 1.9.

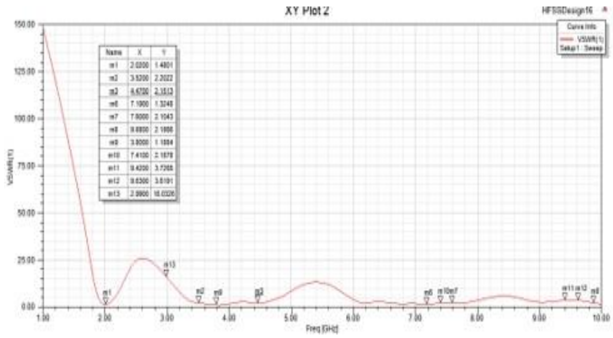

Fig 11: VSWR plot of modified Dumbbell shaped slotted antenna with Circular DGS.

Radiation Pattern: Radiation Pattern: Two-dimensional radiation patterns of Dumbbell shaped slotted patch antenna with Circular DGS is indicated in figure 12.

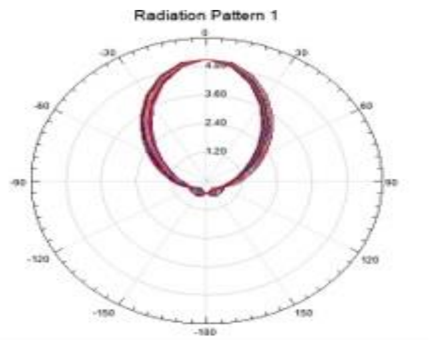

Fig 12: 2D radiation patterns of modified Dumbbell shaped slotted antenna with Circular DGS.

Gain: Gain of Dumbbell shaped slotted patch antenna with Circular DGS is exhibited figure 13. From simulated plot it was noticed that Gain of the antenna is around 4.4dBi.

Fig 13: Gain of modified Dumbbell shaped slotted antenna with Circular DGS

Directivity: Directivity of Dumbbell shaped slotted patch antenna with Circular DGS is indicated in fig. 14. From plot, it is observed that Directivity of slotted patch antenna is around 7.6dBi.

Fig 14: Directivity of modified Dumbbell shaped slotted antenna with Circular DGS

2.3 Simulated Results of Slotted antenna with Elliptical DGS:

Return loss: Return loss of Dumbbell shaped slotted patch antenna with Elliptical DGS is displayed in fig 15. From plot, it is noted that designed antenna is functioned at 4 various frequency bands i.e. 1.7GHz-1.8GHz, 3.3GHz-4.3GHz, 6.6GHz-7.6GHz, 9.7GHz-10GHz.

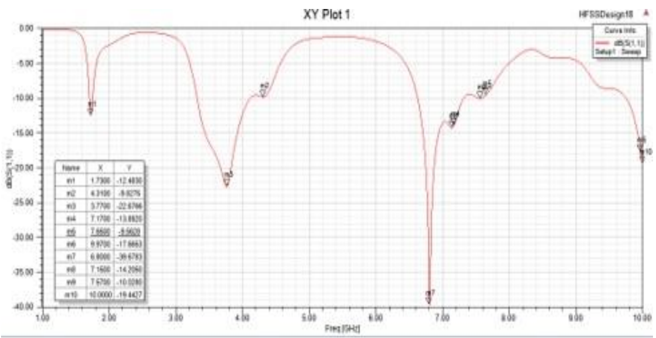

Fig 15: Return Loss plot of modified Dumbbell shaped slotted antenna with Elliptical DGS.

VSWR: Simulated VSWR plot of Dumbbell shaped slotted patch antenna with Elliptical DGS is displayed in fig.16. It was analyzed that at 1.7 GHz band, attained VSWR is around 1.6, at 3.4 GHz band, attained VSWR is around 1.5, at 7.1 GHz band, attained VSWR is around 1.5 and at 9.8 GHz band attained VSWR is around 1.5.

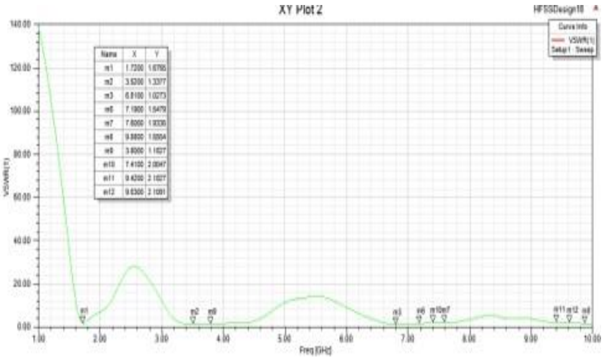

Fig 16: VSWR plot of modified Dumbbell shaped slotted antenna with Elliptical DGS.

Radiation Pattern: Two-dimensional radiation pattern of Dumbbell shaped slotted patch antenna with Elliptical DGS is displayed in fig. 17.

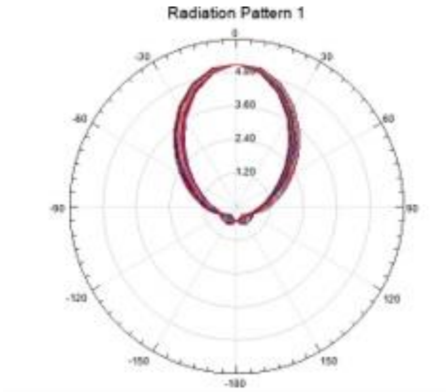

Fig 17: 2D radiation pattern of modified Dumbbell shaped slotted antenna with Elliptical DGS.

Gain: Simulated Gain of the Dumbbell shaped slotted patch antenna with Elliptical DGS is indicated in fig. 18. From the plot, it was noted that Gain of the antenna with Elliptical DGS is around 4.6dBi.

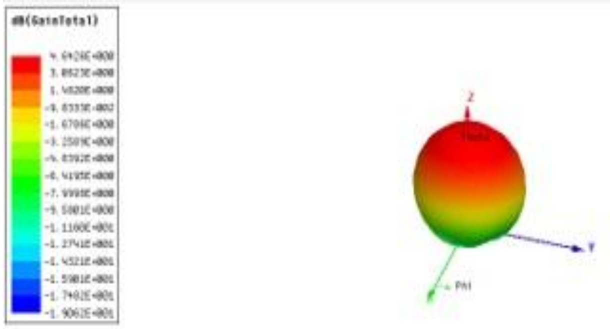

Fig 18: Gain of modified Dumbbell shaped slotted antenna with Elliptical DGS.

Directivity: Directivity of Dumbbell shaped slotted patch antenna with Elliptical DGS is indicated in fig. 19. From the plot, it was noted that Directivity of the antenna is around 7.8dBi.

Fig 19: Directivity of modified Dumbbell shaped slotted antenna with Elliptical DGS.

Table 1: Comparison of proposed Antenna Simulated Results:

Antenna Type	**DGS type**	**Operating Frequency Bands**	**VSWR at Operating Frequency**	**Gain**	**Directivity**
Dumbbell shaped Slotted Antenna with Rectangular DGS	Rectangle	1.5GHz-1.7GHz 3.4GHz-4.3GHz, 6.1GHz-7.9GHz, 9.4GHz-10GHz.	1.5GHz - 1.9, 3.6GHz - 1.3, 4.2GHz - 1.6, 7.4GHz - 1.5, 9.4GHz - 1.8.	4.3dBi	7.5dBi
Dumbbell shaped Slotted Antenna with Circular DGS	Circle	1.9GHz-2.1GHz, 3.6GHz-4GHz, 6.7GHz-7.3GHz, 9.9GHz-10GHz.	2GHz - 1.4, 3.4GHz - 1.3, 7.1GHz - 1.3, 8.2GHz - 1.5, 9.2GHz - 1.9.	4.4dBi	7.6dBi
Dumbbell shaped Slotted Antenna with Elliptical DGS	Ellipse	1.7GHz-1.8GHz, 3.3GHz-4.3GHz, 6.6GHz-7.6GHz, 9.7GHz-10GHz.	1.7GHz - 1.6, 3.4GHz - 1.5, 6.8GHz - 1.2, 7.1GHz - 1.5, 9.8GHz - 1.5.	4.6dBi	7.8dBi

Summary of simulated results of proposed antenna with rectangular, circular, and elliptical shaped defected grounds were tabulated in table 1. It was observed that three defective ground structures operated at 4 bands of frequencies with improved gain from rectangle to ellipse. The gain of Dumbbell shaped Slotted Antenna with Rectangular DGS is 4.3dBi. The gain of Dumbbell shaped Slotted Antenna with Circular DGS is 4.4dBi. Gain of Dumbbell shaped Slotted Antenna with Elliptical DGS is 4.6dBi.

Normally DGS is used in microstrip antennas with different slots to improve antenna gain and reduce higher order harmonics, mutual coupling between elements and improves radiation characteristics of microstrip antenna. It is observed in table1. EBG technology is nothing but having periodical defects on ground that suppress surface currents and intern improves antenna efficiency and gain. Slots of different geometry made on ground plate called as defected ground. These slots may be periodic or aperiodic on ground. Any defect made on ground plane disturbs the current distributions on ground plate and changes some characteristics by altering the parameters like slot resistance, slot inductance and slot capacitance which alters the operating frequency bands.

Table 2: Comparison of Proposed antenna parameters with other existing Techniques:

Antenna Design	Antenna Feeding Technique	Operating Frequency Bands (GHz)	No. of Frequency Bands	Antenna Gain
[1] Patch antenna with Rectangular slots	Microstrip line	2.39 −2.52 GHz	1	2.2 dBi
[2] Inverted L-shape Patch antenna	Microstrip line	2.1-3 GHz	1	3.5 dBi
[3] Rectangular patch antenna	Microstrip line	2.4 GHz	1	4.47 dBi
[4] Tapered shaped octagonal patch antenna	Microstrip line	3.31 GHz, 6.50 GHz, 12.01 GHz	3	3.76 dBi
Proposed Antenna	Microstrip line	(1.625-1.660) GHz, (3.550-3.700) GHz, (3.300-4.200) GHz, (3.300-3.800) GHz, (1.695-1.710) GHz and (6.425-7.125) GHz.	6	4.6 dBi

Summary of simulated results of four existing techniques were compared with proposed antenna and tabulated in table 2. Golak Santra et al. proposed an antenna with Sequentially etched four rectangular slots on patch and four open type diagonal slots on ground plate. Designed antenna operated at 2.39 − 2.52 GHz Wi-Fi bands with gain of 2.2 dBi. Even though lot of complexity made in antenna design, only one frequency band is achieved with low gain. Hattan F et al. proposed Coplanar waveguide antenna with two defected structures of reversed L-shaped elements operated at 2.4 GHz obtaining gain of 3.5 dBi. Even though lot of complexity made in antenna design for coplanar waveguide, only one frequency band is achieved with low gain. Devashree et al. proposed Rectangular shaped patch antenna using DGS is designed, operating at 2.4 GHz frequency only with gain of 4.4 dBi. Tapered octagonal shaped patch antenna with DGS embedded split ring resonators is designed in [4] operated at 3.31 GHz, 6.5 GHz and 12.1GHz. Gain of the antenna at operated frequency is about 3.76 dBi. Hence slotting is made on both patch and ground in this paper with innovative slotting techniques to achieve more frequency bands with enhanced Gain.

3. Conclusion

Modified Dumbbell shaped slotted multiband miniaturized antenna with Rectangular, Circular and Elliptical shaped defected ground structures for future mobile communications are described in this paper. **D**esigned antenna is simulated using HFSS and antenna parameters like returnloss, VSWR, directivity, gain and radiation pattern is measured. Designed antenna have achieved steady radiation patterns and guaranteed return loss. The simulated results shows that the antenna operated at 6 different 5G frequency bands including N24 (1.625- 1.660) GHz, N48(3.550-3.700) GHz, N77(3.3-4.2) GHz, N70(1.695- 1.710) GHz, N78(3.3-

3.8) GHz, and N104(6.425- 7.125) GHz. For Dumbbell shaped slotted patch using rectangular defected ground structure, 4.4dBi gain is obtained. For Dumbbell shaped slotted patch using circular defected ground structure, 4.6dBi gain is obtained. For Dumbbell shaped slotted patch using elliptical defected ground structure, 4.8dBi gain is obtained. From the simulated results of antenna with rectangular, circular, and elliptical DGS, it was analyzed that antenna operates almost at similar frequency bands but Gain of the antenna increased from Rectangular DGS to Elliptical DGS. The proposed Antenna can be employed for future mobile communication covering GPS, Wi-Fi, VOLTE, WIMAX, and 6 5G bands.

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