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BANDWIDTH AND GAIN ENHANCEMENT OF CUP SHAPED UWB MICROSTRIP PATCH ANTENNA WITH DEFECTIVE GROUND PLANE FOR SUB-6 GHZ 5G APPLICATIONS

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ABSTRACT

This paper presents the design of slotted ground plane and a circular ring slotted microstrip patch antenna for new radio (NR) band, sub-6 GHz, WLAN and Licensed Assisted Access (LAA) 5G applications. The design consists of cup -shaped microstrip patch antenna with a defective ground structure (DGS). The circular ring slot at the top of the patch and the modified rectangular slots at the bottom are helpful to improve the performance of the antenna, thereby increase the efficiency, bandwidth, gain and improved s-parameters. The proposed antenna is designed on FR4-epoxy substrate and inset feeding technique. The design and simulation of my proposed work are done using HFSS (ANSYS-Electronics suite 19.2×64 version). The antenna has a bandwidth of 2.56 GHz with maximum gain of 2.27 dB. The antenna operates for the bandwidth from 4.04GHz to 6.6 GHz which covers NR-New Radio band (3.4-4.2 GHz), Sub 6 GHz 5G band (n-79) (4.44-5.0 GHz), WLAN (5.15 - 5.35 GHz) and Licensed Assisted Access (LAA) band.

Keywords: *ANSYS, LAA, N-Bands, Slotted Ground Structure, Sub-6 GHz 5G Communication.*

Introduction

This paper presents the design of slotted ground plane. Wireless communication plays a vital role in all aspects of daily life. One of the most popular types of printed antenna that have significant role is the microstrip antennas. They have many advantages such as light weight, low cost, small in size, therefore they are well suited for modern applications. There are certain limitations of microstrip antennas, that is low gain and narrow bandwidth. The availability of compact, efficient and portable device that can operated at low signal power and at high data rates in modern technologies are in great demand. There are so many techniques that enhance the parameters of conventional microstrip antennas that is, using different feeding techniques, fractal technology, Frequency Selective Surface (FSS), Metamaterial, Defective Ground Structure (DGS), Photonic Band Gap (PBG), Electromagnetic Band Gap (EBG). Among all the techniques, Defective Ground Structure (DGS) technology has been gained popularity now a days. In DGS technology, the slots are etched or cut in the ground plane of microstrip structure. We may consider single or multiple defects on the ground plane. The overall performance of the antenna depends on the shape and position of the DGS. Slotted ground structure microstrip patch for Sub-6 GHz was implemented. Here the ground plane consists of C-Shaped slot. This shape enhances the performance of the antenna [2]. A rectangular patch antenna was designed having Sierpinski carpet fractal slots are applied at the ground plane. The designed structure was used for Wi-Fi applications [3]. For geostationary satellite communication, array antenna was designed having defective ground structure by the utilization of Apollonius circles. A 2×2 array structure was designed [4]. The basic concepts of Defective Ground Structure and evolution of DGS was discussed. The comparison between DGS and other technologies that is PBG & EBG were analyzed. Applications in the field of antennas, amplifier, planar waveguides and filters were presented [5]. To reduce the cross-polarized (XP) radiation of a microstrip patch antenna, a defected ground structure was proposed. Here circular patch act as the radiator and does not affect the dominant mode input impedance. Here etching was done on a Taconic

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substrate [6]. A compact microstrip antenna was demonstrated. Meandering slots was embedded in the antenna's ground plane which reduces the size of antenna and enhanced antenna gain and impedance bandwidth and also reduces the quality factor [7]. Simple circuit model for microstrip filtering structure with defected ground plane was presented. The model consists of series inductance and shunt capacitance [8]. A Novel defected ground structure for planar circuits was demonstrated to design a compact low pass filter (LPF) that reduces the size up to 26.3%. For inductive loading two H-shaped slots are etched. Here RT/Duroid 5880 substrate was used [9]. A single-feed equilateral triangular microstrip antenna having Circular Polarization (CP) was designed to enhance the gain. Three triangular slots are placed below the equilateral triangular radiating patch in the round plane [10]. Dual-band asymmetric slit with ground structure microstrip antenna was proposed. Cutting slit on square microstrip antenna was used to excite the lower resonant band and to excite the upper resonant band, defected ground with truncated corner's structure was used. This results the reduction of size in antenna [11]. For wireless applications, a triple band circularly polarized compact microstrip antenna with three different defected ground structures was proposed. Three antennas show triple band characteristics. Same patch was used for different ground structures. The size of antenna was reduced up to 22.91% [12]. By using the different geometries of DGS, nature of cross polarized radiation from probe-fed circular microstrip antennas and their suppression was studied [13]. The antenna was stacked by a circular patch with air gap and in the ground plane, circular shaped defect is embedded to obtain dual characteristics. It reduces the size of antenna up to 36% [14]. Bandwidth enhancement and cross-polarization suppression in ultra-wide band microstrip antenna with defected ground plane was demonstrated. Impedance bandwidth of 160% was achieved. Here plane was embedded with triangular and square defects which results the compact microstrip antenna [15]. Based on IEEE 802.11a, the band ranging from 5.15-5.35 GHz is used for different WLAN applications (China, Singapore, Japan, USA, South Africa, Israel, Korea and HIPERLAN/2 in Europe).

Antenna Design and Geometry

For antenna design, there are some factors that are very relevant to the performance of the antenna which determines the bandwidth, the size of the antenna and resonant frequency. These factors includes the length, width and height of the antenna and also the substrate used. Trom the transmission line model equation , the width of the antenna is given by [16]:

$$W = \frac{c}{2f_r}\sqrt{\frac{2}{\varepsilon_r + 1}}$$

Where; f_r is the resonant frequency, c is the speed of light, ε_r is the dielectric constant of the substrate.

The effective dielectric constant of the antenna due to fringing affect is given by [16]:

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{\sqrt[2]{1 + \frac{12h}{W}}}$$

The actual length of the patch is given by [16]:

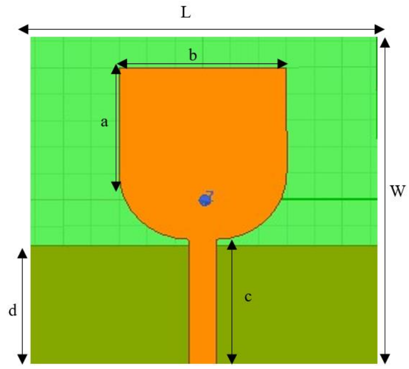
$$L = L_{eff} - 2\Delta L = \frac{c}{2f_r\sqrt{\varepsilon_{reff}}} - 2\Delta L$$

Note that ΔL is given by [16]:

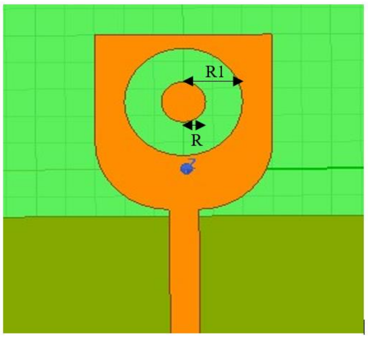
$$\Delta L = \frac{h(0.412)[(\varepsilon_{reff} + 0.3)\left(\frac{W}{h} + 0.264\right)]}{(\varepsilon_{reff} - 0.258)\left(\frac{W}{h} + 0.8\right)}$$

Where h is the height or thickness of the substrate. For this design, we have f_r = 5.66 GHz, h = 0.8 mm and the dielectric constant is 4.3.

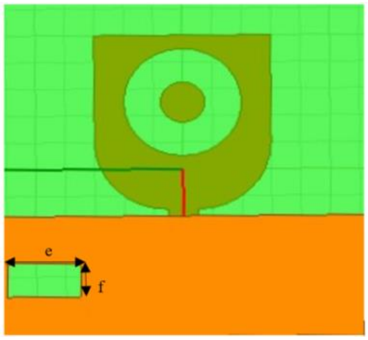
Fig. 1 presents the geometry of the proposed antenna design. The cup shaped patch, patch with ring slot, patch with a single slot at the ground plane, patch with two slots at the ground plane, patch with third slot at the ground plane, patch with two slots and a cross sign slot at ground plane are shown in Fig. 1(a), Fig. 1(b), Fig. 1(c), Fig. 1(d), Fig. 1(e), Fig. 1(f), Fig. 1(g) respectively. The patch consists of a rectangle with a curved path having inset feed, as shown in Fig. 1(a) and matched to a 50Ω feeding impedance.



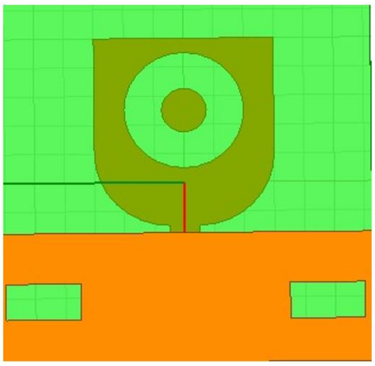
(a) Cup shaped Patch



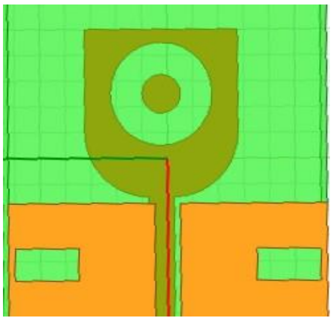
(b) Patch with ring slot



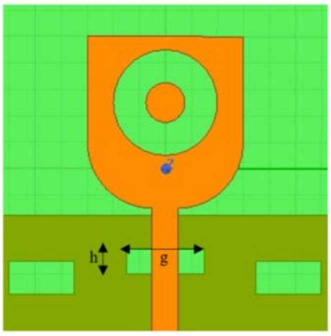
(c) Patch with a single slot at ground plane



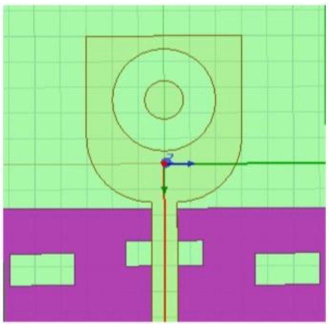
(d) Patch with two slots at ground plane



(e) Patch with third slot at ground plane



(f) Top view final geometry



(g) Bottom view Final Geometry

Fig. 1. Antenna geometry, (a) Cup shaped Patch, (b) Ring slotted patch, (c) Patch with one slot at the ground plane, (d) Patch with two slots at the ground plane, (e) Patch with third slot at ground plane, (f) Top view final geometry, (g) Bottom view final geometry

Table 1: Antenna Dimensions

S. No.	Parameter	Dimension (mm)
1	L	25
2	W	25
3	R1	4
4	R	1.5
5	a	12
6	b	12
7	c	10.5
8	d	10
9	e	5
10	f	2.5
11	g	6
12	h	2

Results and Discussions

The proposed antenna is designed on FR4-epoxy substrate and inset feeding technique. The design and simulation of the proposed work are done using HFSS (ANSYS-Electronics suite 19.2×64) version. The performance of antenna will improve by using the defected ground structure.

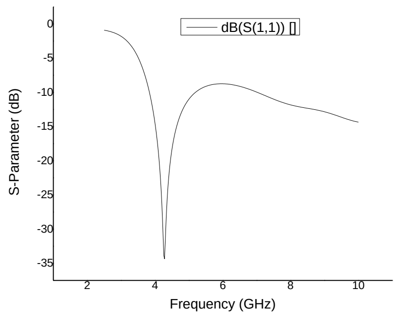


Fig. 2: Reflection coefficient (S11) of Cup Shaped Patch

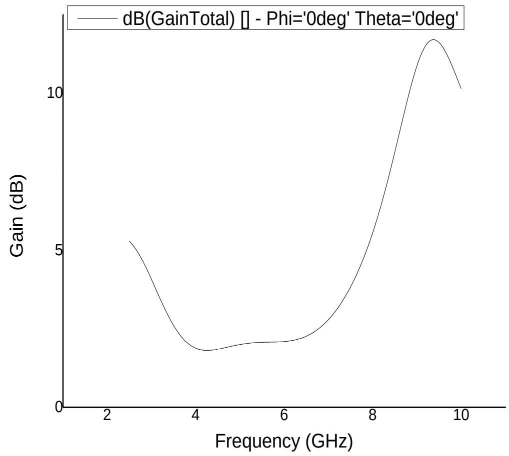


Fig. 3: Gain of Cup Shaped Patch

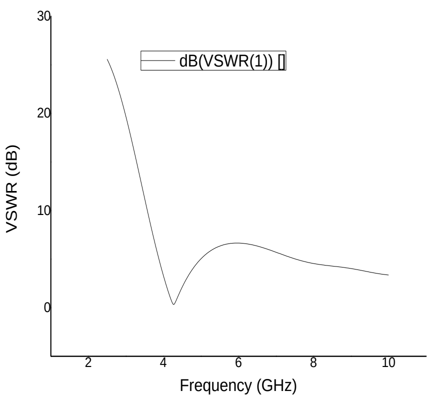


Fig. 4: VSWR of Cup Shaped Patch

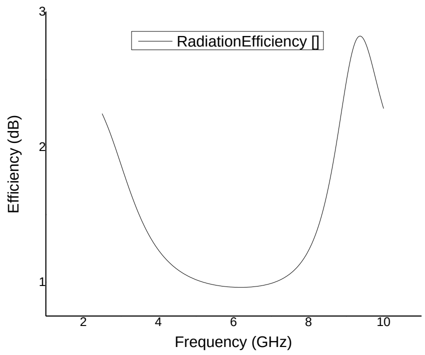


Fig. 5: Radiation Efficiency of Cup Shaped Patch

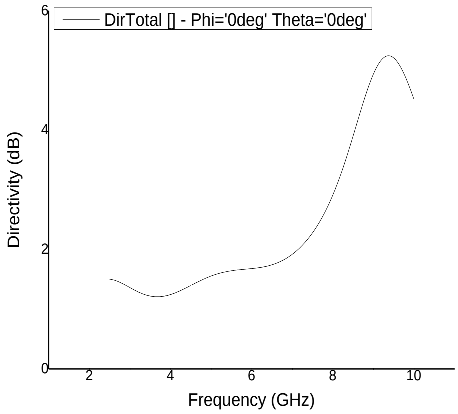


Fig. 6: Directivity of Cup Shaped Patch

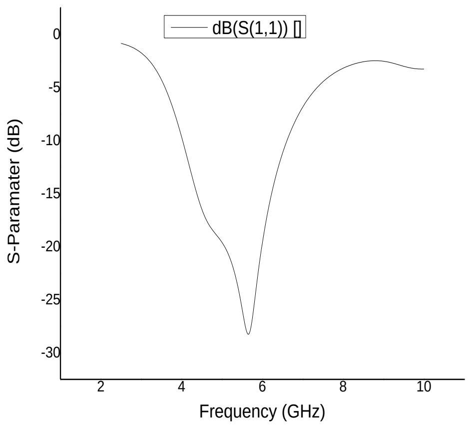


Fig. 7: Reflection coefficient (S11) of Final Geometry

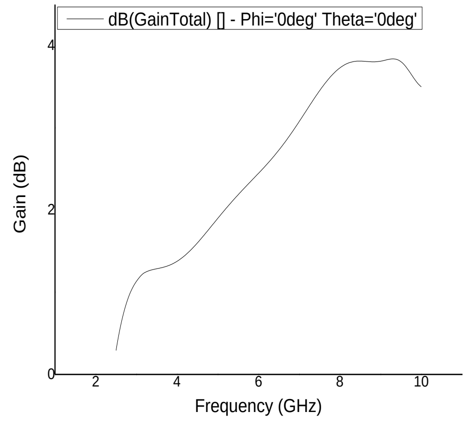


Fig. 8: Gain of Final of Final geometry

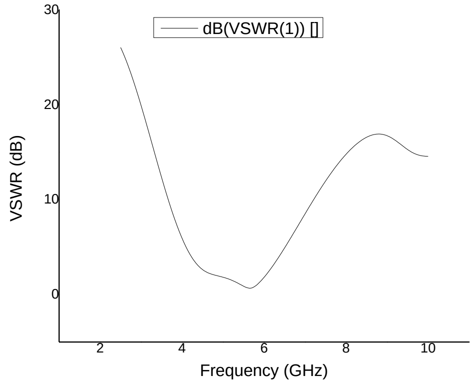


Fig. 9: VSWR of Final Geometry

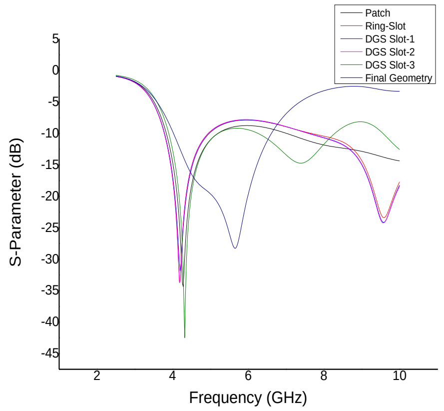


Fig. 10: Comparison between S11 of Patch, Ring slot, DGS Slot-1, DGS Slot-2, DGS Slot-3 and Final Geometry

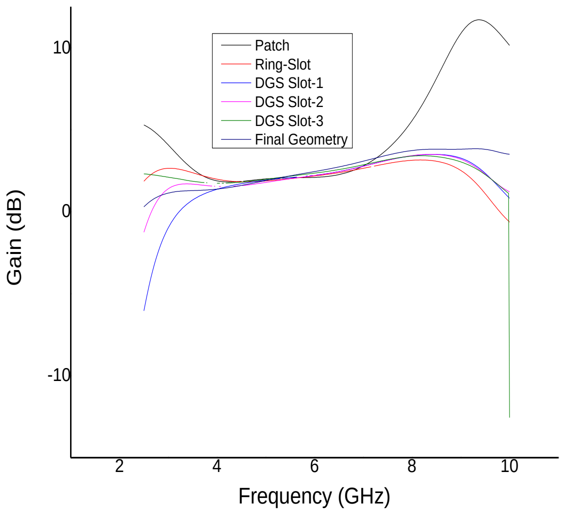


Fig. 11: Comparison between Gain of Patch, Ring slot, DGS Slot-1, DGS Slot-2, DGS Slot-3 and Final Geometry

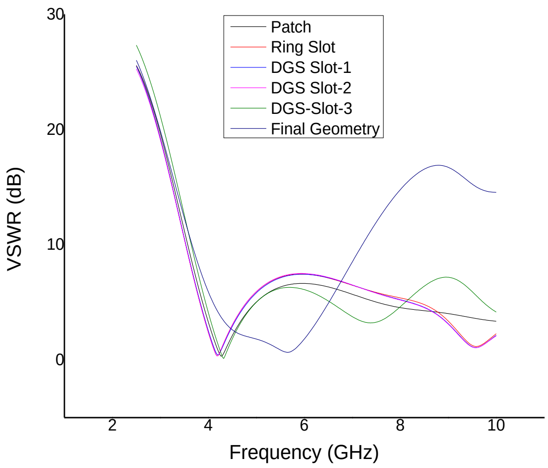


Fig. 12: Comparison between VSWR of Patch, Ring slot, DGS Slot-1, DGS Slot-2, DGS Slot-3 and Final Geometry

Defected Ground Structure (DGS) helps in enhancing the bandwidth and gain of the proposed antenna and also improved the performance. Fig. 2 shows the reflection coefficient of Cup-Shaped patch. The bandwidth at the frequency 4.28 GHz is ranging from 3.84 GHz to 5.18 GHz. The value of reflection coefficient S11 is -34.34 dB. Fig. 3 presents the total gain of the patch geometry. The gain at the frequency of 4.28 GHz is about 1.8123 dB. Fig. 4 shows the voltage standing wave ratio (VSWR) of a Cup-Shaped patch. From fig. it is seen that the value of VSWR is 0.333 which shows the good impedance matching. From fig. 5, it can be observed that the radiation efficiency of the geometry is about 1.148 dB. Fig. 6 shows the directivity of the base shape and its value is 1.32 dB at 4.28 GHz. Fig. 7 presents the reflection coefficient S11 of the final geometry with defected ground structure. The bandwidth at the resonant frequency of 5.66 GHz is ranging from 4.04 GHz to 6.6 GHz and the value of reflection coefficient is -28.252 dB. This results the enhancement of bandwidth. Fig. 8 shows the total gain of the proposed antenna with defected ground structure. The value of gain at 5.66 GHz is about 2.27 dB, which shows the enhancement of gain. Fig. 9 represents the voltage standing wave ratio (VSWR) of the proposed geometry. At resonant frequency, the value of VSWR is 0.6721 which shows the perfect impedance matching. Fig. 10 shows the comparison between the reflection coefficient S11 of Cup-Shaped patch, Ring slotted patch, DGS with single slot, DGS with double slots, DGS with triple slots and the proposed antenna. Fig. 11 shows the comparison between the gain of Cup-Shaped patch, Ring slotted patch, DGS with single slot, DGS with double slots, DGS with triple slots and the proposed antenna. Fig. 12 shows the comparison between the VSWR of Cup-Shaped patch, Ring slotted patch, DGS with single slot, DGS with double slots, DGS with triple slots and the proposed antenna.

The proposed antenna shows the enhancement in bandwidth and gain also the improved performance.

Table 2: Comparison of s11, Bandwidth, Gain and VSWR of the Antenna

S. No.	Geometry	Frequency (GHz)	S11 (dB)	Bandwidth GHz	Difference in BW (GHz)	Gain (dB)	VSWR (dB)
1	Cup-Shaped Patch	4.28	-34.34	3.84 to 5.18	1.34	1.8123	0.3333
2	Patch with Ring-slot	4.18	-33.57	3.80 to 4.94	1.14	1.8930	0.3638
3	Patch with single slot at ground plane	4.20	-31.79	3.80 to 4.96	1.16	1.5234	0.4468
4	Patch with double slots at ground plane	4.18	-33.73	3.80 to 4.92	1.12	1.5313	0.3572
5	Patch with triple slots at ground plane	4.32	-42.47	3.90 to 5.20	1.30	1.7600	0.1305
6	Final geometry	5.66	-28.25	4.04 to 6.60	2.56	2.2700	0.6721

Conclusion

A defected ground plane cup-shaped microstrip patch antenna for Sub-6 GHz 5G applications has been designed and presented in this paper. The antenna is simulated and optimized using HFSS (ANSYS- Electronic suite 19.2×64 version). A ring slot is provided at the patch, two rectangular slots and a cross signed slot at the ground plane. Defected ground structure provides enhanced bandwidth and gain. Due to DGS, it has significantly improved the performance of the proposed geometry. The antenna resonates at 5.66 GHz with a bandwidth ranging from 4.04 GHz to 6.60 GHz and is suitable for Sub-6 GHz 5G communications.

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