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Gain and Bandwidth Enhanced Optimized Notch Loaded Microstrip Antenna for 5G Applications

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Abstract: ***In this paper, a rectangular patch antenna is presented loaded with T-shaped notch as well as having truncated corner for the enhancement of gain and bandwidth which is bring into play for mid band of 5G applications. With design frequency of 3 GHz, this prototyped design antenna having 50 Ω microstrip line feed for impedance matching and simulation has been performed using IE3D Mentor Graphics simulation software. Fractional impedance 51.3% has been observed from 2.39 to 4.04 GHz. An enhanced peak gain of 5.05 dBi and maximum directivity of 6.214 dBi has been observed at 4.22 GHz and 4.34 GHz respectively.***

Keywords: Truncated Corner; Notch; Bandwidth; Resonance frequency; Return loss.

I. INTRODUCTION

Now a day, due to reaching the maturity and completion of development of fourth generation mobile communication, the engineer and researchers have more focus in the development of the fifth generation (5G) of mobile communication. Having their useful characteristics such as low profile, simple structure, light weight and easy fabrication, a microstrip patch antenna has been widely investigated. For the enrichment of gain, directivity and bandwidth, so many designs have been developed on these antennas. Due to above incredible features and for fifth generation (5G) mobile communication system, microstrip antenna is a good contender. The execution of 5G can be categorized in three bands which are as low-band (600 to 850 MHz), mid-band (2.3 to 4.7 GHz) and high band millimeter wave (24 to 40 GHz). For 5G services many countries promoted the range of frequency bands from 3 GHz to 5 GHz. USA uses frequency band ranges from 3.1 to 3.55 GHz and from 3.7 to 3.8 GHz where as in India the frequency band is ranges from 3.3 to 3.6 GHz and in Europe the frequency band is from 3.4 to 3.8 GHz [3]. For the development of bandwidth, directivity and gain of low profile microstrip antenna there are so many studies have been performed. By loading the slot and notch, shorting pin the impedance bandwidth, gain and directivity of antenna structure can also be improved [4]. By positioning above and horizontal to a metal reflector, the peak gain has been improved in dipole antenna having dumbbell shape [5]. The different parameters of proposed antenna by placing inverted T-shaped stub with three reverse U-shape stubs and using elliptical slot has been observed which shows healthier return loss having compact in size [6]. The enhancement of gain has been achieved by implementing frequency selection surface superstrate layer which may be used for wireless communication and imaging systems [7]. Using different profiles of fractal boundary, loading slots and using parasitic patch, the impedance bandwidth and antenna gain of radiating patch enhanced [8][9]. By implementing metamaterial array having epsilon very large behavior and by printing the H-shaped resonator structure in a plane, the gain and bandwidth enhancement of antenna observed [10][12]. A multiband antenna is designed and studied by loading the slot which may be of various shapes like inverted L-shape, U-shape, rectangular ring strip in addition to defected ground plane [13],[14]. By loading H-shape slot, stub loading and E-shaped in microstrip antenna, a bandwidth of 14% and 40% has been observed [16][17][18]. Although an improved impedance bandwidth of approx 45.5% has been observed by loading slot along feed line in patch antenna [19]. A triangular patch antenna also shows the enhanced gain and bandwidth irrespective to the square and rectangular patch, by loading the slot and notch [20]. In this article, a prototype antenna has been designed and simulated using Mentor Graphics IE3D simulation software tool. This prototype designed antenna is applicable for 5G wireless communication system. For variation in resonance frequency and enhancing the gain, directivity and impedance bandwidth, two truncated corner and multi-notched structure is loaded in microstrip patch antenna along with addition in size of ground plane taken place.

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II. DESCRIPTION OF THE DESIGNED ASPECT

The optimized geometry of proposed antenna designed on FR4 dielectric material whose dielectric constant is 4.4, height is of 1.6 mm with loss tangent of 0.01[1,2]. The length and width of the rectangular patch is 23.4 mm and 30.4 mm for design frequency of 3 GHz. For the calculation of the dimensions of rectangular patch the used formulas are given as follows. The width (W) of the design rectangular patch antenna is calculated as [1,2]

$$W = \frac{c}{2f}\sqrt{\frac{2}{\varepsilon_r + 1}} \quad 1)$$

Where c = speed of light, f = antenna design frequency, ε_r = dielectric constant

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The effective dielectric constant (ε_{re}) and extended patch length (ΔL) are calculated as

$$\varepsilon_{re} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-0.5} \quad (2)$$

$$\frac{\Delta L}{h} = 0.412\frac{(\varepsilon_{re} + 0.3)\left(\frac{W}{h} + 0.264\right)}{(\varepsilon_{re} - 0.258)\left(\frac{W}{h} + 0.8\right)} \quad (3)$$

Finally, patch length (L) is calculated as [1]

$$L = \frac{c}{2f\sqrt{\varepsilon_{re}}} - 2\Delta L \quad (4)$$

III. DESCRIPTION OF DESIGN MEASUREMENTS

For the proposed antenna design structure, the initial basic dimensions of the rectangular patch are 23.4 mm long and 30.4 mm wide having ground plane dimensions 33.4 mm long and 40.4 mm wide. A single port microstrip feed line with area of 5 × 3 mm2 has been used for impedance matching in simulation work which is done by using IE3D simulation software tool.

Table1: Design Measurements of Proposed Antenna Geometry

S. No.	Parameters	Value (mm)	S. No.	Parameters	Value (mm)
1.	A	23.4	5.	a	3
2.	B	30.4	6.	b	5
3.	C	33.4	7.	c	2
4.	D	54.4	8.	d	5

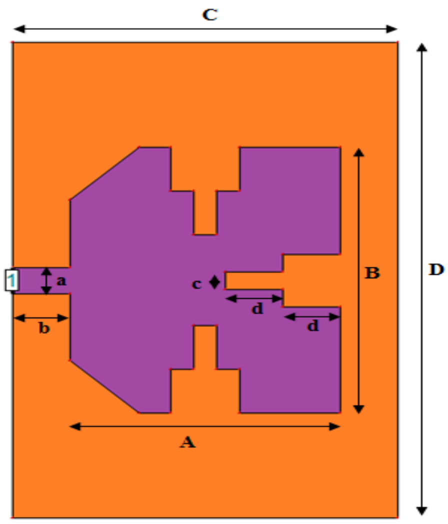
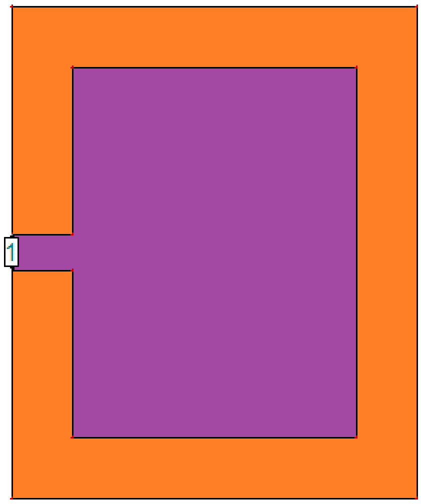


Figure 1. Optimized Geometry of Proposed Antenna

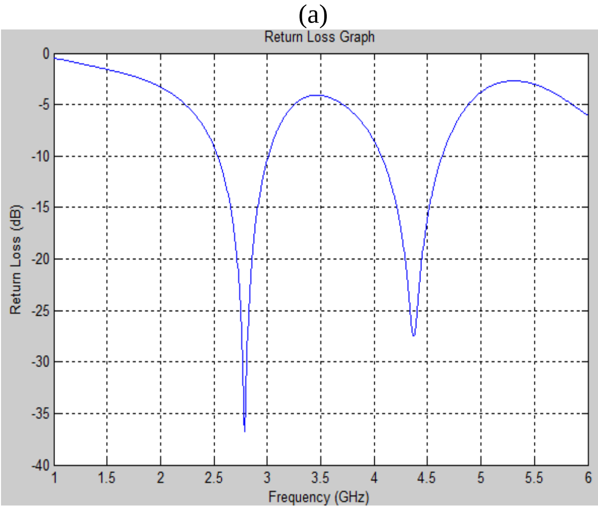
Figure 1 and Table 1 shows the optimized final geometry and design measurements of proposed antenna respectively.

IV. DISCUSSION OF SIMULATED RESULTS

IE3D simulation software tool has been employed to simulate the designed antenna structure. The primary formation and the simulated return loss graph of the fundamental patch antenna are shown in Figure 2.



(a)



(b)

Figure. 2 (a) Basic Structure of Patch antenna (b) Return Loss Graph of Basic Structure of Patch Antenna

From the Figure 2 (b) it has been observed that graph has dual band of frequency. The frequency range of 1st band is from 2.537 GHz to 3.007 GHz having bandwidth 16.96 % and 2nd band is from 4.068 GHz to 4.634 GHz having bandwidth 13 %. The resonance frequencies of 1st and 2nd bands are 2.787 GHz and 4.368 GHz containing return loss of -36.8 dB and -27.5 dB respectively. The simulated design of proposed antenna has been formed by loading the truncated corners at both corner of radiating edge having 6 mm dimension across length side and 6 mm dimension across width side, by increasing the width of the ground and by loading the T-shaped notch at the lower side, upper side and non-radiating side of the patch which is shown in Figure 1. Figure 3 show the return loss of both the patch antenna and proposed antenna against frequency combinedly. From figure it has been observed that proposed antenna graph has two resonance peaks in single broadband span having impedance bandwidth for S11 less -10 dB is from 2.391 GHz to 4.043 GHz with the relative bandwidth of 51.3 %. The resonance frequency of this single broadband span is 2.78 GHz and 3.76 GHz containing return loss of -23.38 and -29.65 respectively.

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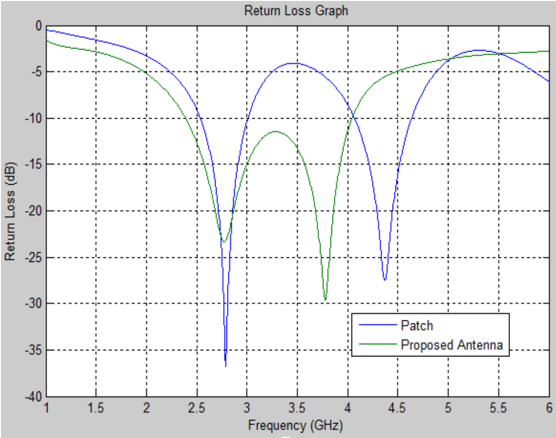

Figure. 3 Return Loss Graph of Patch and Proposed Antenna

The antenna gains of both patch and proposed antenna are shown in Figure 4. The peak gain of patch is 4.39 dBi at 4.42 GHz where as proposed antenna is 5.05 dBi at 4.22 GHz. So, the gain of the antenna has been enhanced by truncating and notch loading in patch. It is also observed that the gain of the proposed antenna at resonance frequency also varies in comparison to the normal patch antenna. The gain of the normal patch antenna is 3.39 dBi and 2.72 dBi at 2.78 GHz and 3.76 GHz resonance peak respectively where as gain of the proposed antenna is 2.57 dBi and 4.33 dBi at 2.78 GHz and 3.76 GHz resonance peak respectively.

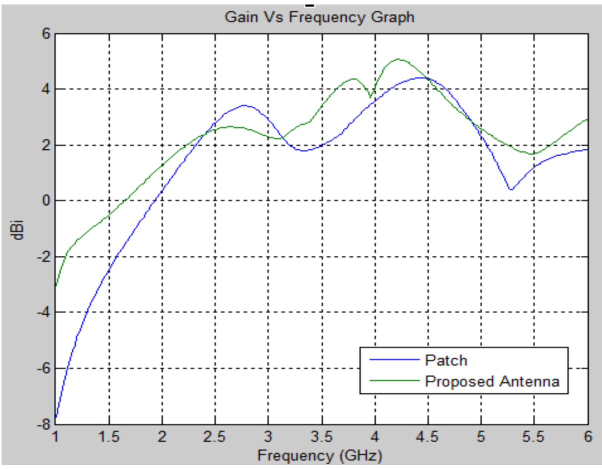

Figure. 4 Gain of Patch and Proposed Antenna

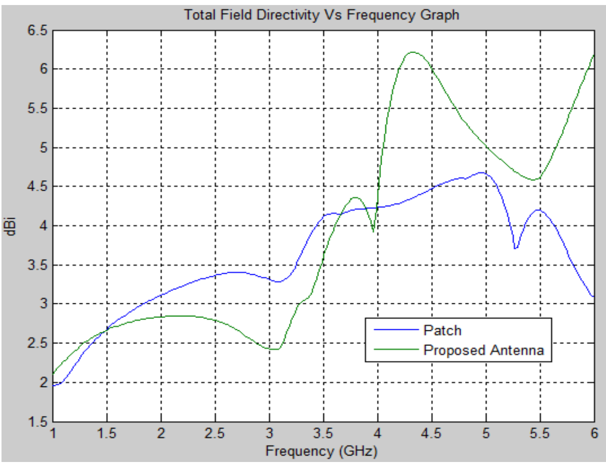

Figure. 5 Directivity of Patch and Proposed Antenna

The antenna directivity of both patch and proposed antenna are shown in Figure 5. The peak directivity of patch is 4.67 dBi at 4.97 GHz where as proposed antenna is 6.21 dBi at 4.34 GHz. So, the directivity of the antenna also enhanced by truncating and notch loading in patch. It is also observed that the directivity of the proposed antenna at resonance frequency also varies in comparison to the normal patch antenna. The directivity of the normal patch antenna is 3.39 dBi and 4.19 dBi at 2.78 GHz and 3.76 GHz resonance peak respectively where as directivity of the proposed antenna is 2.59 dBi and 4.33 dBi at 2.78 GHz and 3.76 GHz resonance peak respectively.

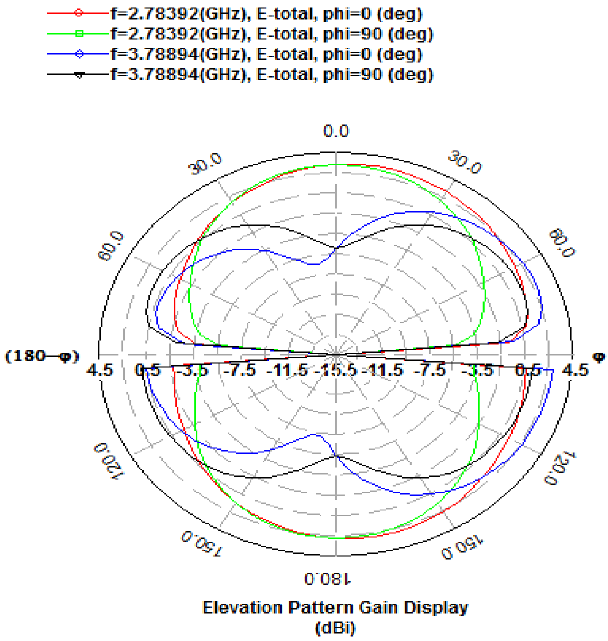

Figure. 6 Radiation Pattern of Patch

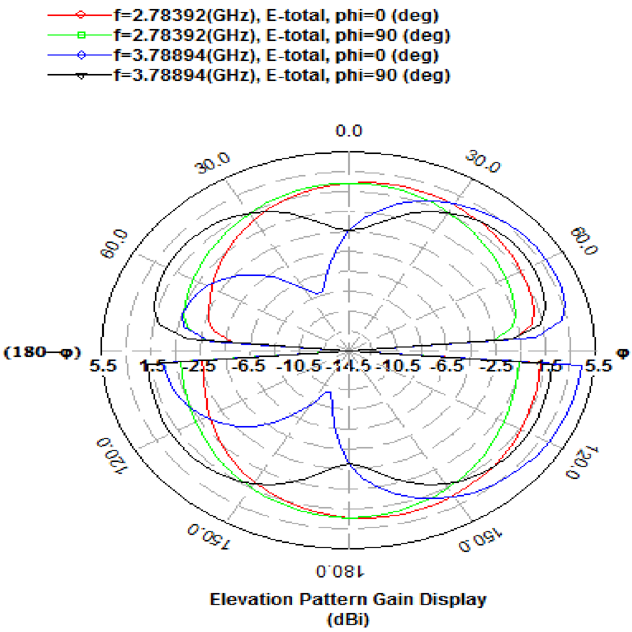

Figure. 7 Radiation Pattern of Proposed Antenna

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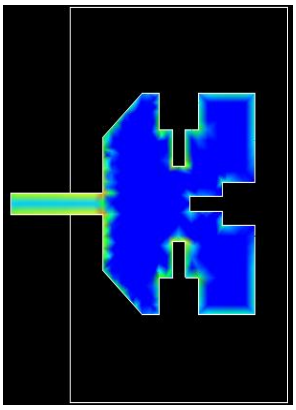
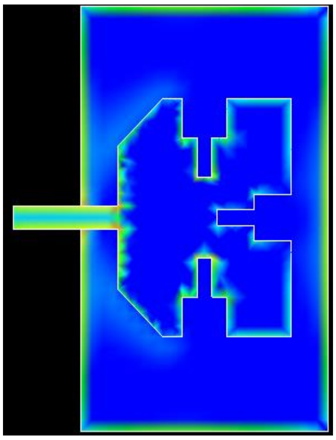


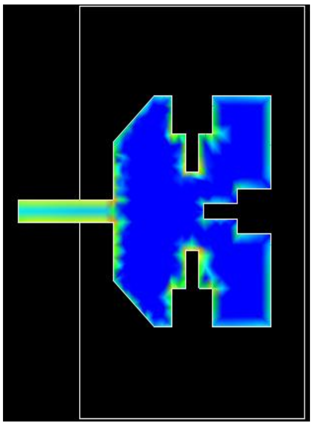
(a) E-current

(b) M-current

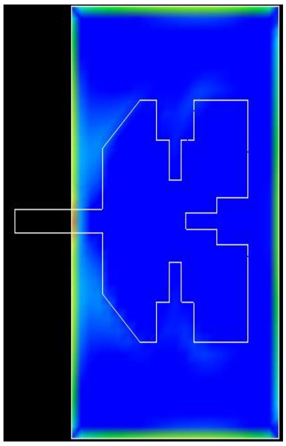


(c) Both E and M-current

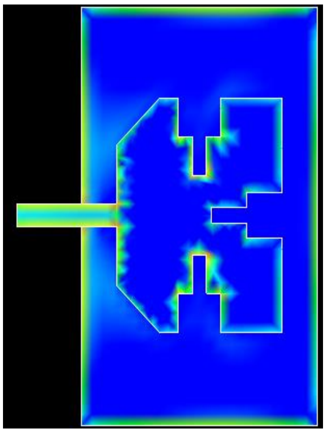
Figure.8. Current distribution plot of proposed antenna at 2.78 GHz resonance frequency



E-current



(b) M-current



(c) Both E and M-current

Figure.9. Current distribution plot of proposed antenna at 3.76 GHz resonance frequency

The 2D elevation radiation pattern of patch and proposed antenna for θ=0 degree and θ=90 degree at both resonance frequency 2.78 GHz and 3.76 GHz are shown in Figure 6 and Figure 7 respectively. It has been also observed that for both the antennas, the radiation patterns are bidirectional.

The different current distribution plots of proposed antenna at 2.78 GHz resonance frequency and at 3.76 GHz resonance frequency are shown in Figure 8 and Figure 9 respectively. The maximum value of E-current due to electric field and M-current due to magnetic field at 2.78 GHz resonance frequency is 1647.86 A/m and 97600.2 V/m respectively whereas the maximum value of E-current and M-current at 3.76 GHz frequency is 1583.39 A/m and 105137 V/m respectively.

V. CONCLUSION

For 5G application, truncated corner and T-shaped notch loaded low-profile and broadband patch antenna has been proposed and simulated with 50 Ω microstrip line feed. By loading two truncated corners as well as three T-shaped notch this proposed antenna has been designed getting improved gain, directivity and bandwidth from simple rectangular patch.

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The proposed design has augmented bandwidth of 51.3% (2.391 GHz – 4.043 GHz) as well as augmented peak gain of 5.05 dBi and improved maximum directivity of 6.214 dBi at 4.22 GHz and 4.34 GHz frequency respectively which shows a noteworthy result and covering mid band of the 5G frequency bands between 3 GHz and 5 GHz. For the 5G wireless communication systems this proposed antenna can be useful.

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