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On the Design of Novel Trident Shaped Triple Wideband Antenna for Wireless 5G Applications

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Abstract

This paper presents compact design of novel modified trident shaped 5G antenna for triple band operation. The key point of antenna design methodology is to increase the electrical length of antenna by defection in antenna patch in the form of three radiating tooth. The radiating patch tooth allows the excited surface current to flow along its periphery and at its center. This increases the electrical length of the antenna, which decreases lower edge frequency of operating band. The magnetic coupling developed between ground slot of plane and radiating patch generates multiple resonant frequency modes, which are merged to give rise enhanced bandwidth. The rejection filters embedded in the antenna geometry play important role in splitting the fractional wide bandwidth of 150 % into triple band operation by rejecting two frequency band centered at 3.5 GHz and 5.2 GHz. The triple band operation achieved impedance bandwidth of 1.07 GHz (2.39 GHz-3.46 GHz), 1.06 GHz (4.11 GHz-5.17 GHz), and 9.7 GHz (5.30 GHz-15 GHz), exhibiting fractional bandwidth of 36.58 %, 22.84 % and 95.57 % respectively. The antenna exhibits a peak gain of 9.32 dB. The proposed antenna is suitable for 5G applications, covering the sub 6 GHz (n77, n78), sub 7 GHz (n96) bands, and broadband communication.

Keywords: Trident Shape; Compact; Rejection Frequency; Slot; Surface Current Distribution; 5G.

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1. Introduction

Recent development in wireless 5G network system have shown its competence and requirement because of its merits such as good signal propagation, maximum data rate and high channel capacity. Future 5G services must be supported by high reliability, good service quality to satisfy the end user needs. In this regard wireless devices must be compact and miniaturized, which indirectly puts limit to dimensions of wideband antennas. The wireless communication industries are taking advantage of commercially available wideband spectrum of 7.5 GHz [1-4] for its use in 5G wireless application. This wideband spectrum covers 5G new radio bands.

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The 5G new radio band includes the frequency bands such as n77 (3.3 GHz- 4.2 GHz), n78 (3.3 GHz to 3.8 GHz) and n79 (4.6 GHz to 5.0 GHz) for sub 6 GHz 5G applications [5]. The n96 sub 7 GHz band covers frequencies from 5.9 GHz to 7.1 GHz [6]. The inherent resonant property of defected ground represents its equivalent circuit in the form of shunt circuit of capacitor and inductor.

The defected structures embedded in the ground plane of antenna increases its bandwidth [7]. The electrical length generated in ground plane due to defected structures results in maximum accumulation of the current on its edge.

The increased electrical length shifts the resonant frequency to the lower side indicating miniaturization of the antenna. Antenna design with defection in ground planes has been reported with size reduction, along with minimum cross polarization [8]. The use of defected ground plane in large size planar antennas design supports bandwidth enhancement [9-13]. A flower bud shaped ultra-wideband antenna [14] has been reported with fractional bandwidth of 125.17 % and peak gain of 5.24 dB. A triple band compact ultra-wideband (UWB) antenna [15] with peak gain of 3.9 dB is presented. It is observed that past reported antenna design uses overall large dimensions. Also antenna gain is not adequately enhanced; though the antennas design use compact structures. The peak gain of these antennas is moderate and not considerable for high data rate wireless application.

A small size four element multiple input multiple output antenna of dimension 50 mm × 25 mm has been designed for ultra-wideband applications with WLAN notch-band characteristics [16]. The design of CPW fed elliptical flexible UWB antenna with triple frequency notches using split ring resonator techniques is described elsewhere [17]. The antenna design reports large substrate dimension of 45 mm × 35 mm and gain of 5.40 dB. Multifunctional wideband antenna with reconfigurable characteristics of large dimension 51 mm × 56 mm and gain of 3 dB – 6 dB across wideband resonant frequencies has been discussed [18]. Furthermore, the design of planar UWB monopole antenna has been documented in the literature [19] with two tuned notch bands and gain of 4.93 dB. The Y shaped radiating patch triple band UWB antenna design is demonstrated for 5G wireless applications [20]. These antennas geometrical structures are complex and possess large physical dimensions, which will not suite for 5G applications.

The miniaturization of antennas is a critical requirement for successful onsite deployment. The high frequency resonance across wideband is generally represented by multiple series connection of shunt R-L-C circuit [21] cell. The decrease in lower edge of wideband due to increase in electrical length of antenna indicates its miniaturization, though there is no physical change in overall dimension of antenna [22]. The antenna with large size and of elliptical shape radiating patch [25] is simulated and analysed for UWB wireless application. As demonstrated [26], the 3G and 4G antenna design show use of dual rectangular ring radiating patch and defected ground structures. The several studies, for instance [27-29], have demonstrated that parasitic and defected structures designed at quarter and half wavelength act as notch filter to reject single or multiple frequencies in the WLAN band. The notch filter embedded at the feed line shows overall increase in antenna dimensions. Hua *et al.* [30] showed design of reconfigurable notch band using external variable DC voltage to make antenna circuit complex. The complicated notch filter circuit of shape omega and T-shape EBG structure [31] using via makes antenna design to tune precisely. Extending similar concepts, triple notch band UWB antenna of dimension 35.4 mm × 28.82 mm is proposed by Chakraborty *et al*. [32] with three frequency band notches. The design presented by Ramineni [33], featured a microstrip patch antenna with a size of 34 mm × 34 mm. However, this dimension appears unusually large for millimetre wave applications, where smaller elements are standard for achieving higher frequencies and compactness.

The drawbacks of past reported methods are design specific approach and complex frequency notch filter structures. From the past reported literature, it is observed that antennas possess large physical size, complex antenna geometry, and moderate radiation peak gain. Also the selection of geometry shape of filter structures and their location in antennas geometry are responsible to increase the size of antenna. These identified gaps from past research survey motivates to design a compact antenna for wireless 5G application. Hence for 5G wireless application it is desirable to have an antenna design with compact size, multi wideband operation and high gain. There is no major change in overall dimensions of the antenna with miniaturization. Hence it is important to design an antenna with compact size rather its miniaturization. These desired characteristics of 5G antenna is fulfilled by proposed trident shaped antenna design presented in this paper.

In this paper the compact antenna design using novel modified trident shape radiating patch is presented for enhancement in bandwidth and gain. The shape of radiating patch is designed in such a way that, the current will flow along periphery of radiating patch as well as at its centre, which will increase in electrical length of the antenna. The proposed antenna design with oval slot defection in the ground plane develops magnetic coupling between slotted ground plane and radiating patch. The proposed antenna design is discussed with step wise evolution radiating patch for fractional bandwidth more than 150 %. Furthermore, the wide bandwidth is split in to triple band using defection in ground plane and radiating patch. Each band generated possesses the bandwidth more than 1 GHz. The detail results and analysis of proposed antenna is presented with study of its electrical characteristics and its 5G applications. The design of the antenna is simulated using CST Microwave Studio and is tested on vector network analyzer.

2. Materials and Methods

The methodology steps adopted for designing the proposed antenna are stated as follows. To set the target specifications of proposed antenna, selection of antenna parameters, comparison of optimized parameters with desired specification, reinitiate parameter optimization process for more accuracy, set the final structural geometry dimensions of antenna, fabrication of the proposed antenna and last step is the measurement of electrical characteristics of antenna using vector network analyzer. The target specifications include antenna substrate thickness and dielectric constant, antenna size, bandwidth more than 1 GHz and high gain. The reflection coefficient, voltage standing wave ratio, resonant frequency, and bandwidth are the parameters selected for antenna optimization. The CAD software is used to prepare the final layout artwork of antenna based on optimized parameters for its fabrication. The CAD file is used to prepare the positive photo film of antenna geometry. The films are exposed on FR4 substrate using lithographic itching process. The proposed 5G triple band antenna gives more than 1 GHz bandwidth for each band and peak gain of 9.2 dBi. The antenna possesses small size of 32 mm × 28 mm, which will be easily accommodated in wireless devices.

3. Design of Novel Trident Shape 5G Antenna

The proposed 5G antenna design followed two design processes. Firstly, the evolution of a novel trident shaped wideband antenna and second development of triple band 5G antenna with defection in ground plane using slit and slot structures.

3.1. *Evolution of wideband antenna*

Antenna design incorporates a novel modified trident shaped radiating patch, which is printed on upper conducting surface of FR4 substrate while ground plane is itched on bottom surface of substrate. The FR4 substrate is characterized by a thickness of 1.6 mm, dielectric constant of 4.4 and tangent loss of 0.02. The width, length and height dimension of proposed antenna is 32 mm × 28 mm ×1.6 mm. The ground plane is made defective by an itching of oval shaped slot. The modified trident shaped radiating patch is excited by a microstrip feed line on the top plane of substrate. To achieve impedance matching over the entire wideband, the dimensions of feed length, trident shaped radiating patch and slot are optimized. Fig. 1 illustrates the evolution stages of wideband modified trident shaped antenna. Antenna 1 has half disc shaped radiating patch. The effective radius of half circular disc is calculated using Eq. (1).

$$a_{eff} = a\{1 + \frac{2h}{\pi a \varepsilon_r}[\ln\left(\frac{\pi a}{2h}\right) + 1.7726]\}^{\frac{1}{2}}, \quad (1)$$

where, a is radius of patch, h is thickness of substrate=1.6 mm, εr is dielectric constant =4.4, f_r is the resonating frequency, which is considered as 2.1 GHz and a is given by Eq. (2)

$$a = \frac{F}{\left\{1+\frac{2h}{\pi F \varepsilon_r}\left[\ln\left(\frac{\pi F}{2h}\right)+1.7726\right]\right\}^{\frac{1}{2}}}, \quad (2)$$

where, F is correction factor which is given by Eq. (3)

$$F = \frac{(8.791 \times 10^9)}{(fr \times \varepsilon_r)}. \quad (3)$$

Antenna 2 is a combination of half circular disc and left side vertical rectangular tooth structure. Antenna 3 is a Y shaped antenna formed by two vertical rectangular teeth mounted on half disc radiating patch. The Antenna 4 is a novel modified trident shaped wideband antenna, which is evolved by embedding short rectangular tooth in between two vertical tooth of Antenna 3. The two teeth located on both side of middle tooth are identical in length L_1 and width W_1. The dimensions of middle short tooth are L_2 and W_2.

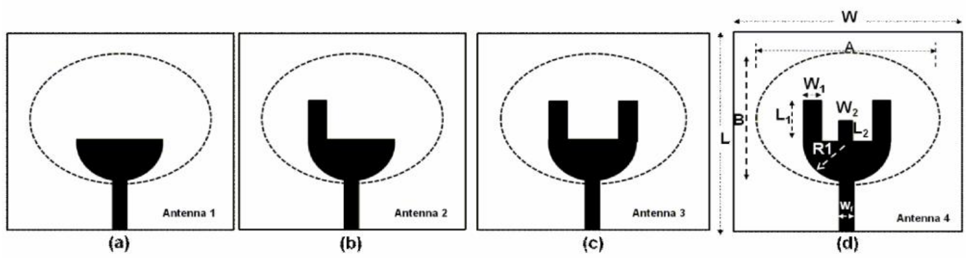


Fig. 1. Evolution of the novel modified trident shaped antenna.

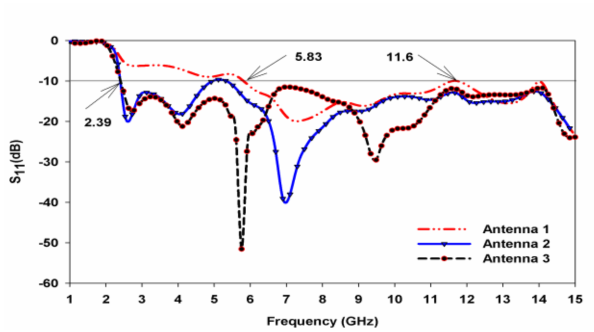


Fig. 2. Reflection coefficient comparisons of Antenna 1, Antenna 2, and Antenna 3.

Fig. 2 depicts the reflection coefficient S_{11} of first three evolution stages of modified trident shaped antenna. The impedance bandwidth of half disc radiating patch antenna is 5.77 GHz ranging from 5.83 GHz to 11.6 GHz. The electrical length of Antenna 2 increases due to change in geometry structure. The increase in electrical length supports improvement in bandwidth by shifting lower edge frequency from 5.83 GHz to 2.39 GHz. The reflection coefficient of Antenna 2 shows a dual wideband operation with resonance at 4 GHz and 6.97 GHz. Antenna 2 can be used for applications in 5G new radio sub bands of n77 and n 79 bands. The major axis A of oval slot in ground plane and dimensions of teeth of radiating patch are optimized for evolution of Antenna 3 and Antenna 4. The modified trident shaped wideband Antenna 4 shows bandwidth enhancement due to the overlapping of multiple resonant modes, which are generated due to magnetic coupling between ground slots and radiating patch. The coupling gap 'g' between oval slot and radiating patch is optimized for 0.3 mm to have 50-ohm impedance matching. Bandwidth enhancement is derived by improving electromagnetic coupling between the oval shaped slot and radiating patch. The empirical equation to determine the lower edge frequency [13,23-28] of enhanced bandwidth of proposed antenna is given by Eq. (4).

$$f_{Lower\ edge} = \frac{30\times 0.32}{(L+r)\times k}. \quad (4)$$

The effective radius r of an equivalent cylindrical monopole and its length L, decides the lower edge frequency of wideband. The length L is given by Eq. (5).

$$2\pi r L = \pi \frac{A\times B}{4}, \quad (5)$$

where, k = 1.15 for the substrate dielectric constant of $\varepsilon_r = 4.4$ [28] and the element factor for the oval slot is 0.32 [13]. The calculated lower edge frequency using Eq. (1) is 2.378 GHz, which is close to an optimized value of 2.39 GHz. Fig. 3 exhibits comparison of simulated and measured reflection coefficient of Antenna 4. It is observed that the physical size of the novel modified trident shaped antenna is compact. The antenna 4 improves the -10 dB return loss in the vicinity of 5.8 GHz and 9.3 GHz. The recorded fractional bandwidth is more than 150 %. The broadside peak gain across the operating band is 7.4 dB. The measured and simulated optimized results of trident shaped wide band antenna are in good agreement and satisfactory. The overall performance of novel modified trident shaped wideband antenna is summarized in Table 1.

Table 1. Comparison of antennas performance.

Parameter	Antenna1	Antenna 2	Antenna 3	Antenna 4
Number of bands	One	Two	One	One
Impedance bandwidth	5.77 GHz (5.83-1.6GHz)	12.61 GHz (2.39-15 GHz)	12.61 GHz (2.39-15 GHz)	12.61 GHz (2.39-15 GHz)
Resonant frequency (GHz)	7.3 GHz	4 GHz 6.97 GHz	5.9 GHz 9.2 GHz	5.8 GHz 9.3 GHz
Return loss (dB)	-19 dB	-17 dB -39 dB	-52 dB -28 dB	-52 dB -45 dB
Gain (dB)	----	-----	7.4 dB	7.4dB

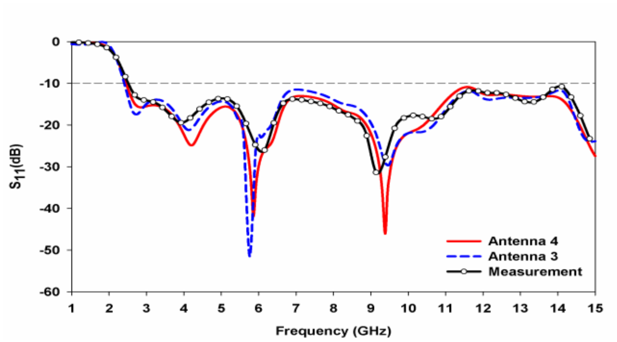
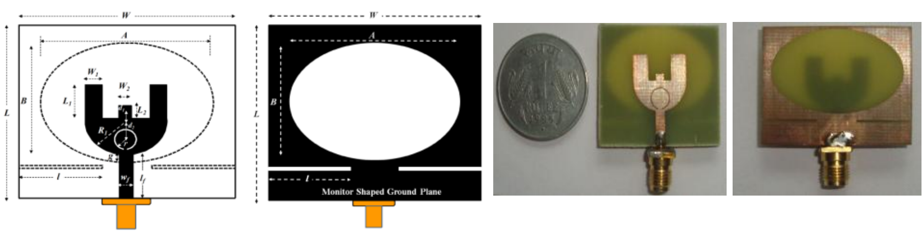


Fig. 3. Simulated and measured reflection coefficient of Antenna 3 and Antenna 4.



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

Fig. 4. The structural geometry of proposed 5G antenna (a) Top side (b) Bottom side (c) and (d) Fabricated antenna.

3.2. *Development of triple wideband 5G antenna*

The proposed novel modified trident shaped triple band 5G antenna is extended version of antenna 4 with itching the slit and slot in antenna geometry. Fig. 4a-b illustrate the structure of proposed antenna showing compact dimension of 32 mm × 28 mm. The two slits of length l = 13 mm each are itched in the ground plane on both sides of feed line. The length l is calculated at wavelength of $\lambda_g/4$ of the center of notch rejection frequency, 3.5 GHz. The λ_g is the guided wavelength and is stated as $\lambda_g = \lambda_0 / \sqrt{\varepsilon_{eff}}$, where ε_{eff} is given as $\varepsilon_{eff} = (\varepsilon_r+1)/2$ and λ_0 is the free space wavelength. A half circular C–shaped slot of circumference dimension 14.42 mm is itched below the middle short tooth in upper radiating plane. It is designed at a wavelength of $\lambda_g/4$ of the center of notch rejection frequency, 5.2 GHz. The defection made in ground plane and radiating patch using slit pair and slot respectively act as band rejection filters. These filters structures reduce antenna gain at 3.5 GHz and 5.2 GHz rejected frequencies across operating wideband. This results in triple band operation. The antennas geometrical parameters are simulated and optimized using high performance 3D electromagnetic analysis CST studio suite software. The optimized dimensions of the proposed novel modified trident shaped triple band 5G antennas are tabulated in Table 2. The proposed antenna is fabricated using FR4 substrate with optimized dimensions. The fabricated triple band antenna is shown in Fig. 4c. The equivalent circuit of the proposed antenna is shown in Fig. 5. The L_f and C_f are the feed inductance and feed capacitance respectively. The radiating patch can be modeled as series connection of R-L-C shunt resonating cells. The R-L-C cell represents R_n, L_n, and C_n respectively.

Table 2. Optimal dimentions of the proposed triple band 5G antenna.

Parameter	W	L	W_1	W_2	L_1	L_2	L
Unit mm	28	32	4	2	6	1.5	13
Parameter	A	B	G	W_f	R_1	l_f	R
Unit mm)	32	22.4	0.30	2.4	7	8.1	2

All R-L-C shunt resonating cells are connected in series with L_f and C_f. The oval slot possesses inductance L_o, capacitance C_o and ground plane resistance R_o. To form the equivalent resonance circuit of proposed antenna, the resonance cell R_o-L_o-C_o is assumed to be parallel with resonance cell formed by R_n, L_n, and C_n as shown in Fig. 5. The magnetic field generated on the circumference of oval slot in the ground plane produces resonance at multiple modes to have maximum radiation in the broadside direction. At resonance frequencies the maximum current will flow around the edges of modified trident radiating patch, which will result in an increase in length of the current path and hence electrical length of antenna. At resonant frequency, the maximum current density is observed along the edge of radiating patch. While at rejection band frequency, the maximum current density is found at defective structures in antenna geometry. Due to less excitation of patch at rejection frequencies, results in antenna negative gain. The resonant frequencies excited by both radiator and slotted ground plane overlap each other, which results in triple band operation.

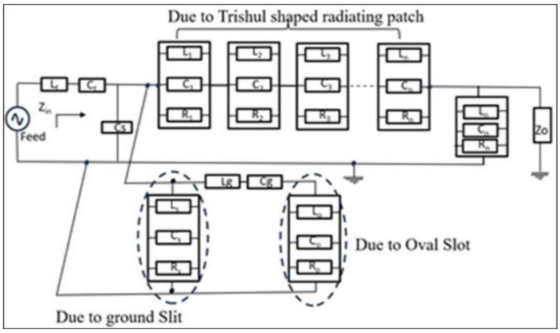


Fig. 5. Equivalent circuit of the proposed 5G antenna.

4. Results and Discussion

The proposed antenna with only slit notch filter demonstrates the rejection of 3.5 GHz frequency using VSWR characteristics as shown in Fig. 6. The slit length samples are selected with 0.1 mm variation. The second notch filter frequency is proposed from 802.11a WLAN band centered at 5.2 GHz. It is obtained by itching a slot of half circular C–shape in the radiating patch with width of 0.202 mm and circumference length 14.42 mm. The inner radius of half circular C–shape slot is indicated by *r*. Fig. 7 demonstrates VSWR characteristics of proposed antenna with two notch filters. It is observed that by tuning *r,* the rejection band travels from higher frequency to 5.2 GHz. The optimized value of radius *r* is 2mm.The comparative study of optimized and measured results of proposed antenna with reference to reflection coefficient is presented in Fig. 8. Thus, by using C shaped slot and pair of slit, two bands are rejected centered at 3.5 GHz and 5.2 GHz to avoid interference of WLAN. These two rejection bands across operating bandwidth develop three operating bands. The impedance bandwidth of first band is 1.07 GHz ranging from 2.39 GHz to 3.46 GHz, that of the second band is 1.06 GHz ranging from 4.11 GHz to 5.17 GHz, and the impedance bandwidth of third band is more than 9 GHz starting from 5.30 GHz. These three bands show fractional bandwidth of 36.58 %, 22.84 % and 95.57 % respectively. As lower edge of wideband frequency travels towards lower side, it indicates antenna miniaturization. The miniaturization of the antenna is mainly due to the modulation in electrical length of antenna. The electrical length of the antenna is increased by the novel trident shape of radiating patch. The increased electrical length allows the maximum current to flow around periphery and center of patch. Thus with reference to the physical ground plane dimension, the antenna miniaturization has been achieved.

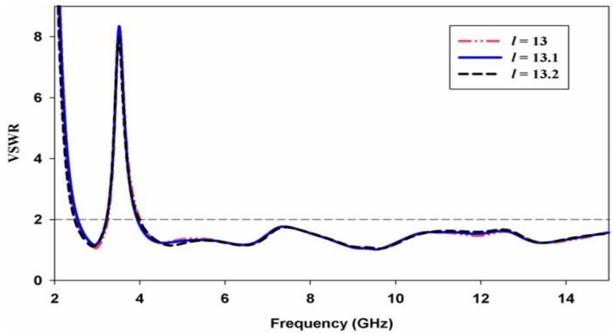


Fig. 6. VSWR with variation in slit length *l*.

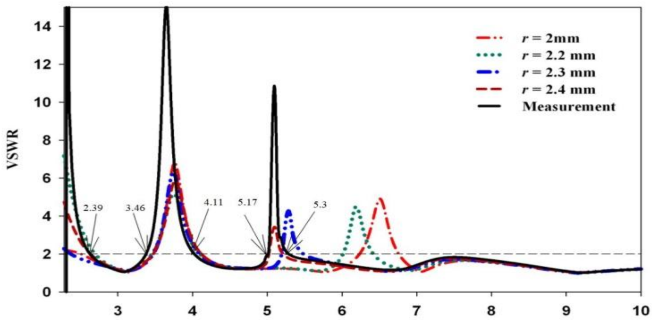


Fig. 7. Measured and optimized VSWR of proposed 5G antenna.

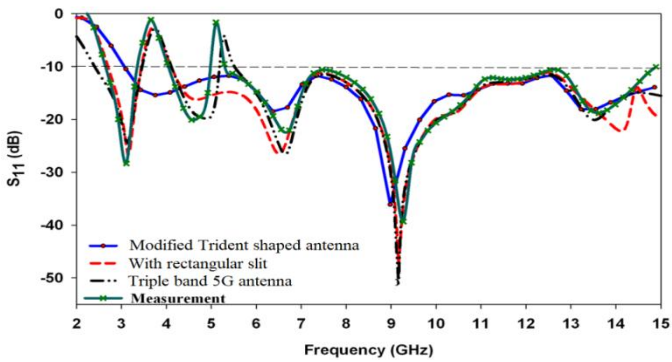
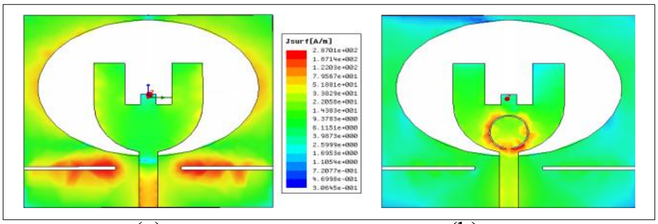


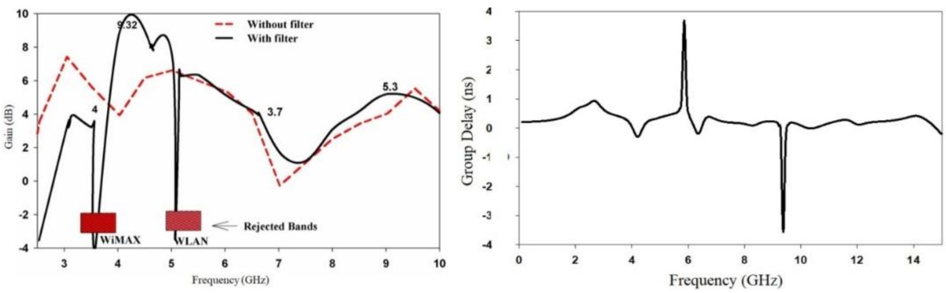
Fig. 8. Comparison of simulated and measured S_{11} of proposed 5G antenna.

The maximum current is concentrated on feed line and edges of radiating patch and oval slot, indicates maximum energy radiation with good impedance match. Fig. 9a-b shows surface current distribution at two selected rejection frequencies 3.5 GHz and 5.2 GHz respectively. It is observed that at 3.5 GHz, the concentration of current density is more along the slit area in the ground plane, while at 5.2 GHz it is found around half circular C-shaped slot. It indicates the functioning of two notch bands at these two frequencies. The three operating bands generated have fractional bandwidth of more than 20 %, indicating wideband characteristics. The proposed antenna can be used for domestic wireless communication, 5G new radio band and wireless mobile applications. The wide bandwidth indicates more channel capacity and hence more data rate transfer. This high data rate fulfils the requirement of 5G wireless application. Fig. 10a shows the comparison of the simulated and measured gain of the proposed 5G triple band antenna. The peak gain of 9.2 dB is noted at sub 6 GHz 5G new radio band ranging from 4.11 GHz to 5.17 GHz. The bandwidth and gain of proposed 5G antenna is enhanced in comparison with past reported antennas [17,20,21,29-31].



(a) (b)

Fig. 9. Surface current distribution (a) at 3.5 (b) 5.2 GHz.



(a) (b)

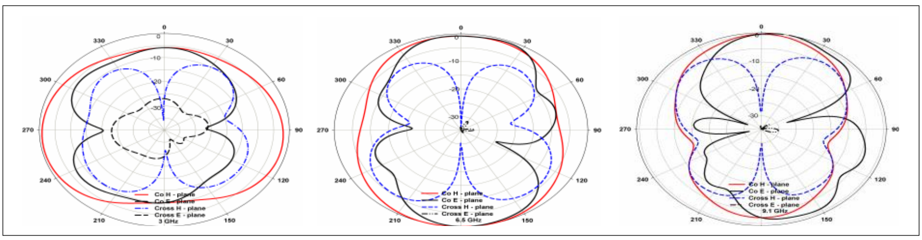
Fig. 10. (a) Comparison of the measured and simulated gain (b) Group delay of 5G antenna.

Fig. 10b shows group delay of the proposed 5G antenna. It is observed that the variation in group delay does not exceed 1ns limit across the operating wideband, whereas it exceeds above 3ns at rejected bands. The nonlinear phase and pulse distortion is observed at rejected frequencies. The radiation pattern in E-plane and H-plane at 3 GHz, 6.5 GHz and 9.1 GHz is as shown in Fig. 11. The radiation pattern at lower frequencies in E plane is of eight shape, while it is omnidirectional in H plane. At higher frequencies minor lobes are observed in E plane.

Table 3 summaries the performance of the proposed triple band 5G antenna in comparison with past reported antennas with respect to the reflection coefficient S_{11}, bandwidth, antennas dimension and peak gain.

Table 3. Comparison of proposed work with past reported antennas.

Reference	Structure Technique Used	Substrate Material type, ε_r, thickness (mm)	Antenna Size mm^2, and Full bandwidth (GHz)	No.of eso. and	10 dB Impe. B.W.	Peak Gain (dB)
[16]	Rectangular patch with DGS	FR4, 4.4, 1.6 mm	18 × 18, 3.1-10.6 GHz	3	100 MHz 4.4 GHz 2.2 GHz	3.9
[17]	UWB MMC	FR4, 4.5, 1.6 mm	50×25, 2.1-12 GHz	2	2.9 GHz 5.6 GHz	5.8
[20]	Y-shaped tri-band rectangular slot DGS antenna	FR4, 4.4, 1.5 mm	50.50 × 41.12	3	356 MHz 443 MHz 287 MHz	2.69 7.27 11.37
[21]	Tunable parasitic strip	RT/DUROID 5880, 2.2, 0.762 mm	36 × 30, 2-14 GHz	3	1.15 GHz 1.24 GHz 8.41 GHz	4.59
[29]	U-shaped slot and bandgap structure	RT/DUROID 5880, 2.2, 1.6 mm	36 × 33, 3.1-10.6 GHz	3	0.7 GHz 0.75 GHz 1.96 GHz	4.93
[30]	Heart shaped planar monopole	RT/DUROID 5880, 2.2, 0.508 mm	42×30, 2.8-11.9 GHz	2	1.6 GHz 6.5 GHz	4.2
[31]	Wrench-shaped patch	FR4, 4.4, 1.2 mm	40×32, 3.04-11.4 GHz	3	2.11 GHz 370 MHz 5.53 GHz	6.2
[32]	Triple notch UWB antenna	FR4, 4.4, 1.57 mm	35.4 × 28.82, 3.0-11.2 GHz	3	0.4 GHz 0.7 GHz 0.7 GHz	-
Proposed Work	Modified trident shaped triple band 5G antenna	FR4, 4.4, 1.6 mm	28 × 32, 2.39 to more than 15 GHz	3	1.07 GHz 1.06 GHz 9.7 GHz	7.4 4.0 9.32



(a) (b) (c)

Fig. 11. Radiation pattern of proposed 5G antenna in E and H plane (a) at 3 GHz (b) at 6.5 GHz (c) at 9.1 GHz.

5. Conclusion

The design and experimental work of novel modified trident shaped triple band 5G antenna is presented in detail with illustrations of reflection coefficient, voltage standing wave ratio, peak gain, group delay, and radiation pattern. The presented results of proposed antenna in comparison with previous studies, shows its good candidature for wireless 5G applications.

The designed 5G antenna shows reduction insize, enhancement in bandwidth, gain and less distortion across the operating band in comparison with past reported antennas. The 5G antenna design is suitable for wireless communication applications such as sub 6 GHz (n77), (n78), sub 7 GHz (n96) bands of 5G new radio and satellite communication. The fractional bandwidth of 150 % is achieved by merger of multiple resonant modes across the wideband. The embedded filter structures in antenna design rejects interference of WiMAX and 802.11 WLAN bands. The gain at rejected bands is below -3.5dB. Thus the use of defective filter structures in antenna geometry results in triple band operation. The enhanced impedance bandwidth of three operational bands is 1.07 GHz (2.39 GHz to 3.46 GHz), 1.06 GHz (4.11 GHz to 5.17 GHz), and 9.7 GHz (5.30 GHz to 15 GHz). The corresponding fractional bandwidth of triple band is 36.58 %, 22.84 % and 95.57 % respectively. The designed antenna reports peak gain of 9.32 dB. The simulated and measured results are in good agreement. The First two operating bands can be used for sub 6 GHz of 5G new radio bands while third band can be used for sub 7 GHz band of 5G new radio and satellite communication. Thus proposed antenna is suitable for 5G networks with high speed data including enhanced mobile broadband, industry 4.0 automation and autonomous vehicles. The antenna size can be further minimised for millimetre wave applications. The bandwidth of proposed antenna can be extended up to 24.5 GHz using band gap structures for ultra-high speed and low latencies wireless applications.

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