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S-Shaped Slotted Multiband High Frequency UWB Antenna for 5G Applications

Research Article

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Abstract: This work introduces two UWB antennas for 5G applications (one single band and one dual band antennas). The proposed antennas are used Rogers RT 5880 as substrate materials, which dielectric constant (ε) of 2.2. The width, length and height of the designed antennas are 7.7 mm, 7.9 mm and 0.254 mm respectively. The projected single and dual band antenna prototypes are comprised of a simple line structure patch and a rectangular ground. An S-shaped slot is added on the patch of second antenna to achieve dual band characteristics and to achieve the enhanced performance. The single band antenna works within the range of frequency bandwidth from 27.67GHz to 28.33GHz, whereas the dual band is operated from 27.02GHz to 27.52GHz and 36.14GHz to 36.71GHz respectively under the return loss of -10dB scale. The operating bandwidth covers the higher band 5G communication band. The proposed designs obtained 7.9 dBi gain and radiation efficiency is observed more than 90% which is better than recently published antenna. The designs offer omnidirectional radiation patterns for cross-polarization with 90° directivity.

Keywords: *5G • Antenna • UWB • Wireless Communication • Multiband Antenna*

1. Introduction

Globally, the wireless communication industry is expanding rapidly. With this growth the demand of high-performance antennas is also increasing exponentially. To achieve the super speedy transmission rate as well as higher channel capability is fully met by the fifth generation (5G) communication systems (Li *et al.*, 2014). It will be the base of new technologies such as driverless cars, artificial intelligence-oriented healthcare systems or smart cities and smart homes (Campolo *et al.*, 2017; Toma *et al.*, 2019). Due to some exclusive features including higher data rate, lower cost and stable multipath fading, UWB is the most suitable candidate for 5G applications. UWB antennas are highly instrumental compared to other kinds of antennas for data throughput.

A variety of UWB antennas for the 5G application have been already proposed. A 28 GHz high-band antenna is presented in (Hong *et al.*, 2014) for the 5G cellular system. In order to create the beam steering towards the direction of the azimuth, a sixteen-element array is eventually arranged. In (Lai and Wong, 2014), a magneto-electric (ME) dipole antenna was designed with an H shaped tapered ground plane. The prototype was intended for fifth generation wireless fidelity (Wi-Fi) applications. Assuming moderate performance, the proposed antenna provides operating bandwidth from 4.98 GHz to 6.01GHz. For the 5G application, a multiple-input-multiple-output (MIMO) antenna is suggested for the 3.4 GHz to 3.6 GHz frequency range (Bian and Chu, 2019). With return loss of less than -15

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dB, the self-coupling mechanism is introduced. For the next generation 5G smart phones, an ultrawideband (UWB) inverted F antenna is offered in (Chen and Chu, 2019). The proposed antenna is equipped with three resonant modes, using meander line feed. For the range of 3.27 to 6.13 GHz frequency, the impedance bandwidth of -6dB is obtained.UWB antennas should usually be electronically compact and inexpensive for wide variety of applications while retaining suitable wideband performance. Therefore, one of the key challenges of developing UWB antennas is to achieve higher bandwidth, efficiency and low profile in the smaller dimensions. By adjusting the shape of the radiating patch, UWB antenna characteristics can be improved. The patch can be rectangular, oval, elliptical, heart-shaped, etc. By modifying the ground structure (Sharma and Shrivastava, 2008; Shaalan and Ramadan, 2010; Yang *et al.*, 2010; Liu *et al.*, 2011), the antenna performance can also be enhanced.

Two UWB antennas for 5G applications are presented in this work. The main objective of this research is to achieve outcome that conforms to the 5G applications covering priority frequency spectrum from 28 to 38 GHz. Both the antennas are implemented by using full copper ground plane. A rectangular shaped patch is introduced on the front side of substrate. An S-shaped cut is placed on patch to optimize the desired results and to achieve dual band character. Omnidirectional radiation patters are obtained for resonance frequencies. Simulated results are presented for different range of frequencies like S-parameter, voltage standing wave ratio (VSWR), efficiency, gain, current distributions, and radiation patterns. The simulation is conducted by 3D simulation package Computer-Simulation-Technology (CST) Microwave studio.

2. Antenna Design

The main initiator element of designing the proposed antenna is a 7.9×7.7 mm^2 rectangular substrate. The substrate has 0.254 mm height. The patch of antenna is placed at the front side whereas the ground plane is placed on opposite sides of the substrate. Due to its simplicity and excellent physical handling, the transmission line model for microstrip design is modified to build and evaluate the antenna. The antenna dimensions (L and W) are measured by using the simplified formula (Balanis, 2016). The proposed antenna width (W) is defined by:

$$W = \frac{c}{2 f_r}\left(\frac{\varepsilon_r + 1}{2}\right)^{-\frac{1}{2}} \tag{1}$$

Where the permittivity of the substrate material is ε_r, f_r is the resonance frequency, and c is the speed of light in free space. Effective permittivity of the substrate is determined by the formula as:

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

Here, h defines the thickness of substrate. The path length(L) can be derived as:

$$L = \frac{c}{2 f_r \sqrt{\varepsilon_{re}}} - 2\Delta L \tag{3}$$

Figure 1 presents the geometry of proposed 5G antenna. Rogers RT 5880 is used as the base component substrate with a dielectric constant of 2.2 and a loss tangent of 0.025. A patch is the main radiating element of the proposed antenna. The antenna patch consists of a simple, modified line structure. At the lower edge of the fed line, a 50 Ω SMA connector is positioned. The width of the fed line is 0.782 mm. Table-1 summarizes the design parameters for the proposed antenna,

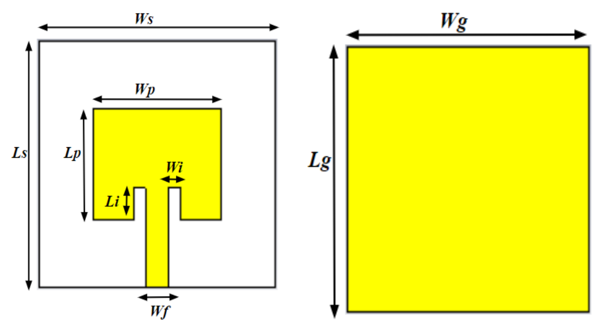
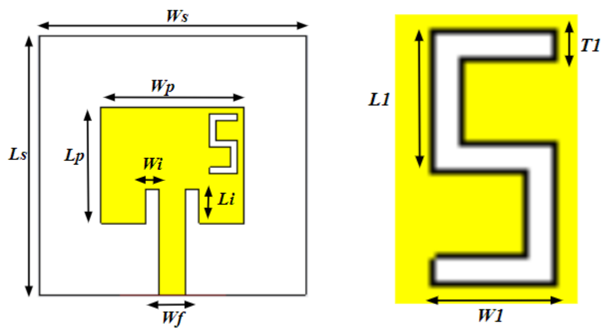


Figure 1. Geometric layout of the proposed antenna (a) Frontage (b) Backside

Table 1. Dimensions of proposed antenna prototype

Parameters	Value (mm)	Parameters	Value(mm)
W_s	7.9	L_s	7.7
W_g	7.9	L_g	7.7
W_p	4.232	L_p	3.466
W_i	0.4	L_i	1
W_f	0.782	H_f	3.45

Another design is proposed on the substrate of same dimension but a little change on patch keeping the ground plane same as before. An S-shaped slot is added on the patch to achieve dual band characteristics and other performances which is depicted on Figure 2.



(a) (b)

Figure 2. Insertion of S-shaped slot on patch

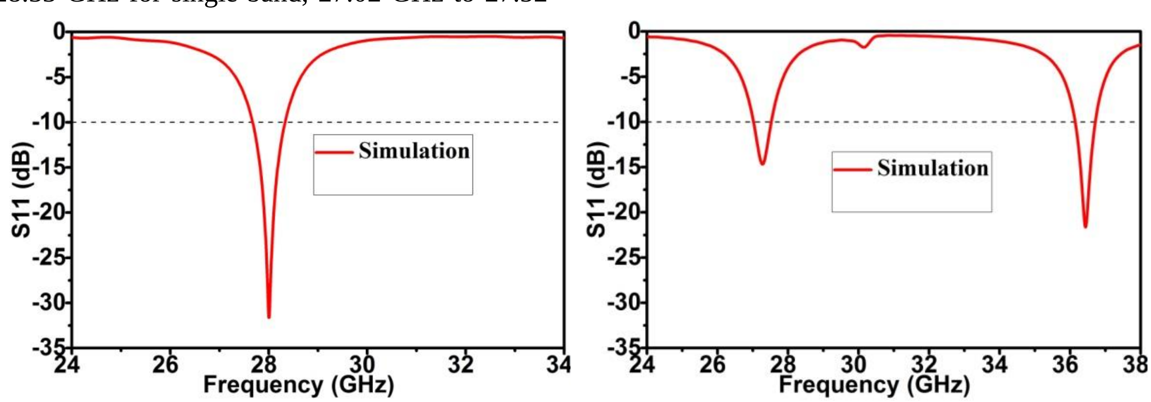
Table 2. Optimized dimensions of proposed prototype

Parameters	Value(mm)	Parameters	Value(mm)
W_s	7.9	L_s	7.7
W_g	7.9	L_g	7.7
W_p	4.232	L_p	3.466
W_1	0.8	L_1	1
W_i	0.4	L_i	1
W_f	0.782	T_1	0.2

3. Results and Discussion

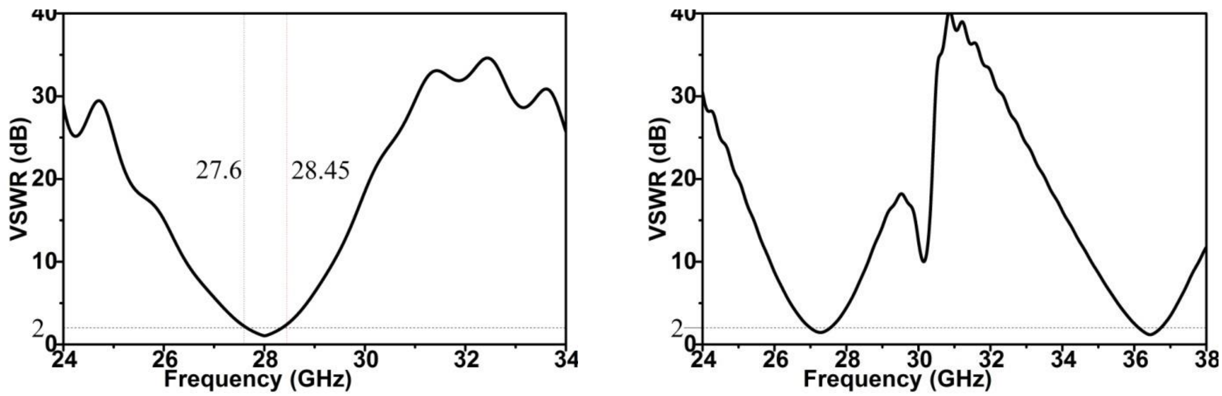
The simulations of these two proposed designs are performed by 3D computer simulation technology (CST) studio suite. In Figure 3, the reflection co-efficient (S11) is depicted. The -10dB working frequency range is 27.67 GHz to 28.33 GHz for single-band, 27.02 GHz to 27.52 GHz and 36.14 GHz to 36.71 GHz for dual-band respectively, almost covering the full frequency range of 5G. At 28 GHz, the resonance is found which almost middle value of entire range is. The reflection coefficient value at the resonant stage on the single band is approximately -31.614 dB, on the dual band it is approximately -14.63 dB and -21.77 dB, ensuring the viability of the design being proposed. Figure-4 indicates the VSWR value of the same design against the frequency. The VSWR value is also the same as the reflection coefficient on a scale of less than 2. The proposed design is smaller than other recently published antennas for related application. Dual and wide operating bandwidth was achieved by the S-slot on the patch. The slot dormant the vertical undesirable surface current that radiates perpendicularly to the outer edge. By inserting slot, the side lobe levels are decreased, the gain in the main lobe is increased and the squint effect is corrected, providing improvement in antenna operating bandwidth. For this, remarkable modifications in the features of the antenna are found.

In Figure 5, the radiation efficiency of proposed design is presented. The peak radiation efficiency is found on single band at 28 GHz, on dual band 27.27 GHz and 36.43 GHz which is very similar to the resonant point. It ensures the durability of the antenna for the proposed 5G application in the resonance area. The performance spectrum is worse than the lower frequency at higher frequencies. It can inflict because of the copper losses and the dielectric losses.



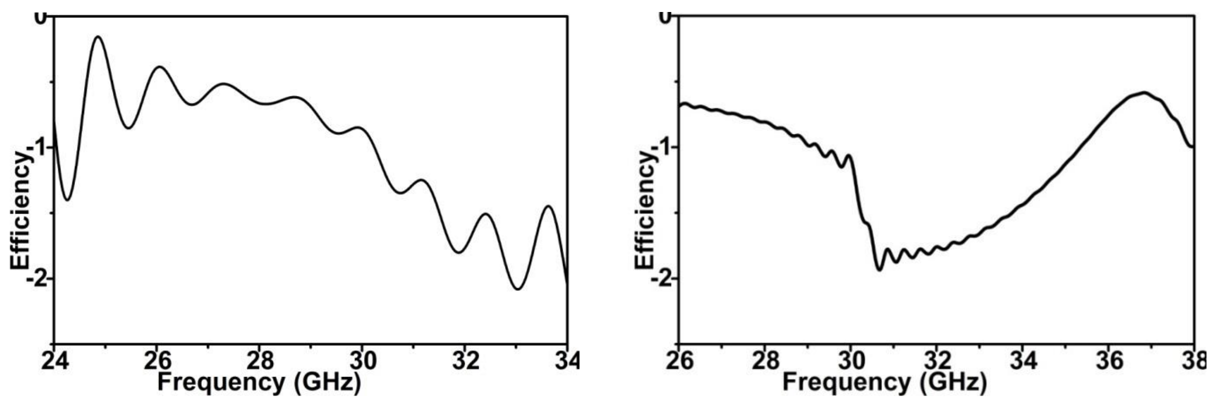
(a) (b)

Figure 3. Simulated reflection coefficients (a) For single band (b) For dual band



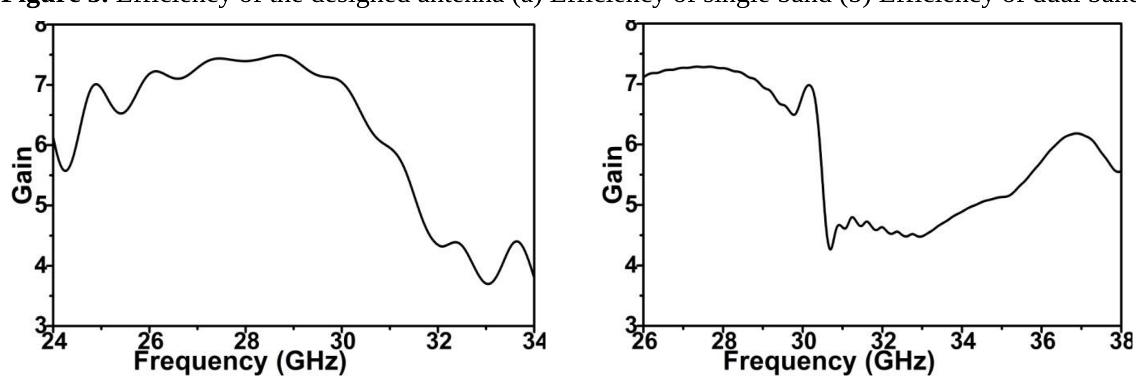
(a) (b)

Figure 4. Simulated VSWR of designed antenna (a) VSWR for single band (b) VSWR for dual band



(a) (b)

Figure 5. Efficiency of the designed antenna (a) Efficiency of single band (b) Efficiency of dual band

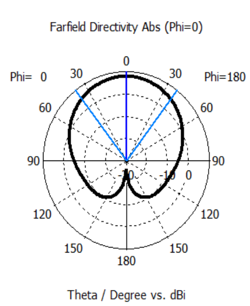


(a) (b)

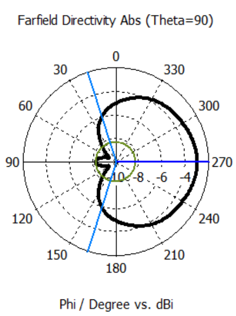
Figure 6. Obtained gain of designed prototype (a) Gain of single band (b) Gain of dual band

The gain of the proposed antenna is presented in figure 6 for both the single and dual band. The gains of both antennas are much higher than recently published antennas for fifth generation application. The modest gain of single band antenna is higher than seven. The range of gain for dual band antenna is six to seven dBi, which confirm the decent performance of proposed antenna.

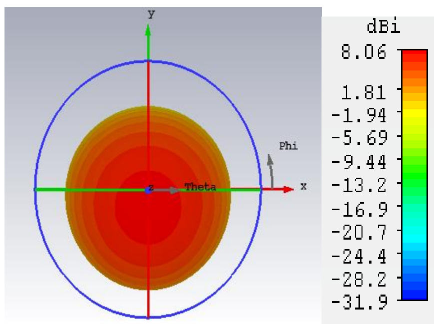
Figures 7 and 8 demonstrate the radiation pattern for both the co-polarization and cross-polarization of the proposed antenna at the resonant frequencies. It is seen from the observation that the antenna shows an omnidirectional pattern of radiation. With 90° directivity, the cross-polarization radiation pattern is elevated. The values of co-polarization are more negative than the values of cross-polarization. The 3-D view of the pattern of radiation at the same frequency is also shown in Figures 7(c) and 8(e) & (f). It is clearly shown from the 3-D view that the radiation pattern of the proposed design is omnidirectional, which is one of the contact antenna prerequisites. Figures 9 and 10 present the absolute directivity of the proposed antenna. Excluding the last quartile of phi, the directivity is almost uniform. The directivity of the single band antenna is 8.056 dB at 28 GHz, while the directivity of the dual band antenna is 8.024 dB and 6.353 dB at 27.7 GHz and 36.43 GHz respectively.



(a)

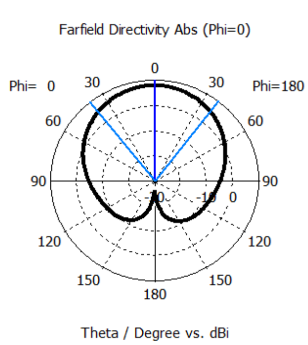


(b)

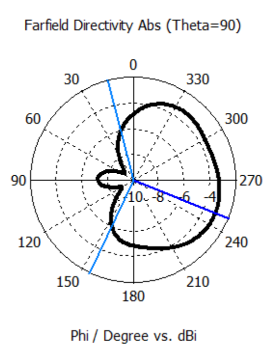


(c)

Figure 7. Radiation pattern of single band (a) E- plane at 28 GHz (b) H- plane at 28 GHz (c) 3D view of radiation pattern



(a)



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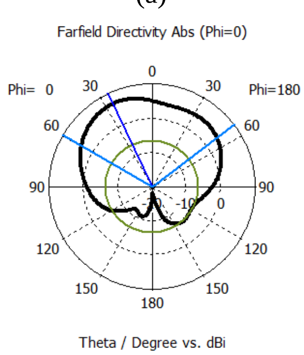

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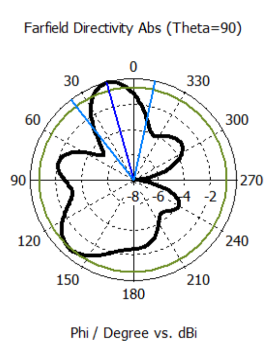
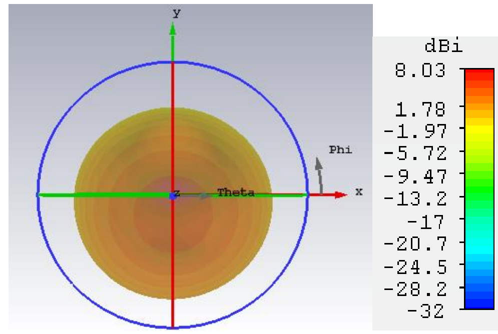


(d)



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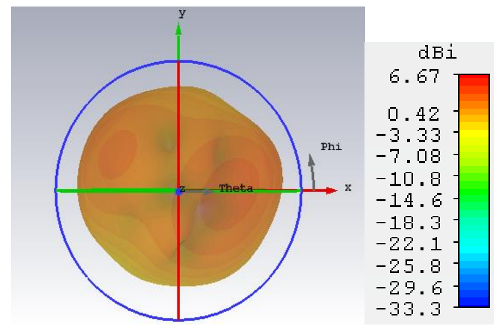


(f)

Figure 8. Radiation pattern of dual band (a) E-plane at 27.27 GHz (b) H-plane at 27.27 GHz (c) E-plane at 36.43 GHz (d) H-plane at 36.43 GHz (e) 3D view at 27.27 GHz (f) 3D view at 36.43 GHz

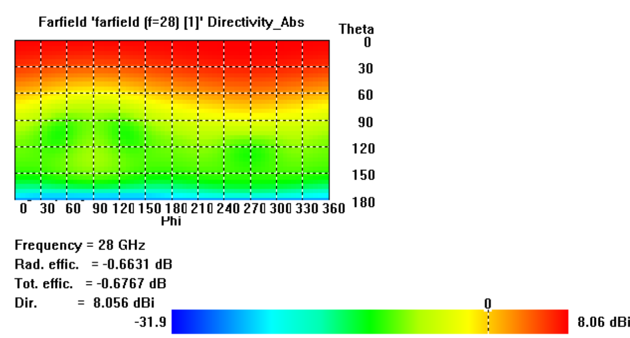
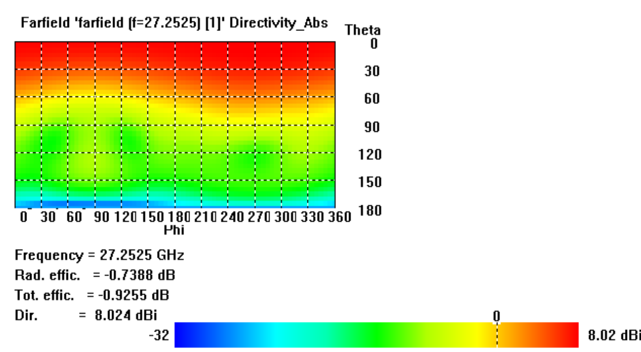
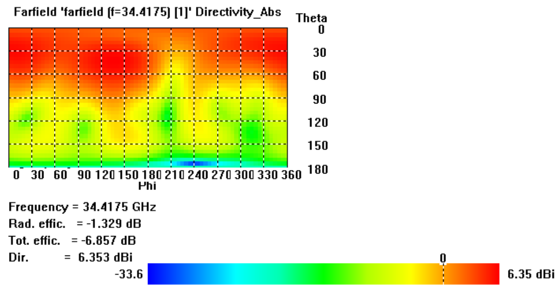


Figure 9. Absolute directivity of the single band antenna (at 28 GHz)



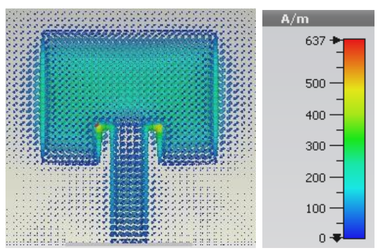
(a)



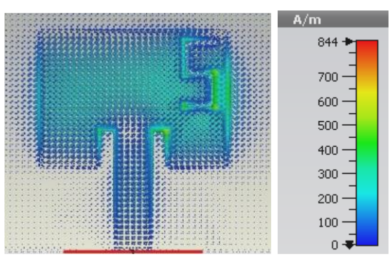
(b)

Figure 10. Absolute directivity of the dual band (a) at 27.25 GHz (b) at 34.41 GHz

The surface current distribution of the design proposed is represented in Figure 11. Over the patch, the current is distributed evenly. For single band antenna the current is mostly distribute around the main radiating element patch. In dual band antenna the current is mostly concentrate over the S-shaped slotted area.



(a)



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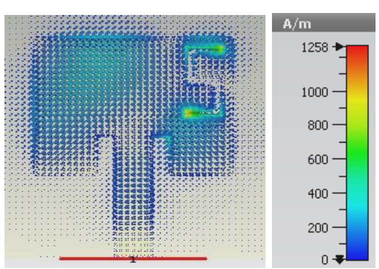

(c)

Figure 11. Current distributions (a) single band at 28 GHz (b) Dual band at 27.27 GHz (c) Dual band at 36.43 GHZ

The comparisons between these two proposed designs are shown on Table 3. From the table it's shows that the performance criteria of 5G communication antenna are mostly fulfilled by the proposed design.

Table 3. Comparison between single and dual band

Parameters	Single Band	Dual Band
Size	7.9×7.7 mm^2	7.9×7.7 mm^2
Operating Frequencies	27.67-28.33GHz	27.02- 27.52GHz 36.14- 36.71GHz
Peak gain	7.39 dB	7.29 dB, 6.05 dB
Directivity	8.05 dB	8.03 dB, 6.67 dB
Efficiency	91%	90%, 90%

4. Conclusion

For 5G wireless communications applications, two Miniaturized UWB Antennas are proposed. The findings obtained conform to the fifth-generation applications covering the high frequency range. The attain performance parameters such as reflection coefficient, antenna-size, fractional bandwidth, region-of-operation, and omnidirectional radiation pattern ensure that the proposed antenna is appropriate for 5G application. The proposed designs are small in size and can be implemented with low production costs into a limited space around microwave circuitry. Therefore, the proposed prototype could be a potential candidate for 5G applications.

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