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A Wideband Compact Antenna for Vehicles Communication in ITS Applications

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Abstract—A wideband compact shark-fin antenna operating in a frequency band from 2.86 GHz to 7.68 GHz is presented. The proposed design is realized on a substrate material of "Rogers 4003C" with $\varepsilon_r = 3.48$, $\tan\delta = 0.0027$, and substrate thickness 0.81 mm. The antenna is designed to operate at a center frequency of 5 GHz with an operating bandwidth of 4.82 GHz (96.4%). The bandwidth covers the lower band and mid band of 5G at resonant frequencies of 3.5 GHz and 5.8 GHz, respectively. The realized gain of the proposed antenna is 4.1 dBi and 5.35 dBi in the lower band and mid band, respectively. The proposed antenna is designed and simulated. It is also fabricated using photolithography techniques and measured using an R&S vector network analyzer. Good agreement is obtained between the simulated and measured results.

1. INTRODUCTION

High speed wireless communication systems are increasing at a rapid rate in the automotive industry. Since the antenna is one of the important parts of any communication system, it has been rapidly developed to meet the requirements of these systems. The trend to apply the 5G technology is because the 3G and 4G technologies still cannot be used in some applications such as vehicle-to-vehicle (V2V) or vehicle-to-everything (V2X) communication systems. Intelligence transportation system (ITS) is built depending on 5G technology which presents a high reliability, low latency, enhanced data rate, and increased bandwidth [1–4]. This system improves the road safety by avoiding car accidents and reducing traffic jams. Vehicle-to-everything (V2X) can be classified into four categories: vehicle-to-vehicle (V2V), vehicle-to-personal (V2P), vehicle-to-infrastructure (V2I), and vehicle-to-network (V2N) [5–7]. The electrostatic discharges (ESD) are considered in the antenna design because these discharges may have an effect on the communication system through the antenna. Therefore, DC grounding to bypass the ESD should be considered as a mandatory requirement for the vehicular antenna which is built on the rooftop of the vehicle [8, 9]. The antenna placement of the V2V system is studied and discussed [10]. There are many V2V antenna designs that are mounted on the rooftop [11–15]. A microstrip planar and conformal antenna, which operates in the X and Ku bands, is discussed [13]. A shark-fin rooftop multiband antenna for the automotive industry is presented [15]. Another technique that is applied to the V2V antenna design is reconfigurable antennas [16–20]. A novel planar shark-fin reconfigurable antenna based on an electronically switched parasitic (ESP) array radiator, operating at 5.9 GHz, is introduced [16]. A printed wideband pattern reconfigurable antenna using ESP stubs, operating from 1.88 to 2.55 GHz, is also presented [20].

Ultra-wideband (UWB) coplanar antennas have been growing rapidly as a suitable technology for many 5G applications such as ITS, vehicle communications, and location tracking [21–23]. A compact

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dual band antenna suitable for 5G applications is discussed in [24, 25]. UWB is mainly used to short-range applications due to the limitations of power spectral density [26]. UWB antenna has several advantages, such as small size, easy fabrication and feed, good immunity against fading effects, and suitable gain, which are needed for 5G applications. A hexagon broadband microstrip antenna loaded with V-shape slots with different sizes and shorting pins, operating from 4.74 GHz to 6.79 GHz, is presented in [22]. A compact coplanar stripline-fed UWB antenna with a staircase-shaped radiating element and a shorted strip is introduced. A high reduction in size is achieved in this design [26].

In this paper, a multiband compact antenna is designed, simulated, and fabricated for a V2V wireless communication system. The proposed antenna operates at a wideband of 2.86–7.68 GHz to cover the lower and mid bands of 5G applications. This structure has a low profile, planar geometry, is easy to fabricate, and has low complexity. It can be used in a shark-fin mobile system.

2. PROPOSED ANTENNA DESIGN

A compact antenna design is presented to cover the low and mid bands of 5G applications. The geometry of the proposed antenna is shown in Fig. 1. The antenna is designed on a substrate of type "Roger 4003C" with $\varepsilon_r = 3.48$, loss tangent $\tan\delta = 0.0027$, and 0.81 mm thickness. The size of the antenna is $L_{sub} = 39.6$ mm and $W_{sub} = 28.35$ mm. The structure consists of a circular patch slot antenna cut on the top ground. Six parasitic strips are added to the designed antenna, three on the left side and three on the right side. The antenna is fed with a 50 Ohm microstrip feed line placed at the center of the substrate. Table 1 shows the dimensions of the structure in mm. The proposed structure passed through four stages to reach the final design. Fig. 2 shows the four steps that explain the antenna

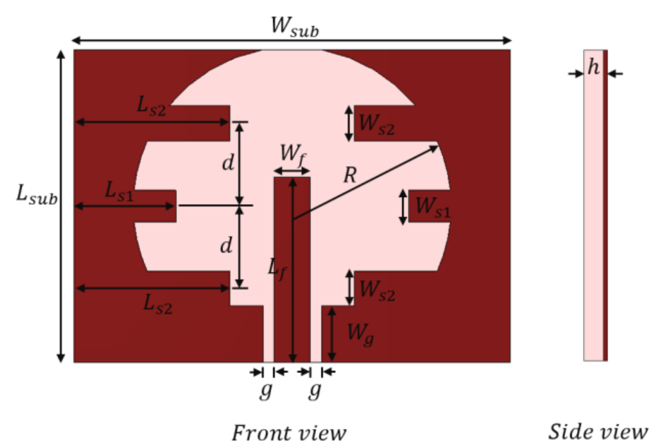


Figure 1. The geometry of the proposed antenna, (a) complete geometry, and (b) dimensions of the proposed antenna.

Table 1. The dimensions of the proposed antenna element in the designed structure.

Parameter	**Length [mm]**	**Parameter**	**Length [mm]**
L_{sub}	28.35	W_{sub}	39.6
L_{S1}	9.23	W_{S1}	2.9
L_{S2}	14.15	W_{S2}	3.2
L_f	16.83	W_f	3.3
g	1	W_g	5.12
R	14.43	d	7.5

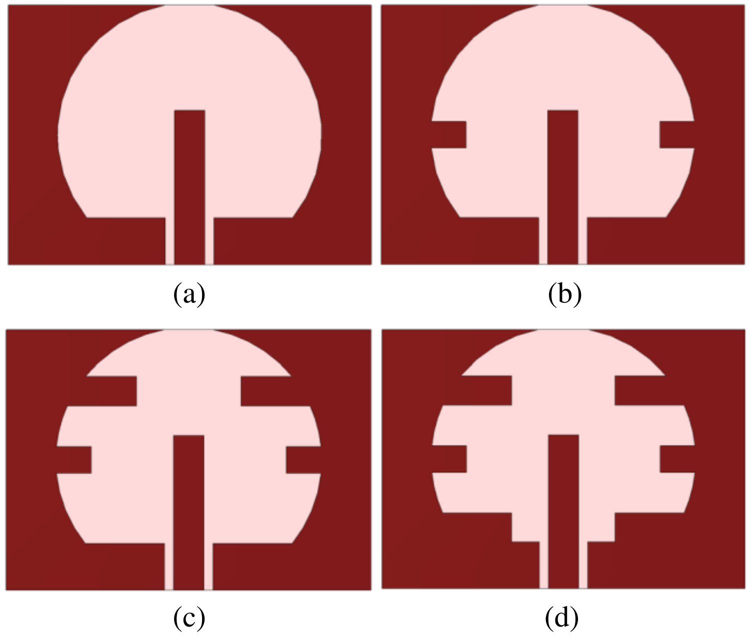


Figure 2. Improvement procedures for the designed antenna.

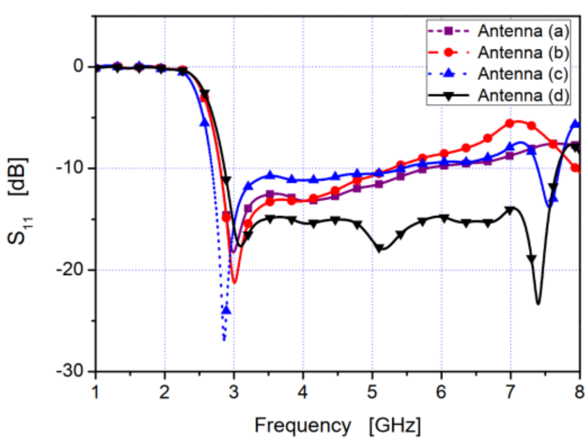


Figure 3. The change in the return loss (S_{11}) for each design step.

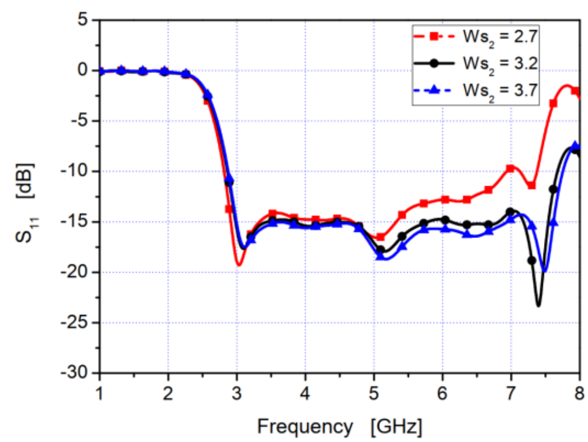


Figure 4. A parametric study of the increase and decrease in the width W_{S2}.

design procedures. The first step initiates the design of a coplanar circular slot antenna with a partial stub to connect the feeding ground. In the next step, two strips are added at the center of the circular slot from the left and right. The impedance matching is improved, but the bandwidth is decreased. Then, another two strips are placed at the top of the proposed design. Both impedance matching and bandwidth are improved. In the last step, two strips are placed at the bottom of the proposed design. Fig. 3 shows the change in the return loss (S_{11}) for each design step. By tuning the width of the three strips W_{s1}, W_{s2}, the length of the middle strip L_{s1}, the length of the upper and lower strips L_{s2}, and their position d, the bandwidth and return loss of the antenna are changed.

A parametric study is obtained for each dimension individually while the other parameters are constant. The change in the width of the strips affects the bandwidth of the proposed antenna. In Fig. 4, increasing W_{S2} tends to increase the impedance bandwidth as well as improve the return loss (S_{11}). The width W_{S2} is chosen to be 3.2 mm. Fig. 5 shows how changing the length of L_{s2} tends to improve the return loss (S_{11}) at the high band. However, as the length increases, the bandwidth

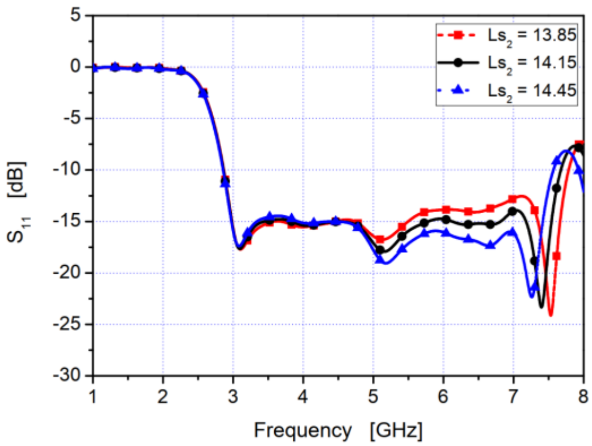


Figure 5. A parametric study of the increase and decrease in the length L_{S2}.

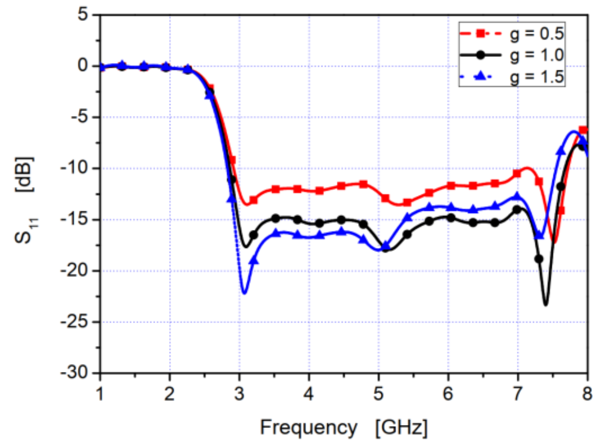
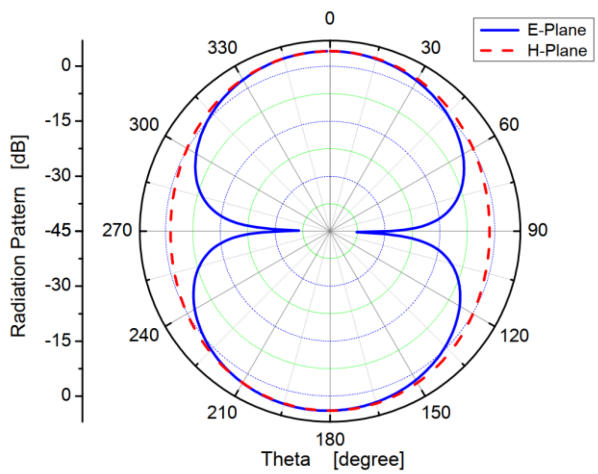
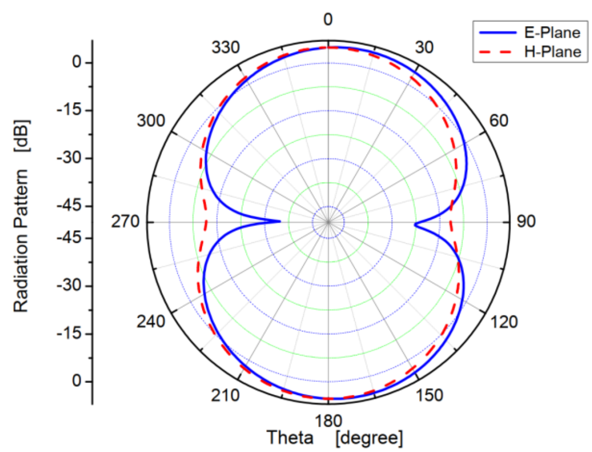


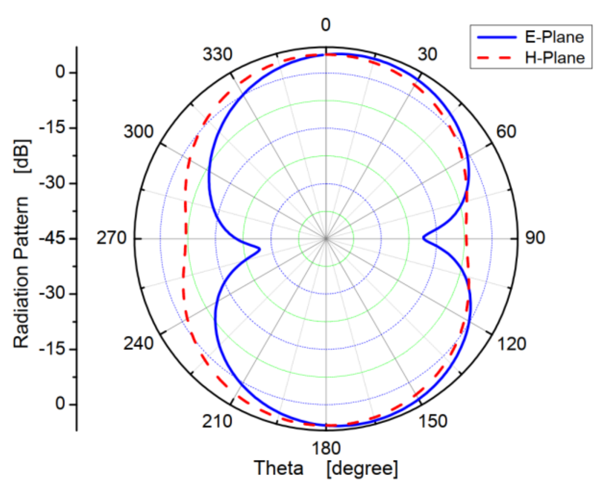
Figure 6. A parametric study of the increase and decrease in the width g.



(a)



(b)



(c)

Figure 7. The simulated radiation pattern of the proposed antenna structure at frequencies of (a) 3.5 GHz, (b) 5.8 GHz, and (c) 7 GHz.

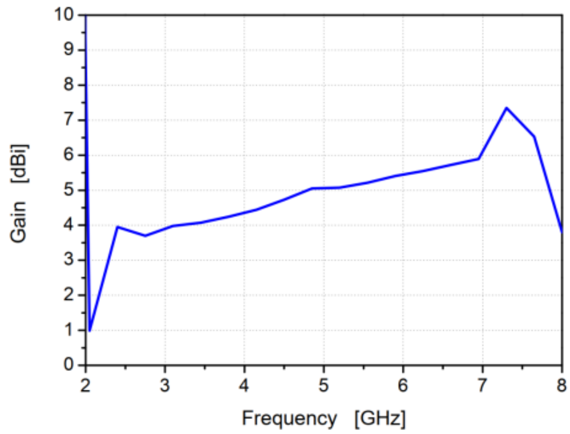


Figure 8. The overall antenna gain for the single patch antenna.

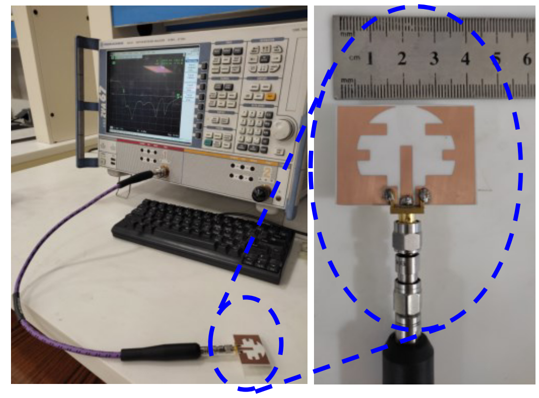


Figure 9. The fabricated antenna design.

decreases. A tradeoff between improving the return loss and decreasing the bandwidth has occurred. The length L_{s2} is chosen to be 14.15 mm. Fig. 6 illustrates the effect of changing the gap between the feedline and ground g, which tends to improve the return loss (S_{11}) in the overall band. The width of this gap effects on the impedance matching of the proposed antenna and the most suitable dimension is 1 mm. Elaborating results of all parametric studies, it is easy to choose the proper dimensions that achieve the overall bandwidth from 2.86 to 7.68 GHz based on the required specifications and application. Fig. 7 shows the radiation pattern of the proposed antenna at the frequencies 3.5 GHz, 5.8 GHz, and 7 GHz. In Fig. 8, the overall antenna gain for the designed antenna is presented. The designed antenna has a maximum gain of 7.35 dBi at a frequency of 7.3 GHz, while the gain at 3.5 GHz and 5.8 GHz is 4.1 dBi and 5.35 dBi, respectively.

3. RESULTS AND DISCUSSION

The proposed antenna is designed and simulated by the CST software. This structure operates at a wideband of frequency stared from 2.86 GHz to 7.68 GHz (96.4%) to cover the ITS and 5G applications at low and mid bands. It has a return loss below the −14 dB at the overall bands of the proposed structure. The antenna is fabricated using the photolithography method and measured using a vector network analyzer (R&S ZVA 67). Fig. 9 shows the fabricated antenna. Good agreement is achieved between the simulated and measured results.

The return loss comparison curves are shown in Fig. 10. Because of the necessary usage of cables during tests and manufacturing, losses may cause tiny variations in the resonant frequency, but generally, the measured and simulated results are similar. Minor jumps in return loss are detected owing to the tester's poor connection of the cable to the connector during measurement. However, the observed bandwidth of proposed antenna is similar to the simulated one. The gain of the antenna is also measured, and Fig. 11 shows the comparison between measured and simulated results. As shown in Fig. 12, the comparison between simulated and measured radiation patterns is introduced. There are some slight deviations between the measured curve and simulated curve, but the results are generally acceptable. Fig. 13 shows a comparison between the total efficiencies of the proposed design as calculated from CST and HFSS. In CST, the proposed antenna has a total efficiency of 97.3% and 94.6% at 3.5 GHz and 5.8 GHz, respectively. In HFSS, it has a total efficiency of 95.6% and 95.8% at 3.5 GHz and 5.8 GHz, respectively. The comparison between this work and previous works is tabulated in Table 2. Although there are some previous designs that have a higher gain, the proposed antenna is distinguished by being small in size compared to designs in the same frequency bands and having dual bands, not a single band. Moreover, its bandwidth (at −10 dB) is up to 96.4%, which is very large compared with previous designs.

Table 2. Comparison with pervious works.

Paper	[1]	[16]	[17]	[22]	[24]	[25]	**This Work**
Center Frequency [GHz]	3.5	5.8	5.9	5.8	3.5 5	28 39	**3.5** **5.8**
Single or Dual bands	Single	Single	Single	Single	Dual	Dual	**Dual**
Bandwidth (at −10 dB) [%]	12.57	8.27	6.78	35.55	14.28 28	11.7 10.25	**96.4**
Gain (dBi)	7	6.15	5.4	4.2	2.5 4.1	5.6 9.4	**4.1** **5.35**
Size (in mm)	37.4 × 37.4	200 × 200	37 × 32	60 × 60	32 × 20	6.34 × 7.6	**39.6 × 28.35**

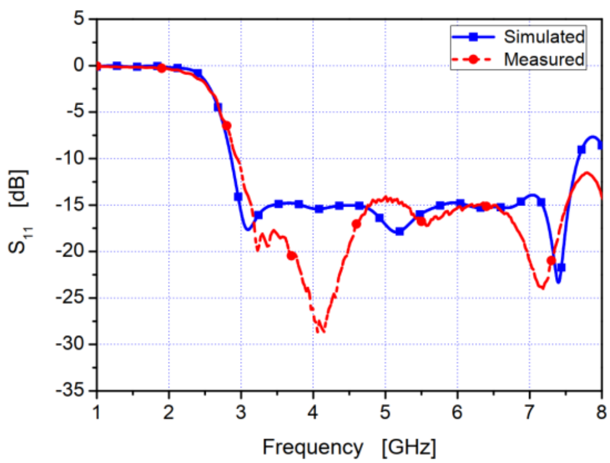


Figure 10. The comparison of simulated and measured S_{11}) results for single element antenna.

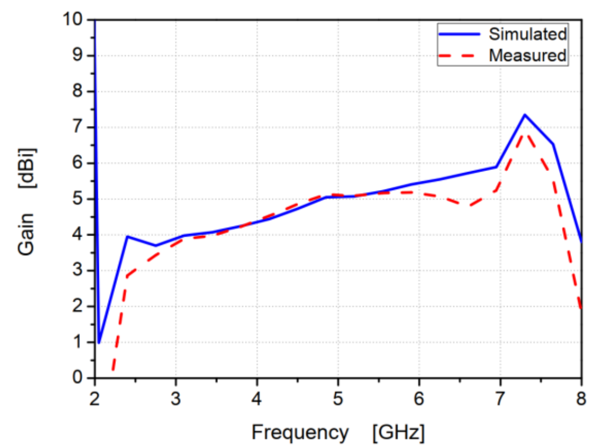
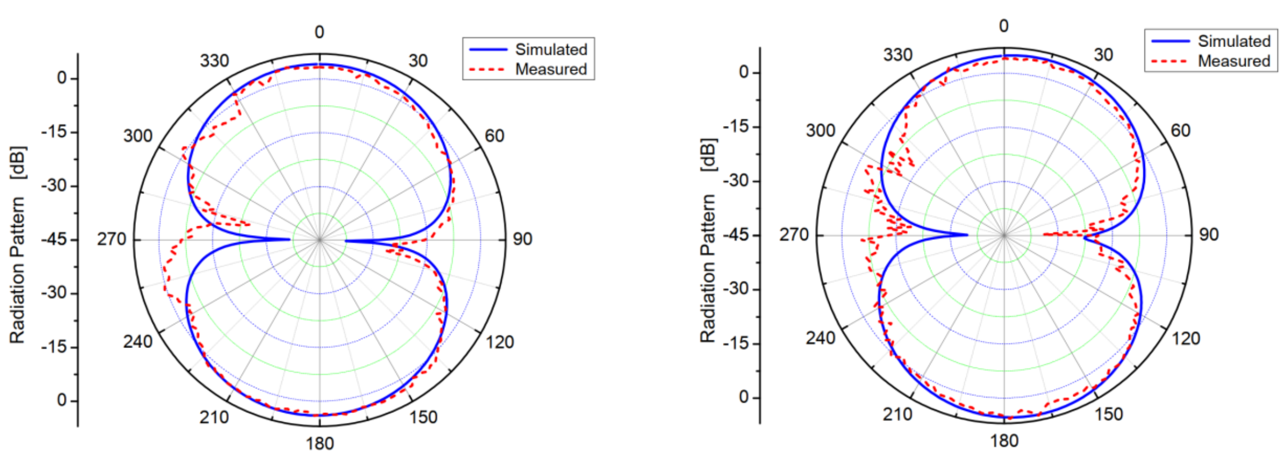
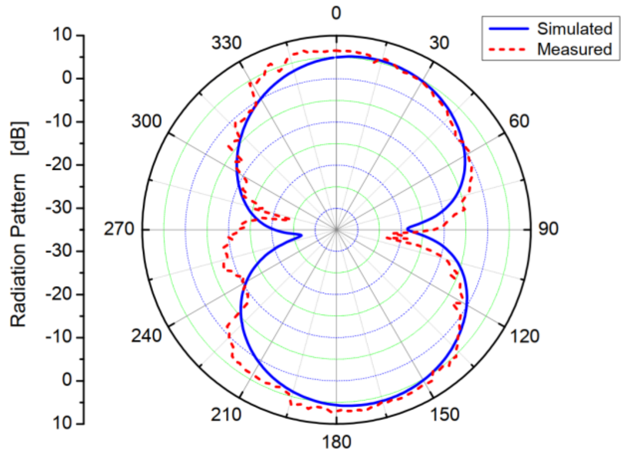


Figure 11. The comparison between simulated and measured overall gain versus frequency.





(c)

Figure 12. The comparison between simulated and measured radiation pattern E-plane at, (a) 3.5 GHz, (b) 5.8 GHz, and (c) 7 GHz.

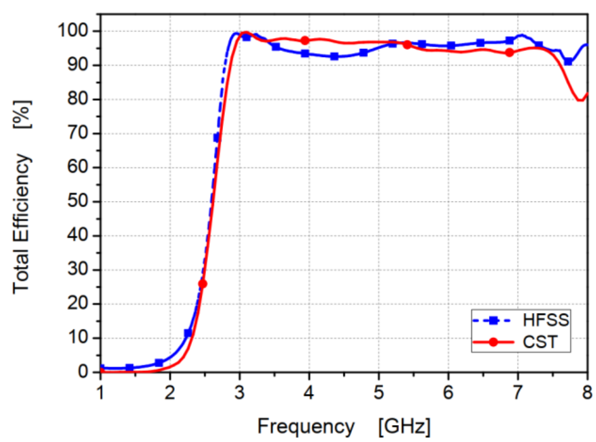


Figure 13. The total efficiency of the proposed antenna.

4. CONCLUSION

A wideband compact shark-fin antenna operating at a frequency band of 2.86 GHz–7.68 GHz to cover the lower and mid bands of 5G applications has been introduced. The designed antenna achieves a wide bandwidth of 96.4% around the operating center frequency of 5 GHz. Because of its features, such as a low profile, planar geometry, ease of fabrication, and low complexity, it can be used in the shark-fin mobile system. The achieved gain of the proposed antenna is 4.1 dBi and 5.35 dBi in the lower band and mid band, respectively. The antenna is fabricated and measured.

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