

Extremely Close Integration of Dual Band Sub-6 GHz 4G Antenna with Unidirectional mmWave 5G Antenna

Shakeel A. Malik¹, Khalid Muzaffar^{1, *}, Ajaz H. Mir², and Ayaz H. Moon¹

Abstract—An extremely close integration of a dual band sub-6 GHz 4G antenna with a 28 GHz 5G antenna is proposed in this article. Firstly, a dual band 4G LTE (Long term Evolution) antenna is designed on an inexpensive substrate. The proposed antenna operates in the 2.5 GHz and 3.5 GHz LTE bands. The antenna has dimensions of $63 \times 5.6 \times 0.5 \text{ mm}^3$, indicating an electrically small design. As the width of the antenna is less than 7 mm, it could be easily mounted on commercial mobile devices. The patterns for both the bands are almost omnidirectional as desired by the low frequency antennas. The proposed antennas do not carry any additional miniaturization or tuning circuitry hence simplifying fabrication process. Secondly, an angled dipole with Yagi topology is proposed, which works in the 28 GHz mmWave 5G band. The angled dipole has dimensions $28.3 \times 5.6 \times 0.5 \text{ mm}^3$, which is also electrically compact and has a high front to back ratio. The microwave and millimetre wave antennas are placed orthogonally for minimal mutual coupling. The characteristics of both the antennas are not affected by the presence of the other element. Detailed results are shown in this article.

1. INTRODUCTION

Research staff in the industry and academic leaders across the world firmly believe that future cellular communication system design would be built upon higher frequencies perhaps several octaves away from the current commercial systems [1]. Several models of commercially available smartphones have been integrated with millimeter wave radios, which invariably means that the antennas based on 28 GHz frequencies would be the future. Even though the global 5G coverage is questionable, the validity of using 28 GHz for cellular communication has been proved in [2]. The research article has received thousands of citations till date. As commercial smartphones need to be designed and developed for 5G systems, it means that the transceiver radios for various wireless services has to be crammed into precious real-estate of the smartphone. The design and integration of antennas required for 4G and previous generations has been well established and commercialized as seen in numerous models in the smartphone market. With the advent of 5G, it is important to design not only high gain antennas with very small size which fits inside the panel of the mobile device but also these 5G antennas with that of the previous generations to support backward compatibility, which means that the sub-6 GHz antennas must be electrically small and be a viable element for the back-end electronics. The co-designed antennas reported in [3] have a phased array for millimeter wave application and an electrically small antenna for 4G applications. The phased array has a low gain for the given electrical size, and the remedy to this problem is attempted in this paper. The design in [3] also uses different substrates to realize the design. This is a classic example of design evolution, and as with the deployment of 5G networks, 4G/3G/2G/Bluetooth/Wi-Fi, etc. would also coexist with 5G, which in turn would mean that the co-located antennas must have low interference on the antennas belonging to other standards.

Received 21 December 2020, Accepted 4 February 2021, Scheduled 8 February 2021

* Corresponding author: Khalid Muzaffar (khalid.muzaffar@islamicuniversity.edu.in).

¹ Department of Electronics and Communication Engineering, Islamic University of Science & Technology, Awantipora 192122, J&K, India. ² Department of Electronics and Communication Engineering, National Institute of Technology, Srinagar 190006, J&K, India.

This co-existence has forced the designers to design antenna systems which support multiple wireless standards with small size. The 5G antenna to be housed within the mobile device needs to have a high front to back ratio to enable a plausible link budget, hence high gain antenna with a clever placement of the same is necessary. The design requirements are not that tight for a 4G antenna as these are electrically small, low efficiency omnidirectional radiators. In recent years, several designs have been published discussing the 4G-5G antenna designs [3–7]. Even though the design reported in [4] is built on a single substrate, the antenna might be incompatible with commercial mobile devices as these devices have a panel height requirement of 7 mm or less. The shared ground published in [5] might have a compact solution to the antenna problem, but the slot radiators for 5G applications leads to low gain and radiation towards the user, when being activated. The conformal antenna proposed in [6] has an antenna height greater than 10 mm and might be unsuitable for commercial applications. The radiation would be towards the user when 5G antenna is switched on with the design of [7]. The ACS (Asymmetric Coplanar Stripline) feeding technique for miniaturization might be incompatible with the underlying electronics which prefer microstrip feeding [8,9]. Even though end-fire antennas such as Vivaldi based antennas have high front to back ratio, they might be unsuitable for panel mounting with mobile devices, as the width of the antennas to achieve high gain would be higher than the required panel height [10–12]. It might appear that reconfigurable antennas such as the ones published in [13–15] could be used to achieve band switching between 4G and 5G, but the issue with design logic is that realizing the appropriate diodes at 28 GHz would be challenging, also the bias lines and other parasitics would detune the antennas. Most of these designs have large electrical size, which might not be feasible with current mobile phones. In this article, a dual-band 4G antenna is integrated with a 28 GHz antenna, and both the antennas have a width less than 6 mm, which could be easily panel mounted with modern devices. The design techniques followed by experimental results are presented.

2. INEXPENSIVE SUBSTRATE BASED DUAL BAND 4G LTE AND 28 GHz 5G ANTENNA DESIGN

The antennas for both the commercial wireless services namely 4G LTE (Long term evolution) and mmWave (millimeter wave) 5G are designed on an inexpensive substrate. The chosen polycarbonate substrate is inexpensive due to a multitude of its applications in the plastics industry. Both the antennas are designed on a polycarbonate substrate with a relative permittivity, ϵ_r of 2.9 and loss tangent of 0.01. Lower dielectric constant is ideal for radiators as it prevents additional surface wave modes. Even though the dielectric loss tangent is a little higher than Rogers/Neltec/Arlon substrates, the forward gain is not significantly hampered by this value. All the antenna designs along with the placement studies have been simulated in Computer Simulation Technology (CST) Microwave studio in the frequency domain as both the antennas have relatively narrow band or multiband. The thickness of the current substrate is 0.5 mm, which is electrically thin for 5G applications. The problem with polycarbonate substrate is that the Copper clad substrates are not commercially available, hence Copper tape has to be pasted initially and etched according to the geometry.

2.1. Dual Band Microwave Antenna

Schematics of the proposed extremely close integrated design of dual band microwave antenna and 28 GHz 5G antenna are displayed in Figs. 1(a) and (b). All the dimensions in the sketches are in millimetres. Both the antennas are designed on a single contiguous polycarbonate substrate, but the structure is bent at right angles at the end of the 4G antenna. The proposed 4G antenna has a separate feed as shown in the figure. The antenna has a microstrip feed with a close to $50\ \Omega$ characteristic impedance line. This microstrip line feeds an L-shaped structure which aids in creating a band at the higher band of the operating spectrum. The primary line of the radiator is looped back within the constraints of the substrate, which is evident from the figure. This looping technique helps in miniaturization with a compromise in the bandwidths of the element.

A photograph of the integrated prototype is shown in Fig. 2. The microwave antenna has a defected ground for feeding the antenna. The defected ground also helps in size miniaturisation similar to the ultra-wideband monopole designs. The protrusion of the microwave antenna is meant to accommodate

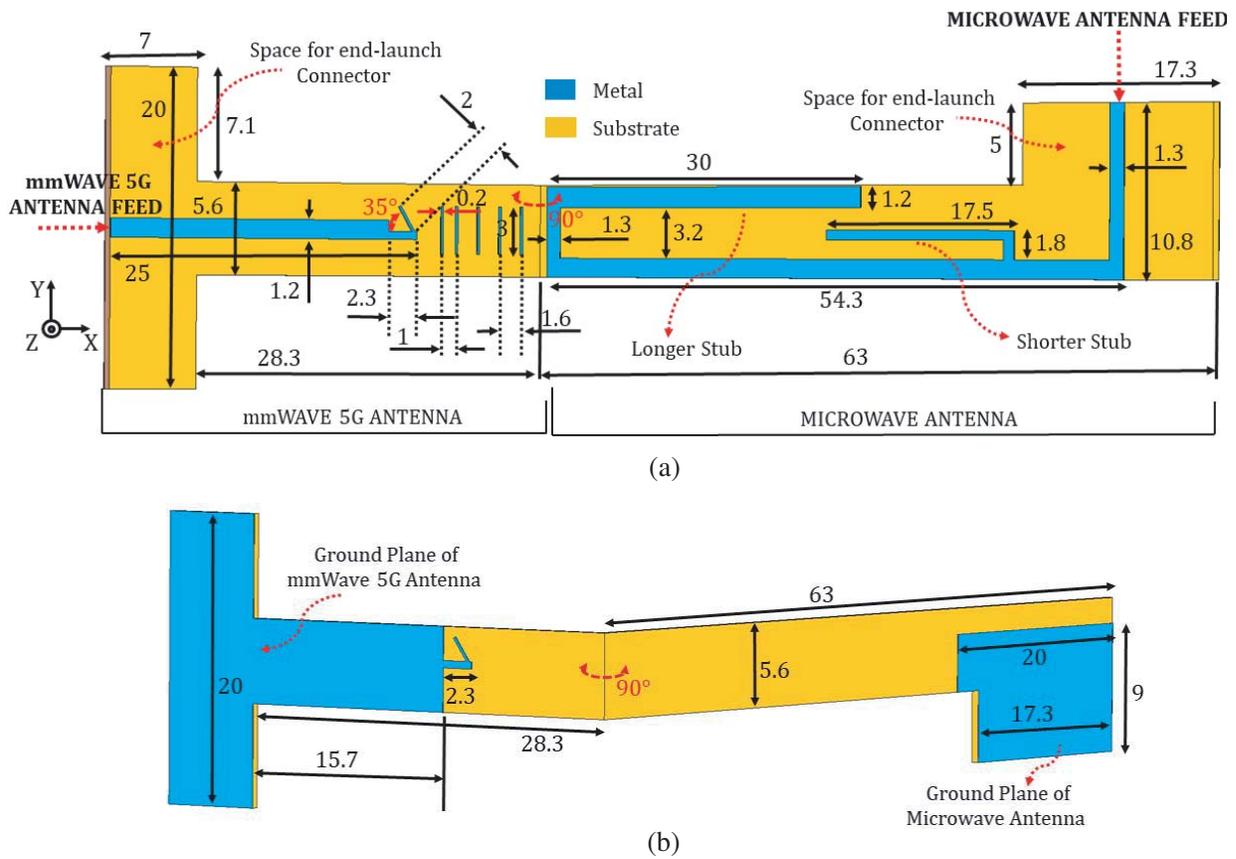


Figure 1. Schematics of the extremely close integrated design of dual band microwave antenna and 28 GHz 5G antenna. (a) Top plane (isometric view) and (b) bottom plane (isometric view) (Units: mm).

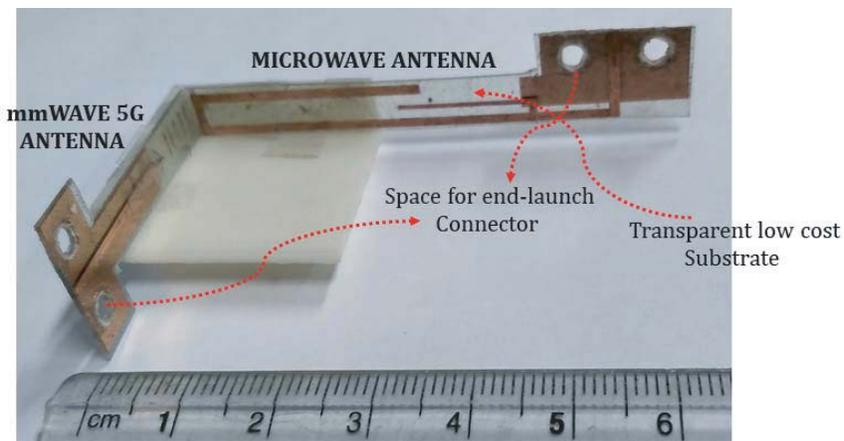


Figure 2. Photograph of the prototype accommodated along the panel edge of typical mobile phone case.

the end-launch connector as polycarbonate based design does not support soldering due to the low melting temperature of the plastic. The connector extension could be neglected in an actual deployment scenario without any loss of the performance metrics. A typical design for lower frequency involves an electrically large ground, which is the system ground of the smartphone or might use multiple tuning

elements for low profile design. Even Asymmetric Coplanar Stripline (ACS) has been used to make a smaller sized low frequency antenna [8, 9]. The current design avoids both and is also scalable for an extended MIMO design. The electrical size of the proposed antenna is $0.525\lambda \times 0.046\lambda \times 0.004\lambda$. The simulated and measured S_{11} are shown in Fig. 3(a).

Measured S -parameters of the proposed antenna were obtained using Agilent PNA E8364C. Dual bands are achieved by optimizing the lengths of L-shaped stubs as depicted in Fig. 1(a). The lengths of longer and shorter stubs are around half-wavelength which accounts for resonance of low frequency 4G LTE bands and high frequency sub-6 GHz 5G band, respectively. Peak gain is shown in Fig. 3(b). As the connector was not included in the full-wave simulations, there is a slight discrepancy between simulated and measured values.

The E -plane radiation patterns of the 4G antenna for both the bands are shown in Fig. 4. The patterns are almost omnidirectional as expected from electrically miniaturized antenna design. The measured values deviate slightly at some of the angles due to the poor characteristics of the oblique incidence of the absorbers within an anechoic chamber.

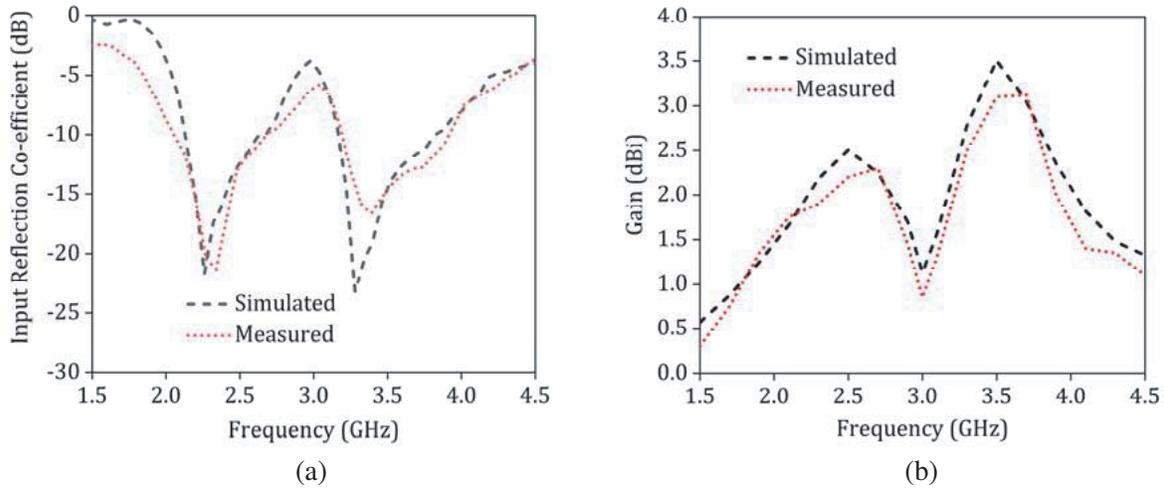


Figure 3. (a) Simulated and measured $|S_{11}|$ of the microwave antenna within the integrated system and (b) gain of the proposed microwave antenna.

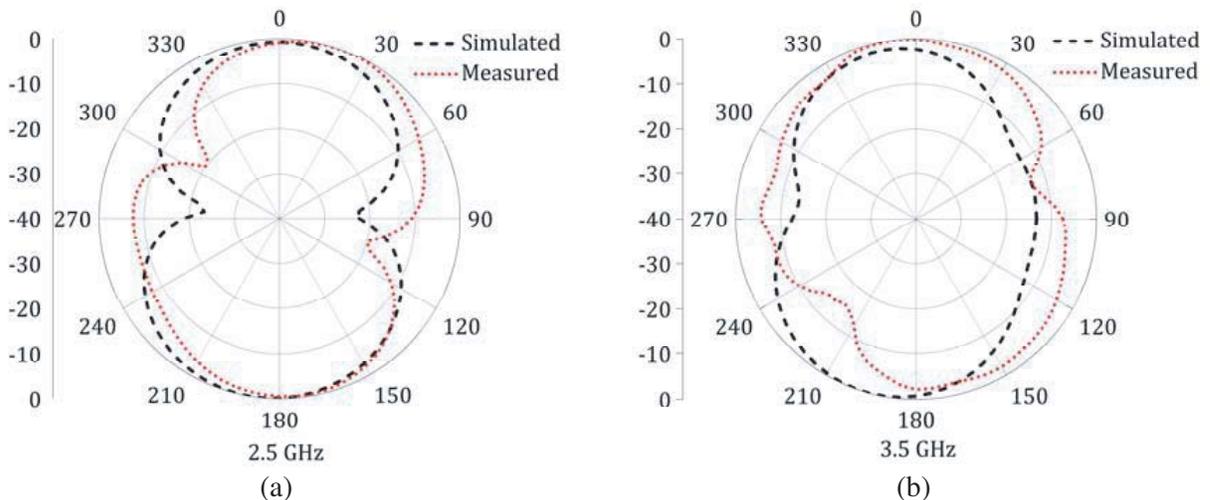


Figure 4. E -plane radiation patterns of the proposed 4G antenna.

2.2. Unidirectional 28 GHz 5G Antenna

For the millimeter wave antenna, the angled dipole was initially designed based on the printed dipole design concept, wherein a typical half-wavelength dipole was designed on the given substrate, post which angling of the dipole was introduced to achieve compaction of the antenna laterally. Since the antenna would be placed along the Y -axis, the substrate width reduction would be helpful for miniaturization. In order to design a 28 GHz antenna with high front to back ratio, broadside radiators such as patch antennas are avoided as the radiation would be towards the user, when being engaged in data consumption. End-fire antennas such as Vivaldi or tapered slot antenna might be a solution [10–12] to solve the back radiation issue, but the integration with the panel of the mobile device is compromised due to its electrically large size, even when being scaled to 28 GHz band. Hence, a polycarbonate based angled dipole integrated with parasitic radiators is proposed as displayed in Fig. 1. The length of the dipole arms is 2 mm, and both the arms of the dipole are angled with respect to the radiating axis. The idea of angling reduces the actual occupied space of the antenna along the width of the antenna. It is also interesting to note that the lateral width of the antenna is only 5.6 mm, which is 0.52λ calculated at 28 GHz. The design of the parasitic radiators is to achieve gain enhancement in the end-fire orientation. The number of parasitic radiators would be decided by the desired gain of the 5G antenna intended for the mobile device. Gain could be further enhanced by adding a couple of more parasitics according to the standard Yagi-Uda design logic. As the antenna would be vertically placed along with the side-edge of the mobile device, the antenna requires only 0.5 mm from the panel, which is the thickness of the substrate. The antenna is wideband as observed in the input reflection co-efficient curves of Fig. 5(a). Bandwidth could be further increased by adding a balun in the feedline.

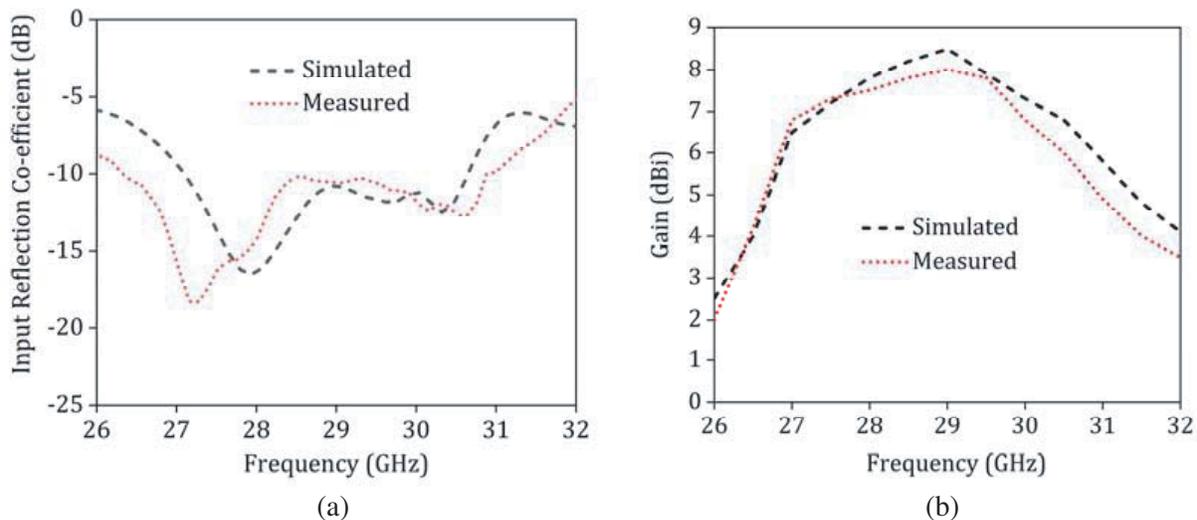


Figure 5. (a) $|S_{11}|$ of the 28 GHz 5G antenna. (b) Forward gain.

Measured radiation patterns were performed in the anechoic chamber, and experimental setup for measuring radiation cuts of mmWave 5G section of proposed antenna is depicted in Fig. 6. The distance between antenna under test and Ka-band standard horn antenna is around 50 cm. For measuring radiation patterns of microwave section of proposed antenna, a large horn antenna is used with distance of more than 1 meter between AUT and standard horn antenna. The peak gain of proposed mmWave 5G antenna is shown in Fig. 5(b). The end-fire radiation patterns are shown in Fig. 7; the patterns have a clear unidirectional beam with a corresponding front to back ratio of greater than 15 dB. This feature clearly indicates that the 5G antenna would radiate away from the user when the antenna is plugged into a mobile device. This feature is unique to this design as most of the reported designs lack mobile device placement analysis.

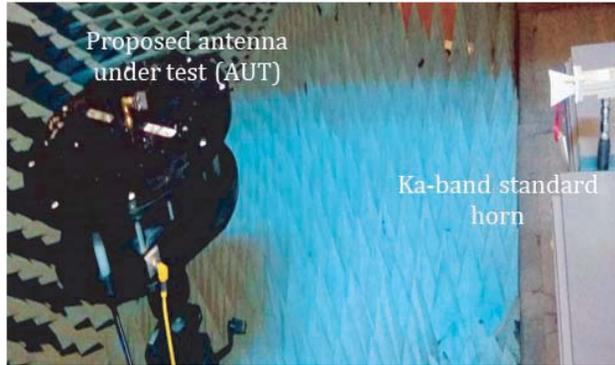


Figure 6. Experimental set-up for measuring various characteristics of proposed antenna module.

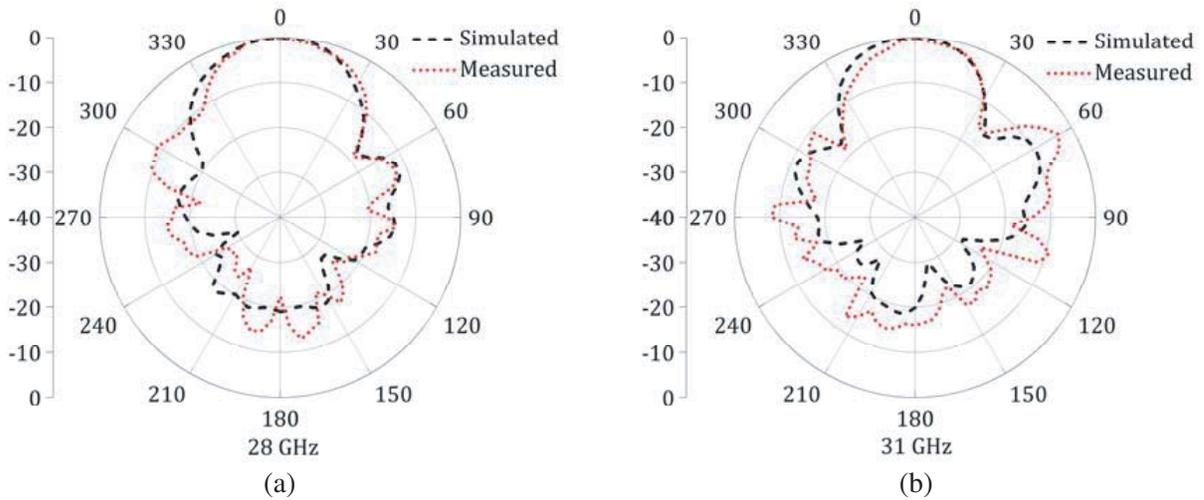


Figure 7. *E*-plane radiation patterns of the 5G antenna at 28 GHz and 31 GHz.

2.3. Extremely Close Integration of Dual Band 4G and 28 GHz Antennas

The co-designed or integrated design of both the microwave and millimetre antennas is shown in the schematic of Fig. 2, wherein the electrically small 4G LTE antenna is placed at right angle to the electrically small millimetre wave 5G antenna. A typical three-dimensional mobile phone case made of Poly Lactic Acid (PLA) is designed for accommodating proposed antenna along its thin panel edge. As both the antennas are placed at right angles, the mutual coupling is minimal as seen in Fig. 8. The magnitude of mutual coupling is lower than 25 dB in spite of the electrically close placement of the antennas. Moreover, corner bending results in the reduction of effective radiating volume. It is important to note that the patterns and other radiation characteristics are not affected by the presence of the lower frequency antenna. This implies that the proposed antenna topology would radiate a unidirectional beam in the 5G frequency band. For realizing MIMO configuration, another integrated microwave and mmWave 5G antenna element can be introduced to the opposite corner of smartphone. Since the distance between two antenna elements will be electrically large, mutual coupling will be therefore minimal [4]. Table 1 provides a comparison between proposed antenna module and other recently reported antenna designs.

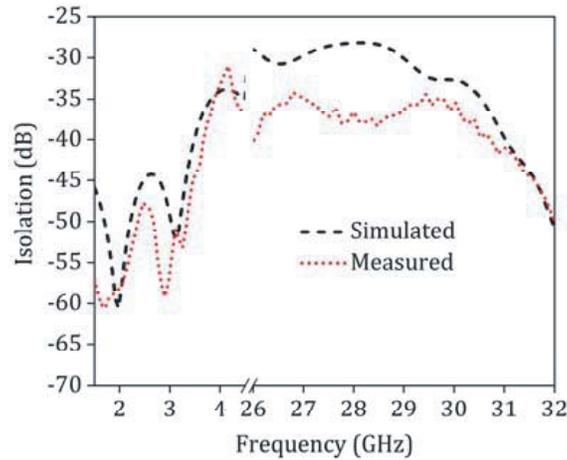


Figure 8. Mutual coupling of the integrated antenna design.

Table 1. Comparison of the proposed antenna architecture with other recently reported designs.

Figures of Merit	Proposed Design	[3]	[4]	[5]
4G LTE ANTENNA				
Area of single element	$5.6 \times 63 \text{ mm}^2$	$75 \times 8 \text{ mm}^2$	$14 \times 30 \text{ mm}^2$	$9 \times 30 \text{ mm}^2$
Fractional Bandwidth (BW)	26% (2.5 GHz band), 20.2% (3.5 GHz band)	31%-Low Band, 44%-High Band (-6 dB BW)	55% (-10 dB BW)	30% (-6 dB BW)
Operating LTE Bands	LTE 2300/2500/3500	LTE700/1900/2300/2500	LTE1900/2300/2500	LTE1900/2300/2500
MIMO	Expandable	No	Yes	Yes
Cost	Low	Relatively High	Relatively High	Relatively High
Corner Bent	Yes	No	Yes	No
Edge Panel Integration for future smartphones	Yes, less than 6 mm	Not feasible due to large physical footprint	Not feasible due to large antenna width	Not feasible due to large antenna width
mmWAVE 5G ANTENNA				
Area of antenna	$5.6 \times 18 \text{ mm}^2$ (Single Element)	$23 \times 7 \text{ mm}^2$ (1 \times 4 array)	$17.5 \times 14 \text{ mm}^2$	$23.2 \times 8.3 \text{ mm}^2$ (2 \times 4 array)
Impedance Bandwidth	27–31 GHz	25–30 GHz	25–38 GHz	26–28.4 GHz
Peak Realized Gain	7 dB	7 dB	10.5 dB	8.2 dB
MIMO	Extendable	No	Yes	No
Cost	Low	Relatively High	Relatively High	Relatively High
Corner Bent	Yes	No	Yes	No
Edge Panel Integration for future smartphones	Yes, less than 6 mm	Not feasible due to large physical footprint	Not feasible due to large antenna width	Not feasible due to large antenna width

3. CONCLUSION

An electrically small 4G LTE antenna is proposed, whose dimensions are consistent with the modern slim smartphones. The proposed 4G antenna is operational in the 2.5 GHz and 3.5 GHz bands. In addition, a millimetre wave 5G angled dipole antenna with parasitic radiators is proposed. Both the antennas are designed and fabricated on an inexpensive polycarbonate substrate. The 5G antenna offers a unidirectional beam, hence radiating towards the base station when being activated. A novel

placement topology of both the antennas is proposed and characterized. The proposed antennas might be a potential solution to realize compact antennas for future mobile devices which need backward compatibility.

REFERENCES

1. Hong, W., K. Baek, Y. Lee, Y. Kim, and S. Ko, "Study and prototyping of practically large-scale mmWave antenna systems for 5G cellular devices," *IEEE Communications Magazine*, Vol. 52, No. 9, 63–69, September 2014.
2. Rappaport, T. S., et al., "Millimeter wave mobile communications for 5G cellular: It will work!," *IEEE Access*, Vol. 1, 335–349, 2013.
3. Kurvinen, J., H. Kähkönen, A. Lehtovuori, J. Ala-Laurinaho, and V. Viikari, "Co-designed mm-wave and LTE handset antennas," *IEEE Transactions on Antennas and Propagation*, Vol. 67, No. 3, 1545–1553, March 2019.
4. Idrees Magray, M., G. S. Karthikeya, K. Muzaffar, and S. K. Koul, "Corner bent integrated design of 4G LTE and mmwave 5G antennas for mobile terminals," *Progress In Electromagnetics Research M*, Vol. 84, 167–175, 2019.
5. Hussain, R., A. T. Alreshaid, S. K. Podilchak, and M. S. Sharawi, "Compact 4G MIMO antenna integrated with a 5G array for current and future mobile handsets," *IET Microw. Antennas Propag.*, Vol. 11, No. 2, 271–279, February 2017.
6. Idrees Magray, M., G. S. Karthikeya, K. Muzaffar, and S. K. Koul, "Compact co-design of conformal 4G LTE and mmwave 5G antennas for mobile terminals," *IETE Journal of Research*, 2019.
7. Sharawi, M. S., M. Ikram, and A. Shamim, "A two concentric slot loop based connected array MIMO antenna system for 4G/5G terminals," *IEEE Transactions on Antennas and Propagation*, Vol. 65, No. 12, 6679–6686, December 2017.
8. Li, X., X. Shi, W. Hu, P. Fei, and J. Yu, "Compact triband ACS-fed monopole antenna employing open-ended slots for wireless communication," *IEEE Antennas and Wireless Propagation Letters*, Vol. 12, 388–391, 2013.
9. Rajkumar, R. and U. K. Kommuri, "A compact ACS-fed mirrored l-shaped monopole antenna with SRR loaded for multiband operation," *Progress In Electromagnetics Research C*, Vol. 64, 159–167, 2016.
10. Jarufe, C., et al., "optimized corrugated tapered slot antenna for mm-wave applications," *IEEE Transactions on Antennas and Propagation*, Vol. 66, No. 3, 1227–1235, March 2018.
11. Muzaffar, K., M. I. Magray, G. S. Karthikeya, and S. K. Koul, "High gain broadband vivaldi antenna for 5G applications," *2019 International Conference on Electromagnetics in Advanced Applications (ICEAA)*, 496–497, Granada, Spain, 2019.
12. Kota, K. and L. Shafai, "Gain and radiation pattern enhancement of balanced antipodal Vivaldi antenna," *Electronics Letters*, Vol. 47, No. 5, 303–304, March 3, 2011.
13. Febvre, P. and M. Donelli, "An inexpensive reconfigurable planar array for Wi-Fi applications," *Progress In Electromagnetics Research C*, Vol. 28, 71–81, 2012.
14. Moriyama, T., M. Manekiya, and M. Donelli, "A compact switched-beam planar antenna array for wireless sensors operating at Wi-Fi band," *Progress In Electromagnetics Research C*, Vol. 83, 137–145, 2018.
15. Rocca, P., M. Donelli, G. Oliveri, F. Viani, and A. Massa, "Reconfigurable sum-difference pattern by means of parasitic elements for forward-looking monopulse radar," *IET Radar, Sonar and Navigation*, Vol. 7, No. 7, 747–754, 2013.