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RESEARCH ARTICLE

Low-cost, low-profile and miniaturized single-plane antenna design for an Internet of Thing device applications operating in 5G, 4G, V2X, DSRC, WiFi 6 band, WLAN, and WiMAX communication systems

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Abstract

An integrated multi-band monopole antenna with three radiating strips having a compact structure to provide a double-wideband operation in an Internet of Things (IoT) device is studied and presented. The proposed antenna is very suitable for the heterogeneous multi-access network integration trend applications in mobile or fixed IoT devices, which can cover the 4G and 5G operating frequencies, the vehicle-to-everything and dedicated short range communication band from the IEEE 802.11p based wireless technology, the WiFi 6 band from the IEEE 802.11ax, the WLAN, and the WiMAX operating frequencies. The proposed antenna is manufactured on a single side of high quality FR4 substrate, which has a compact dimension of 8(L) × 8(W) × 0.8(T) mm^3, and is composed of multibranch strips, namely, multiple curved shapes, L shapes to be embedded in the IoT device as an built-in antenna. There are two operating bands designed between 2355-5000 and 5112-7000 MHz with well radiation efficiencies. The measured results show that the two operating bands are satisfied with reflection coefficient better than −6 dB, and total efficiencies of higher than 44% to 83%. In addition to that, the proposed antenna with multiband operation having a single side structure is simple to manufacture, low cost, low profile, and compact advantages.

KEYWORDS

4G, 5G, DSRC, IoT device, multi-band monopole antenna, V2X, WiFi 6 band, WiMAX

1 | INTRODUCTION

The next generation of mobile broadband networks, commonly called 5G, is promising wider coverage, much faster data speeds, very low latency, and highly reliable connections for smartphones and other devices than ever before. Working alongside 3G/4G systems and coexisting with Low Power Wireless Area, 5G will be crucial for new domains of smart services and applications without human interactions, such as Machine-to-Machine, Internet-of-Things (IoT), Vehicle-to-Vehicle or Vehicle-to-Everything (V2X), sensors gateways or servers' communications, surveillance cameras, Unmanned Aerial Vehicles, autonomous vehicles, medical robots, etc.

The main features of fifth-generation (5G) mobile communication include high throughput, low latency, high mobility, and high connection density.[1] However, other wireless communication systems (eg, WiFi, 2G, 3G, and LTE, etc.) still need to work together with 5G mobile communication system and live in peace. The new spectrum is critical to the success of 5G terrestrial mobile service.[2,3] It is expected that 5G services will cover a wide range of applications, which are generally categorized into enhanced Mobile Broadband, Ultra-reliable and Low Latency Communications, and massive Machine Type Communications.[4-6] The different physical properties of the spectrum (eg, range, penetration of structures, and propagation around obstructions) result in some applications being more suitable and expected to be deployed in certain spectrum ranges.[7] The spectrum from 3.4-3.6 GHz is globally allocated to mobile users and identified for International Mobile Telecommunications (IMT), and another 50 countries also have 3.3-3.4 GHz for International Mobile Telecommunications (IMT). Europe has announced that it intends to open 3.4-3.8 GHz to regional 5G spectrum.[8]

In addition, the US Federal Communications Commission proposed to release the 3.7-4.2 GHz band for 5G in May 2018, and they intend to make a proposal to use the 500 MHz spectrum more intensively, including seeking additional investment to make it available for commercial ground use.[9]

What is more worth mentioning is that the rapid evolution and cooperation of these mobile communications are for applications that have excellent results in the commercial application of the IoT. The IoT is a network of physical Objects, vehicles, buildings, and other elements—Integrated with electronic devices, software, sensors, and network connection allows these objects to collect and share data. The use of fifth-generation mobile communications and existing communication systems can make cloud computing more efficient and accurate.[1,10,11]

With the increase in wireless communication specifications for IoT devices and the shrinking of IoT modules, the design space of the antennas can be challenged. Therefore, how to make space for the antenna design has become an increasingly important issue. Moreover, the design of wireless communication products using multiband and broadband antennas has attracted great attention. The IoT scenario is defined as events in which the communication ecosystem links and captures certain physical parameters such as humidity, pressure, and temperature to translate these events into meaningful information.[12-14] Therefore, IoT devices must be small, compact, and installed in the required system. In addition to the miniaturization of integrated circuit design solutions that can miniaturize IoT devices, the space for antenna design also requires an attempt to reduce the size area. Although it is designed to meet the miniaturized size, it does not affect its own antenna performance. Regardless of any wireless communication product, the theme of antenna design needs to be considered as one of the important topics. Look for any possible design practices. IoT device design makes engineers more challenging in design decisions, and its design considerations include measuring costs, dimension, design workload, and manufacturing complexity. Antenna types commonly used in IoT products include chip antennas and printed circuit board (PCB) designs.[15,16] For the above reasons, the design goals of today's IoT device antennas need to be considered, including sufficient frequency band and bandwidth, simple design and miniaturized size. So far, monopole antenna design with multiband operation technology is an attractive and promising solution, which recently discussed and proposed one of many novel antenna technologies.[17-36] In Refs. 17-20, the authors used a modified inverted-F antenna (IFA) or monopole structure with multiple branches to create multiband operation and in line with the application of wireless communication devices in Bluetooth/WLAN, WiMAX, and Wi-Fi. In References 21 and 22, planar inverted F-type and monopole antenna with broadband design are proposed. Although these designs have good bandwidth coverage characteristics, the antenna area is relatively large. It is stated in the literature,[23,25,28] and that these antennas have open slots in the ground plane for multiband operation and are designed for the WLAN 2.4/5.2/5.8 GHz and LTE 2300/2500 MHz bands. Moreover, some antenna designs are composed of CPW-Fed (CPW is coplanar waveguide) structure and radiating rectangular patch, such as references in References 24-27 and 29-35. From the literature surveyed above, compact design recommendations and the effectiveness of multiband operation appear to be embedded in portable electronic and IoT devices.

This study, we present an embedded monopole antenna with three radiating strips having a compact structure, low cost and low profile to produce a double-wideband operation in the IoT device for the fourth-generation/fifth-generation (4G/5G), the V2X, the dedicated short range communication (DSRC), WiFi 6 band, WLAN, and WiMAX communications. The proposed antenna with stable radiation patterns is very suitable for the heterogeneous multi-access network integration trend applications in mobile or fixed IoT devices, which can cover the 4G long-term evolution (LTE) operating frequencies in 2300-5925 MHz with the bands of 7/38/40/41/42/43/46, the 5G operating frequencies in 2500-5000 MHz with the bands including n7/n38/n41/n77/n78/n79/n257/n258/n260, the V2X and DSRC band from the Institute of Electrical and Electronics Engineers (IEEE) 802.11p based wireless technology in 2500-5000 MHz, the WiFi 6 band form the IEEE 802.11ax in 5925-712 5 MHz, the WLAN operating frequencies in 2450-24 835, 5150-5350, and 5725-5850 MHz, the WiMAX operating frequencies in 2300-2690, 3400-3690, and 5170-5930 MHz. The bandwidths under the condition of $|S11| \leqq -6$ dB of the proposed antenna are 2645 MHz (2355-5000 MHz) and 1888 MHz (5112-7000 MHz), respectively. The proposed antenna consists of three meander shaped patch on the single copper foil printed circuit board, which is simulated by a commercial full-wave electromagnetic (EM) simulator ANSYS HFSS (ANSYS HFSS is 3D electromagnetic simulation software for designing and simulating high-frequency electronic products such as antennas, antenna arrays, RF.) and fabricated on a FR-4 substrate (FR-4 glass epoxy is the most common insulating substrate). The ground plane is close to the ground plane size of 8 mm × 35 mm, which is very small. Compared to the antenna proposed in the literature,[19-38] the proposed antenna can achieve a compact and small size. The performance of the proposed antenna is analyzed by high frequency finite element simulator and the measurement is verified in the anechoic chamber. In addition, the antenna is successfully simulated and measured, and stable radiation patterns and gains are observed over the entire operating band. Experimental results show that the proposed antenna with compact size of $8 \times 8 \times 0.8\ mm^3$ has nearly omnidirectional radiation characteristics and stable gains across all the operating bands with a simple structure. Measured results are in good agreement with EM simulation indicates that the proposed antenna is a good candidate for the fourth-generation/fifth-generation (4G/5G), the V2X, the DSRC, WiFi 6 band, WLAN, and WiMAX communication applications. The author will describe the concept and details of the antenna design in the next section, as well as the performance characteristics of the antenna, including the S-parameters, the radiation pattern, and the antenna gain compared to other proposed texts. Do a full discussion.

2 | PROPOSED ANTENNA CONFIGURATION

Figure 1 shows the proposed configuration of a monopole antenna with two operating band coverages between the frequency ranges of 2355-5000 and 5112-7000 MHz for the 4G LTE operating frequencies in 2300-5925 MHz with the bands of 7/38/40/41/42/43/46, the 5G operating frequencies in 2500-5000 MHz with the bands including n7/n38/n41/n77/n78/n79/n257/n258/n260, the V2X and DSRC band from the IEEE 802.11p based wireless technology in 2500-5000 MHz, the WiFi 6 band form the IEEE 802.11ax in 5925-712 5 MHz, the WLAN operating frequencies in

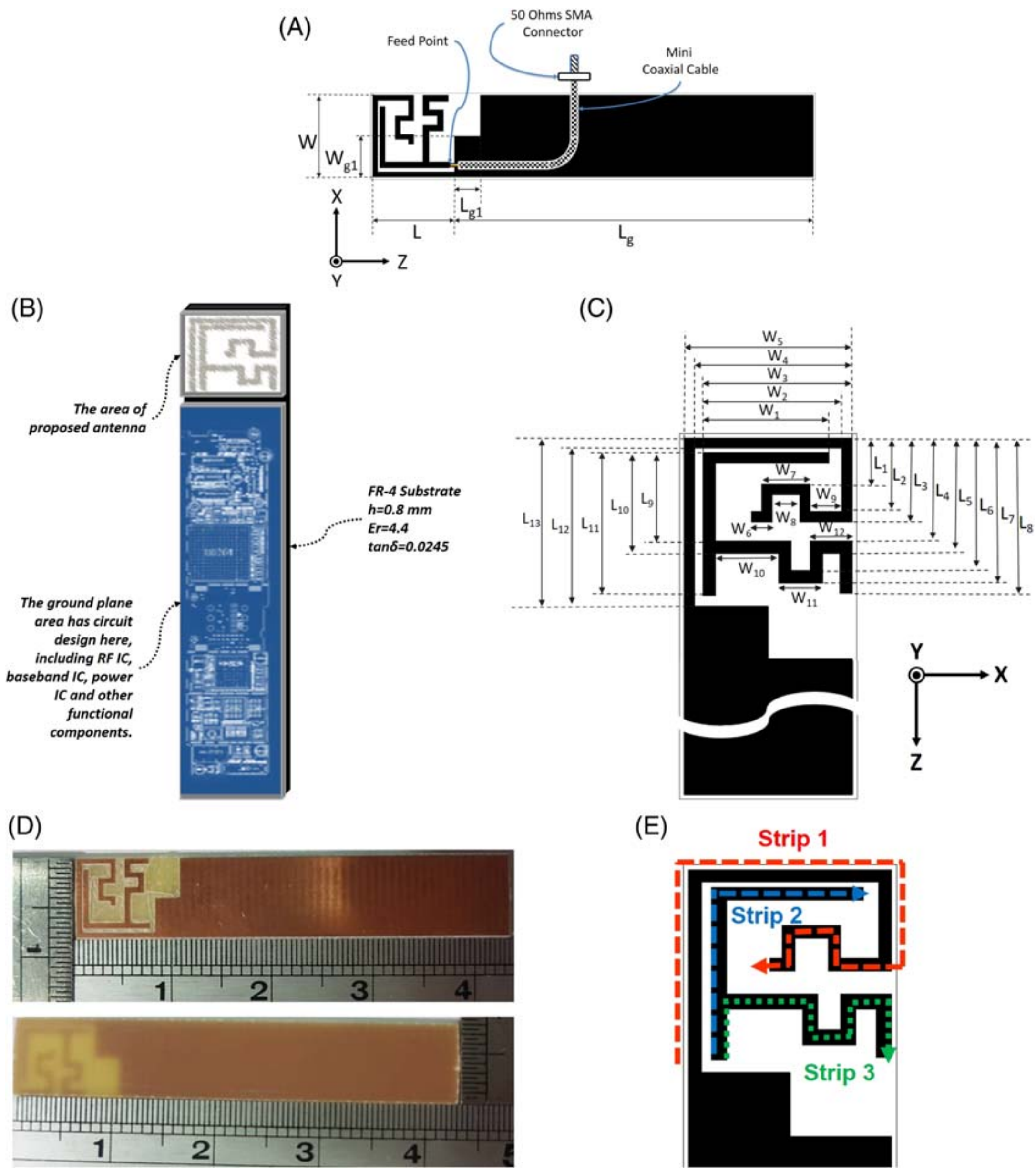

FIGURE 1 Configuration of the proposed design. A, Overall view of the antenna geometry; B, Single-sided copper surface design architecture and IoT device layout. C, The detailed dimensions on the top layer; D, Photograph of the fabricated multiband antenna with the top and bottom views. E, The proposed monopole antenna comprises three branch strips (Strip 1, Strip 2, and Strip 3) [Color figure can be viewed at wileyonlinelibrary.com]

2450-24 835, 5150-5350, and 5725-5850 MHz, the WiMAX operating frequencies in 2300-2690, 3400-3690, and 5170-5930 MHz in the IoT device.

A 0.8 mm thick FR4 substrate is used as the material for the antenna, which had a relative dielectric constant of 4.4 and a loss tangent of 0.024. The whole system circuit board has a total size of 43 mm × 8 mm (length × width) with an antenna portion of 8 mm × 8 mm (length × width) and a ground plane of 35 mm × 8 mm, as shown in Figure 1A, C. Figure 1B shows a single side copper surface design architecture with the system layout diagram. The proposed antenna is composed of a monopole antenna acting as three branch lines including the Strip 1 path to the system ground plane and the paths of the Strip 2 and Strip 3 to the main feed point on the top layer as shown in Figure 1E. The architecture is simple and easy to embed as an internal antenna inside the IoT device. The proposed multiband antenna prototype is fabricated and tested, and its front and back photographs are shown in Figure 1D. The antenna is fed by a 50-Ω coaxial cable line. The detailed dimensions are also listed in Table 1. A 50-Ω coaxial cable is connected across the feeding point between the meander-line and the system ground plane to excite the antenna. The antenna design uses three branches on the top layer and has better impedance matching. Therefore, a wide operating frequency bandwidth is produced between 1355-5000 and 5122-7000 MHz. The patch connected to the 50 Ω feeder through the match line mainly enhances the bandwidth of the entire operating frequency, including two frequency bands. The Strip 1 is mainly designed for the lower frequency band, while The Strips 2 and 3 are mainly designed

TABLE 1 Detail dimensions of proposed antenna. (Unit: mm)

W	W_{g1}	L	L_g	L_{g1}
8	3.5	7.5	35	2.5
W_1	**W_2**	**W_3**	**W_4**	**W_5**
6	6.6	7.1	7.5	8
W_6	**W_7**	**W_8**	**W_9**	**W_{10}**
1	2.3	1.3	1.5	3
W_{11}	**W_{12}**	**L_1**	**L_2**	**L_3**
2.1	2	2.2	3.5	4
L_4	**L_5**	**L_6**	**L_7**	**L_8**
4.9	5.5	6.3	6.9	7.4
L_9	**L_{10}**	**L_{11}**	**L_{12}**	**L_{13}**
4.2	4.8	6.8	7.5	8

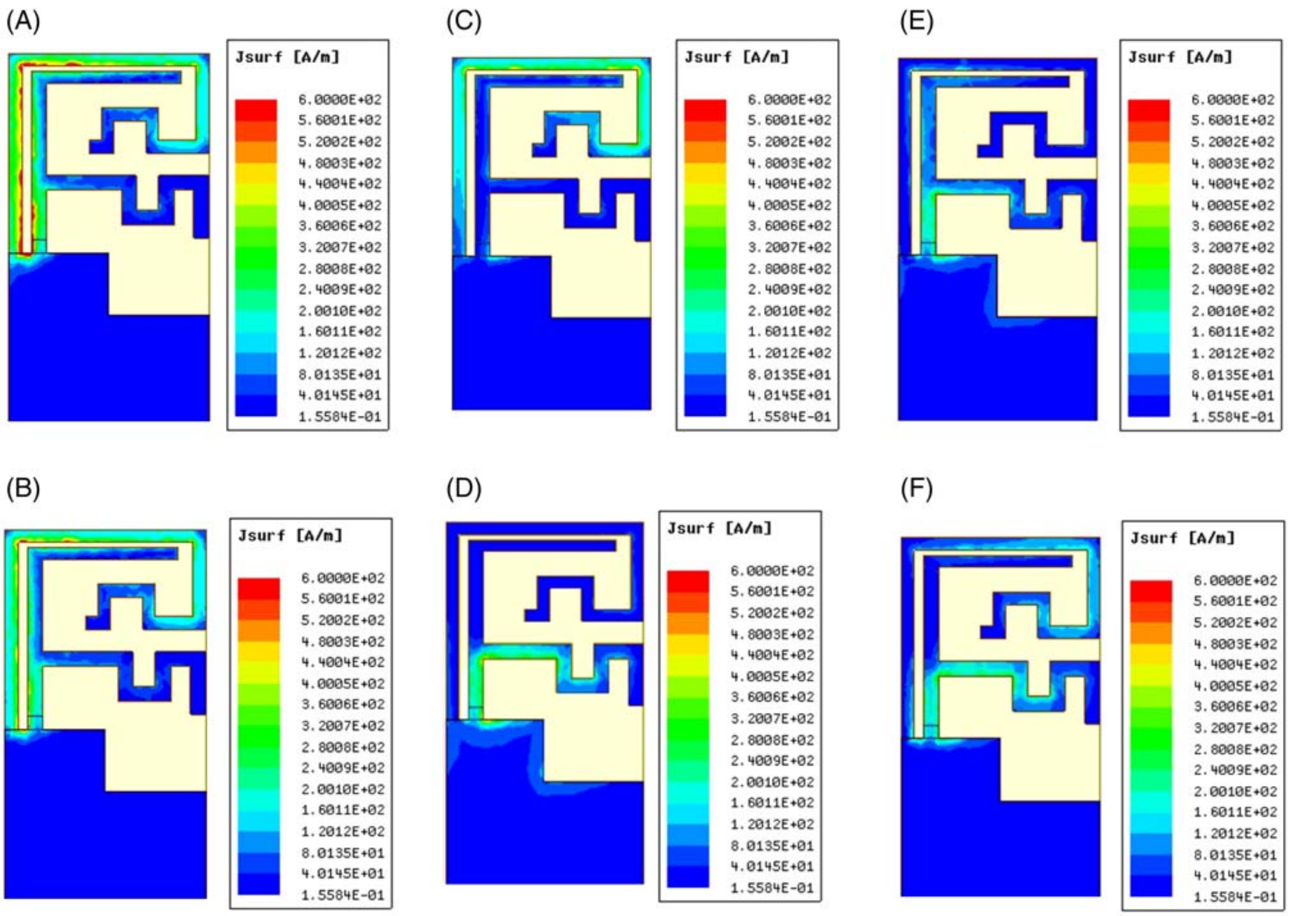

FIGURE 2 Simulated surface current distributions with cable and SubMiniature version A (SMA) model at different operating frequencies. A, 2.45 GHz. B, 3.2 GHz. C, 3.8 GHz. D, 5 GHz. E, 5.5 GHz. F, 6 GHz [Color figure can be viewed at wileyonlinelibrary.com]

for the higher frequency band. The operating frequencies of these strips are each designed to be about a quarter-wavelength. Furthermore, the proposed antenna employs a single copper foil PCB on the top layer, so that the bandwidth of the two bands meet the 4G LTE operating frequencies in 2300-5925 MHz with the bands of 7/38/40/41/42/43/46, the 5G operating frequencies in 2500-5000 MHz with the bands including n7/n38/n41/n77/n78/n79/n257/n258/n260, the V2X and DSRC band from the IEEE 802.11p based wireless technology in 2500-5000 MHz, the WiFi 6 band form the IEEE 802.11ax in 5925-712 5 MHz, the WLAN operating frequencies in 2450-24 835, 5150-5350, and 5725-5850 MHz, the WiMAX operating frequencies in 2300-2690, 3400-3690, and 5170-5930 MHz. In order to simulate the IoT device close to the real product, the ground plane design of the antenna is selected as a length of 35 mm, and a width of 8 mm, as a discussion of antenna design. Therefore, the antenna is mounted on the top edge of the IoT device and is suitable for the fourth-generation/fifth-generation (4G/5G), the V2X, the DSRC, WiFi 6 band, WLAN, and WiMAX communication applications. This study has used an EM simulator to analyze the antenna performance, including electrical and radiative properties.

Figure 2A simulates a current distribution of 2.45 GHz. For the proposed antenna, it can be observed that there is a strong current effect around the main path of the Strip 1 connecting ground plane and a coupling effect with the edge of the Strip 2. It is worth noting that the total length of the current path is calculated to be approximately 17.17 mm, which corresponds to a quarter wavelength of the operating frequency at 2.45 GHz. In addition, the surface current distribution at the operating frequencies of 3.2 and 3.8 GHz, the resonance of the lower frequency band can be observed from the current distributions shown in Figure 2B, C, respectively. Corresponding to the lower frequency band of the 3.2 GHz resonant mode, the current distribution clearly flows along the path of the Strip 1 and accompanied with the coupling effect of the Strip 2, as shown in Figure 2B. The total length of these paths for the resonant with 3.2 GHz are obtained about 13 mm, which are similar a quarter-wavelength of 3.2 GHz. The Figure 2C is shown that the current distribution at 3.8 GHz is displayed the mainly path of the Strip 1, which is

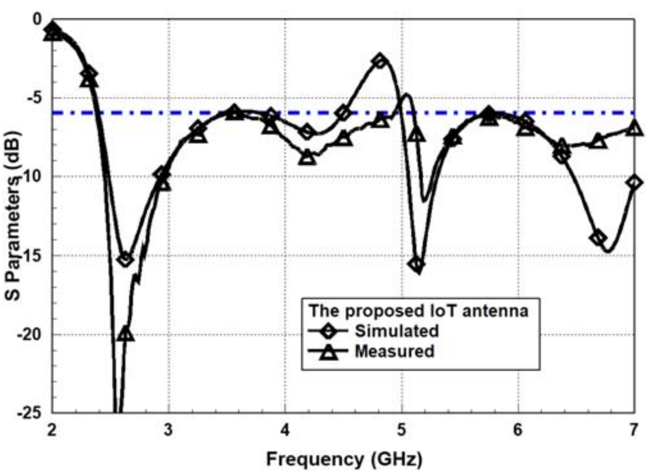

FIGURE 3 Simulated and measured reflection coefficients of the proposed monopole antenna [Color figure can be viewed at wileyonlinelibrary.com]

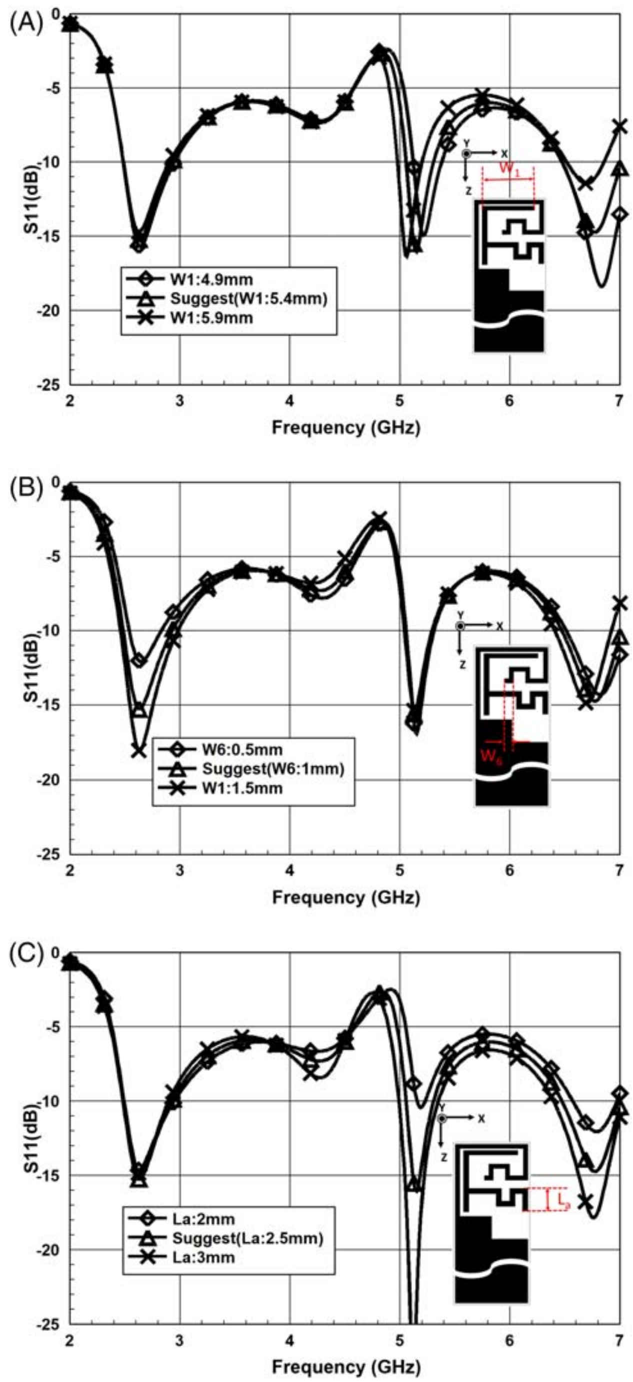

FIGURE 4 Simulated reflection coefficients with various lengths of the strips for the proposed antenna. A, Strip length W_1 for Strip 2. B, Strip length W_6 for Strip 1. C, Strip length L_a for Strip 3 [Color figure can be viewed at wileyonlinelibrary.com]

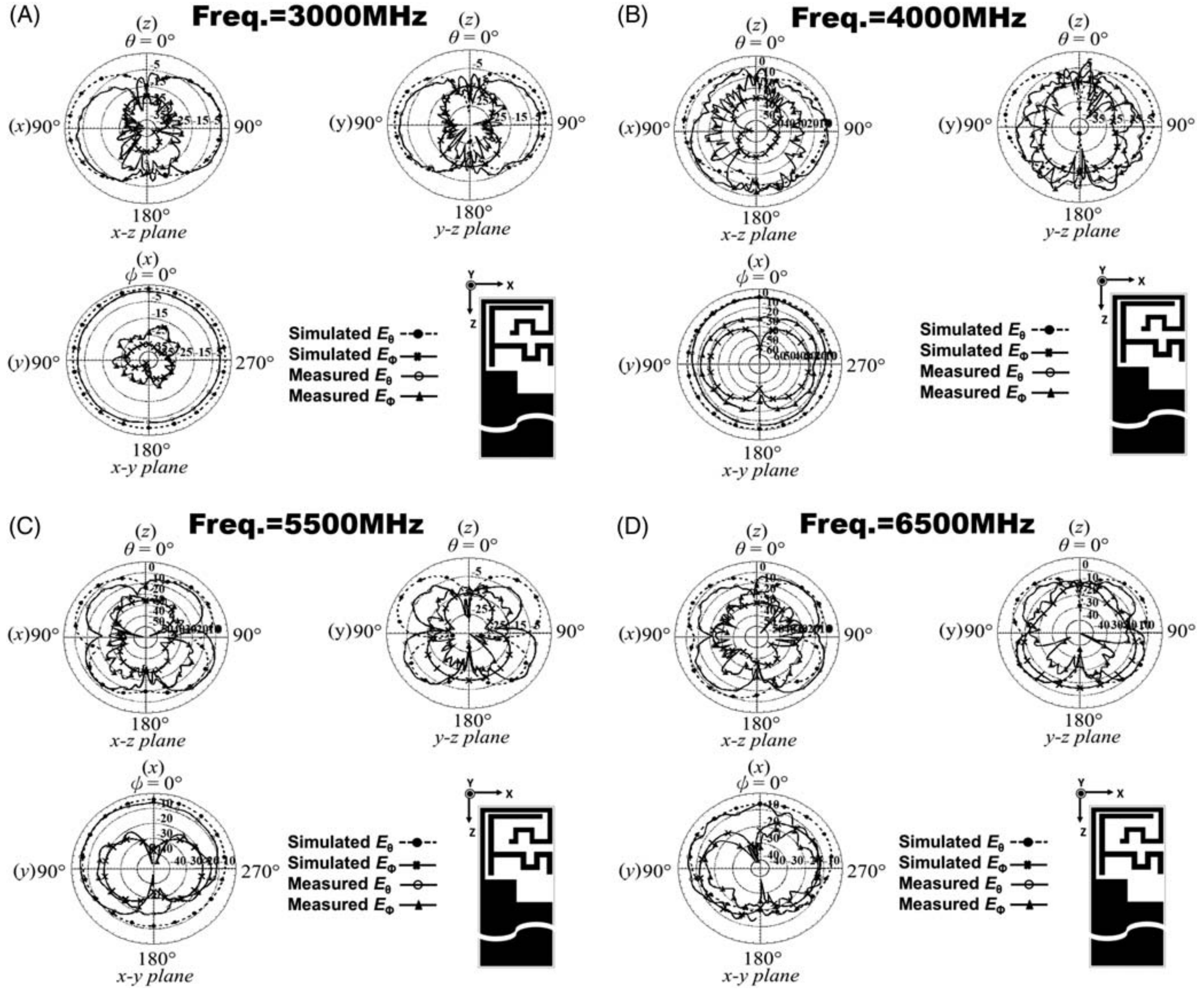

FIGURE 5 Simulated and Measured radiation patterns at different operating frequencies. A, 3 GHz. B, 4 GHz. C, 5.5 GHz. D, 6.5 GHz

obtained the total lengths about 9.53 mm, and also meet a quarter-wavelength of 3.8 GHz.

In addition, in the upper frequency band of 5 GHz, the current distribution is only the path of the Strip 3, and its total length is about 7.96 mm. These lengths are also about a quarter of a wavelength, as shown in Figure 2D. The current distribution at 5.5GHz is including the paths of the Strip 2 and 3, which is obtained the total lengths about 7.2 mm, as shown in Figure 2E. Finally, the current distribution with the upper band at 6 GHz is mainly shown the Strip 3 on the top layer accompanied with the end of the Strip 1 which are gotten the total lengths about 6.5 mm, as shown in Figure 2F.

As described above, the proposed monopole antenna comprises three branch strips and also covers an extremely wide bandwidth with the lower and upper band are 2645 MHz (2355-5000 MHz) and 1888 MHz (5112-7000 MHz), respectively. Section 3 will present a study of the parameters used to evaluate the effect of strip length on the reflection coefficient.

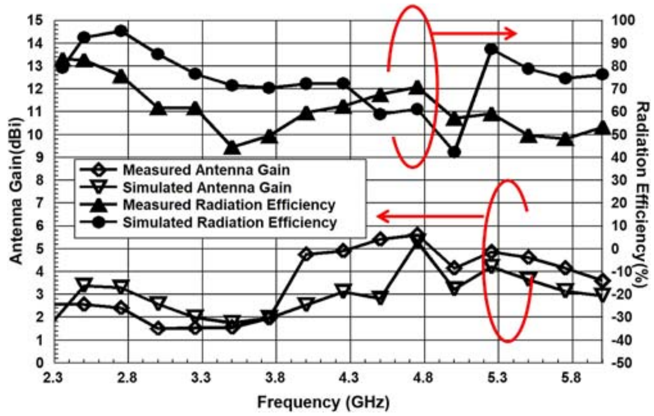

FIGURE 6 Simulated and measured peak gain and radiation efficiency [Color figure can be viewed at wileyonlinelibrary.com]

3 | RESULTS AND DISCUSSIONS

In this section, the proposed antenna is studied covering the antenna design and tuning analysis process with the results of

TABLE 2 Comparisons of antenna size among proposed antenna and other studies

Published literature	System ground size comparison (L mm × W mm)	Radiator physical size comparison (L mm × W mm)	Supported band (GHz)
Al-Khaldi et al[19]	33 × 13	7 × 33	2.5-3.5, 5-5.5
Gonçalves et al[20]	20 × 29	9 × 29	2.3-2.69
Saini et al[21]	44 × 25	20 × 18	2.3-2.7, 3.4-3.6
Yang et al[22]	54 × 15	50 × 33.55	1.39-1.48, 1.75-4.2, 5.04-6.0
Chen et al[23]	45 × 13	13 × 10	2.4-2.484, 4.7-5.825
Ullah et al[24]	35 × 13	35 × 40	2.3–2.69, 3.4-3.7, 5.15-5.85
Saxena et al[25]	30 × 13.5	30 × 21.5	2.3-2.62, 2.63-2.9, 3.3-4.8, 5.5-8.02
Hsu et al[26]	50 × 19	50 × 31	1.43-3.29
Kou et al[27]	40 × 11	40 × 29	2.21-2.53, 3.2-3.83, 5.41-8.37
Li et al[28]	18 × 8.7	18 × 25.3	2.41-2.63 3.39-3.70 4.96-6.32
Pandit et al[29]	21 × 7.3	21 × 16.7	2.35-2.53, 3.2-4.26, 5.24-6.06
Swathi et al[30]	40 × 17.5	40 × 27.5	1.68-2.71, 3.26-4.06, 5.03-6.25
Tangthong et al[31]	20.8 × 19.2	25 × 16.1	2.29-2.98, 3.23-4.16, 5.08-6.38.
Yu et al[32]	35 × 10	35 × 25	3.2-3.9, 5.75-5.85
Kuma et al[33]	24 × 5	24 × 25	2.50-2.71, 3.37-3.63, 5.20-5.85
Kim et al[34]	40 × 15	40 × 35	2.39-2.59, 3.1-3.57, 5.45-6.5
Ali et al[35]	22 × 8.3	22 × 16.7	2.26-2.57, 3.27-3.60, 5.69-5.98
Wong et al[36]	150 × 75	150 × 4	2.41–2.63, 5.15-5.85
Chung et al[37]	40 × 10	10 × 10	2.27-2.79 3.11-3.72 5.10-5.92
Wang et al[38]	140 × 70	23 × 5	2.4-2.484 5.15-5.35 5.725-5.825
Proposed	35 × 8	8 × 8	2.355-5, 5.122-7

measurement and simulation. The proposed multiband antenna has been fabricated using an FR4 substrate as shown in Figure 1D. The return loss performance of the prototype is measured and confirmed by utilizing a vector network analyzer (Agilent E5071C). Figure 3 shows the measured and simulated reflection coefficients of the proposed antenna. A good agreement between simulation and measurement is obtained. Also, two operating bands with 6 dB return loss have been obtained in 2355-5000 and 5112-7000 MHz, corresponding to 71.92% and 31.17% bandwidths, respectively. This method is used to measure radiated radio frequency (RF) power and receiver performance according to the CTIA-Wireless Association Wireless Device Air Performance Test Plan (CTIA is Cellular Telecommunications and Internet Association). The simulation and measurement impedance bandwidth defined by 3:1 voltage standing wave ratio (VSWR) has been widely used in internal wireless wide area network (WWAN) antenna design specifications.

Thence, the proposed antenna can be used for the 4G LTE operating frequencies in 2300-5925 MHz with the bands of 7/38/40/41/42/43/46, the 5G operating frequencies in 2500-5000 MHz with the bands including n7/n38/n41/n77/n78/n79/n257/n258/n260, the V2X and DSRC band from the IEEE 802.11p based wireless technology in 2500-5000 MHz, the WiFi 6 band form the IEEE 802.11ax in 5925-712 5 MHz, the wireless LAN (WLAN) operating frequencies in 2450-24 835, 5150-5350, and 5725-5850 MHz, the Worldwide Interoperability for Microwave Access (WiMAX) operating frequencies in 2300-2690, 3400-3690, and 5170-5930 MHz for heterogeneous multi-access network integration trend applications in mobile or fixed IoT devices. The parametric studies of the proposed antenna are proposed, discussed and performed by using the commercially available high-frequency structure simulator, as shown in Figure 4.

The simulated return loss for the various branch lengths W_1 of the antenna is compared and is shown in Figure 4A. When increasing the length of the branch W1, the resonance frequency of the band will move toward low frequencies. This adjustment affects the resonant mode of the upper band. In our proposed antenna design, the branch W_1 is chosen to be 5.4 mm in this design. However, the lower band does not change significantly. The performance variation of the proposed antenna with different strip lengths W_6 is shown in Figure 4B. The resonant frequency in the lower and upper bands is lowered when the length of the strip W_6 is increased. The length W_6 is selected to be 1 mm in the proposed antenna design. However, the bandwidth of the lower frequency band is reduced at the operating frequency of 2355-5000 MHz. The resonant frequency in the upper band can be lowered when the length of the strip L_a is increased, as shown in Figure 4C. The length of the strip L_a is optimized to be 2.5 mm. From the above, it is known that the frequency offset caused by various manufacturing conditions can be appropriately captured when the proposed antenna structure is employed. Good impedance matching over the frequency band of interest can also be achieved. Therefore, this antenna can be used as an internal antenna in an IoT device and has the advantage of dual ultra-wideband operation.

The antenna gain and radiation efficiency are measured in a far-field anechoic chamber [ETS-Lindgren measurement system, http://www.ets-lindgren.com]. Figure 5A-D shows the simulated and measured radiation patterns in the xy, yz, and zx planes for the case shown in Figure 1A at 3, 4, 5.5, and 6.5 GHz, respectively. Obtaining almost all omnidirectional modes at these operating frequencies. Good coverage and quality of communication for the 4G LTE operating frequencies in 2300-5925 MHz with the bands of 7/38/40/41/42/43/46, the 5G operating frequencies in 2500-5000 MHz with the bands including n7/n38/n41/n77/n78/n79/n257/n258/n260, the V2X, and DSRC band from the IEEE 802.11p based wireless technology in 2500-5000 MHz, the WiFi 6 band form the IEEE 802.11ax in 5925-712 5 MHz, the WLAN operating frequencies in 2450-24 835, 5150-5350, and 5725-5850 MHz, the WiMAX operating frequencies in 2300-2690, 3400-3690, and 5170-5930 MHz systems can be implemented for the proposed antenna. Furthermore, Figure 6 are displayed the peak gains and radiation efficiencies of simulated and measured. The antenna performance in the lower and upper bands is obtained in Figure 6. The antenna gain varies from 1.5 to 5.3 dBi for the lower band and 1.5 to 5.6 dBi for the upper band. The efficiency variation is from 42% to 95% for the lower band and 44 to 83% for the upper band. The proposed monopole design is with stable antenna gain and radiation efficiency and is suitable for the 4G LTE operating frequencies in 2300-5925 MHz with the bands of 7/38/40/41/42/43/46, the 5G operating frequencies in 2500-5000 MHz with the bands including n7/n38/n41/n77/n78/n79/n257/n258/n260, the V2X, and DSRC band from the IEEE 802.11p based wireless technology in 2500-5000 MHz, the WiFi 6 band form the IEEE 802.11ax in 5925-7125 MHz, the WLAN operating frequencies in 2450-24 835, 5150-5350, and 5725-5850 MHz, the WiMAX operating frequencies in 2300-2690, 3400-3690, and 5170-5930 MHz. In Table 2, comparisons of the proposed antenna with those reported in References 19-38 on antenna and system ground sizes are listed. It can be seen that the proposed design is very compact and can be embedded in the IoT wireless communication device.

4 | CONCLUSION

This work successfully reported a built-in, highly compact multiband monopole antenna for the 4G LTE operating frequencies in 2300-5925 MHz with the bands of 7/38/40/41/42/43/46, the 5G operating frequencies in 2500-5000 MHz with the bands including n7/n38/n41/n77/n78/n79/n257/n258/n260, the V2X and DSRC band from the IEEE 802.11p based wireless technology in 2500-5000 MHz, the WiFi 6 band form the IEEE 802.11ax in 5925-712 5 MHz, the WLAN operating frequencies in 2450-24 835, 5150-5350, and 5725-5850 MHz, the WiMAX operating frequencies in 2300-2690, 3400-3690, and 5170-5930 MHz operations. This antenna is suitable for embedding in the IoT wireless communication device. Typical results such as S-parameters, radiation efficiency, antenna gain, and radiation pattern are simulated and measured, and they can meet the requirements of IoT systems. The manufactured antenna has also been tested. The experimental data is usually consistent with the simulation results. This miniaturized antenna is expected to be used in practical applications of emerging wireless communication devices.

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REFERENCES

[1] Akpakwu GA, Silva BJ, Hancke GP, Abu-Mahfouz AM. A survey on 5G networks for the internet of things: communication technologies and challenges. *IEEE Access*. 2018;6:3619-3647.

[2] Feng L, Zhao P, Zhou F, et al. Resource allocation for 5G D2D multicast content sharing in social-aware cellular networks. *IEEE Commun Mag*. 2018;56:112-118.

[3] Liu J, Au K, Maaref A, et al. Initial access, mobility, and user-centric multi-beam operation in 5G new radio. *IEEE Commun Mag*. 2018;56:35-41.

[4] Sachs J, Wikström G, Dudda T, Baldemair R, Kittichokechai K. 5G radio network design for ultra-reliable low-latency communication. *IEEE Network*. 2018;32:24-31.

[5] Hu Y, Gursoy MC, Schmeink A. Relaying-enabled ultra-reliable low-latency communications in 5G. *IEEE Network*. 2018;32:62-68.

[6] Mukherjee A. Energy efficiency and delay in 5G ultra-reliable low-latency communications system architectures. *IEEE Network*. 2018;32:55-61.

[7] Hu F, Chen B, Zhu K. Full spectrum sharing in cognitive radio networks toward 5G: a survey. *IEEE Access*. 2018;6:15754-15776.

[8] New GSMA Report Sets Out Industry Vision for the 5G Era [Online]. https://www.gsma.com/newsroom/press-release/new-gsma-report-sets-out-industry-vision-for-the-5g-era/.

[9] FCC proposes to free up 3.7GHz-4.2GHz band for 5G [Online]. https://www.telegeography.com/products/commsupdate/articles/2018/05/24/fcc-proposes-to-free-up-3-7ghz-4-2ghz-band-for-5g/.

[10] Khan AA, Abolhasan M, Ni W. 5G next generation VANETs using SDN and fog computing framework. *Proceedings of the 15th IEEE Annual Consumer Communications & Networking Conference (CCNC)*; Las Vegas, NV, USA, 2018:1-6.

[11] Schmoll R-S, Pandi S, Braun PJ, Fitzek FHP. Demonstration of VR/-AR offloading to Mobile Edge Cloud for low latency 5G gaming application. *Proceedings of the 2018 15th IEEE Annual Consumer Communications & Networking Conference (CCNC)*; Las Vegas, NV, USA, 2018:1-3.

[12] Miorandi D, Sicari S, De Pellegrini F, Chlamtac I. Internet of things: vision, applications and research challenges. *Ad Hoc Netw*. 2012;10:1497-1516.

[13] Al-Fuqaha A, Guizani M, Mohammadi M, Aledhari M, Ayyash M. Internet of things: a survey on enabling technologies, protocols, and applications. *IEEE Commun Surv Tutorials*. 2015; 17:2347-2376.

[14] Zanella A, Bui N, Castellani A, Vangelista L, Zorzi M. Internet of things for smart cities. *IEEE Internet Things J*. 2014;1:22-32.

[15] Sojuyigbe S, Daniel K. Wearables/IOT devices: challenges and solutions to integration of miniature antennas in close proximity to the human body. *Proceedings of the IEEE Symposium on Electromagnetic Compatibility, Signal Integrity*; Santa Clara, CA, USA, 2015:75-78.

[16] Lizzi L, Ferrero F, Danchesi C, Boudaud S. Design of antennas enabling miniature and energy efficient wireless IoT devices for smart cities. *Proceedings of the IEEE International Smart Cities Conference (ISC2)*; Trento, Italy, 2016:1-5.

[17] Chen W-S, Lin G-L, Yang C-K. Small monopole antenna with two curved strips for wireless USB applications. *Proceedings of the Asia-Pacific Symposium on Electromagnetic Compatibility (APEMC)*; Taipei, Taiwan, 2015:200-203.

[18] Chen W-S, Lin G-Q, Liu H-M. The multi-band monopole antenna for USB devices. *Proceedings of the Asia-Pacific Symposium on Electromagnetic Compatibility (APEMC)*; Taipei, Taiwan, 2015: 204-207.

[19] Al-Khaldi M. A highly compact multiband antenna for Bluetooth/WLAN, WiMAX, and Wi-fi applications. *Microw Opt Technol Lett*. 2017;59:77-80.

[20] Gonçalves R, Carvalho NB, Pinho P. Small antenna design for very compact devices and wearables. *IET Microw Antennas Propag*. 2017;11:874-879.

[21] Saini HS, Thakur A, Kumar R, Sharma A, Kumar N. A small size wideband planar inverted-F antenna for USB dongle devices. *Proceedings of the IEEE 1st International Conference on Power Electronics, Intelligent Control and Energy Systems (ICPEICES)*; Delhi, India, 2016:1-3.

[22] Yang Y, Liu Y. A CPW-fed triple-band planar monopole antenna for internet of things applications. *Proceedings of the International Conference on Cyber-Enabled Distributed Computing and Knowledge Discovery*; Shanghai, China, 2014:380-383.

[23] Chen W-S, Yang C-K, Lin G-Q. Compact design of printed antenna with a ground slot for USB applications. *Proceedings of the IEEE 5th Asia-Pacific Conference on Antennas and Propagation*; Kaohsiung, Taiwan, 2016:127-128.

[24] Ullah S, Hayat S, Umar A, Ali U, Tahir FA, Flint JA. Design, fabrication and measurement of triple band frequency reconfigurable antennas for portable wireless communications. *AEU-Int J Electron C*. 2017;18:236-242.

[25] Saxena S, Kanaujia BK, Dwari S, Kumar S, Tiwari R. A compact microstrip fed dual polarised multiband antenna for IEEE 802.11 a/b/g/n/ac/ax applications. *AEU-Int J Electron C*. 2017;72:95-103.

[26] Hsu C-W, Shih M-H, Wang C-J. A triple-strip monopole antenna with dual-band circular polarization. *Proceedings of the IEEE 5th Asia-Pacific Conference on Antennas and Propagation (APCAP)*; Kaohsiung, Taiwan, 2016:137-138.

[27] Kou H-R, Zhang B-Z, Duan J-P, Ge S-L. Triple-band monopole planar antenna designed for WLAN/WiMAX application. *Proceedings of the IEEE International Conference on Microwave and Millimeter Wave Technology (ICMMT)*; Beijing, China, 2016:555-557.

[28] Li L, Zhang X, Yin X, Zhou L. A compact triple-band printed monopole antenna for WLAN/WiMAX applications. *IEEE Antennas Wireless Propag Lett*. 2016;15:1853-1855.

[29] Pandit VK, Harish AR. A compact CPW-fed triple band monopole antenna for WLAN/WiMAX applications. *Proceedings of the Asia-Pacific Microwave Conference (APMC)*; New Delhi, India, 2016:1-4.

[30] Swathi S, Bhanumathi V. Triple band monopole antenna for WLAN and WIMAX applications. *Proceedings of the International Conference on Recent Trends in Information Technology (ICRTIT)*; Chennai, India, 2016:1-4.

[31] Tangthong N, Moeikham P, Akatimagool S. A compact multi band CPW-Fed monopole antenna using L-shaped and straight slots. *Proceedings of the 13th International Conference on Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology (ECTI-CON)*; Chiang Mai, Thailand, 2016:1-4.

[32] Yu K, Li Y, Wang Y. Multi-band metamaterial-based microstrip antenna for WLAN and WiMAX applications. *Proceedings of the International Applied Computational Electromagnetics Society Symposium—Italy (ACES)*; Florence, Italy, 2017:1-2.

[33] Kuma A, Jhanwar D, Sharma MM. A compact printed multistubs loaded resonator rectangular monopole antenna design for multiband wireless systems. *Int J RF Microw Comput-Aided Eng*. 2017; 27(9):1-10.

[34] Kim C-Y, Yang D-G, Ahmad MS. Multiband omnidirectional planar monopole antenna with two split ring resonator pairs. *Microw Opt Technol Lett*. 2017;59:753-758.

[35] Ali T, Biradar RC. A compact multiband antenna using λ/4 rectangular stub loaded with metamaterial for IEEE 802.11N and IEEE 802.16E. *Microw Opt Technol Lett*. 2017;59:1000-1006.

[36] Wong K-L, Lu J-Y. Small-size narrow open-slot antenna for the 2.4/5.2/5.8-GHz WLAN operation along the side edge of the metal-framed smartphone. *Microw Opt Technol Lett*. 2016;58:886-892.

[37] Chung M-A. Miniaturized triple band monopole antenna with a coupled branch strip for bandwidth enhancement for IoT applications. *Microw Opt Technol Lett*. 2018;60:2336-2342.

[38] Wang H, Ying L. A very compact internal WLAN antenna. *Microw Opt Technol Lett*. 2019;61:2150-2154.

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