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Wearable Wonder: A compact dipole antenna for triple band Sub-6 GHz 5G and WLAN applications

***Abstract**.This paper presents a detailed design of a compact dipole antenna for triple band sub-6 GHz 5G and WLAN applications. The design procedure, divided into three stages, primarily focuses on enhancing impedance bandwidth and gain across all three resonant frequency bands but keeping the dimensions small. The proposed antenna was designed to work at 2.45 GHz, 3.5 GHz and 5.8 GHz with maximum gains 3.275 dB, 3.45 dB and 6.25 dB respectively. The proposed antenna a good candidate for the application of Sub-6 GHz 5G as well as WLAN in wearable devices.*

***Streszczenie.** W artykule przedstawiono szczegółowy projekt kompaktowej anteny dipolowej do zastosowań trójpasmowych 5G i WLAN w paśmie poniżej 6 GHz. Procedura projektowa, podzielona na trzy etapy, koncentruje się przede wszystkim na zwiększeniu szerokości pasma impedancji i wzmocnieniu we wszystkich trzech pasmach częstotliwości rezonansowych, przy zachowaniu małych wymiarów. Proponowana antena została zaprojektowana do pracy w pasmach 2,45 GHz, 3,5 GHz i 5,8 GHz z maksymalnymi zyskami odpowiednio 3,275 dB, 3,45 dB i 6,25 dB. Proponowana antena jest dobrym kandydatem do zastosowania w sieciach 5G Sub-6 GHz oraz WLAN w urządzeniach przenośnych. (**Wearable Wonder: kompaktowa antena dipolowa do zastosowań w potrójnym paśmie Sub-6 GHz 5G i WLAN**)*

Keywords: Balun, dipole antenna, triple band antenna, WLAN.
Słowa kluczowe: Balun, antena dipolowa, antena trójpasmowa, WLAN.

Introduction

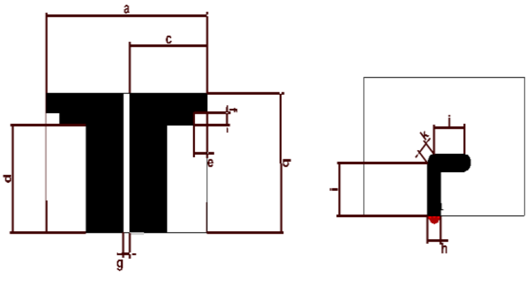
Within the last few years, a tremendous lot of effort has been focused in wireless communications toward multiband antennas. These antennas are becoming extremely hot topics for research, as modern communication systems have a very wide applicability. Compared to its counterpart, the single-band antenna, multiband antennas can support more than one frequency band, which makes them especially suitable for the Sub-6 GHz 5G mobile communication and WLAN systems. The advent of 5G technology and wide WLAN systems has led to the need for a multifrequency antenna in operation. Modern communication systems happen to require the simultaneous support of multiple frequency bands to operate effectively. For example, the Sub-6 GHz band is important for 5G mobile communication, whereas WLAN systems operate on different frequency bands. The use of single-band antennas in the present-day systems, which have remained traditional, is not feasible to satisfy the ever-growing bandwidth requirements. With a rapid increase in consumer electronics and communication consumption, the need for higher bandwidths also increased. The requirement cannot be fulfilled by single-band antennas as their frequency spectrum is extremely limited in range. So, to eliminate this problem, researchers have focused on the compact dipole antenna for triple band. The mentioned antenna is designed with a particular three-frequency band so that the attained bandwidth is much higher than that corresponding to the performance of a single-band antenna. Due to compact size, this antenna can also be utilized in space-constrained applications.

This design and development of the triple-band antenna are being considered for application in Sub-6 GHz 5G and WLAN applications used with wearable devices. If so executed, the discussed antenna can genuinely revolutionize the approach to wireless communication with a solid and efficient answer to bandwidth shortcomings in the system designs of the moment. Conclusion Shift towards multiband antennas is a huge step forward in wireless communication. Multiband antennas, such as the proposed compact triple band dipole, represent an indispensable element in making history while continuing to advance the boundaries of what we consider technology. These antennas support multiple frequency bands and are compactly sized, hence holding promise for realizing an ever-increasing demand on the bandwidth needed in this modern world. Complementary artificial magnetic conductor metamaterials for broadband wireless transceivers is proposed in [1]. Metamaterial antenna loaded with double hexagonal SRR is intended for WLAN/WiMAX applications [2]. The cost of design will be low and the overall system of communication will be improved by this [3]. Magneto-electro-dielectric planar waveguided metamaterials that can be loaded into a compact microstrip antenna gain enhancement [4]. CPW fed method is used for the triple band antenna [5, 6, 8, 13, 24, 27, 28]. Metamaterial is used to improve gains [7, 11,12, 15]. Compact tri-band wide-slot monopole antenna with dual-ring resonator for WLAN/WiMAX applications [9]. Cross dipole antenna for 4G and Sub-6 GHz 5G base station applications [10]. A metamaterial inspired tapered patch antenna for WLAN/WiMAX applications [16]. Miniaturization of multi-band antennas is a quite challenging task and hence attracted many researchers to develop different possible techniques. Using an integrated suspended meta surface wide bandwidth and enhanced gain achieved in a low-profile dipole antenna [18]. A compact CPW feeds multiband antennas for WLAN/ INSAT/ WPAN applications [14]. Recent developments in triple band antennas [19, 23]. A metamaterial antenna for 2.4 GHz Wi-Fi applications in [20]. Slots are formed in fractal, metamaterials proposed for dual-band applications [21].

A new microstrip feed for WLAN/WiMAX dielectric resonator antenna [22]. Hybrid-coupled SRRs is utilized for meta loop antennas to realize multiband [26]. In [29], the low-profile dual-band dual-polarized antenna is utilized for AMC surface. Metamaterials are used for polarization conversion [17, 25, 30]. A lot of available literature had focused on obtaining higher gain and wider bandwidth in antennas. However, such designs are mainly complex metamaterials, which in fact represent considerable disadvantages. This paper comes forth with an overall in-depth study on a compact triple band dipole for application in Sub-6 GHz 5G mobile communications and WLAN communications. The proposed antenna is designed using a very low-cost FR4 substrate, which has double-sided copper coating. Using these materials, the choice is not only cost-effective but also enhances the performance of the antenna. To this point, the paper explains the design procedure for the proposed antenna along with parametric studies. This will be achieved by the approach and thus give deep insight into the design procedure as well as all the factors that could influence the performance of the antenna. The CST simulation software is used for the present work as a rather reliable tool in the sphere of antenna design. The more important feature is the compact size, 15.5 mm x 24 mm x 1.6 mm. But despite that, the proposed antenna allows triple band applications. Thus, this design becomes very promising in the context of modern communication systems. In conclusion, this paper deals with a novel design concept for an antenna, surpassing the conventional challenges related to the complexities of metamaterial structures. This concludes to a compact dipole antenna design that offers additional benefits in terms of gain and bandwidth for possible applications within 5G and WLAN applied in wearable devices. It explains a detailed procedure of design and further parametric study that leads to new development in the future.

Antenna Design

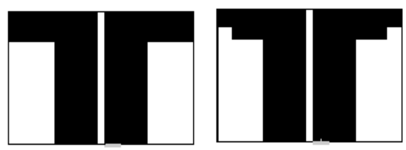
The design procedure of the antenna as proposed here, as shown in Fig. 1, consists of the steps which are very complicated and intricate. The antenna is of overall dimensions 15.5 mm × 24 mm, with a modified dipole type structure at the top part and a modified balun at the bottom. Its mentioned modifications are critical for the performance of the antenna and will be designed in a way that maximizes its functionality. The proposed antenna has a total dimension of 15.5*24 mm2. The proposed antenna structure consists of a modified top dipole and a modified bottom balun. The dimensions of the given antenna are as follows: a = 24 mm, b= 15.5 mm, c= 11.5 mm, d= 12 mm, e= 2 mm, f= 1.4 mm, g= 1 mm, h= 2 mm, i= 6 mm, j= 4.50 mm, k= 1 mm respectively. All these dimensions have been carefully chosen for maximum performance over the three frequency bands. The proposed antenna is fabricated on cheap FR4 substrate. FR4 substrate is widely used in electronics fields as it is cost-effective and easier to fabricate. Here, FR4 substrate has a dielectric constant of 4.4 and a thickness of 1.6 mm. The substrate is covered with a double-sided copper cladding, and it has electrical conductivity of 5.8e+007 and the thickness of 0.035 mm. This copper cladding allows the antenna to effectively transmit and receive signals, and in this respect, the copper plating is the most important part of the antenna, and therefore designing this proposed antenna includes a series of steps and choices of materials. All parts of the design - the modified dipole structure along with the balun, the substrate and cladding choice - contribute to the performance of the antenna and its appropriateness for the applications to be used on Sub-6 GHz 5G and WLAN functionalities for wearable devices.



(a) (b)

Fig.1. Layout of the proposed antenna design (a) Top view (b) Bottom view

The design evolution of the proposed antenna is a stepwise process involving changes in the structure of the dipole and balun. This is schematically represented in Fig. 2 and Fig. 3, showing each alteration applied at various stages of the design evolution at each step of the development process. The first step of the design evolution is the creation of initial dipole and balun structures. These structures provide the primary structure for the antenna and are an integral part of its working. In the second phase, these structures are further modified to improve their performance. Such modifications are done after careful planning so that they aid in improving the overall performance of the antenna. In the third phase, the modified structures are further optimized. This step is critical for optimizing the antenna's performance across the three frequency bands. Throughout this design evolution, changes in the return loss characteristics of the antenna are carefully monitored. These changes, shown in Fig. 4, give deep insights into the effectiveness of the design modifications. From these changes, a design team can understand when to make and how much modification is required to its structure. From the above discussion, it can be concluded that the design evolution of the proposed antenna is a time-consuming process that requires careful planning execution and analysis. These all processes significantly impact on the antenna performance to make it suitable for Sub-6 GHz 5G and WLAN applications. Fig. 2, Fig. 3, and Fig. present corresponding images. 4. They can be used to shed some light on this process, as well as on the principles put forth behind the design of the proposed antenna.



(a) (b)

Fig.2. Evolution of Proposed Design: Modified Dipole Structure (a) step 1 (b) step 2

With Step 1, the initial step toward the evolution of the proposed antenna, a simple dipole of size 15.5 mm x 24 mm is designed along with a straight balun. At this stage, the antenna exhibits dual-band resonance at 2.4 GHz and 5.8 GHz for return losses of -19.78 dB and -17.84 dB, respectively. The achieved bandwidths at the two frequencies are 172 MHz at 2.4 GHz and 181 MHz at 5.8 GHz. A gap of 1 mm is chosen between the dipole elements as the capacitive gap for better isolation. In step 2, the design is further optimized for achieving three bands. This is done by shortening the dipole strips with a cut having dimensions of 2 mm by 1.4 mm, as shown in Fig. 2. This creates another new band at 3.5 GHz while the already existing resonant frequency 2.4 GHz and 5.8 GHz remains a resonant frequency. The return losses at these frequencies come up as -27.31 dB, -26.25 dB, and -27.77 dB, respectively. Bandwidths obtained at the three resonant frequencies were 130 MHz for 2.4 GHz, 261 MHz for 3.5 GHz, and 329 MHz for 5.8 GHz. Briefly, the design evolution of the proposed antenna includes a careful procedure of changing the dipole and balun structures to achieve the desired triple-band characteristics. Each stage of the design and implementation of the process has been carefully orchestrated so that the antenna it produces can work efficiently over a range of different frequency bands. In the final stage of design, Step 3, the straight balun is translated into a bend version as shown in Fig. 3. The use of a balun here is very advantageous. It acts as a transformer, which converts the unbalanced signal from the feed line to a balanced one for the two printed dipole strips. Transformation is thus the most crucial for proper working of the antenna. A balun is placed between the microstrip line and the coplanar stripe line. This is done to match the input impedance to the 50-ohm feed line, which is a standard in RF communication systems. In this manner, if the impedances are well-matched, it will guarantee that the highest amount of power will be transferred from the feed line to the antenna. To make the performance even better, the end of the microstrip balun is shorted by a shorting pin. The feeding point of the antenna has a dimension of 1 mm and has an associated shorting pin. It serves to aid the radiation efficiency of the antenna by providing a return path for the current from one end of the pin. Conclusion: Step 3 in the design evolution is comprised of a series of modifications that have been made to the balun structure. These changes include the introduction of bending in the balun and its combination with the microstrip line and the coplanar stripe line while incorporating a shorting pin for the optimal performances of an antenna across the three bands of frequency. The proposed compact, efficient, and effective antenna is quite suitable for applications in the range of Sub-6 GHz 5G and WLAN.

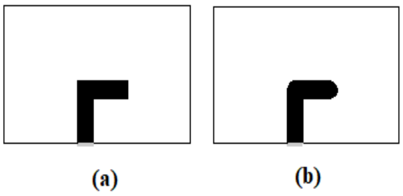


Fig.3. Evolution of Proposed Design: Modified Balun Structure (a) step 2 (b) step 3

The three changes made all increased impedance at the three resonant frequencies: 2.45 GHz, 3.5 GHz, and 5.8 GHz-to thus improve performance. Values of return loss come as -35.48 dB, -31.23 dB, and -41.22 dB, respectively. Bandwidth obtained at these frequencies has been expanded: 461 MHz for 2.4 GHz, 448 MHz for 3.5 GHz, and 605 MHz for 5.8 GHz; together, all these have resulted in better performance and stability of the signal.

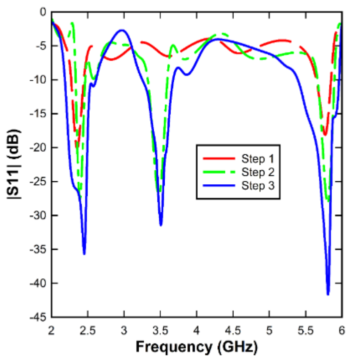


Fig.4. Return loss observed during evolution of design

Parametric Study

The objective of the parametric study is to determine optimum values for two significant parameters: cut length, h, and bend radius. In Fig. 5, the change of cut length during step 2 has been presented in the range from 0 mm to 2 mm. At the initial step 1 cut length value of 0 mm, the dual bands at 2.4 GHz and 5.8 GHz resonant frequencies mean no cut has been applied. This was accompanied at the step 2 cut of 1.4 mm by an increased frequency at 3.5 GHz and the improvements of the impedance for the resonant frequencies formed. For step 3, it was raised to a cut length of 2 mm. The resonant frequencies became absent at some points. A new band appeared at -13.69 dB at 2.8 GHz. This means that resonant impedance matching will be best reached with cut length being 1.4 mm. The variation of bend radius from 0 mm to 1.5 mm in the design evolution is depicted in Figure 6. In addition, the straight balun is converted into a bend structure for the improvement in the impedance bandwidth during the design evolution. At first, the design is obtained with the resonant frequencies at 2.45 GHz, 3.5 GHz, and 5.8 GHz with the -10 dB bandwidths of 152 MHz, 280 MHz, and 233 MHz, respectively. This process starts with introducing a bend radius of 0.5 mm in step 1, which shows significant improvements to the impedance and bandwidth but with slight variations to the resonant frequencies.

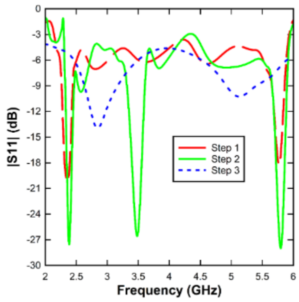


Fig.5. Return loss observed during variation in cut length

For bend radius 0.5 mm, resonant frequencies 2.4 GHz, 3.5 GHz, and 5.8 GHz were obtained with corresponding return losses of -27.31 dB, -26.25 dB, and -27.77 dB, and respective impedance bandwidths at -10 dB were 130 MHz, 261 MHz, and 239 MHz. The highest performance was achieved at step 2, at a bend radius of 1 mm, and optimum -10 dB impedance bandwidth at the resonant frequencies of 2.45 GHz, 3.5 GHz and 5.8 GHz were obtained. Return losses for these frequencies were -35.48 dB, -31.23 dB, and -41.22 dB, respectively. Corresponding -10 dB impedance bandwidths for each frequency were 461 MHz, 448 MHz, and 605 MHz, respectively. However, beyond the bend radius of 1 mm, unwanted oscillations were induced on the resonant frequencies at step 3. This creates an important requirement for maintaining the optimal bend radius.

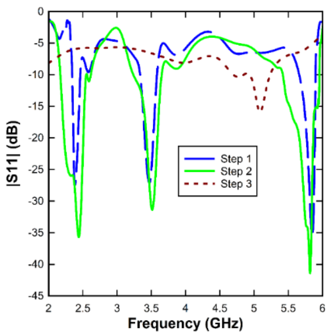


Fig.6. Return loss observed during variation in bend radius

Results and Discussion

Fabrication involves the use of a 1.6 mm thick FR4 substrate with a tangent loss of 0.02. In terms of the structure of the antenna, a dual-layer copper of a thickness of 0.035 mm is meticulously placed down on the substrate material. The fabrication method adopted is chemical etching. The antenna in Figure 7 is the actual tangible output that was obtained during the fabrication process.

Using the proposed design, an antenna is successfully fabricated whose performance parameters have been measured.

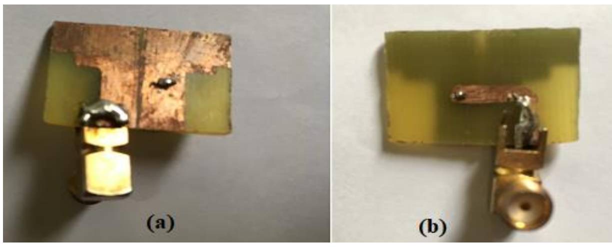


Fig.7. Fabricated Prototype of the proposed design (a) Front View (b) Back View

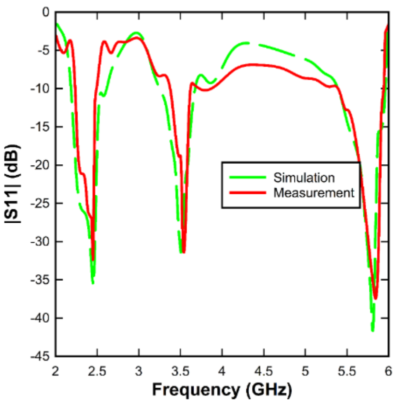


Fig.8. Comparison of simulated and measured return loss

The measured return loss (|S11| dB) of the fabricated prototype is accurately found by using a vector network analyzer. A comparison of simulated and measured return losses of the presented antenna is shown in Figure 8. The graph shows that the proposed working frequencies, 2.45 GHz, 3.5 GHz, and 5.8 GHz, are tolerably in good agreement both in simulation as well as in measurement. Seen, the returned loss values are -35.48 dB, -31.23 dB, and -41.22 dB, respectively; the corresponding -10 dB bandwidths are 461 MHz, 448 MHz, and 605 MHz. Measured results: the corresponding return loss values are -32.37 dB, -31.41 dB, and -37.39 dB; the -10 dB bandwidths are 272 MHz, 323 MHz, and 566 MHz, obviously fitting well with the simulated data. The close agreement between simulated and measured results is observed and shows an efficient antenna. The measured antenna has enough bandwidth for Sub-6 GHz 5G and WLAN applications, especially in wearable devices. For a better understanding of the antenna's behavior, surface current distributions at all three different resonant frequencies are depicted in Figure 9. Sectional analysis supports each part of the design that is responsible for the different resonant frequencies shown in the scatter plots. From Figure 9(a), the maximum current at 2.45 GHz is concentrated within the 12 mm microstrip lines, which can be attributed to the cause of resonance. The cut on the dipole arms structure creates the introduction of the band at 3.5 GHz as revealed in Figure 9(b). From Figure 9(c), it is also clear that the modified structure of the balun resulted in a return loss of -41.22 dB at 5.8 GHz to enhance the feeding into the proposed antenna. The above improvement is also further justified from the distribution of current along the entire radiating patch; the maximum concentration of current to reduce back reflections was found at selected points.

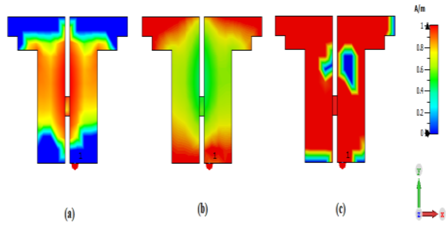


Fig.9. Surface current distribution at (a) 2.45 GHz (b) 3.5 GHz (c) 5.8 GHz.

Graphical representations are made for the simulated and measured patterns of the radiation at resonating frequencies - 2.45 GHz, 3.5 GHz, and 5.8 GHz. From this analysis, it is inferred that the simulated and measured patterns go nearly together and, therefore, can be trusted for the performance of the antenna. In addition, the behavior of the radiation is also consistent at both the lower and the higher resonance frequencies. In Figure 10, E-plane (XY-plane) and H-plane (YZ-plane) distributions of the proposed antenna are shown, and it can be observed that the antenna is bidirectional and omnidirectional. Such plots provide a lot of insight to the characteristics of radiation from an antenna, thereby providing full understanding on the performance of the antenna across different planes.

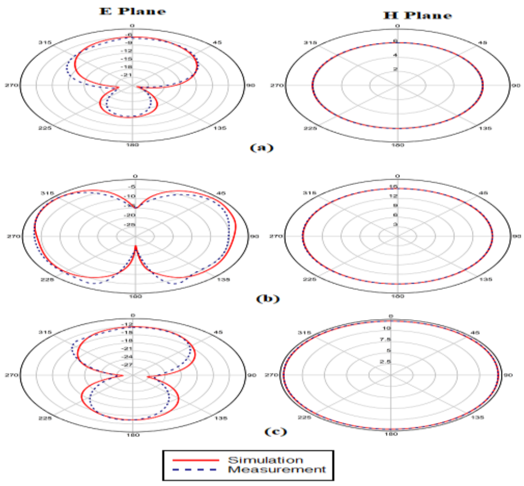


Fig.10. Radiation Patterns (a) 2.45 GHz (b) 3.5 GHz (c) 5.8 GHz

In Fig. 11, it is well established that the realized peak gain and efficiency of the proposed antenna over its entire bandwidth. For instance, when the frequency is 2.44 GHz, the realized gain is 3.275 dBi together with an efficiency of 82.30%. For the frequency at 3.51 GHz, the realized gain is 3.45 dBi, aided by an efficiency of 76.79%. The last measurement is at 2.82 GHz, at which the antenna has a measured gain of 6.25 dBi with an efficiency of 84.40%. The results obtained herein give an overview of the whole range of performance of the antenna at various frequency points in its operation range. The comparative analysis of the proposed antenna with state-of-the-art antennas reported in the literature is summarized in Table 1. In general, the data tells us that the proposed antenna is compact in size and further has better gain values and wider bandwidths as compared to the designs that have been documented in the literature. The findings stress the possible advantages and performance characteristics of the proposed antenna over the present designs.

Table 1. Comparison of the final design with the survey on existing antennas

Ref.	Dimension in mm	Operating Frequency in GHz	Gain in dBi
1.	40*35	2.76	4.45
2.	30*20	2.61,4.12,6.24	2.45,3.38,4.16
3.	40*45	3.5	4.9
4.	32*40	1.78,2.44,3.48	2.48,2.18,1.16
5.	40*24	2.33,3.56,5.70	1.62,2.34,2.53
6.	39.2*40	5.6	7.8
7.	30*34	2.17,3.52,5.25	1.0,1.0,3.50
8.	28*32	2.45,3.50,5.70	3.95,4.25,1.95
9.	32*28	7.7	7.2
10.	63*108	3.75	7.32
Proposed	39.2*40	5.6	7.8

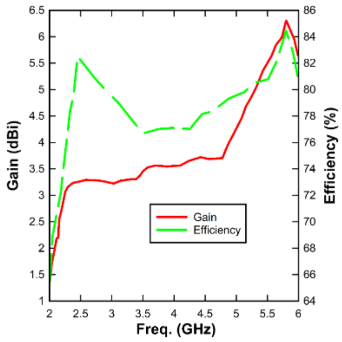


Fig.11. Realized peak gain and efficiency over the operating bandwidths.

The new antenna is relatively small in size with 15.5*24 mm². Measured return loss demonstrates resonance bandwidths at the frequency: 272 MHz, 323 MHz and 566 MHz and, therefore, accounts for the operational frequencies of 2.45 GHz, 3.5 GHz and 5.8 GHz. Moreover, it yields realized peak gain equal to 3.275 dB, 3.45 dB, and 6.25 dB at these frequencies, respectively. This basically draws attention to the efficiency and suitability of the proposed antenna design in applications which require compact dimensions, showing improvements within several frequency bands.

Conclusion

The developed work highlights the design and development of compact dipole antennas with an aim of establishing triple-band operation. Triple-band operation is noticed at 2.45 GHz, 3.5 GHz, and 5.8 GHz from the designed antenna with achieved peak gain at 3.275 dB, 3.45 dB, and 6.25 dB, respectively. It also maintains stable radiation in both E-plane and H-plane coupled with acceptable impedance matching at operating frequencies. These characteristics determine the applicability of the antenna to Sub-6 GHz 5G and WLAN. Its compactness, 15.5*24 mm, and simple structure make it possible to integrate with microwave circuitry easily, so it is a promising candidate for modern wireless applications, especially for wearable devices, whose size and characteristics of performance meet the imperatives of contemporary technology.

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