Miniaturised tri-band microstrip patch antenna design for radio and millimetre waves of 5G devices

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ABSTRACT

This research presents an extremely small, cheap and simple structure of multiple bands antenna, where is the proposed design comprise square-slotted a microstrip patch antenna with triple bands of RF and mm-wave for 5G. The conducting material is a perfect electrical conductor on both sides. The antenna is printed on FR-4 lossy with a 3.9 of epsilon. Our tiny antenna has a size of 1.5357x1.5357 mm^2. First, the design parameters were calculated using formulas and then these were simulated by the CST MWS. The simulation results show the antenna performance at the RF band from 0 to 3.4096 GHz with 3.29 gain, a value of return loss S_{11} and bandwidth of -13.229644 and 3.4096 GHz. The designed antenna works at the mm-wave band ranges 43.5-64 GHz with 3.49 gain, -42.419084 S_{11} and 20.252 GHz BW. Our antenna can also operate at the mm-wave from 81-95 GHz with -22.269547 S_{11}, 4.52 gain, and 14.085 GHz BW. The small size and supported bandwidth of the designed antenna is suitable for thin and fast transmission devices.

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1. INTRODUCTION

One of the most common names in the world of modern wireless communication is an antenna, which is a high paramount of electrical device that uses the space to transmit information. The systems requirements of wireless communication are increasingly smaller size and easily manufactured antennae working in different bandwidths. Around world standards of communication, such as "wireless local area network" (WLAN), "radio frequency identification" (RFID), "worldwide interoperability of microwave access" (WiMAX) and Mobile network such as the five-generation (5G) [1] are being deployed. Hence, multi-bandwidth antennae must be compatible with these standards. In the last few years, three types antenna with printed shapes to fulfill multi-band requirements have been developed, these being the slot antenna (SA), monopole antenna (MA), and patch antenna (PA) [2-11].

Diverse methods have been applied to get a multi-band antenna from a single-band antenna [12-17]. Traditional techniques of investigation on the antenna with a property of multi-band are either by making notches in the radiation element of an SA [9-11] or adding elements to obtain multiple radiations in patch of a PA [6-8] or MA [2-5]. The idea of these mechanisms is to get various paths of current at the surface of the antenna that resonate at different frequencies. The physical shape and size of radiation element lead to difficulty miniaturisation antenna to support various bands.

Previous investigation by researchers into multi-band or miniaturisation are as follows. In 2018, A. Sardi, et al [18] introduced a divider with a new shape of microstrip power to work with wide-band ranges (1.5-4.5 GHz) including ISM, DCS and WiMAX of wireless applications. The design was implemented by converting impedances and lengths of quarter-wavelength part at traditional Wilkinson power divider to Pi-shaped part. In 2019, Jabar, et al [19] proposed quad-band miniaturised microstrip patch antenna (MPA) to operate at 915MHz (UHF-band), 2.45 GHz, 5.8 GHz (ISM-band) and 3.5GHz (WiMAX-band). The antenna has a strip patch square- spiral dual-arm, coplanar waveguide (CPW) feed to the nutrition of substrate (FR-4) and is called the modified square-spiral antenna (MSSA). In 2018, D. A. J. Al-khaffaf, et al [20] developed a simple antenna with a square shape suitable for WLAN at 2.4GHz, with high gain and a very small return loss S_{11}. The antenna has size of 28.45×28.45×0.035mm^3 printed on copper and FR-4 as the conducting and dielectric materials, respectively. In 2019, Farhood, et al [21] proposed an antenna for ultra wide-band (UWB) (1.1-10.69 GHz), for use with Bluetooth at 2.4GHz and application for radar at 9.1GHz. The antenna has a hexagonal patch and two tucked capacitance load-line resonators (CLLRs) on the left side of the patch of the antenna. In 2020, Ali et al [22] designed a microstrip Nano antenna with WIFI shape and slot, which operates at THz band area and in the proximity of infrared. The conducting materials of the antenna are gold printed on silicon substrate. In 2019, Shah et al [23] satisfied the design of microstrip patch antenna has a reconfigurable with two-band presented a tunable apparatus. In 2019, Ali et al [24] introduced a compact microstrip antenna for applications of WBAN at ISM (2.4 GHz). Other researchers also designed microstrip antennae by using CST [25-43]. The aforementioned designed antennas are generally small size, work on single-band or little multi-band with a large size and have an expensive and complicated geometrical composition. The problem with the antenna relates to the low frequency ranges of the RF band and the antenna dimensions. The low frequency antenna has very large dimensions and vice versa. The supported band and gain of microstrip antenna represent the second issue

In this research, a cheap, small, thin, simple structure tri-band microstrip patch antenna for radio and millimetre wave applications is proposed. The designed antenna uses the PEC and RF4lossy materials as conducting and dielectric layers, respectively. The antenna patch has dimensions of 1.5357 x 1.5357 x 0.035 mm^3 with an inset-feed mechanism. The antenna serves many wireless communication systems in licensed and unlicensed applications with three different wide bands. Our proposed tiny antenna has an excellent performance, gain, VSWR reflection coefficient and very substantial supported bandwidth. We have been working to improve the performance and reduce the size. To date, there has been no very small antenna that works on 0-3.4 GHz until now. Our small simple structure triband antenna design operates on this range and also other two mm wave bands to be supported. The proposed antenna design has not a complex structure and sharply slots.

The organisation of this article is as follows. Section 2 presents the design considerations and mathematical constraints of a microstrip patch antenna. In section 3, the key performance indicators of the designed antenna and discussion are provided. In Section 4, a comparison of the results of the proposed design with previously constructed antennas is presented. The main findings the research is summarized in Section 5.

2. SMALL ANTENNA GEOMETRY AND DESIGN CONSIDERATIONS

There were challenges with the fabrication of our small antenna in terms of the measurements of the mm wave reflection coefficients. The designed antenna has been simulated using the CST platform. Figure 1 depicts the geometry design of the simple originally proposed antenna. We designed the miniaturised antenna with a resonant frequency of 60 GHz following the recommendations in [20]. At the beginning, all the antenna dimensions were mathematically calculated using antenna design equations. Then, the design was applied to the antenna simulation platform optimise the slots creation in terms of performance.

The description of the different layers for designing antenna is provided. A long time of research on antenna parameters and dimensions is taken to design the antenna. The microstrip antenna consists of three layers: patch, substrate and ground. Inception will discuss antenna's parts with the attention of size, expenditure, and serving, where are some considerations in the design of microstrip antenna such as the length of the patch ($0.3333\lambda_0<Lp<0.5\ \lambda_0$), and thickness must be very slim ($t<<\lambda_0$), where λ_0 represents the wavelength of free space. Furthermore, the substrate has height in the range ($0.003\lambda_0\leq h\leq 0.5\lambda_0$), whilst the dielectric constant in the range ($2.2\leq \varepsilon_r \leq 12$) [44-46]. The isolation power wastage of an antenna can be decreased by down of loss tangent to the substrate. The parameters of the patch should be selected by using the wisdom same as place and technique of feed line, length, and thickness [47].

The resonant frequency can be changed by shortening the position of the pin, which leads to a change in the distribution of the field and provokes inductive loading of the patch, as well as changing the dual bands with a parallel notch or felling slots on the radiant edges [48]. In our proposed small multiband antenna very small dimensions (L and W) are used, these being 1.5357mm square patch with a thickness 0.035mm. It is made from PEC material printed on a square substrate of 3.0714mm of square shape (Lg and Wg) dimensions, with a 0.8 mm height (h), using FR-4 lossy and with epsilon 3.9 as the dielectric constant. The ground layer has similar thickness as the patch plane and is the same size as the substrate. The central feed line mechanism has been given many features with the patch such as an easy excited, match, fabrication and impedance matching. The feed line has dimensions of the gap between patch and feed (GPF) is 0.35 mm with 0.5 mm the inset feed (Fi). The width of the feed line (Wf) is 0.3921 mm. The simulation results of our antenna design are provided in the next section.

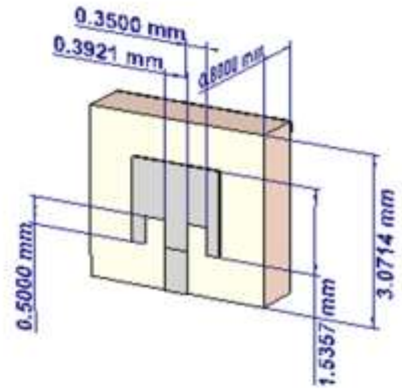


Figure 1. 3D schematic diagram of multiband small microstrip patch antenna design with dimensions

3. RESULTS AND PERFORMACE ANALYSIS

The software used to design the proposed antenna is the CST STUDIO SUITE Version 2018; the simulation is carried out in the method of time domain. There is tradeoff between the supported frequencies and antenna dimensions. In the other words, large antenna dimensions can provide low frequency ranges and vice versa. However, researchers can design the antenna dimensions with difficult slots to support low frequency range. Our small simple structure triband antenna design without slots can support radio and mm-wave and easily fabricated. The antenna is approximately a 3 mm square shape, which is appropriate for small and thin 5G devices. The reflection coefficient of our antenna design is shown in Figure 2.

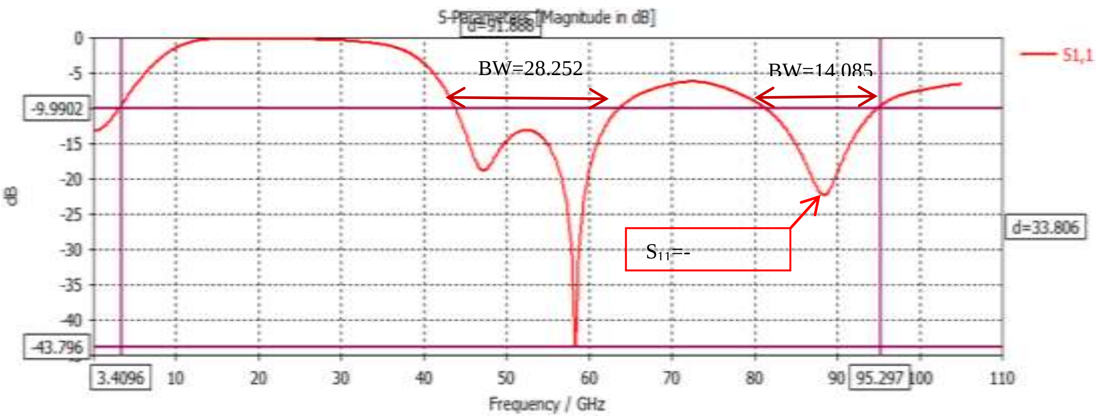
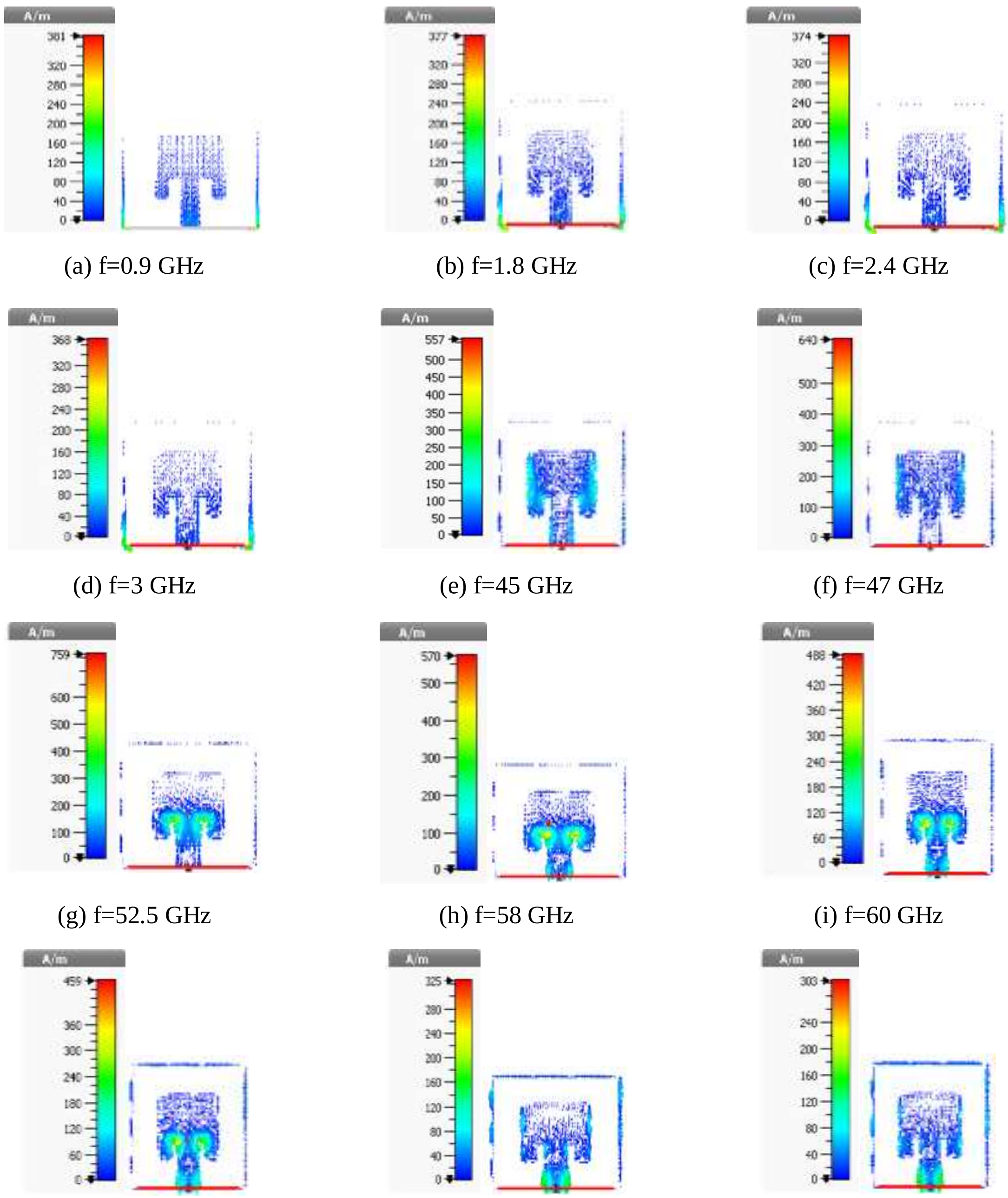


Figure 2. Depicts the CST simulated return loss scheme with calculated bandwidths and reflection coefficients of the small antenna design

The graph Figure 2 visualises the reflection coefficient S11 of our small antenna that is -13.2296dB, -42.419dB, and -22.2695dB at the minimum points of supported bands 0-3.4096 GHz, 43.5-64GHz, and 81-95GHz respectively. The first challenging supported band of low range frequencies is calculated with proportional to -10dB, where the first band 0-3.4096 GHz appears 3.29 gain and contains bands to supporting the industrial, scientific, and medical radio band (ISM), global system for mobile communication (GSM or 2G), UMTS (3G), RFID, Zigbee, Bluetooth, and WLAN, while the other 43.5-64 GHz with 3.49 gain included the V-band used in WLAN IEEE 802.11ad standard, and satellite constellations, and the third band ranges from81 to 95 GHz has a 4.52 gain, the W-band spectrum (92-95 GHz) is covered that is utilised for satellite communications, tracking applications, military radar targeting, mm-wave radar research and several non-military applications. Moreover, the upper E-band (81-86 GHz license-light) is also included in third supplied band of our proposed small patch antenna. The VSWR is discerning fulfillment adaptation of the antenna to the line of transmission, where the values attained to the three bands nearest to one and this is mean that good results as the one known is approximately an ideal value. Figure 3 shows the allocation of current surface distribution for the triple-band proposed antenna design. It is evident from the above graphs that the current distributions near the slots and feed line. The obtained gains of triple bands antenna are high agreeable values with comparison to the directivity, as shown in Figure 4.



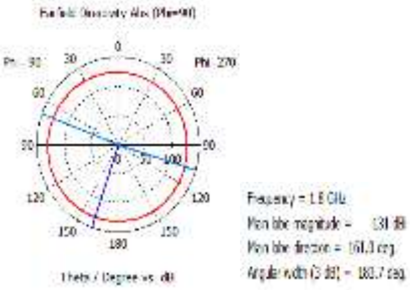
(a) f=0.9 GHz (b) f=1.8 GHz (c) f=2.4 GHz

(d) f=3 GHz (e) f=45 GHz (f) f=47 GHz

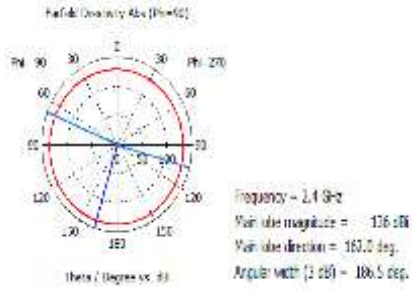
(g) f=52.5 GHz (h) f=58 GHz (i) f=60 GHz

(j) f=62 GHz (k) f= 88 GHz (l) f=90 GHz

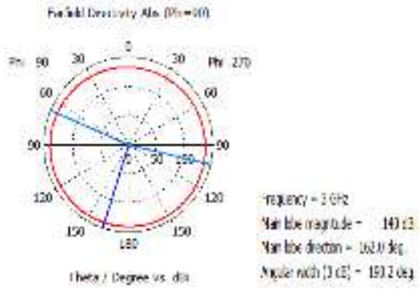
Figure 3. Simulated surface current distribution of the resonant frequency for the simple small microstrip antenna



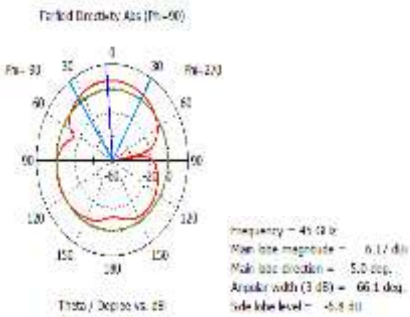
(a) f=1.8 GHz



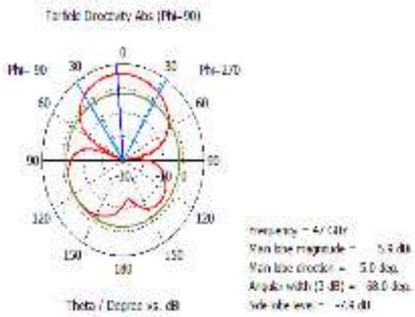
(b) f=2.4 GHz



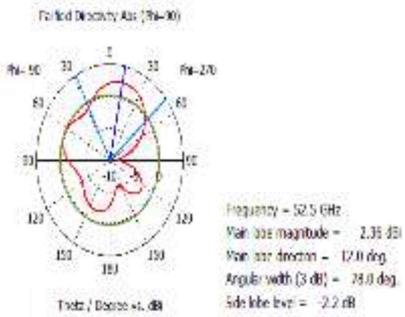
(c) f=3 GHz



(d) f=45 GHz

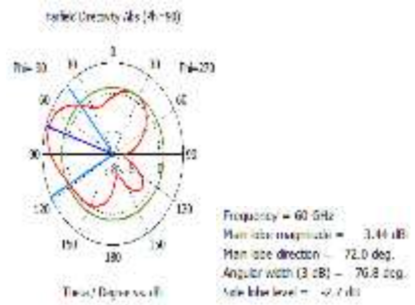


(e) f=47 GHz

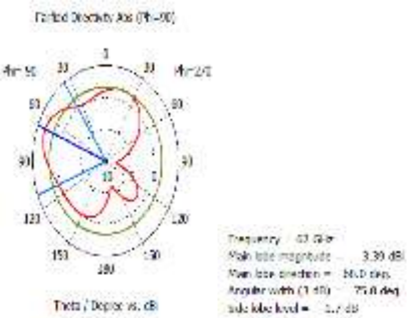


(f) f=52.5 GHz

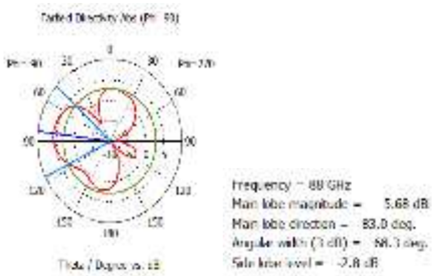
(g) f=58 GHz



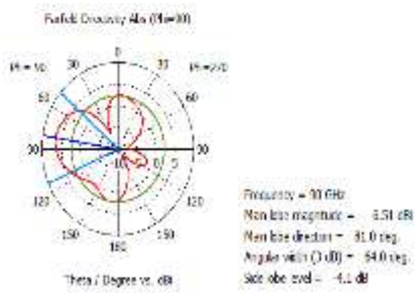
(h) f=60 GHz



(i) f=62 GHz



(j) f= 88 GHz



(k) f=90 GHz

Figure 4. 2D electromagnatic radition pattren of our simulated small patch antenna

4. PERFORMANCE COMPARISON WITH SOME RECENT PREVIOUS WORKS

The performance comparison between our proposed miniaturised antenna with some recent multi-band antennas is provided in the Table 1. It can be seen that the designed antenna, with an overall size of just 3.0714mm^2, is the smallest of those antennas working on RF and mm waves. As mentioned above, the proposed antenna is miniaturised and gives higher efficiency than with previous works. It has been demonstrated that our design is much smaller than previously reported antennas. The designed antenna in [22] has been applied to the THz band not on RF or mm waves.

Table 1. A comparison between recently published multiband antennas and the that introduced in this work

[Ref.]	physical size (L_p,W_p)	Resonance frequency	Return loss	Gain	Bandwidth
[18]	22 x 28 mm^2	2.8GHz	Lower than 12 dB	good agreement	1.5GHz-4GHz efficient for the three bands
[19]	28 × 28mm^2	915 MHz	-26 dB	11.33 dB	(872 - 929 MHz)
		2.45 GHz	-13 dB	1.17 dB	(2395 - 2510 MHz)
		3.5 GHz	-12 dB	1.45 dB	(3470 - 3550 MHz)
		5.8 GHz	-25 dB	1.96 dB	(5698 - 5900 MHz)
[21]	26 × 30 mm^2	2.4 GHz	- 34 dB	Excellent gain	(1.1 - 10.69 GHz)
		9.1 GHz	-23.22 dB		operating on a wide-range of the frequencies
[22]	900 × 900nm^2 Nano antenna	106 THz	-31.3 dB	6.2 dB	(103.3 - 110.3 THz)
	900 × 900nm^2 Slot-nano antenna	126 THz	-18.2 dB	6.57 dB	(124.5 - 127.8 THz)
[23]	19.9 × 25.9mm^2	3.38 GHz	-21.8 dB	good agreement	(3.315 - 3.5 GHz)
		5.37 GHz	-21.1 dB		(5.3 - 5.55 GHz)
[25]	32 × 32 mm^2	2.6 GHz	-20.5 dB	0 dB	(2.50 - 2.70 GHz)
		3.35 GHz	-20 dB	1.6 dB	(3.2 - 3.55 GHz)
		5.15 GHz	-19.5 dB	1.2 dB	(4.95 - 5.53 GHz)
		6.1 GHz	-12 dB	-2.1 dB	(5.65 - 7.20 GHz)
[26]	105 × 175 mm^2	0.704 GHz			
		2.4 GHz	< -10 dB	1.3 dB	(703 - 788 MHz)
		3.5 GHz		4 dB	(2400 - 2500 MHz)
		5.8 GHz		6.5 dB	(3400 - 3600 MHz)
				7.2 dB	(5725 - 5875 MHz)
[27]	69.6 × 72 mm^2	915 MHz	-32.9 dB	3.25 dB	(122 MHz)
		2.45 GHz 5.8	-20.1 dB	2.62 dB	(68 MHz)
		GHz	-24.6 dB	3.31 dB	(184 MHz)
Our proposed antenna	1.5357 x 1.5357 mm^2	2.4 GHz	-13.229644 dB	3.29 dB	(0 - 3.4096 GHz)
		60 GHz	-42.419084 dB	3.49 dB	(43.5 - 64 GHz)
		90 GHz	-22.269547 dB	4.52 dB	(81 - 95 GHz)

5. CONCLUSION

A very small simple structure of a multiple band square-slotted microstrip patch antenna has been introduced. Our designed small antenna has symmetrical dimensions and slots. It has a width of 1.5357 x 1.5357 mm^2, and it is excited by an inset-fed technique. The proposed antenna design can effectively work with three wide bandwidths appropriate for current and upcoming 5G applications. The antenna prototype has been designed using the CST MWS platform. According to the simulated results, the tri-band frequency range provides from 0-3.4096 GHz, 43.5-64 GHz and 81-95 GHz for supporting 3.3, 20.252 and 14.085 GHz of bandwidth, respectively. These are suitable for radio and mm wave applications with a very high data rate. Our proposed antenna design is easy to fabricate, because it has a small and simple structure as well as, using the FR-4 substrate, which has a very cheap price.

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