Design, fabrication and performance analysis of floodlight shaped microstrip antenna for Wi-Fi/IoT applications

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ABSTRACT

This paper proposes a design and fabrication of a floodlight-shaped microstrip patch antenna using flame-retardant (FR)-4 substrate within the frequency band of 1-6 GHz. The proposed antenna resonating at a multi-frequency band (2.01-2.2 GHz, 3.7-3.8 GHz, 4.82-4.96 GHz, and 5.61-6 GHz) is suitable for Wi-Fi and IoT applications. The proposed antenna has a size of 50×60×1.6 mm^3. The design was implemented using CADFEKO software, and the same was fabricated and measured using a vector network analyzer. Further, the performance analysis of the structure is carried out using the CADFEKO software, firstly by shifting the location of the microstrip feed line along the width of the patch and secondly by amending the structure. The verdicts show that the proposed antenna provides high impedance matching at multi-frequency bands and shows a very good agreement between simulated and fabricated results. The changed feed-line location and modified structure provide improved performance, which can be utilized for various other wireless communication channels.

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1. INTRODUCTION

The advancement of headway in wireless communication innovations and ever-increasing requests by clients for compact communication gadgets has required a move within the planned approach to realize antenna structures that are compact and strong. Owing to the assorted communication prerequisites, antenna frameworks working over wide groups have ended up a need [1]. Wireless communication has advanced due to rising microstrip antenna printing technology. This exponentially growing Microstrip patch antenna has attracted the attention of most researchers, mainly because it is comparatively inexpensive to produce and informal to design due to its simplicity of two-dimensional structure [2]. The dual-band and multi-band antennas are picking up consideration in later, a long time for multimode communication frameworks [3], [4] These are considered as the basic antennas for successfully supporting the likelihood of a present-day individual communication framework by the integration of more than one communication standard in a single compact framework [3]-[5]. The internet of things devices and their applications are advancing due to the easy integration of microstrip antennas into these devices [6]. The web of everything indicates the synchronization of different smart electronic gadgets such as laptops, smartphones, tablets, different machines such as smart vehicles prepared with sensors with IoT communication, and remote or wired association of buyer apparatuses associated through the internet [7]. As IoT modules proceed to shrivel, consolidating more remote advances, making space for antennas, is getting to be a progressively noteworthy challenge [8]. Microstrip antennas are crucial radiating components of a wireless communication system as they radiate electromagnetic waves into the free space in transmitting and receiving mode [9]-[11]. Multiband antennas play an imperative part in portable communications, since they can be utilized in different recurrence groups such as digital personal communication system (DCS), wireless fidelity (Wi-Fi), wireless local area network (WLAN) groups (802.11 b/n/g), and worldwide interoperability for microwave access (WiMAX) (IEEE 802.16) [12]-[14]. As seen in Figure 1, and sub-figure of Figures 1(a) and (b), this microstrip antenna has a radiating patch made up of copper material printed on a grounded dielectric substrate. It is excited using various feeding line techniques such as microstrip feedline, proximity-coupled, and co-axial probe feedline. having a 50-ohm impedance. The maximum radiation is produced in the broadside direction (perpendicular to the substrate). The fringing electrical field around the microstrip patch produces this radiation. The microstrip patch is considered as a resonating cavity and thus can be represented by an equivalent parallel R-L-C circuit as depicted in Figure 1(b) where $\mathrm{R_P}$, $\mathrm{L_P}$, and $\mathrm{C_P}$ are resistance, inductance and capacitance respectively and its input impedance is represented as Z_P. The resonance or centre frequency of operation of an antenna is approximately given by [15]:

$$f_c = q\frac{c}{2L\sqrt{\varepsilon_r}} \quad (1)$$

where c is the velocity of the light, q is the fringing factor, L is the length of the patch, and ε_r is the relative permittivity of the dielectric substrate.

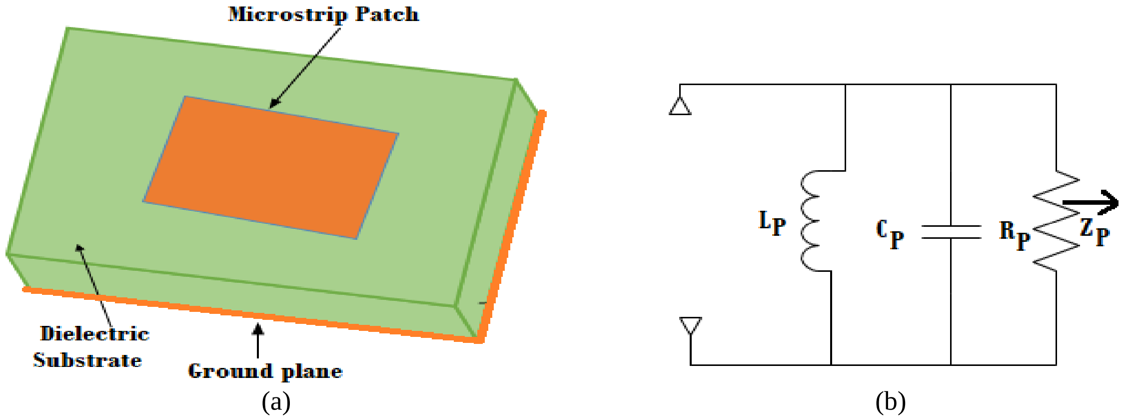
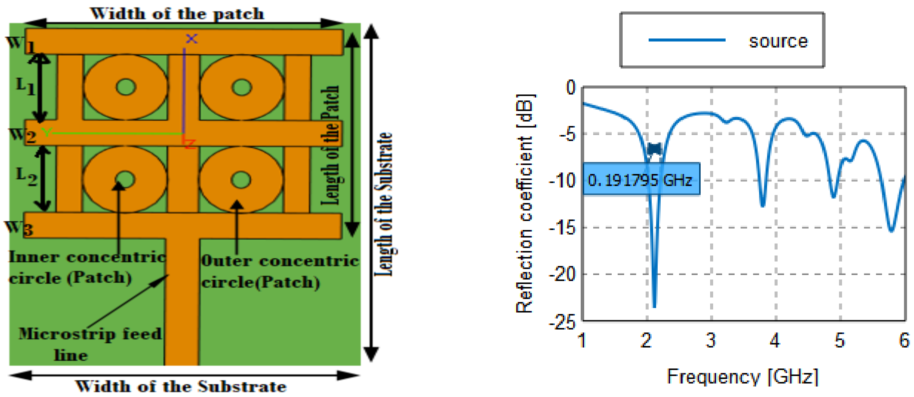


Figure 1. Microstrip patch antenna (a) general view and (b) equivalent circuit diagram

The authors have proposed a design of a multiband microstrip antenna for wireless communication resonating in the frequency band of 2-11 GHz using FR-4 substrate [16]. The authors have proposed a butterfly-shaped microstrip antenna with a coaxial feeding technique resonating at a multi-frequency band in the range of 4-7.5 GHz for a modern wireless system [17]. In the frequency band 2-8 GHz, the authors have presented a multi-band microstrip antenna etched with U- and L-shaped slots using FR-substrate applicable for Wi-Fi Max/Wi-Fi/WLAN [18]. By using flame retardant (FR)-substrate, a miniaturized multi-band microstrip antenna composed of three layers of different parasitic and aperture shapes to increase the radiation properties is proposed at 2.4 GHz for wireless communication [19]. In this research, the coplanar waveguide fed octagonal-shaped microstrip antenna obtained through triangular cuts is proposed at a frequency of 2.45 GHz/5.8 GHz applicable for RFID applications [20]. Placed on FR-4 substrate, the authors have proposed a slotted rectangular-shaped microstrip antenna resonating in the frequency band of 1.5–3.5 GHz for Wi-Fi, long-term evolution (LTE), and Wi-Fi max communication [21]. The authors have proposed a dual-band microstrip antenna loaded with a U-shaped dipole for radio frequency identification (RFID) application in the frequency band 0-3 GHz [22]. The authors have also proposed an ultra-wideband microstrip antenna with dual-band notch features in the frequency band 2.73-11.34 GHz applicable for WLAN and satellite applications [23]. In the frequency band 2-6 GHz, a dual-band with frequency reconfiguration microstrip antenna for Wi-Fi applications is proposed [24]. Using FR-4 substrate, the authors have designed an inset fed rectangular-shaped patch antenna for dual-band operation at 2.4 and 5.8 GHz for Wi-Fi and Wi-Fi max applications, and the same is optimized for having a U-shaped structure [25]

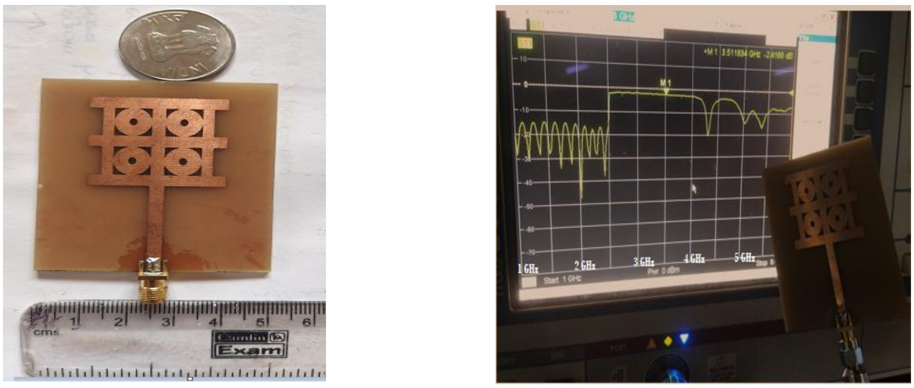
2. DESIGN AND FABRICATION OF FLOODLIGHT SHAPED MICROSTRIP ANTENNA

Figure 2 is depicting the designed floodlight shaped microstrip antenna and its sub-figure Figures 2(a) and (b) are depicting the top view of the proposed floodlight shaped microstrip patch antenna its simulated return loss, respectively. From Figure 2(a), the proposed antenna has the size of 50×60×1.6 mm^3. It is fed with a 50-ohm microstrip transmission line of length 18 mm and width 3.15 mm. The length of the patch is calculated as $W_1+L_1+W_2+L_2+W_3$=3.66+9.44+3.66+3.66+9.44+3.66=29.86 mm and the width of the patch is 29.29 mm. The radius of each outer concentric patch is 4.75 mm and the radius of each inner concentric patch is 1.1 mm. The proposed antenna is designed using FR-4 substrate and simulated using CADFEKO. From Figure 2(b), it is seen and observed that the proposed antenna resonates in the frequency band at 2.1 GHz, 3.8 GHz, 4.9 GHz and 5.8 GHz between 2.01-2.2 GHz, 3.7-3.8 GHz, 4.82-4.96 GHz, and 5.61-6 GHz respectively. Now, the minimum requirement for a good impedance match, i.e., the maximum power delivered to the microstrip antenna, should be $20\log_{10}|S_{11}|\leq-10$ dB or $|S_{11}|<<0.3$ which will lead to only 10% or less power loss [26]. In other words, the power efficiency to the antenna can be calculated using equation $[1-|S_{11}|^2]\times100$. So, when the magnitude of the reflection coefficient is less than or equal to 0.3, only 10% or less power is reflected. Hence, the power delivery efficiency at these frequencies is more than 90% considering a minimum -10 dB return loss as there is a high impedance matching at these frequencies. It covers an impedance bandwidth of 191 MHz at 2.1 GHz with a return loss of -23.5 dB, 94 MHz at 3.8 GHz with a return loss of -12.7 dB, 124 MHz at 4.9 GHz with a return loss of -11.7 dB, and 345 MHz at 5.8 GHz with a return loss of -15.2 dB. This shows that the proposed floodlight-shaped antenna which can also be regarded as sports-inspired antenna, can be used for various Wi-Fi/IoT applications. Figure 3 is depicting the fabricated proposed microstrip antenna and its sub-Figures 3(a) and (b) are depicting the view of the fabricated proposed microstrip antenna and measured return loss obtained through a spectrum analyzer, respectively.



(a) (b)

Figure 2. Floodlight shaped microstrip antenna (a) geometrical top view and (b) simulated return loss



(a) (b)

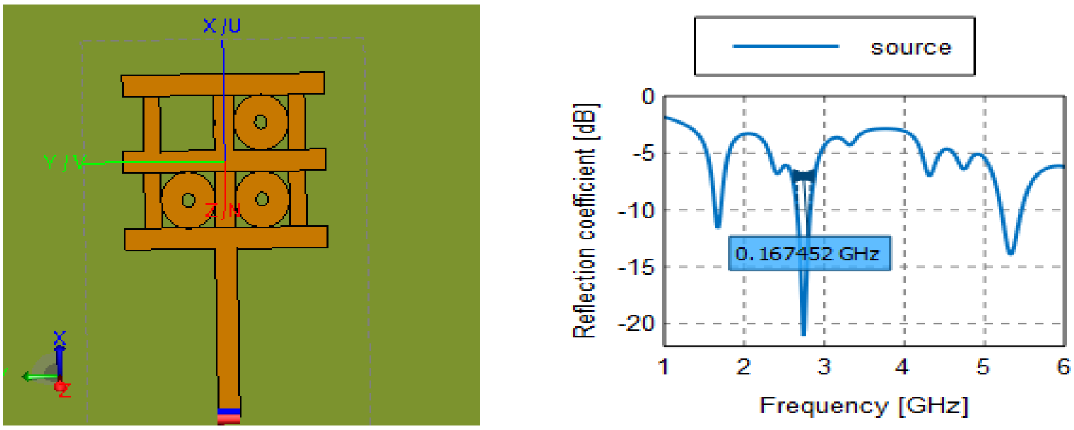
Figure 3. Fabricated proposed microstrip antenna (a) fabricated view and (b) measured return loss

3. PERFORMANCE ANALYSIS OF MODIFIED PROPOSED ANTENNA

In this section, using CADFEKO. The performance analysis of the proposed antenna is carried out by modifying the structure as shown in sub-section 3.1. Moving the microstrip feed location along the width of the patch as in sub-section 3.2.

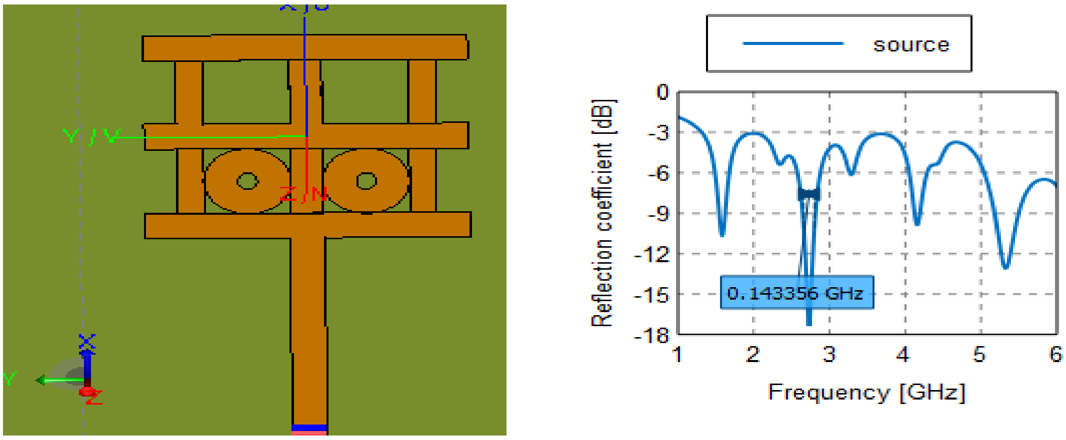
3.1. Modification of the proposed antenna

In this, the concentric circular patches are detached from the proposed antenna one by one and performance analysis is carried out. Figure 4, depicts modified microstrip antenna 1 along with its findings at Table 1 and its sub-Figures 4(a) and (b) depicts view with three circular patches and return loss, respectively. Figure 5, depicts modified microstrip antenna 2 along with its findings at Table 2 and its sub-Figures 5(a) and (b) depicts view with two circular patches and return loss, respectively. Figure 6, depicts modified microstrip antenna 3 along with its findings at Table 3 and its sub-Figures 6(a) and (b) depicts view with one circular patches return loss (1 circular patch) respectively. Figure 7, depicts modified microstrip antenna 4 along with its findings at Table 4 and its sub-Figures 7(a) and (b) depicts view with no circular patches and return loss, respectively. As seen from Tables 1-5, there are improvements in the performance with an additional frequency band. Antenna 3 and 4 shows improved return loss, bandwidth and more frequency bands as compared to the proposed antenna, as well as antenna, 1 and 2.



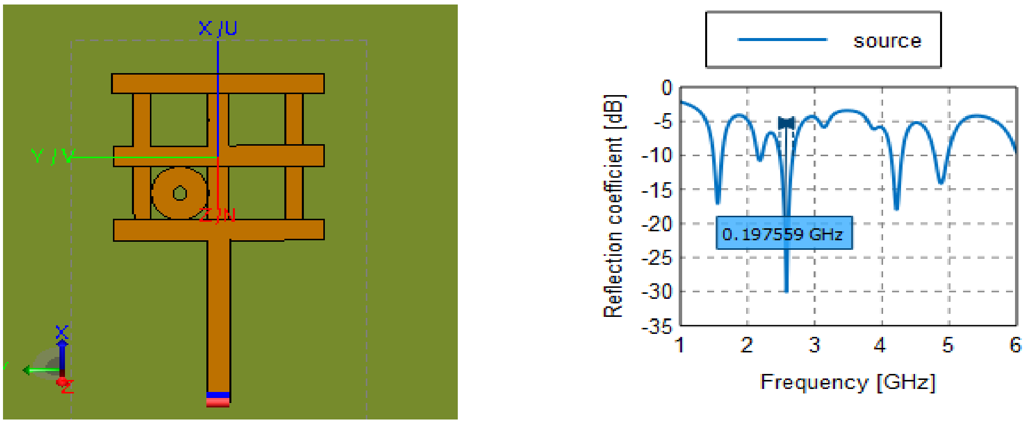
(a) (b)

Figure 4. Modified microstrip antenna 1, (a) view with three circular patches and (b) return loss (3 circular patches)



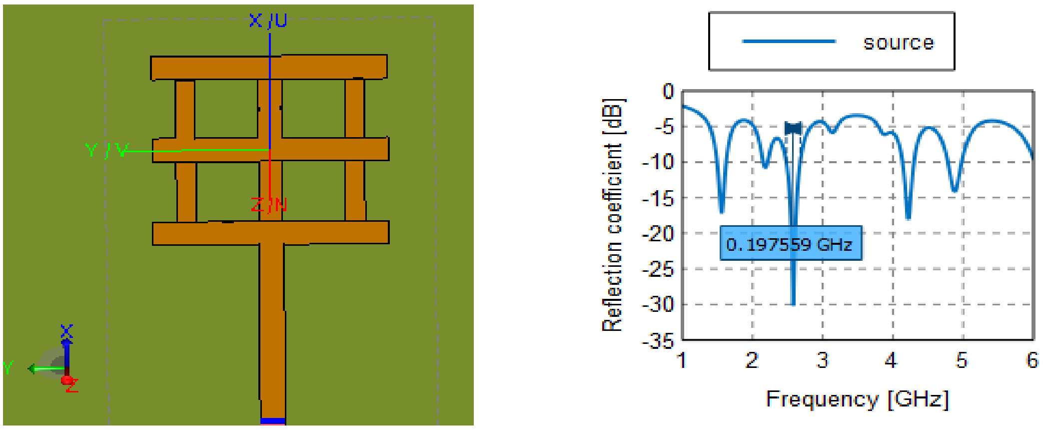
(a) (b)

Figure 5. Modified microstrip antenna 2 (a) view with two circular patches and (b) return loss (2 circular patches)



(a) (b)

Figure 6. Modified microstrip antenna 3 (a) view with two circular patches and (b) return loss (2 circular patches)



(a) (b)

Figure 7. Modified microstrip antenna 4 (a) without circular patches and (b) return loss (zero circular patches)

Table 1. Findings of the modified microstrip antenna 1

Frequency (GHz)	Return loss (dB)	Bandwidth (MHz)
1.67	-11.5	65
2.75	-20.5	167
5.3	-14.0	257

Table 2. Findings of the modified microstrip antenna 2

Frequency (GHz)	Return loss (dB)	Bandwidth (MHz)
1.67	-10.5	40
2.75	-17.5	143
5.3	-13.1	242

Table 3. Findings of the modified microstrip antenna 3

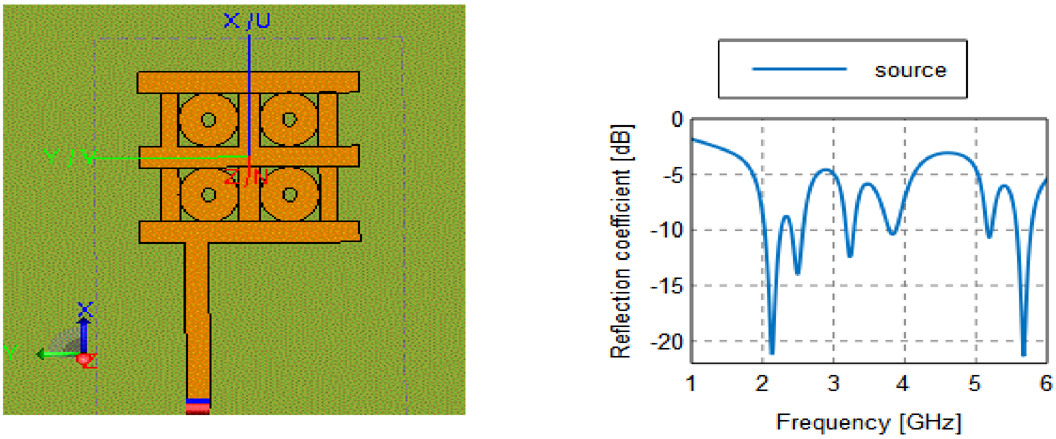
Frequency (GHz)	Return loss (dB)	Bandwidth (MHz)
1.55	-12.5	95
2.67	-40.5	185
4.0	-11.0	60
5.2	-12.8	297

Table 4. Findings of the modified microstrip antenna 4

Frequency (GHz)	Return loss (dB)	Bandwidth (MHz)
1.55	-17	126
2.2	-10.5	55
2.6	-27.4	198
4.2	-18.0	161
4.9	-14.1	191

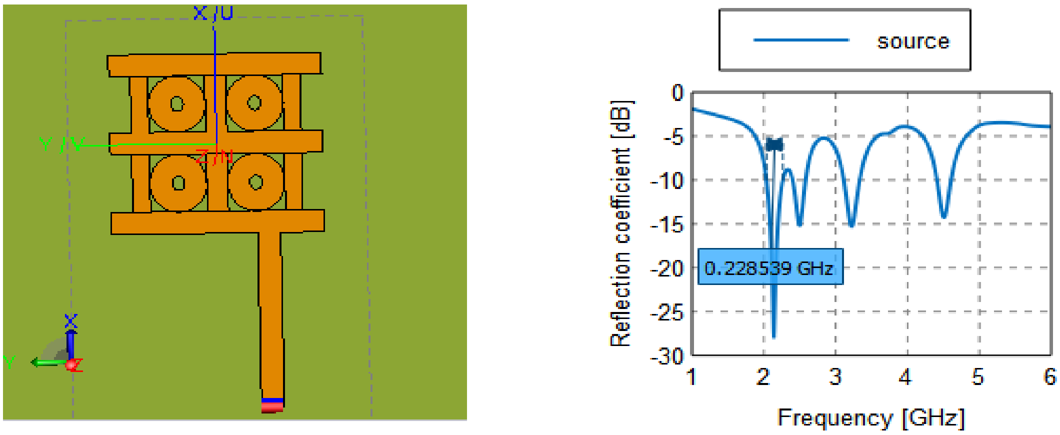
3.2. Change of feed location

Changed feed location towards the left of the proposed microstrip antenna as shown in Figures 8 and 9. In this performance analysis, the microstrip transmission line which is fed at the centre of the proposed microstrip patch is moved half of the width of the transmission line towards negative y-direction (left) and positive y direction (right) of the patch as depicted in Figure 8(a) and Figure 9(a) respectively and Figures 8(b) and 9(b) depicts its corresponding return loss.



(a) (b)

Figure 8. Changed feed location towards the left of the proposed microstrip antenna (a) view and (b) return loss (left movement)



(a) (b)

Figure 9. Changed feed location towards right of the proposed microstrip antenna (a) view (b) return loss (right movement)

Tables 5 and 6 depicts the findings of the moved microstrip transmission line feed at the left and right of proposed floodlight microstrip antenna. There are improvements in the performance with respect to return loss and bandwidth and generation of additional frequency bands. Table 7 depicts the comparative performance of the proposed work with existing work.

Table 5. Findings of changed feed location towards the right of the proposed microstrip antenna

Frequency (GHz)	Return loss (dB)	Bandwidth (MHz)
2.1	-28.0	228
2.5	-15.2	176
3.2	-15.3	216
4.5	-14.3	191

Table 6. Findings of changed feed location towards the right of the proposed microstrip antenna

Frequency (GHz)	Return loss (dB)	Bandwidth (MHz)
2.1	-21.0	236
2.5	-13.2	176
3.2	-12.42	154
3.8	-10.40	103
5.2	-10.64	75
5.6	-21.3	203

Table 7. The comparative performance with existing design

References	Operating frequencies (GHz)	Type of frequeny band	Total No. of frequency bands
[16]	1.8/2.4/5.8/3.5/5.2	Multi-band	4
[17]	4.5/5.5	Dual-band	2
[18]	3.5/5.2/5.8/4.3	Multi-band	4
[19]	2.4	Single-band	1
[20]	2.44/5.8	Dual-band	2
[21]	1.9/2.1/3.6	Multi-band	3
[22]	0.9/2.46	Dual-band	2
[23]	5.5/7.5	Dual-band	2
[24]	1.8/2.4	Dual-band	2
[25]	2.4/5.8	Dual-band	2
This work	2.4/5.8	Multi-band	6

4. CONCLUSION AND FUTURE RESEARCH WORK

The design of a low-cost and reliable floodlight shaped microstrip antenna is successfully implemented for use in Wi-Fi and IoT applications. Since this work presents six operating frequencies in the frequency band between 1-6 GHz, it could also be suitable for any wireless applications such as Bluetooth, Wi-Fi Max, RFID, WLAN, and 5G NR. The analysed movement of the microstrip feed line along the width of the patch and detaching the circular patches has greatly influenced the resonance behaviour of the proposed microstrip antenna resulting in improved performance and reliability. A very good agreement between simulated and measured return loss results have been obtained. Future research work can be carried out by forming an array of various sizes and incorporating metamaterial structures to enhance efficiency.

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