A Microstrip Patch Antenna with Defected Ground Structure for Triple Band Wireless Communications

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Abstract —In this article, a triple band microstrip antenna is designed and developed. The rectangular patch is loaded with slots and the ground is made defective for achieving triple band operation. The proposed design is optimized and simulated using CST microwave studio simulator. The optimized structure of the proposed design for triple mode operates at 1.2 GHz, 2.45 GHz and 5.6372 GHz. The prototype of the proposed antenna is developed and measured. The simulated and measured results are presented. Various antenna patterns such as reflection coefficient, E-plane and H-plane radiation patterns, gain, directivity etc are presented and discussed. The reflection coefficient plot of the proposed antenna both in simulation and in measurement confirms the triple band characteristics. The maximum gain and maximum directivity of the antenna are 6.307 dB and 7.279 dBi, respectively. The proposed antenna is suitable for wireless video transmission, wireless security systems, industry, scientific and medical (ISM) radio, and wireless local area networks (WLANs) applications.

Index Terms—Defected ground structure, elliptical slots, microstrip patch antenna, rectangular strip slots, reflection coefficient, triple band.

I. Introduction

In the modern wireless systems, there is requirement of the antennas with characteristics such as wide bandwidth, compact size, polarization diversity, multiband operations etc. To achieve these characteristics in microstrip antennas, researchers are continuously working on the performance improvement of the microstrip antennas. The performance of the microstrip can be improved by changing the substrate parameters [1], [2], by using gap-coupling [3], [4], by using frequency selective surface [5], by using electronic band gap structures [6], by stack-coupling [7], by using metamaterials [8], using polarization diversity techniques [9], [10], by impedance matching technique [11], by low cross polarization technique [12] etc.

Multiband operation of the antennas minimizes the number of antennas in the wireless communication systems. In [13], a dual band antenna is proposed for the 0.92 GHz near field and 2.45 GHz far field applications. The designed antenna shows a strong magnetic field for the 0.92 GHz near field applications and the circular polarized field for the 2.45 GHz far field applications. A dual band compact microstrip antenna is presented in [14]. The slot loading technique is used and the designed antenna resonates for dual band operation. In [15], the concept of metamaterial is utilized for achieving dual band operation. The designed antenna can be used in LTE, Bluetooth, WiMAX systems. A simple dual narrow band antenna is designed for dual band applications in [16]. The rectangular patch is modified to achieve the dual band operation and suitable for WLANs and telemedicine applications.

Due to simple fabrication, the defected ground structure technique is getting popularity and used in the microstrip design. Using defected ground structure in the microstrip antennas the parameters of the microstrip antennas can be improved [17]. In [18], the mutual coupling of the multi-band microstrip patch array is reduced. In [19], a defected ground structured compact plus shaped slot loaded rectangular patch antenna is designed for multiple frequency band operation. The maximum gain of the designed antenna is 5.03 dBi. The bandwidth of the proximity coupled feed rectangular microstrip antenna is enhanced using defected ground structure in [20]. The concept of defected ground structure is utilized for size reduction of the microstrip antenna in [21].

The design of a triple band microstrip patch antenna is presented in this paper. The patch is loaded with slots and the ground plane is made defective in order to generate multiple resonances and decrease the reflection loss in the structure. The proposed antenna is simulated and optimized using CST microwave software. The antenna with optimized dimensions is fabricated and measured. The simulated and measured results are presented and discussed. The triple frequency bands at 1.2 GHz, 2.45 GHz and 5.6372 GHz of the proposed antenna make it suitable for wireless security systems/wireless video transmission etc., WLAN/Bluetooth applications etc. and WLAN applications etc., respectively. The organization of the paper is as follows. The design, geometry and dimensions of the proposed antenna are given in section II. The results with discussion are presented in section III. Finally, section IV gives the conclusions.

II. The Proposed Antenna Structure

The structure of the proposed microstrip patch antenna is shown in Fig. 1. The rectangular patch loaded with

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slots and the defected ground structure are utilized in the proposed structure to achieve triple band operation and reduce return loss. The top view, side view and bottom view are shown in Fig. 1(a), Fig. 1(b) and Fig. 1(c), respectively. The optimized dimensions of the antenna are listed in Table I. The antenna consists of a rectangular radiating patch which is fed by a coaxial or probe feed line positioned at $x_f = -4.5\,\text{mm}$ and $y_f = 0\,\text{mm}$ as shown in Fig. 1. The antenna is designed on an FR4 dielectric substrate with a thickness of $1.5\,\text{mm}$ and a dielectric constant of $\varepsilon_r = 4.4$. The rectangular strips slots i.e. slot A and slot B have been introduced on the patch to drive the antenna into dual resonances and two elliptical slots i.e. slot C and slot D have been introduced in the ground plane to reduce the reflection losses and enhance the bandwidth. The third resonance is achieved by incorporating an additional rectangular strip slot i.e. slot E, as shown in Fig. 2 (c). The location of the feed point and the structure is optimized to provide the desirable antenna performance.

It is common practice to use the lowest frequency for multiband antennas to calculate the dimensions of the rectangular patch. In this design this is not followed because the dimensions obtained with a resonant frequency of 1.2 GHz introduces more resonances (i.e., undesirable harmonics of TM modes) at undesired frequencies which was difficult to suppress. The resonant frequency of 2.4 GHz is then used to compute the dimensions of the antenna, because of its attractive resonant nature.

The rectangular patch antenna is designed using the transmission line model. The width of the patch (W) is computed by [2]:

$$W = \frac{c}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}} \tag{1}$$

where f_r is the resonant frequency of the antenna, c is the velocity of light in free space and ε_r is the dielectric constant of the substrate.

The length of the patch is computed using the following expression [2]:

$$L = L_{eff} - 2\Delta L \tag{2}$$

where L_{eff} is the total effective length of the rectangular patch considering fringing fields and ΔL is the additional length due to fringing fields.

The total effective length and additional length due to fringing effect of the patch are computed by the following expressions [2]:

$$L_{eff} = \frac{c}{2f_r\sqrt{\varepsilon_{reff}}} \tag{3}$$

$$\Delta L = 0.412h\,\frac{(\varepsilon_{reff}+0.3)\left(\frac{W}{h}+0.264\right)}{(\varepsilon_{reff}-0.258)\left(\frac{W}{h}+0.8\right)} \tag{4}$$

where ε_{reff} is the effective dielectric constant of the substrate and is computed by;

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left(1+\frac{12h}{W}\right)^{-1/2} \tag{5}$$

The equivalent circuit of slot loaded rectangular patch [22] and the defected ground structure unit [23] is given in Fig. 2. The values of the circuit parameters depends upon the dimensions of the defected ground structure unit. The structure is optimized using CST microwave studio and the optimized dimensions are given in Table I.

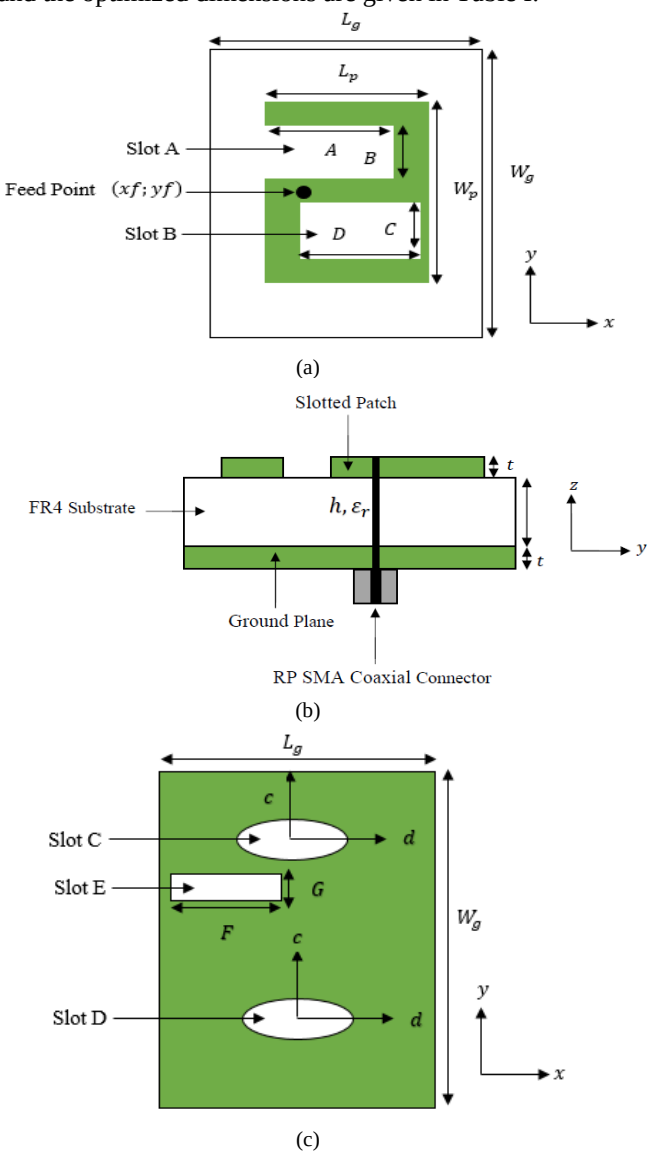
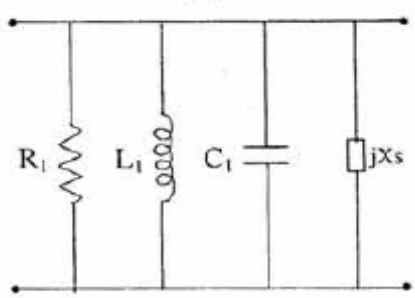
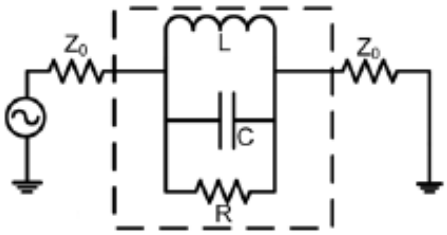


Fig. 1. Geometry of the proposed antenna (a) top view, (b) bottom view and (c) side view.



(a)

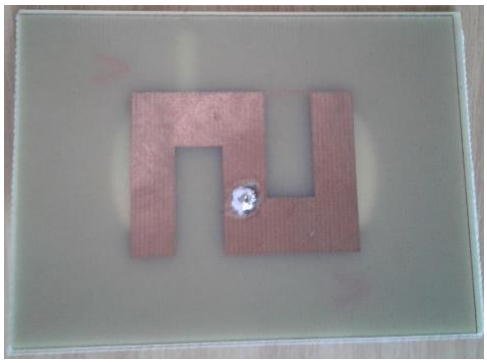


(b)

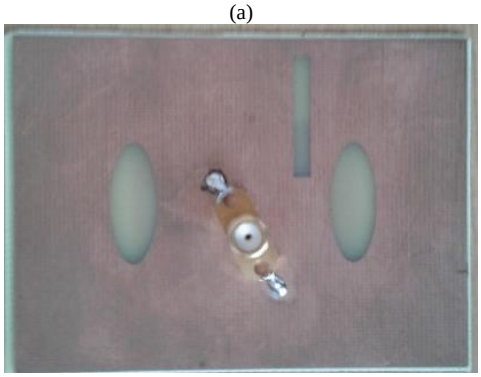
Fig. 2. Equivalent circuit diagram of (a) slot loaded rectangular microstrip patch antenna [22], (b) Equivalent circuit diagram of defected ground structure cell [23]

TABLE I: DIMENSIONS OF THE PROPOSED ANTENNA

S. No.	Parameter	Value
1	Substrate dielectric constant, ε_r	4.4
2	Substrate thickness, h (mm)	1.5
3	Ground plane length, L_g (mm)	50
4	Ground plane width, W_g (mm)	50
5	Copper thickness, t (mm)	0.02
6	Patch length, L_p (mm)	25
7	Patch width, W_p (mm)	25
8	Inner radius of SMA connector, ri (mm)	0.65
9	Outer radius of SMA connector, ro (mm)	2.335
10	x-coordinate of the feed point, x_f (mm)	-1
11	y-coordinate of the feed point, y_f (mm)	6.5
12	Length of the rectangular slot, G (mm)	18
13	Width of the rectangular slot, F (mm)	8
14	Length of the rectangular slot, C (mm)	17.5
15	Width of the rectangular slot, D (mm)	8
16	Major axis of the elliptical slot, c (mm)	10
17	Minor axis of the elliptical slot, d (mm)	4



(a)



(b)

Fig. 3. Fabricated antenna (a) top view, (b) bottom view.

The antenna with the optimized dimensions is fabricated and the measurement of the developed prototype is carried out. The photographs of the prototype and measurement setup are shown in Fig. 3. The top view, and bottom view of the prototype are shown in Fig. 3(a), and Fig. 3(b), respectively.

III. RESULTS AND DISCUSSION

In this section, the input chacterstics and radiation characteristics of the proposed antenna are presented. The reflection coefficient, radiation patterns, gain, directivity etc are presented and discussed. In Fig. 4, the reflection coefficient plot for the proposed triple band antenna is presented. It is evident from Fig. 4 that the proposed antenna resonates at 1.2064 GHz, 2.45 GHz and 5.6372 GHz. The simulated and measured results show reasonable agreement except some deviation at higher frequency side. It may be possibly due to losses in connector and substrate at higher frequencies. Also the limitation of fabrication machine resolution at corners may be other possible reason for the deviation at higher frequencies. The resonance at 2.9862 GHz and at 4.1032 GHz are referred to as harmonics and they are not effective to radiated energy. At 1.2064 GHz, 2.45 GHz and 5.6372 GHz there are sharp deeps which has crossed -10 dB line and there are no other sharp deeps in the graph that have crossed this line, which confirms that it is indeed a triple band antenna. The reflection coefficient plot first crosses the -10 dB line for the first frequency band at 1.1987 GHz and secondly at 1.2115 GHz. Hence the bandwidth for the 1.2064 GHz resonance is 12.76 MHz. The reflection coefficient plot for the second frequency band crosses the -10 dB line firstly at 2.4169 GHz and secondly at 2.4699 GHz. Hence the bandwidth for 2.4169 GHz resonance is 52.979 MHz. The reflection coefficient plot of the third frequency band crosses the -10 dB line firstly at 5.5651 GHz and secondly at 5.7077 GHz. Hence the bandwidth of 5.6372 GHz resonance is 52.979 MHz.

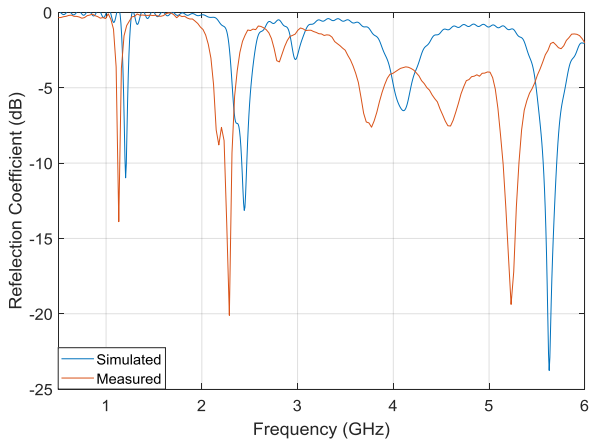
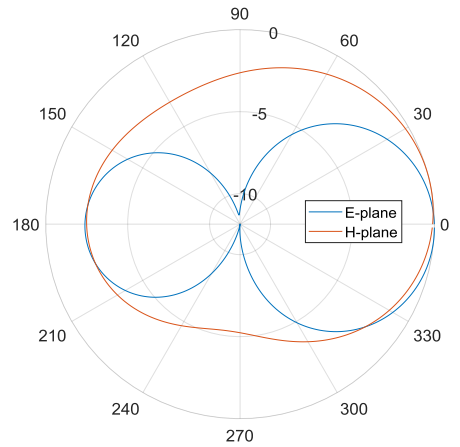


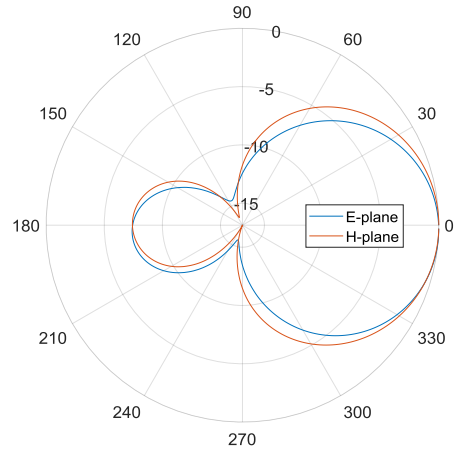
Fig. 4. Reflection coefficient of the proposed antenna.

The radiation patterns of the proposed antenna are depicted in Fig. 5. The normalized E-plane and H-plane patterns at the three resonant frequencies are shown. The normalized E-plane and H-plane patterns at 1.2 GHz, the normalized E-plane and H-plane patterns at 2.4 GHz, the

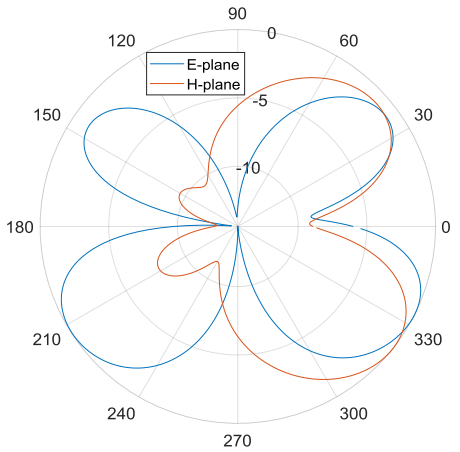
normalized E-plane and H-plane patterns at 5.63 GHz are shown in Fig. 5(a), Fig. 5(b) and Fig. 5(c), respectively. The detailed pattern parameters are presented in Table II. Fig. 6 shows the maximum gain and maximum directivity of the antenna. The maximum value of gain and directivity achieved by the proposed antenna are 6.307 dB and 7.279 dBi, respectively. The efficiencies of the antenna are depicted in Fig. 7. The maximum value of the total efficiency and radiation efficiency by the antenna are 87.16% and 87.55%, respectively. The proposed antenna is suitable for the triple band wireless applications.



(a)



(b)



(c)

Fig. 5. Radiation pattern of the antenna (a) at 1.2 GHz, (b) at 2.4 GHz, (c) at 5.63 GHz.

TABLE II: RADIATION PATTERN PARAMETERS OF THE ANTENNA

S. No.	Parameter	Value (at 1.2 GHz)	Value (at 2.4 GHz)	Value (at 5.63 GHz)
1	3 dB beamwidth in degrees (E-plane)	91.9	77.4	49.6
2	Direction of main lobe in degrees (E-plane)	2.0	3.0	27.0
3	Side lobe label in dB (E-plane)	-2.4	-7.4	-0.9
4	3 dB beamwidth in degrees (H-plane)	153.8	90.1	56.1
5	Direction of main lobe in degrees (H-plane)	12	0.0	37.0
6	Side lobe label in dB (H-plane)	-2.5	-7.4	-1.1

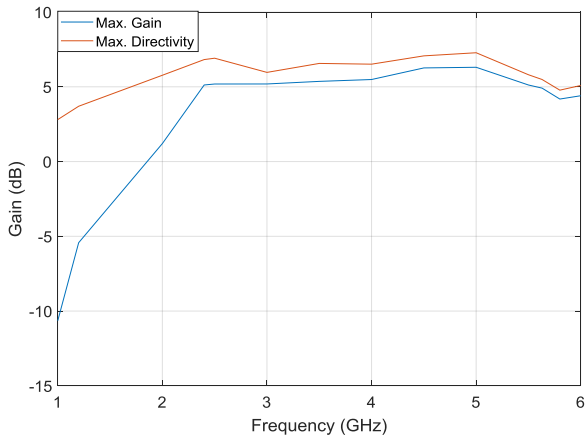


Fig. 6. Maximum gain and maximum directivity of the antenna.

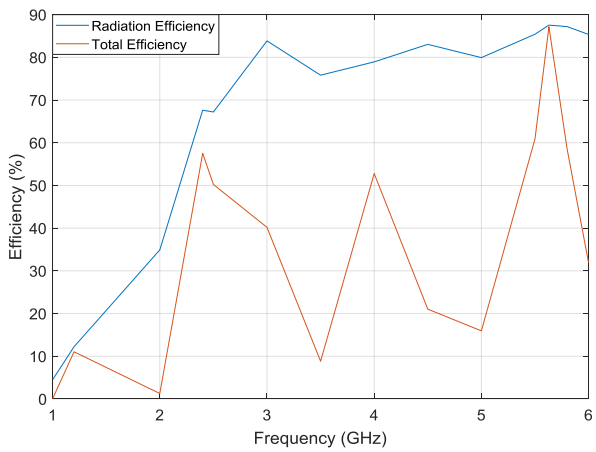


Fig. 7. Radiation efficiency and total efficiency of the antenna.

IV. CONCLUSIONS

The design and development of a triple band microstrip patch antenna have been presented. The results of the proposed triple band antenna reflected useful characteristics that are closely suitable for the acceptable standards of various wireless applications such as security systems, video transmission, ISM and WLANs etc. The triple mode has been achieved by loading slots on the patch and the defected ground structure. The simulated and measured reflection coefficient show the triple band

operation. The proposed antenna gives a maximum gain of 6.307 dB and a maximum directivity of 7.279 dBi. Although multiband antennas can be used in different wireless applications, but they do not have the flexibility to accommodate new services, and therefore authors wish to further design from multiband antennas to frequency reconfigurable multiband antenna.

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REFERENCES

[1] R. Garg, P. Bhartia, I. Bahl, and A. Ittipiboon, *Microstrip Antenna Design Handbook*, Artech House Publishers, Boston, London, 2001.

[2] C. A. Balanis, *Antenna Theory: Analysis and Design*, Wiley, 2005.

[3] P. Kumar, "Computation of resonant frequency of gap-coupled ring microstrip antennas," *International Journal of Automation and Computing*, vol. 11, no. 6, pp. 671-675, 2014.

[4] P. Kumar and G. Singh, "Gap-coupling: A potential method for enhancing the bandwidth of microstrip antennas," *Advanced Computational Techniques in Electromagnetics*, vol. 2012, pp. 1-6, 2012.

[5] S. Narayan, B. Sangeetha, and R. M. Jha, "Directivity enhancement of microstrip antenna loaded with FSS based superstrate," in *Proc. IEEE International Microwave and RF Conference (IMaRC)*, 2014, pp. 159-161.

[6] R. Pandey and D. K. Vishwakarma, "A fractalized meander - line EBG - based microstrip teeth - like patch slot antenna for use in satellite and defense applications," *Microwave and Optical Technology Letters*, vol. 58, no. 8, pp. 2010-2015, 2016.

[7] P. Kumar and N. Bisht, "Stacked coupled circular microstrip patch antenna for dual band applications," in *Proc. Progress in Electromagnetics Research Symposium*, Suzhou, China, 2011, pp. 629-632.

[8] V. V. Yem and N. N. Lan, "Gain and bandwidth enhancement of array antenna using novel metamaterial structure," *Journal of Communications*, vol. 13, no. 3, pp. 101-107, 2018.

[9] P. Kumar and J. L. Masa-Campos, "Dual polarized microstrip patch antennas for ultra-wideband applications," *Microwave and Optical Technology Letters*, vol. 56, no. 9, pp. 2174-2179, 2014.

[10] P. Kumar and J. L. Masa-Campos, "A novel dual polarized waveguide fed circular patch antenna for Ku band applications," *Microwave and Optical Technology Letters*, vol. 59, pp. 1743-1750, 2017.

[11] K. M. Morshed, D. K. Karmokar, and M. Talukder, "Numerical and experimental analysis of impedance matched Inverted-L and stair Inverted-L antenna for 5 GHz WLAN operation," *Journal of Communications*, vol. 5, no. 8, pp. 612-619, 2010.

[12] P. Kumar, "Design of low cross-polarized patch antenna for ultra-wideband applications," *International Journal on Antenna Communications and Propagation*, vol. 7, no. 4, pp. 265-270, 2017.

[13] Z. Xing, K. Wei, L. Wang, and J. Li, "Dual-band RFID antenna for 0.92 GHz near-field and 2.45 GHz far-field applications," *International Journal of Antennas and Propagation*, vol. 2017, pp. 1-9, 2017.

[14] A. Roy, S. Bhunia, D. C. Sarkar, and P. P. Sarkar, "Slot loaded compact microstrip patch antenna for dual band operation," *Progress in Electromagnetics Research C*, vol. 73, pp. 145–156, 2017.

[15] M. M. Hasan, M. R. I. Faruque, and M. T. Islam, "Dual band metamaterial antenna for LTE/Bluetooth/WiMAX system," *Science Reports*, vol. 8, no. 1240, pp. 1-17, 2018.

[16] A. Salam, A. A. Khan, and M. S. Hussain, "Dual band microstrip antenna for wearable applications," *Microwave and Optical Technology Letters*, vol. 56, no. 4, pp. 916-918, 2014.

[17] M. K. Khandelwal, B. K. Kanaujia, and S. Kumar, "Defected ground structure: Fundamentals, analysis, and applications in modern wireless trends," *International Journal of Antennas and Propagation*, vol. 2017, pp. 1-22, 2017.

[18] F. Y. Zulkifli, E. T. Rahardjo, and D. Hartanto, "Mutual coupling reduction using dumbbell defected ground structure for multiband microstrip antenna array," *Progress In Electromagnetics Research Letters*, vol. 13, pp. 29-40, 2010.

[19] N. P. Yadav, "Plus shaped notch loaded rectangular patch with D.G.S. antenna for multiband operation," in *Proc. Antenna Test & Measurement Society (ATMS India-16)* 2016, pp. 1-5.

[20] D. Fistum, D. Mali, and M. Ismail, "Bandwidth enhancement of rectangular microstrip patch antenna using defected ground structure," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 3, no. 2, pp. 428- 434, 2016.

[21] R. Er-rebyiy, J. Zbitou, A. Tajmouati, M. Latrach, A. Errkik, and L. El Abdellaoui, "A new design of a miniature microstrip patch antenna using defected ground structure DGS," in *Proc. International Conference on Wireless Technologies, Embedded and Intelligent Systems*, 2017, pp. 1-4.

[22] Shivnarayan, S. Sharma, and B. R. Vishwakarma, "Analysis of slot loaded microstrip patch antenna," *Indian Journal of Radio and Space Physics*, vol. 34, pp. 424-430, 2005.

[23] D. Guha, S. Biswas, and C. Kumar, "Printed antenna designs using defected ground structures: A review of fundamentals and state-of-the-art developments," in *Proc. Forum for Electromagnetic Research Methods and Application Technologies*, 2014, pp. 1-13.