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Design of circularly polarized irregular octagonal-shaped and dumbbell slotted planar and conformal patch antennas

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Axial ratio of the beam width.

Abstract. High gains with highly efficient Circularly Polarized (CP) microstrip planar and conformal cylindrical patch antennas are designed for the Industrial Scientific Medical (ISM) band. A dumbbell-shaped slot is incorporated in the centre of an irregular hexagonal radiator to produce circular polarisation with high gain. The simulation results yielded the impedance mismatch loss (S11) bandwidth of 78.8 MHz and axial ratio bandwidth (AR) of 10.3 MHz for the planar patch. In this study, the values of the impedance mismatch loss and AR bandwidths of the conformal cylindrical patch antenna were obtained as 46.2 MHz and 10.6 MHz, respectively, indicating that the return loss bandwidth in this case decreased by almost 42% while the axial ratio bandwidth remained almost the same. The axial ratio of the beam-width for $Phi = 0°$ was 83° and for planar patch and conformal patch, it was 61°. Consequently, in the planar patch, the gain was obtained as 8.79 dBic with 96.33% efficiency while in the conformal patch, the gain was measured as 4.16 dBic with 95% efficiency.

1. Introduction

Exponential advances in wireless communication have given rise to greater demand for Circularly Polarized (CP) antennas, which are unidirectional in nature, mainly owing to their interesting characteristics such as low back radiation, cost effectiveness, and stable gain. Of note, they are environmentally friendly, as well. In recent years, CP patch antennas have gained high popularity owing to their certain design advantages such as light weight, low profile, and capability of being conformal to the mounting structure, to name a few, which make them widely applicable in practice [1–5].

Recent technological advancements in the field of smart wireless devices have made human life easier and changed the way humans interact with technology. These wireless devices are capable of operating at the same frequency band, i.e., 2.4 GHz ISM (Industrial Scientific Medical) band, improving the ability to shift between various wireless systems with no need for licensing procedure [4,5].

Bluetooth with Zig Bee is an instance of a widespread major system at the ISM band. This system is mostly used for short-ranged communication.

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In this regard, the present study introduced novel antenna designs to examine the operation of antennas at the mentioned frequency band [4,5].

Wireless communication and WLAN (Wireless Local Area Network) act as the backbone of any organization. It is not possible to imagine the operation of industries without a robust wireless connection system. Wireless communication requires high channel capacity and high isolation along with high data rate. This surge has resulted in increasing demand for the broadband and miniaturized antennas [6]

This paper aims to propose two novel designs for CP patch antenna. The patch antenna is taken up as it is different from other types of antennas, mainly owing to its light weight, low cost, and desirable costing and compact size [7–10].

In order to overcome the problem of mismatched orientation between the transmitter and receiver, circular polarization was used [9,10]. The circular polarized EM waves tend to travel in a helical path, which makes it possible for them to be fitted with any orientation [7,8]. Circular polarization is always preferred since this type of polarization is a suitable solution to the polarization mismatch [7–10].

Despite having low bandwidth and gain, the conformal microstrip antenna is used so that it can be fit for camouflaging and be able to bend with respect to the surface shape to save space [11–14]. For different applications like WLAN, satellite communication, spacecraft, and missile communication, etc., different types of slotted antennas have been developed and reported [15–21].

Circular and elliptical polarization can be obtained using different feed arrangements. Circular polarization can be produced if two orthogonal modes are excited with a $\pi/2$ time-phase difference between them. This can be achieved by using single or multiple feed systems. For a square shaped patch, the ideal circular polarized excitation can be done by feeding the elements at two adjacent edges in order to excite TM_{10} and TM_{01} at two adjacent edges [7–10].

2. Proposed planar and conformal patch antenna design on air substrate at 2.40 GHz.

Figures 1 and 2 show an irregular octagonal patch radiator with both squared and almost-cylindrical ground

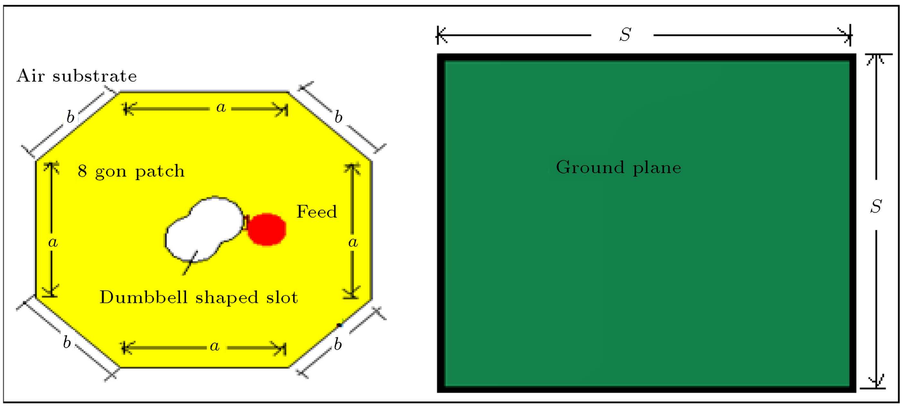

Figure 1. Labeled diagram of the proposed planar patch antenna design on air substrate [7–10].

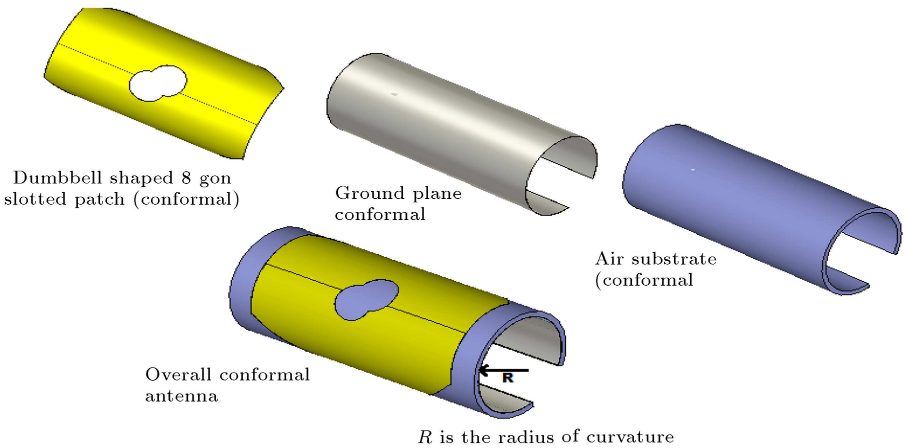

Figure 2. Labelled diagram of proposed conformal patch antenna design on air substrate [11–14].

Table 1. Optimized dimensional comparison of planar antenna and conformal antenna on the air substrate.

Antenna type	Radius of curvature, R	Radius of crossed Circular slots (Dumbbell shaped slot) on the patch	Distance between Centres of two circles 'c'	Dimension of octagonal patch		Dimension of ground plane (S)
				a	b	
Planar	Infinite	5.16 mm	5.91 mm	15.3 mm	21.58 mm	75 mm × 75 mm
Conformal	13.77 mm	5.16 mm	5.93 mm	15.3 mm	21.58 mm	Equivalent to the ground plane of planar patch with radius of curvature = 13.77 mm

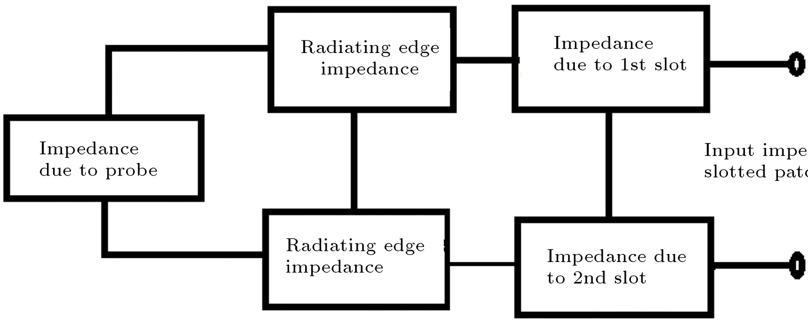

Figure 3. Labelled diagram of input impedance of proposed planar and conformal patch antenna design on air substrate [7–9].

planes with air substrate that are designed for its circular polarization at 2.4 GHz ISM band operation. Patches in both structures shown in Figures 1 and 2 can be mechanically supported on the air substrate with the help of eight plastic pins placed at each corner of the octagonal patch to the ground plane. Two crossed circular slots (also known as dumbbell shaped slot) with different circular loci and identical radii are cut off at the centre in both planar and curved radiators, as shown in Figures 1 and 2 [15–17], respectively. For the production of circular polarization, two orthogonal modes of electric field are generated using crossed circular slots (dumbbell shape) at the centre of the patches in both of the antennas. These crossed slots are responsible for the production of two orthogonal modes of TM_{10} and TM_{01}, which result in the rotation of the field tips in either clockwise or anticlockwise directions.

Figure 1 represents a cross-sectional view of the proposed microstrip patch antenna on the air substrate with crossed circular slots of radii (r) cut out diagonally in the centre of the asymmetrical octagonal radiator whose dimensions are denoted by 'a' and 'b' [18–20]. The dimension of the squared ground plane is denoted by 'S' [7–10] and feeding is given along the X axis from the origin.

Almost all other dimensions of the planar antennas on the air substrate were kept constant while the curvature radius of the conformal cylindrical-rectangular patch antenna on air substrate varied to obtain optimized results for return loss and axial ratio at an operating frequency of 2.40 GHz. Finally, as shown in Figure 2, at an optimized curvature radius of 13.77 mm, the best result in terms of its return loss was obtained: the axial ratio bandwidth of 3 dB and axial ratio beam width and gain of 3 dB associated with the respective antennas [11–14, 18–20]. This paper conducted a systematic study to optimize the parameters in the EM simulator CST MWS [22].

The values of all dimensions of the planar and conformal cylindrical-rectangular patch antennas are given in Table 1.

The concept of series-parallel impedance, shown in Figure 3, arises due to the impedance of the radiating patch and impedance of two circular slots diagonally placed on the radiator.

2.1. Results and discussions: Planar patch antenna on air substrate versus conformal antenna on the air substrate with optimized dimension.

Figure 4(a)–(f) shows the results from different types

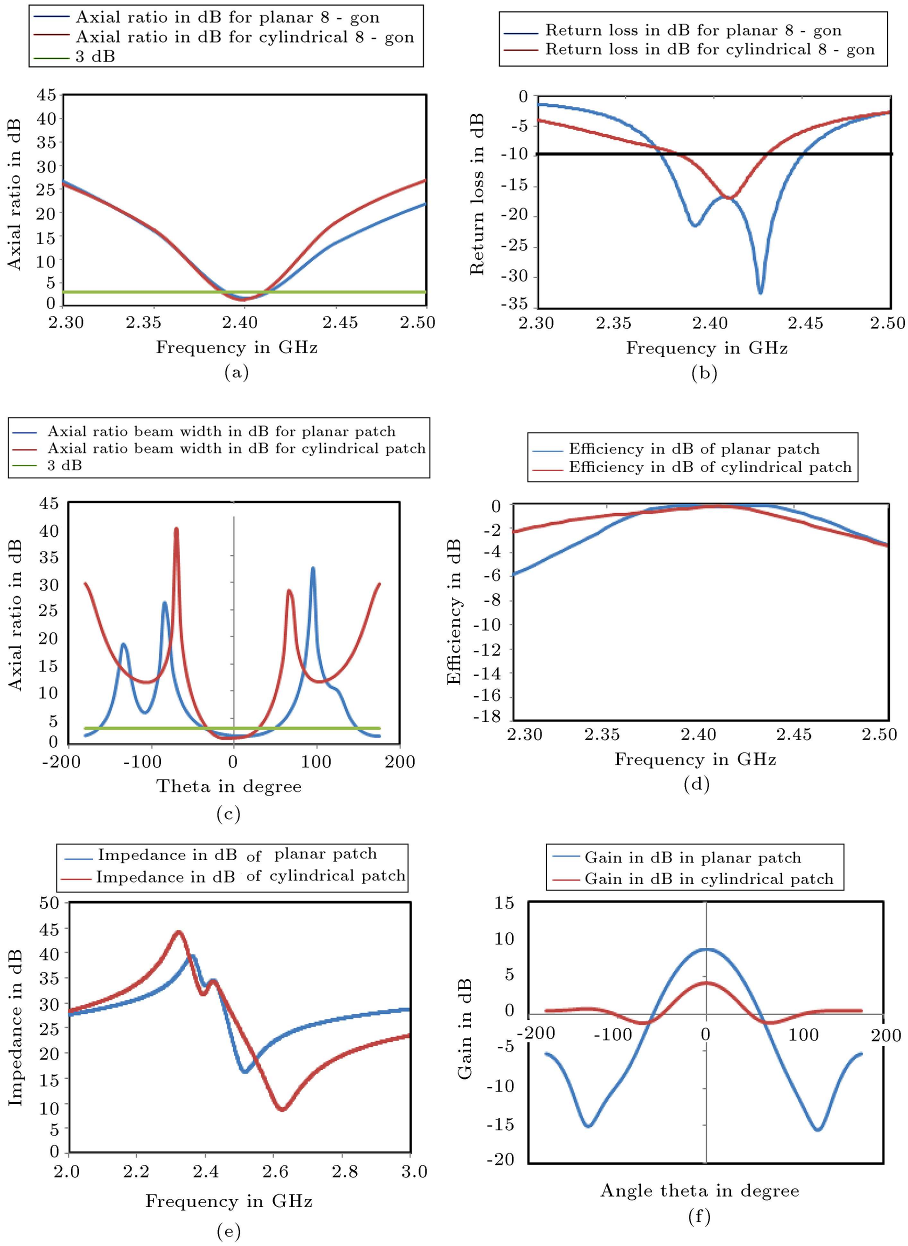

Figure 4. Simulated results of both antennas (a) axial ratios (3 dB) (b) return loss, (c) axial ratio beam-width (3 dB) (at $Phi = 0°$), (d) efficiencies, (e) impedance in dB vs. frequency and (f) gains.

of plots that illustrate the effect of slots on the circular polarization. Here, the blue and red curves are indicative of different antenna parameters of both planar and conformal antennas on air substrate. The return loss and axial ratio bandwidth values in the planar patch antenna are 78.8 MHz and 10.3 MHz, respectively. In the conformal patch, the values of the return loss bandwidth and axial ratio bandwidth are 46.2 MHz and 10.6 MHz, respectively. The axial ratio of the beam-width at $Phi = 0°$ for the planar and conformal patches is 83° and 61°, respectively. The gain for the planar patch is 8.79 dBic, while it is 4.16 dBic for the conformal cylindrical-rectangular patch with the efficiencies of 96.38% and 95%, respectively.

The magnetic field distribution at $\omega t = 0$, 45, 90, 135, and 180° confirms variations of the distribution of the field, as shown in Figure 5. At 0 and 180°, the field directions are in opposite, clearly showing Left-Handed Circular Polarization (LHCP) [18–20]. The magnetic field vector lines rotate their direction continuously at instant times, indicating the circular polarisation, as observed in the phenomenon of circular polarization where the tips of both electric and magnetic fields rotate continuously which gives either LHCP or Right-

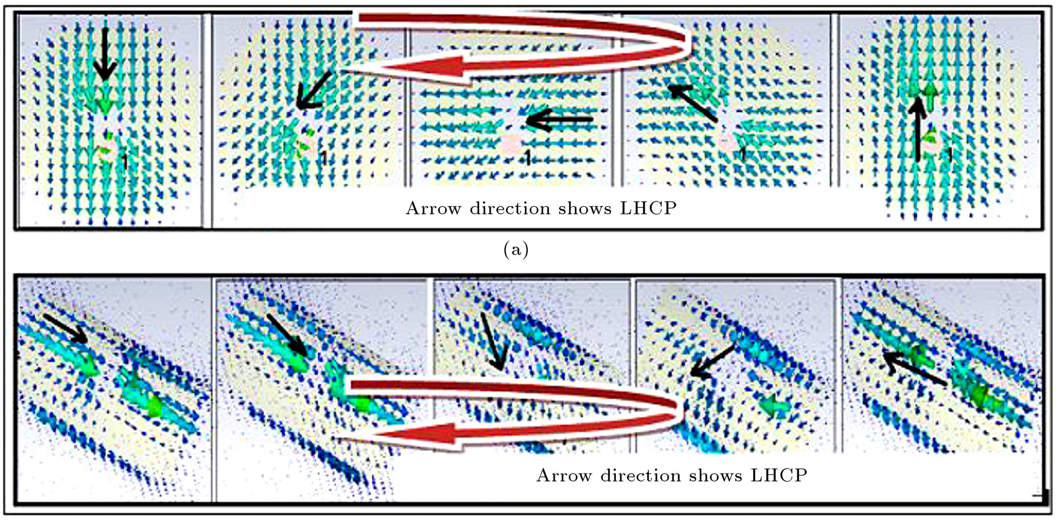

Figure 5. Magnetic field distributions at 2.4 GHz on patch of (a) planar type patch antenna and (b) conformal cylindrical-rectangular patch antenna at different time instants. Both antennas are on air substrate.

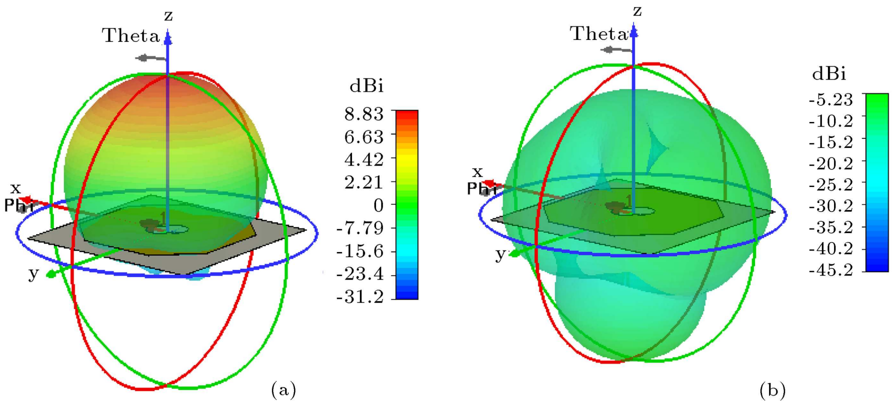

Figure 6. 3-D radiation pattern planar antenna (a) LHCP pattern and (b) RHCP pattern.

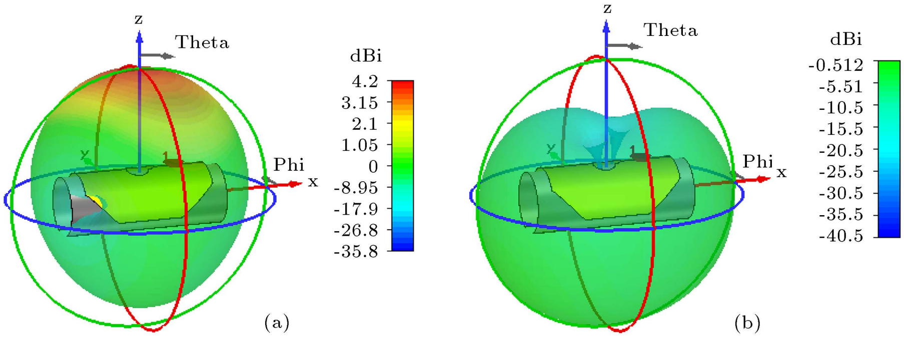

Figure 7. 3-D radiation pattern cylindrical antenna (a) LHCP pattern and (b) RHCP pattern.

Handed Circular Polarization (RHCP). In Figure 5, the tip of the magnetic field clearly shows the LHCP.

Figures 6(a) and (b) and 7(a) and (b) depict the radiation pattern of the planar and cylindrical conformal antennas with LHCP and RHCP configurations. Both figures clearly indicate the LHCP radiation pattern.

3. Conclusion

Recently, circularly polarized patch antenna designs have gained increasing popularity owing to their extensive applications in different fields like Radio Frequency Identification (RFID), Wireless Local Area Network (WLAN), and satellite communication systems. These

Table 2. Result comparison for planar and conformal patch antennas on the air substrate.

Antenna parameters	Planar type	Conformal type
Return loss bandwidth in MHz	78.8	46.2
Axial ratio bandwidth in MHz	10.3	10.6
Gain in dBic	8.79	4.16
Efficiency in %	96.6	95
Axial ratio beam-width at $Phi = 0$ in degree	83	61

patch antennas are flexible in shape and design [15–20]. The projection area of the patch antenna was greatly reduced with the addition of slots. In the presented paper, two novel circularly polarized antenna designs namely a planar and a conformal counterpart were proposed, and their design characteristics are summarized in the following:

According to the results given in Table 2, two different cases can be observed:

1. In the planar patch antenna, the return loss bandwidth increased up to almost 1.7 times than that of the conformal antenna on an air substrate;
2. The gain in the planar patch increased up to almost 2 times the gain in the conformal cylindrical patch antenna. However, there was a significant drop in the axial ratio beam width in the conformal antenna at $Phi = 00$.

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22. CST MWS: Supported by Manipal University Jaipur Rajasthan

Biographies

Muskaan Kapahi completed her BSc of Technology in Electronics and Communication Engineering at Maharaja Agrasen Institute of Technology, New Delhi, India. She received her 12th standard degree from Hans Raj Model School in New Delhi in the year of 2017. She has authored some research papers, two of which are under consideration for publication by international journals. She has presented academic as well as research-based papers in international and national conferences. Her research and academic activities are currently twofold: (i) Her major field of interest is incorporation of the fundamentals of Electronics and communication with IT development to generate the best possible solution in the field of ICT and (ii) She aims to fill the gap between the academic research and educational technology.

Ekagra Gupta completed his BSc of Technology in Electronics and Communication Engineering from Maharaja Agrasen institute of Technology, Delhi, India in 2021. In the initial years of his bachelors, he indulged himself with different workshops regarding the communication mechanisms to understand antennas in a greater depth. To do so, he simulated different antennas including ultrawide band and conformal patch types. Some of his research works were presented in national and international conferences. In addition to the knowledge about CST microwave studio suite, MATLAB, despite being an esoteric language since it is used in designing robots and other autonomous devices, was his interest. His aim is to study a machine as a whole by understanding its signal transformation and detection followed by the mechanism. He has a fresh eye on stmcube software which introduces assembly language coding on various pics and arms as a whole in order to brush up his skills profoundly.

Sumanta Kumar Kundu is presently working as an Assistant Professor in ECE Department of Maharaja Agrasen Institute of Technology, New Delhi, India. He has an excellent teaching experience of 15 years in the field of Electronics and Communication Engineering with 20 years of technical backgrounds in the latest avionics equipment in Indian Air Force. He is well-versed in a variety of concept and practices in this field. He also have a strong background in engineering and other related fields with the ability to conduct research and feasibility studies in fields of interest. He earned his PhD degree in the area of conformal non planar antenna. He has been actively involved in this study and the development in the field of non-planar structure as well. He published more than 26 papers in peer-reviewed international journals, book series, IEEE/Springer conferences, and national conferences.

Sanyog Rawat is currently associated with Electronics and Communication Engineering Department, Manipal University Jaipur. He has working in the teaching and research areas for more than seventeen years. He graduated with Bachelor of Engineering (B.E.) in Electronics and Communication, Master of Technology (MTech) in Microwave Engineering, and PhD in the Planar Antennas. Dr. Rawat has been actively engaged in the research areas and published more than 90 research papers in peer-reviewed international journals, book series, and IEEE/Springer conferences. He has organized several workshops, seminars, and national and international conferences. He has supervised nearly 30 MTech Dissertations, 05 PhD, and guiding 06 scholars for PhD. He has also edited the books on proceedings of the International conference on Soft Computing Theories and Applications (SoCTA-2016, 2017), proceedings of International Conference on Smart Systems, Innovations and Computing (SSIC-2017) and International Conference on Engineering Vibrations, Communication, Information Processing (ICoEVCI, 2018) and International Conference for Wireless Communications (ICCWC-2021) for Springer publication. His current research interests include reconfigurable RF printed circuits, passive and active microwave integrated circuits. He is on the board of reviewers of many Web of Science and Scopus indexed journals like AEU-International Journal of Electronics and Communications Journal (Indexed in Web of Science, Scopus, and Impact Factor: 2.92), Optik-International Journal for Light and Electron Optics (Indexed in Web of Science, Scopus, and Impact Factor: 2.18), Transactions on Emerging Telecommunications Technologies Journal (Indexed in Web of Science, Scopus, and Impact Factor: 1.258), Measurement Journal of the International Measurement Confederation (Indexed in Web of Science, Scopus, and Impact Factor: 3.36) etc. He has visited countries like Japan, Thailand, Malaysia, UAE, and Indonesia for academic and research works. He is also a member of several academic and professional bodies, i.e., Fellow IETE, Life Member IE, and ISLE.