Circularly Polarized Circular Slit Planar Antenna for Vehicular Satellite Applications

Ebenezer Abishek B. [1], **Arun Raaza** [1], **S. Ramesh** [2], **S. Jerritta** [1], **and V. Rajendran** [1]

[1] Department of Electronics and Communication Engineering
Vels Institute of Science, Technology & Advanced Studies (VISTAS), Chennai, 600117, Tamil Nadu, India
abishek.se@velsuniv.ac.in, director.card@velsuniv.ac.in, jerritta.se@velsuniv.ac.in, director.ece@velsuniv.ac.in

[2] Department of Electronics and Communication Engineering
SRM Valliammai Engineering College, Chennai, 603203, Tamil Nadu, India
rameshs.ece@valliammai.co.in

Abstract **─** A compact, ultra light weight and efficient asymmetric circular slit circularly polarized patch antenna is proposed for vehicular satellite communications. The circular slit in the corners of the patch is utilized for achieving circular polarization and an edge-fed through a microstrip feed line incorporates a quarter-wave transformer for impedance matching. Simulation results indicate an improvement in cross polarization isolation. The proposed antenna is fabricated using RT/DUROID 5880 material which is lighter, flexible and less expensive compared to the commercially existing ceramic corner curtailed patch antennas. The measured results indicate a reflection coefficient of -24.1 dB at resonant frequency, impedance bandwidth of 490 MHz ranging from 11.03 GHz to 11.52 GHz, axial ratio bandwidth of 180 MHz ranging from 11.16 GHz to 11.34 GHz and constant gain through the operating bandwidth with an apprehended peak gain of 5.6 dB. Experimentations affirmed that measured radiation results of the suggested antenna are similar to the simulation results and can be utilized as vehicle roof mounted antennas for diverse satellite communication applications.

Index Terms **─** Asymmetric circular slit, circular polarization, patch antenna, vehicular satellite communication.

I. INTRODUCTION

The rapid growth in satellite communication attributes to the numerous services such as navigation, weather prediction, remote sensing, mobile communication, vehicular communication and so on [1]–[4]. Vehicular communication has recently become very important to carry out a good roadway management. The road accidents and burglary have increased in the urban areas to a level which is alarming. The accidents cause loss of human life which can be avoided if the accident victim is rescued at the earliest and given the necessary treatment. Similarly the thief can be caught at the earliest, if information of his vehicle is immediately sent to the corresponding authorities. Vehicular communication becomes inefficient due to the problem of losing vital information due to missed clusters [5], [6]. The only option to overcome this disadvantage is by utilizing satellites for vehicular communication called as vehicular satellite communication. Satellites have a larger footprint and provide communication even to the region where there are no communication systems [7]–[9]. In particular, vehicular satellite applications in the X band are widespread and are found to be robust across a variety of moving vehicles such as land vehicles, aero planes and even ships [10]–[12]. Parabolic Reflector antennas are conventionally used as X band satellite antennas which are generally large and hefty like a viable dish antenna or a reflector which has a diameter of 50 cm [13]. Such antennas degrade the radiation characteristics due to aerodynamic drag at high speed and are not best suited to be mounted on the roof of fast movable automobiles [14]. Applications utilizing satellite in automobiles and other moving vehicles will need a low-cost, light weight and high performance roof mountable antenna. In addition, circular polarized antennas are needed for satellite systems because the circularly polarized antennas are more immune to faradays rotation effect caused in ionosphere, reduction in degradation of signals due to fading or multipath interferences and orientation of transmitting and reception antenna need not be the same. Cross polarization isolation for these mobile satellite systems also require improvement for efficient communication [15].

To obtain miniaturization of an antenna for communication devices fitted in automobiles, investigators have also considered utilizing ceramic patch antennas but these antennas have reduced gain,

Submitted On: December 27, 2018
Accepted On: July 29, 2019

increased weight and increased cost; making it less affordable for day to day users [16].

Efforts have been made by researchers to design the circularly polarized (CP) patch antennas which are low cost, easy to fabricate and with good radiation characteristics like wide angle axial ratio bandwidth and improved cross polarization isolation. Apart from patch antennas, CP antenna can be constructed utilizing other antennas like helical antennas, spiral antennas, magneto-electric dipoles or slot antennas [17]–[20]. In microstrip patch antenna, the circular polarization can be achieved in any feed structure. Single feed is preferred because of its simpler feed structure. A recognized method of obtaining circular polarization in a single-feed patch antenna is by marginally perturbing the patch utilizing stubs, slits, notches, slots and curtailed corners[21], [22].

In this research, a circular shaped asymmetric slit edge feed microstrip patch antenna is proposed for CP radiation with a compact antenna size. The design was arrived by studying and analyzing different circularly polarized microstrip antennas. The slit circumference plays an important role in reduction of patch dimension and hence obtains the desired compact size. The performance of the antenna was compared with the conventional CP microstrip antenna with truncated corners using Ansys HFSS Electromagnetic simulation. The overall antenna dimensions were optimized and fixed to enhance and achieve the desired radiation characteristics. The proposed antenna has good cross polarization isolation compared to the conventional CP microstrip antenna with truncated comers. The proposed design was fabricated easily and inexpensively. The information of the proposed antenna design, simulated radiation results, fabrication and measured results are given in the following sections.

II. ANTENNA DESIGN METHODOLOGY

Figure 1 depicts the geometry of the proposed antenna and the optimized dimensions are listed in Table 1. The proposed antenna is printed on RT/DUROID 5880 substrate with thickness of 0.79 mm. The relative permittivity of this substrate is 2.2. The dimensions were calculated for the quarter wave transformer edge fed rectangular microstrip patch antenna using the design equations [23]. To achieve circular polarization, the rectangular patch is converted to a square patch by changing the dimensions and the inclusion of perturbation elements. A pair of symmetric perturbation elements in the form of circular slits in the main diagonal corners is inserted on the square patch as shown in Fig. 1. Another pair of circular slits in the corners of secondary diagonals are also inserted with a smaller radius when compared with the circular slits in the main diagonal corners. The corner slit structure in the patch radiator is asymmetric due to the difference in circumference of the two pairs of circular slits. The four circular slits are connected to the corresponding corners of the patch through a slit gap Sgl x Sg as shown in Fig. 1 given below.

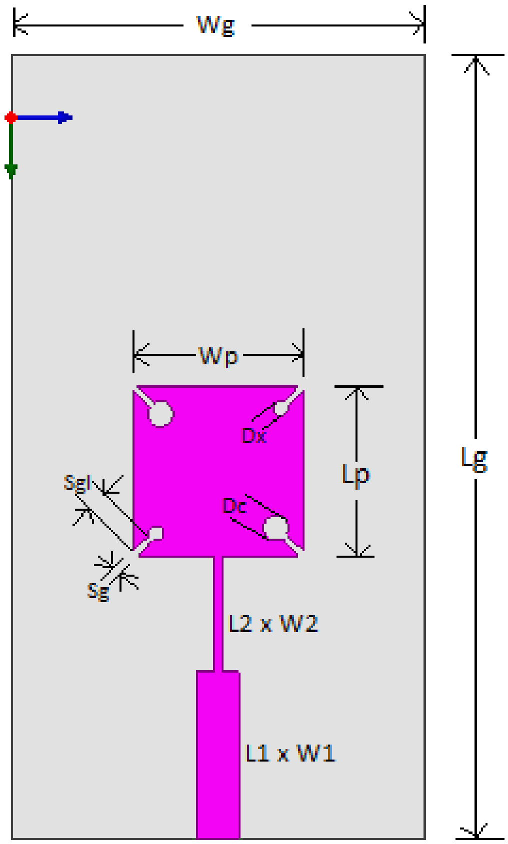

Fig. 1. Structure of the CP asymmetric slit patch antenna.

Table 1: Optimum parametric values of the proposed antenna

Parameters	Values (mm)
Lg	37.18
Wg	19.6
Lp	8
Wp	8
Dc	1.2
Dx	0.69
L1	7.8
W1	2
L2	5.6
W2	0.4
Sg	0.28
Sgl	1.1
Substrate thickness	0.79

The presented antenna is edge fed by quarter wave transformer. Circular slits in the main diagonal direction of the patch acts as a perturbation to the microstrip patch which excites two modes which are orthogonal and has a 90° phase shift, thus causing CP radiation. Two modes Ex and Ey are excited from the corner slits which has larger radius. This excitation of the two modes causes vector rotation of current to achieve left handed circular polarization. The corner slits in secondary diagonal corners suppresses cross polarization. This improves the cross polarization isolation of the antenna. When the two pairs of the corner slits in main diagonal and secondary diagonal are swapped- right handed circular polarization is achieved.

Variation of the diameter of the circular slits on the main and secondary diagonal direction of the proposed antenna causes variation in the resonance frequency of the antenna [24]. The optimal dimensions of the antenna are obtained by Ansys HFSS Electromagnetic simulation.

III. RESULTS AND DISCUSSION

A. Simulation of proposed asymmetric circular slit circularly polarized patch antenna

The simulation results of the proposed CP patch antenna are shown Figs. 2, 3, 4 and 5. Figure 2 shows the reflection coefficient (S_{11}) simulated over a frequency range of 9 GHz to 13 GHz and it's seen that S11 values for the frequency range of 11.02 GHz to 11.52 GHz is less than -10 which is the industrial standard for measuring impedance bandwidth. Thus the impedance bandwidth of 500MHz is achieved.

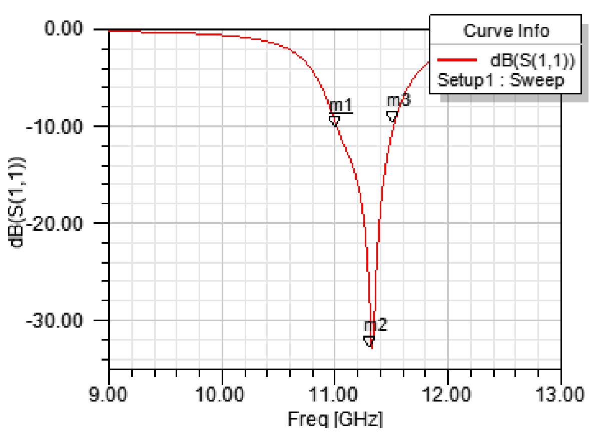

Fig. 2. Reflection coefficient (S11) of the proposed antenna.

The simulated result of axial ratio is shown in Fig. 3. The axial ratio values are simulated over the frequency range of 11.00 GHz to 11.5 GHz with the step size of 0.02 GHz and the angle Phi=90deg is kept constant for selecting the electric field component. Its seen that the axial ratio for the frequency range of 11.16 GHz to 11.34 GHz is less than 3 which is the industrial standard required for circular polarized antennas. The axial ratio bandwidth is 180MHz.

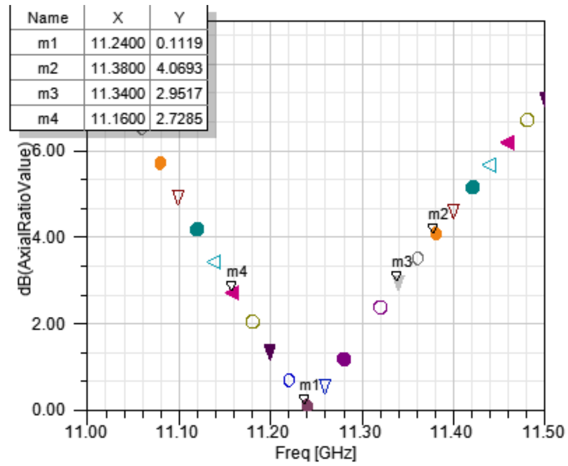

Fig. 3. Axial ratio of the proposed antenna.

The peak gain is found to be 6.6985dB in simulation. Figure 4 and Fig. 5 given below shows the radiation pattern of the proposed antenna and conventional truncated corner patch antenna respectively.

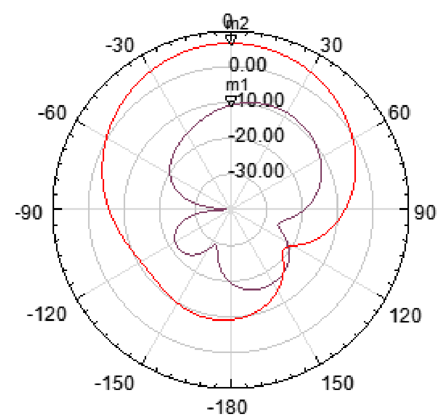

Fig. 4. Radiation pattern of the proposed antenna.

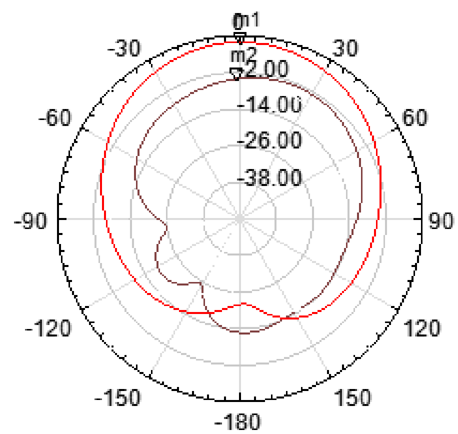

Fig. 5. Radiation pattern of the conventional corner truncated antenna.

The red colour trace in Fig. 4 and Fig. 5 indicates the co-polarization plot which is left-handed circular polarization plot. Similarly, the lavender colour trace in both the figures indicate the cross-polarization plot which is right handed circular polarization plot. The cross polarization isolation is the difference between the co-polarization and cross-polarization at 0 dB. The radiation pattern proposed single element circularly polarized microstrip patch antenna and conventional corner truncated circularly polarized patch antenna is shown in Fig. 4 and Fig. 5 respectively. These results indicate a significant improvement of cross polarization isolation by 4dB in the proposed single element circularly polarized microstrip patch antenna which will be very useful in enhancing the efficiency of the mobile satellite communication systems [15]. This enhancement in cross polarization isolation is due to the smaller slits in the secondary diagonal that suppresses the cross polarization.

B. Fabrication, testing and validation of the proposed asymmetric circular slit circularly polarized patch antenna

The optimized antenna design was fabricated on a RT/DUROID 5880 substrate. The fabricated circularly polarized asymmetric slit patch antenna is shown in Fig. 6. The external dimensions are 37.18 mm × 19.6mm × 0.79mm. All the dimension values including patch, feed etc are specified in Table 1.

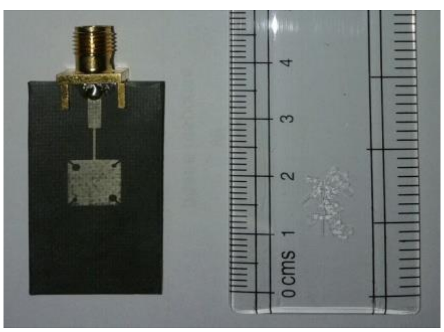

Fig. 6. Fabricated circularly polarized asymmetric slit patch antenna.

This circularly polarized asymmetric slit patch antenna is designed to operate at the centre frequency of 11.3 GHz for vehicular satellite communication applications. Agilent N9917A vector network analyzer was utilized to measure the reflection coefficient. Figure 7 shows the comparison plot of measured and simulated reflection coefficient of the proposed antenna. The simulated -10dB impedance bandwidth was 500 MHz (11.02 to 11.52 GHz) and the measured impedance bandwidth was 490 MHz (10.9 to 11.39 GHz). The Fig. 7 also shows a small shift in the resonant frequency due to manufacturing errors.

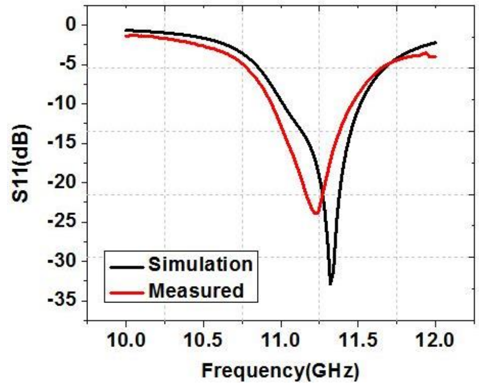

Fig. 7. Reflection coefficient of proposed antenna.

The radiation patterns were measured in a test setup which consists of an anechoic chamber with a Verdant JR12 horn antenna as the transmitting antenna of the measurement system for validation of the proposed antenna design.

The measured Vs. simulation radiation patterns of proposed antenna at the resonant frequency of 11.3 GHz in E and H principal planes is shown in Fig. 8 and Fig. 9 respectively. These figures show left-handed circularly polarized broadside radiation pattern with maximum directivity along 0deg. The axial ratio is found to be less than 3-dB across a 100° beamwidth over the axial-ratio bandwidth frequency range in both the principal planes and the side lobe level of this proposed antenna is measured as -14.9 dB. The test setup comprising of anechoic chamber and JR12 transmitting horn antenna was used to measure the radiation pattern. The direct measurement of gain was not possible utilizing this test setup. Therefore, the gain of the proposed antenna was determined manually using Friss's transmission formula by applying the measured received power obtained by the test setup. There is a slight reduction in gain which occurs due to losses in the connector. But still the simulated results are in good agreement with the measured results and the radiation patterns of simulated and measured results are similar.

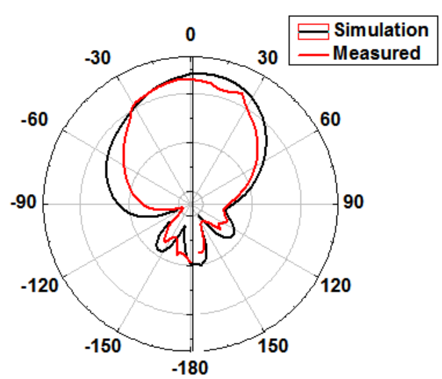

Fig. 8. E-plane pattern of the proposed antenna.

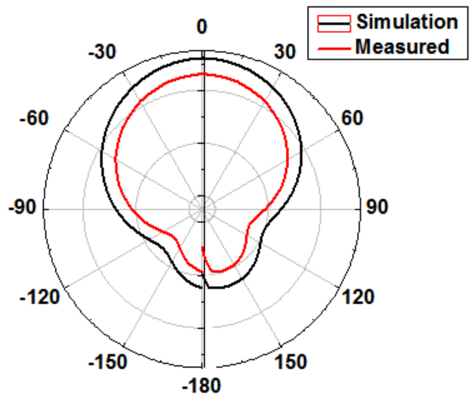

Fig. 9. H-plane pattern of the proposed antenna.

The simulated vs. measured results of the proposed antenna discussed in this section is consolidated and given in Table 2 shown below.

Table 2: Optimum parametric values of the proposed antenna

Parameters	Simulated	Measured
Axial ratio bandwidth	180 MHz	170 MHz
Impedance bandwidth	500 MHz	490 MHz
Peak Gain	6.6985 dB	5.6 dB

IV. CONCLUSION

The compact circularly polarized asymmetric slit patch antennas have been presented on low loss RT/DUROID 5880 substrate. The antenna has a 3-dB axial ratio bandwidth of 180 MHz and impedance bandwidth of 490 MHz. The proposed antenna has improved cross polarization isolation when compared to the conventional corner truncated patch antenna. The measured gain 5.6 dB was lower by 1dB for the antenna when compared with simulation results on the RT/DUROID 5880 substrate. The largest possible slit without changing the required characteristics enabled size reduction to get a compact structure. The proposed antenna because of its improved cross polarization isolation besides the good radiation characteristics is best suited for vehicular satellite applications.

REFERENCES

[1] W. Lin and H. Wong, "Circularly polarized conical-beam antenna with wide bandwidth and low profile," *IEEE Trans. Antennas Propag.*, vol. 62, no. 12, pp. 5974-5982, 2014.

[2] Q. X. Chu, W. Lin, W. X. Lin, and Z. K. Pan, "Assembled dual-band broadband quadrifilar helix antennas with compact power divider networks for CNSS application," *IEEE Trans. Antennas Propag.*, vol. 61, no. 2, pp. 516-523, 2013.

[3] A. R. Weily and Y. J. Guo, "Circularly polarized ellipse-loaded circular slot array for millimeter-wave WPAN applications," *IEEE Trans. Antennas Propag.*, vol. 57, no. 10 PART 1, pp. 2862-2870, 2009.

[4] S. I. Jeon, Y. W. Kim, and D. G. Oh, "A new active phased array antenna for mobile direct broad-casting satellite reception," *IEEE Trans. Broadcast.*, vol. 46, no. 1, pp. 34-40, 2000.

[5] J. Chen, G. Mao, C. Li, W. Liang, and D. G. Zhang, "Capacity of cooperative vehicular networks with infrastructure support: Multiuser case," *IEEE Trans. Veh. Technol.*, vol. 67, no. 2, pp. 1546-1560, 2018.

[6] Y. A. Shah, H. A. Habib, F. Aadil, M. F. Khan, M. Maqsood, and T. Nawaz, "CAMONET: Moth-flame optimization (MFO) based clustering algorithm for VANETs," *IEEE Access*, vol. 6, pp. 48611-48624, 2018.

[7] R. De Gaudenzi, S. Member, and F. Giannetti, "DS-CDMA satellite diversity reception for personal satellite communication: Satellite-to-mobile link performance analysis," vol. 47, no. 2, pp. 658-672, 1998.

[8] M. Buck et al., "An advanced satellite UMTS testbed for laboratory and over-the-air experiments of third-generation mobile services: Part I - System design aspects," vol. 57, no. 1, pp. 169-179, 2008.

[9] K. Kaneko, "Construction of a flexibility analysis model for flexible high-throughput satellite communication systems with a digital channelizer," vol. 67, no. 3, pp. 2097-2107, 2018.

[10] J. Huang, et al., "A new compact and high gain circularly-polarized slot antenna array for ku-band mobile satellite TV reception," *IEEE Access*, vol. 5, pp. 6707-6714, 2017.

[11] M. T. Zhang et al., "Design of novel reconfigurable reflect arrays with single-bit phase resolution for ku-band satellite antenna applications," *IEEE Trans. Antennas Propag.*, vol. 64, no. 5, pp. 1634-1641, 2016.

[12] S. Ye, et al., "High-Gain planar antenna arrays for mobile satellite communications," *IEEE Antennas Propag. Mag.*, vol. 54, no. 6, pp.256-268, 2012.

[13] A. K. Kundu, M. T. Hossain Khan, W.Sharmin, M. O. Goni, and K. A. Barket, "Design and performance analysis of a dual band parabolic reflector antenna with waveguide dipole feed and link budget optimization," *Proc. 2013 2nd Int. Conf. Adv. Electr. Eng. ICAEE 2013*, pp. 309-312, 2013.

[14] A. Liu, Q. Yang, X. Zhang, and W. Deng, "Collision avoidance radar system for the bullet train: Implementation and first results," *IEEE Aerosp. Electron. Syst. Mag.*, vol. 32, no. 5, pp.4-17, 2017.

[15] R. Touzi, P. W. Vachon, and J. Wolfe, "Requirement on antenna cross-polarization isolation for the operational use of C-band SAR

constellations in maritime surveillance," *IEEE Geosci. Remote Sens. Lett.*, vol. 7, no. 4, pp.861-865, 2010.

[16] X. Tang, H. Wong, Y. Long, Q. Xue, and K. L. Lau, "Circularly polarized shorted patch antenna on high permittivity substrate with wideband," *IEEE Trans. Antennas Propag*., vol. 60, no. 3, pp. 1588-1592, 2012.

[17] Q. Zhu, K. B. Ng, and C. H. Chan, "Printed circularly polarized open loop antenna array for millimeter-wave applications," *2017 IEEE Antennas Propag. Soc. Int. Symp. Proc.*, vol. 2017-Janua, no. 2, pp. 2561-2562, 2017.

[18] Y. Li and K. M. Luk, "A 60-GHz Wideband circularly polarized aperture-coupled magneto-electric dipole antenna array," *IEEE Trans. Antennas Propag*., vol. 64, no. 4, pp. 1325-1333, 2016.

[19] J. Wu, Y. J. Cheng, and Y. Fan, "Millimeter-wave wideband high-efficiency circularly polarized planar array antenna," *IEEE Trans. Antennas Propag*., vol. 64, no. 2, pp. 535-542, 2016.

[20] H. W. Lai, D. Xue, H. Wong, K. K. So, and X. Y. Zhang, "Broadband circularly polarized patch antenna arrays with multiple-layers structure," *IEEE Antennas Wirel. Propag. Lett*., vol. 16, pp. 525-528, 2017.

[21] Y. F. Lin, C. H. Lee, S. C. Pan, and H. M. Chen, "Proximity-fed circularly polarized slotted patch antenna for RFID handheld reader," *IEEE Trans. Antennas Propag*., vol. 61, no. 10, pp. 5283-5286, 2013.

[22] Nasimuddin, Z. N. Chen, and X. Qing, "A compact circularly polarized cross-shaped slotted microstrip antenna*," IEEE Trans. Antennas Propag*., vol. 60, no. 3, pp. 1584-1588, 2012.

[23] C. A. Balanis, *Antenna Theory*, 3rd ed., John Wiley & Sons, Inc., 1997.

[24] Nasimuddin, X. Qing, and Z. N. Chen, "Compact asymmetric-slit microstrip antennas for circular polarization," *IEEE Trans. Antennas Propag*., vol. 59, no. 1, pp. 285-288, 2011.

Ebenezer Abishek B. received his B.E. in Electronics and Communication Engineering from Anna University, M.E. in VLSI Design from Anna University, Chennai and Ph.D. in Electronics and Communication Engineering from VISTAS in 2010, 2012 and 2019 respectively. He is currently, working as an Assistant Professor in the department of Electronics and Communication Engineering, VISTAS, Chennai with teaching experience of 6 years. His area of interest includes Antennas & Propagation and Electromagnetic Applications. His ORCiD is 0000-0003-2908-7069.

Arun Raaza holds a Master of Research degree from Institute of Advanced Telecommunications, Swansea University, UK and Ph.D. – ECE at VISTAS, Chennai. His research work in Antennas include the completion of the CABS/DRDO funded project titled "Design and Simulation study of Low profile Ku band airborne SATCOM antenna unit for early warning system" in 2017. He has contributed towards 6 Govt. of India projects (2 for DAE, 2 for DSIR, 2 for DRDO), several Industry funded projects, 30+ National patents, 2 International patents and 8 Transfer of Technologies.

S. Ramesh received his B.E. in Electronics and Communication Engineering from University of Madras, M.Tech. in Communication Engineering from VIT University, Vellore and received his Ph.D. degree on from SRM University, Chennai, in 2001, 2004 and 2015 respectively. He is currently working as an Associate Professor in the Department of Electronics and Communication Engineering, SRM Valliammai Engineering College, Chennai. He is a senior member (S'10-M'17-SM'18) of IEEE Antennas & Propagation Society. His ORCiD is 0000-0002-2946-5296.

Jerritta Selvaraj is an Associate Professor in the Department of ECE at VISTAS, Chennai, India. She holds a Ph.D. degree in Biomedical Electronics Engineering from University Perlis Malaysia (UniMAP). Her research focuses on electromagnetic applications.

V. Rajendran received his M.Tech. from Indian Institute of Science (IISc), Bangalore, India and received his Ph.D. degree from Chiba University, Japan in 1981 and 1993 respectively. He is currently, Professor and Director of the Department of ECE in VISTAS, Chennai.