International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075 (Online), Volume-8 Issue-12, October 2019

Design Techniques for Elliptical Micro-Strip Patch Antenna and Their Effects on Antenna Performance

Jerry V. Jose, A. Shobha Rekh, Jose M.J.

Abstract: Elliptical Micro-strip Patch Antenna (EMPA) has been emerged as a peculiar and significant category among the different shaped micro-strip patch antennas because of its circular polarization and dual-resonant frequency features with a single feed. Elliptical and its derived shapes such as semi-elliptical, half-elliptical, slotted-elliptical and elliptical ring are found to be particularly instrumental for bandwidth enhancement and these antennas find great applications in Ultra Wide Band (UWB) and Super Wide Band (SWB) communications. Compared to antennas with circular or rectangular shapes, the design of EMPA is a research area of high potential as there is higher flexibility in its design due to more degrees of freedom. The reported literature in the field of EMPA is very less and there is ample scope for new researchers to work on. This review paper is an attempt to summarize and critically assess the-state-of-the-art design techniques as reported in literature and understand their effects on performance of elliptical patch antenna for suggesting new research fronts in the field of EMPA.

Keywords – Elliptical Micro-strip Patch Antenna, Circular polarization, Eccentricity, UWB.

I. INTRODUCTION

Circular polarization and dual resonant frequencies are required in many real time applications such as radar, communication, telecommunication and navigation systems. For wireless applications, the circular polarization can be achieved by varying the shape of or by the use of multiple feeds for rectangular micro-strip patch antenna. But, with the help of only a single feed, circular polarization can be achieved for an elliptical patch antenna which is fed along a radial line inclined at $\pm 45^0$ to its major axis [1]. The positive sign yields Left-Hand Circularly Polarized (LHCP) wave and the negative sign yields Right-Hand Circularly Polarized (RHCP) wave. For EMPA with small values of eccentricity, left-hand or right-hand circular polarization may be achieved in a narrow frequency band and the currents, internal fields and radiated fields of antenna are expressed in terms of Mathieu Functions.

Revised Manuscript Received on October 30, 2019.
***** Correspondence Author
Jerry V. Jose*, Dept. of Electronics & Communication Engineering, Karunya Institute of Technology & Sciences, Coimbatore, Tamil Nadu, India. Email: jerryv@karunya.edu.in
A. Shobha Rekh, Dept. of Electronics & Communication Engineering, Karunya Institute of Technology & Sciences, Coimbatore, Tamil Nadu, India. Email: shobhapaulson@karunya.edu
Jose M.J., Dept. of Mechanical Engineering, Govt. College of Engineering Kannur, Kerala, India. Email: josemj@gcek.ac.in

A theoretical study was conducted to calculate the dual-resonant frequency of the dominant even and odd modes and for predicting the existence of circular polarizations of EMPAs [2].

A simple resonant circuit model was developed to predict the input impedance of an EMPA and this model was used to determine the impedance and bandwidth as a function of the size, eccentricity and thickness of the radiator [3]. A more accurate and simple technique to calculate the resonant frequency of dominant even and odd modes of elliptical patch antennas was discussed [4]. The even mode was found to have a low value of bandwidth when the eccentricity was large. Also, it was observed that the even mode had a broader radiation pattern with a lower level of cross-polarization in comparison with the odd mode. A better approach that could determine resonant frequencies of EMPA more closer to experimental values was proposed [5]. Also, elliptical structure is said to have a wider frequency band of operation than the circular one. Eccentricity value was listed as an additional degree of freedom [6]. Method of Moments (MoM) along with the reaction integration method was employed to analyze the EMPA for circular polarization where the continuity and singularity of the currents in the patch-probe conjunction point was ensured using the attachment mode [7]. A model to predict the dual resonant frequencies of an elliptical patch micro-strip printed on isotropic or anisotropic substrate was developed [8]. An analytical approach was presented for the characterization of metasurfaces consisting of elliptical patches printed on grounded dielectric slab [9]. The behavior of radiated fields and impedance of elliptical radiator as a function of frequency, eccentricity and dielectric thickness was investigated through an experimental study [10]. The eccentricity was varied from 1.00 to 0.96 for five different ellipses for two different thicknesses of printed circuit board. The antenna which produced the best circular polarization was having an eccentricity value of 0.976.

The EMPA finds immense applications in Wireless Local Area Network (WLAN) [11][12], Ultra Wide Band (UWB) communications [13][14][15][16][17][18][19], GPS (1.57-1.58 GHz) [14][20], GSM1800 (1.71-1.88) GHz, PCS1900 (1.93-1.99) GHz, Multi-band GNNS [14], WiMax communication systems [21], Microwave communications [22], L-band and S-band communications [23][24], Super Wide Band (SWB) communications [25][26], Ultra High Frequency (UHF) band communications, GSM900, Radio Frequency Identification (RFID) band communications [27], mobile satellite service, radio astronomy, amateur radio services, C-band communications, X-band communications [28], radiolocation (8.50-10.55 GHz) services [29] and holographic antennas [9].

The enormous applications of EMPAs demand faster development of design techniques which requires greater efforts from scientific community.

A thorough knowledge of current techniques and practices used among researchers is a prerequisite to such an adventure and this is exactly the motivation behind preparing such a review paper. This paper tries to summarize and critically assess the state-of-the-art design techniques for EMPAs and their effects on the performance of antennas. The paper also envisages identifying the less traversed paths in design of EMPA and thus opening up new and promising research fronts for scientists. The paper is organized as follows – section 2 gives the important formulae to determine the dual resonance frequency which is an important characteristic of an EMPA and section 3 describes the classifications of design techniques and their effects on performance parameters of antenna in detail. Table-I provides a summary of different design techniques and their effects on EMPA performance. Section 4 is a discussion on the significance of eccentricity values on the design of EMPAs and section 5 suggests some directions for future work in the field of EMPA.

II. FORMULAE TO CALCULATE DUAL RESONANCE FREQUENCY

In an elliptical patch antenna, the semi-major axis, semi-minor axis and effective semi-major axis are designated as a, b and a_{eff} respectively. Circularly polarized waves are produced at two orthogonal modes, known as even and odd modes, using a single feed along a line inclined at 45^0 to the semi-major axis. Determination of dual resonance frequency can be carried out using the approximated Mathieu function as given below [2][10][5][30].

$$a_{eff} = a\left[1 + \frac{2h}{\pi \varepsilon_r a}\left\{\ln\left(\frac{a}{2h}\right) + (1.41\, \varepsilon_r + 1.71) + \right.\right.$$
$$ha\ 0.268\ \varepsilon r+1.65\ 12 \quad (1)$$

$$f_{11}^{e,o} = \frac{15}{\pi e a_{eff}}\sqrt{\frac{q_{11}^{e,o}}{\varepsilon_r}} \quad (2)$$

$$q_{11}^{e} = -0.0049e + 3.7888e^2 - 0.7278e^3 + 2.314e^4 \quad (3)$$

$$q_{11}^{o} = -0.0063e + 3.8316e^2 - 1.1351e^3 + 5.2229e^4 \quad (4)$$

Where,

$a =$ length of semi-major axis; $h =$ height of dielectric substrate; $a_{eff} =$ effective length of semi-major axis; $\varepsilon_r =$ permittivity of dielectric substrate; $e =$ eccentricity of elliptical patch; $f_{11}^{e,o} =$ dual resonance frequency; $q_{11}^{e,o} =$ approximated Mathieu function of the dominant ($TM_{11}^{e,o}$) mode.

Table-I: Summary of effects of different design techniques on EMPA performance

No.	Design techniques		Effects on EMPA performance
1	Use of FSS[a] Superstrate or Parasitic patch		Gain improvement [31][28]
2	Stacked structures		Multiple resonant bands, higher gain, dual polarization [11], gain improvement [32]
	Hybrid structures		Improvement in bandwidth and radiation efficiency, smaller size [33]
3	Fractal techniques		Gain improvement, multiple resonance, compact size [34]
4	Introduction of slots		Reduction in effective patch size [12], wider bandwidth [13] [18] [21], smaller size [13] [29], notch in WLAN[b] band [15]
5	Modified Ground plane structures		Wider bandwidth [19] [25] [14] [26]
6	Introduction of metamaterials		Gain improvement [35]
7	Elliptical annular ring antennas		Smaller size [27] [20]
8	Miscellaneous techniques	Ellipse-loaded circular slot array	High gain [36]
		GA[c] for creating amorphous shape using ellipses	Wider bandwidth, less reflection loss [37]
		ANN[d] for synthesis of EMPA	All the other design parameters can be extracted at a particular frequency and gain [24]
		Edge truncated elliptical patch	Reduction in effective patch size [38]

[a]FSS – Frequency Selective Surface; [b]WLAN – Wireless Local Area Network; [c]GA – Genetic Algorithm; [d]ANN – Artificial Neural Network.

III. DIFFERENT DESIGN TECHNIQUES FOR EMPA

A. Use of FSS Superstrate or Parasitic Patch

The use of Frequency Selective Surface (FSS) Superstrate along with elliptical patch (with circular slots at different locations) at resonant frequency 5.38 GHz achieved a peak gain of 9.8 dBi and impedance bandwidth of 0.49 GHz [31].The FSS is any surface construction designed as a 'filter' for plane waves. Without the suprstrate layer, the gain and impedance bandwidth achieved were 4.7 dBi and 0.36 GHz respectively. Thus the performance parameters were reported to be improved with use of highly reflective superstrate layer. CST microwave studio was used to optimize the slot radii (R1 and R2) and spacing between patch and superstrate. The optimized air gap between the patch and the superstrate was 28.5 mm.

Antenna #1, Antenna #2 and Antenna #3 are the stepwise modifications in the proposed antenna geometry as shown in Fig. 1 and Antenna #4 is the proposed resonant cavity patch antenna, the side view of which is shown in Fig. 2. Photograph of the FSS layer is shown in Fig. 3.

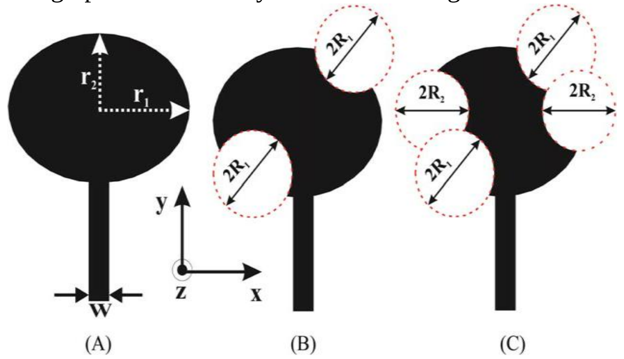


Fig. 1 Stepwise modifications in the proposed antenna geometry. (A) Antenna #1, (B) Antenna #2, and (C) Antenna #3 [31]

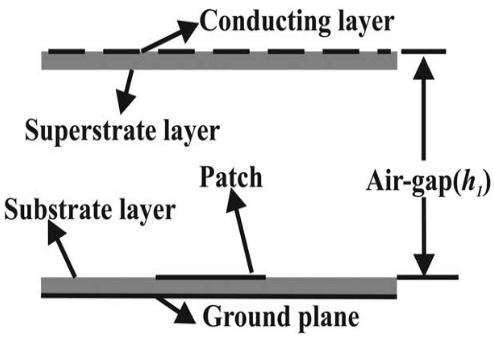


Fig. 2 Side view of the resonance cavity (Antenna #4) [31]

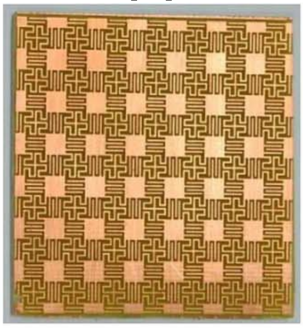


Fig. 3 FSS layer [31]

Use of elliptical parasitic patch has caused improvement in antenna characteristics [28]. A compact antenna for multiband wireless communication was presented and the structure consisted of a wide elliptical slot on the substrate. A micro-strip line was provided at the other side of the patch. A parasitic patch of elliptical shape was placed at the center of the elliptical slot. The proposed type of antenna was comparatively smaller in size. Experimental studies revealed that the designed antenna was suited for different applications such as mobile satellite service (1.6465-1.66 GHz), radio astronomy (1.6605-1.6684 GHz), broadband personal communication service (1.85-2 GHz) and amateur radio services (2.305-2.31 GHz).

An Ultra Wide Band (UWB) antenna of broader impedance bandwidth with good impedance matching from 3 to 11 GHz was designed and fabricated by using carved semi-elliptical parasitic patch that was electromagnetically coupled to the directly fed main patch [17]. Two sectors were carved on the bottom side of elliptical patch. The truncated ground plane, main patch and parasitic patch were in the shape of a half-ellipse. The design helped to achieve the wider bandwidth. An extra inverted patch was attached to the main patch to omit the undesired frequency band of 5.1 to 5.9 GHz. HFSS software was used to analyze and optimize the antenna design. Fig. 4 shows different views of the fabricated prototype of antenna.

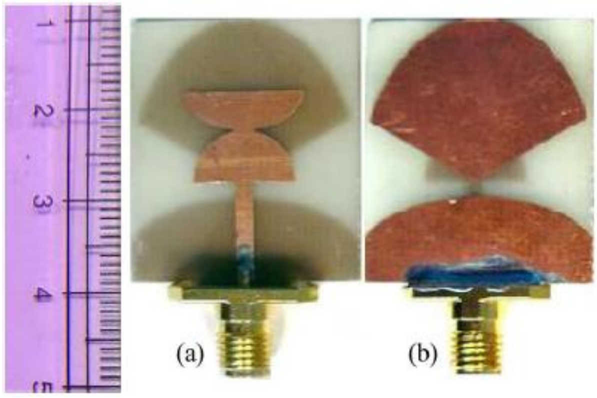


Fig 4. Photograph of prototyped UWB antenna (a) top view (b) bottom view [17]

B. Stacked and Hybrid Structures

The stacked patch antenna consists of multiple patches stacked one over the other. Stacked rectangular and circular patch antennas have been amply reported, but stacked elliptical patch antenna is less reported in literature. A single coaxial feed dual polarized triple band stacked micro-strip patch antenna was designed and analyzed by Dinesh et al.[11]. The antenna consisted of two resonating elements with lower layer made up of truncated corner square patch and upper layer with an elliptical patch. RT Duroid 5880 substrate (ε_r= 2.2) was used for both the patches. The resonant frequencies of the antenna were 4.2, 4.8 and 5.8 GHz. The eccentricity of ellipse was as high as 0.6. The proposed stacked antenna is claimed to be suitable for different wireless applications including WLAN. Fig. 5 shows the top view of the proposed stacked antenna design.

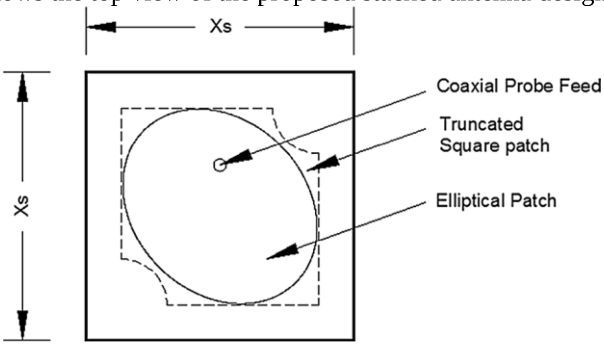


Fig. 5 Top view of the proposed stacked antenna design [11]

The hybrid patch antenna is made as a combination of patch antennas of different shapes. Printed monopole antenna with a hybrid trapezoidal-elliptical radiator was designed and fabricated, within which an overlapping region was introduced between the trapezoidal and elliptical patches to enhance the impedance bandwidth [33]. Fig. 7 shows the overlap region between the trapezoidal and elliptical patches.

Further improvement in the bandwidth was attained by providing two quarter elliptical slots on the ground and optimizing the ellipticity ratio. Total size of antenna was only 25 x 25 x 1.2 mm^3 and it was reported to have achieved smaller size and wider bandwidth. The hybrid antenna covered the frequency range of 2.4-18.6 GHz. Ansoft HFSS software was used to optimize the design. The fabricated prototype featured nearly omnidirectional radiation patterns, desirable gain, high radiation efficiency and almost constant group delay.

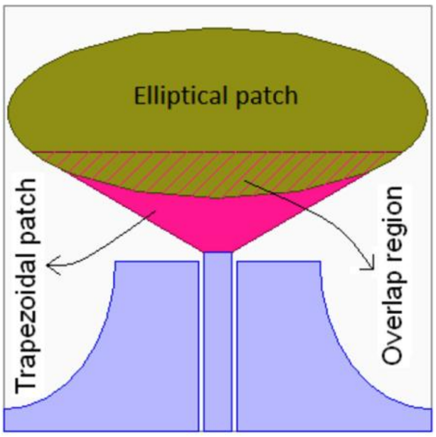


Fig. 7 (a) Overlap region between the trapezoidal and elliptical patches [33]

A double layered circularly polarized elliptical patch reflectarray antenna structure was designed for broadband applications [32]. The reflectarray element was composed of two elliptical patches stacked on top and middle surfaces of two substrates (RO4003C) with the same dielectric constant ($\mathcal{E}_{r1}=\mathcal{E}_{r2}=3.38$). Fig. 8 shows the construction details of the stacked reflectarray antenna.

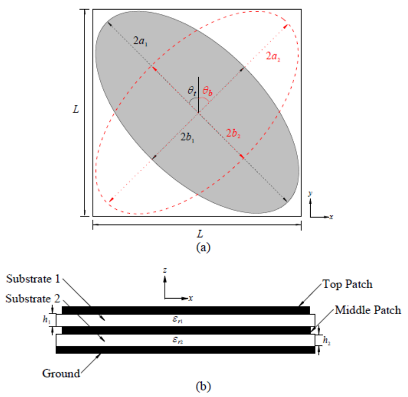
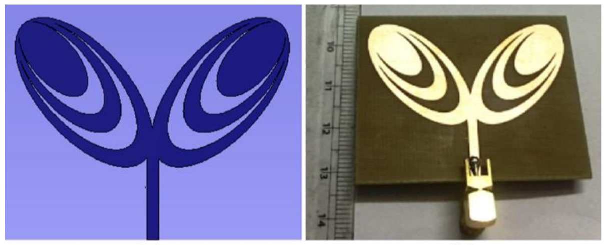


Fig. 8 (a) Top view in which the middle patch is highlighted in dotted lines (b) Side view of double-layered elliptical patch element [32]

C. Fractal Techniques

A fractal is a never ending and self-similar pattern that repeats itself at different scales. Fractals are structures of infinite complexity and they are made by repeating a simple process. There are natural fractals like trees and river networks and mathematical fractals like Mandelbrot Set. Fractals may be used in two ways to enhance antenna designs, one as a design technique for miniaturized antenna elements and the other one as the use of its self-similarity in the geometry to blueprint antennas. A compact fractal elliptical monopole antenna was designed for wide variety of applications like satellite communication transmissions, some Wi-Fi devices, cordless telephones and weather radar systems [34]. The Lorentz fractal shape was introduced on ellipse and thereby multiband applications were achieved. The proposed patch was obtained by joining two ellipses at an angle of 45^0 and fed by a micro-strip feed. The obtained resonant frequencies were 1.7, 3.2, 3.9, 5.9, 7.8, 8.6, 9.7, 11.4 and 12.6 GHz with VSWR ≤ 2.The fractal antenna was printed on FR-4 ($\mathcal{E}_r$ = 4.4) substrate of thickness 1.6 mm. Fig. 9 shows the design of Lorentz fractal structure and photograph of proposed fractal antenna.



(a) (b)

Fig. 9 (a) Design of Lorentz fractal structure (b) Photograph of proposed fractal antenna [34]

D. Introduction of Slots

The performance of micro-strip patch antenna can be improved by introducing slots of different shapes on the patch and there are several such works reported in literature in the case of rectangular and circular patch antennas. Number of research works where slots are employed on elliptical patch to enhance its performance is comparatively less. Circular slotted elliptical patch antenna was designed and fabricated with an elliptical notch in ground for L-band and S-band applications [23]. Elliptical patch with a circular notch and micro-strip line was printed on the top layer of FR4 substrate with thickness of 1.6 mm. An elliptical wide slot with an eccentricity of 0.97 and another elliptical notch were printed on the bottom side of the substrate. Impedance matching of the antenna was improved mainly due to the elliptical notch on the ground plane. Coaxial feed was provided with a micro-strip line. Fig. 10 shows the geometry of proposed antenna. This antenna covered the bandwidth of 102.58% from 1.32 GHz to 4.1 GHz for $|S_{11}|$ < -10 dB. It covered the bandwidth from 5.58 GHz to 6.0 GHz also.

Inclusion of orthogonal sector slots on elliptical patch was found to be resulting in less effective patch area and improved bandwidth [12]. The EMPA had two sector slots arranged opposite to each other along the major axis and a sector slot was provided along the minor axis orthogonal to these two slots. Location and dimensions of these sector slots were determined through optimization. The optimum values of radius and sector angle of each sector slot were found to be 8.0 mm and 20^0 respectively. The antenna geometry was simulated using IE3D simulation software. The improvement in bandwidth was close to 10.96% which was claimed to be four times higher than that of a conventional EMPA under similar test conditions. Also the effective patch area of proposed antenna was comparatively less.

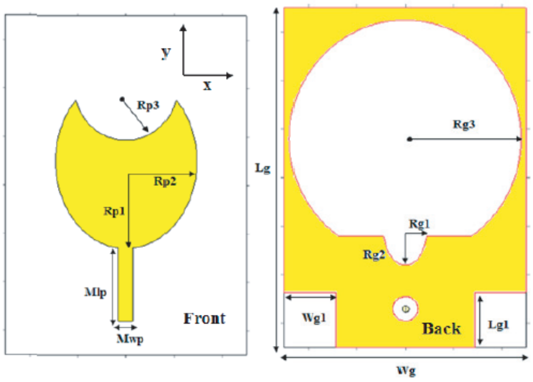


Fig. 10 Geometry of circular slotted elliptical patch antenna [23]

This antenna may be used for WLAN communications covering the 5.15 – 5.85 GHz frequency bands adopted by IEEE 802.11 a5.

Two slots were incorporated along the edges of the elliptical monopole micro-strip patch antenna for UWB applications [16]. Fig. 11 shows the schematic of elliptical monopole antenna with two slots. Overall performance of the UWB antenna could be improved by adjusting the size and locations of these slots. The UWB antenna response could be reconfigured from the band-notch type to the conventional one and vice versa with the use of a switch, like a PIN diode switch. Fig. 12 shows the topology of the UWB antenna with a notch frequency, in which switch is added to the centre of the slot. When the switch is 'ON', current may pass through it and the single slot will split into two slots leading to a UWB antenna without a notch filter.

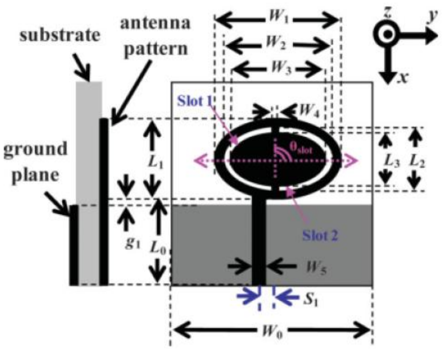


Fig. 11 Schematic of elliptical UWB antenna with two slots [16]

When the switch is 'OFF', the antenna becomes a band-notch UWB antenna.

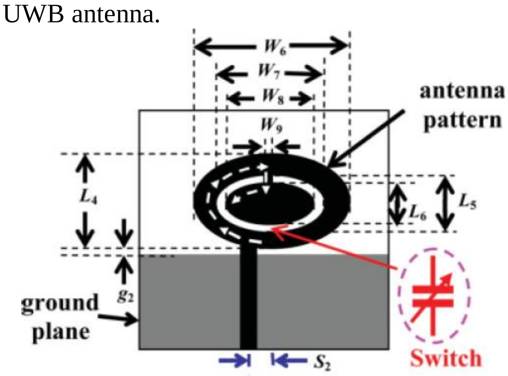


Fig. 12 Topology of the elliptical UWB antenna with a notch frequency [16]

A crescent shaped monopole micro-strip patch antenna for UWB applications in the 3-10 GHz band was designed and fabricated by removing a circular disc from an elliptical patch [13]. Prototype of the crescent shaped antenna was found to be having similar radiation properties as that of a full elliptical antenna, even if it possessed only 60% of patch area of the later. Thus the inclusion of circular slot in the elliptical patch here resulted in a 40% reduction in the effective area of patch. The prototype design was performed using the simulation software Ansoft HFSS. The crescent patch prototype was printed on an FR4 material with no ground plane directly underneath it. Thickness of substrate was 0.762 mm. Fig. 13 shows the structure and photograph of the crescent shaped patch antenna.

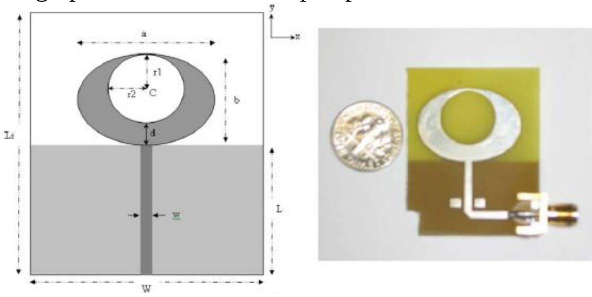


Fig. 13 Structure and photograph of the crescent shaped patch antenna [13]

An elliptical patch was inserted into an elliptical slot while designing a probe-fed EMPA for radiolocation applications within the band of 8.50 – 10.55 GHz [29]. The offset distance from elliptical patch to the nearest side of elliptical slot, designated as'd', was varied to control the impedance matching. The prototype was printed on an FR4 dielectric substrate with dielectric constant $\mathcal{E}_r$ = 4.3 and thickness of 1.575 mm. The patch was fed by a 50 Ω coaxial probe of 0.9 mm diameter. Simulations were carried out using CST Microwave Studio. Fig. 15 shows the configuration of probe-fed micro-strip patch antenna with an elliptical patch within elliptical slot. This antenna, with offset distance d = 0, had an impedance matching bandwidth of around 5.75% (between 9.650 and 10.222 GHz). It was also found that when the offset distance was decreased, the centre operating frequency and the impedance matching bandwidth were increased and the antenna gain was reduced. The maximum radiation gain obtained was 6.278 dBi at 9.845 GHz.

A small band-notched printed monopole antenna for UWB applications was prepared by introducing a slot along the major diameter of the elliptical patch [15].

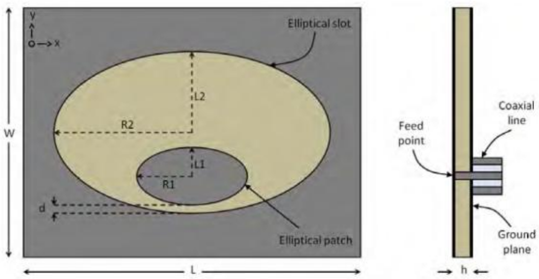


Fig. 15 Configuration of probe-fed micro-strip patch antenna with an elliptical patch within elliptical slot [29]

The antenna was printed on a dielectric substrate with thickness of 1.00 mm and relative permittivity of 4.4. It was fed by a 50 Ω micro-strip line. The first resonant frequency was found to be decreased because of this slot, and a notched-band that covers the 5 GHz WLAN band was attained.

The antenna achieved an impedance bandwidth ranging from 3.00 GHz to over 10.75 GHz for return loss $\leq$ -10 dB and a notched-band of 4.85 – 6.10 GHz for return loss $\geq$ -10 dB. Fig. 16 shows the configuration of proposed antenna.

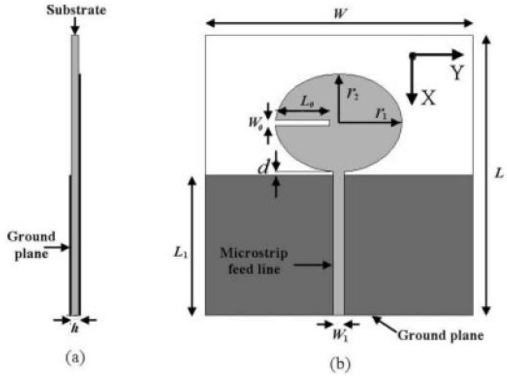


Fig. 16 Configuration of slotted elliptical monopole patch antenna for UWB applications (a) side view (b) top view [15]

Crescent-shaped elliptical patch monopole antenna with a T-shaped stub and square ground board plane was designed for UWB applications [18]. The T-shaped stub was added to provide the broadband radiation pattern and band-notched characteristics. The radiating element was a 0.5 mm thick copper sheet placed vertically over the rectangular ground plane. It was reported that the design produced a bandwidth of 3.1 – 10.6 GHz with VSWR < 2 dB and avoided interference from existing wireless systems in the 5.11 – 5.47 GHz or 5.15 – 5.825 GHz bands. Fig. 17 shows the schematic of the crescent-shaped elliptical antenna. It was observed that the design parameters of the

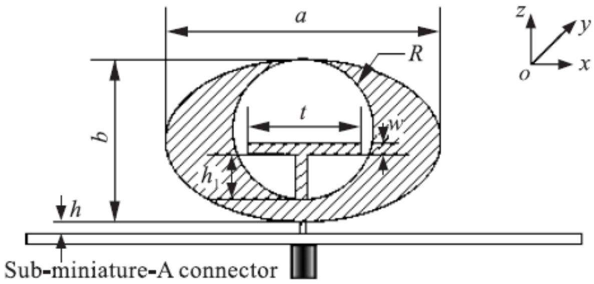


Fig. 17 Schematic of the crescent-shaped elliptical monopole band-notched antenna [18]

T-shaped stub greatly affected the bandwidth and the central frequency of the notched band.

Semi-elliptical patch antenna structure with semi-circular ring slot was designed and fabricated for WiMax applications [21]. The antenna was made of multilayered substrate material having two glass epoxy FR4 substrates separated by a thin foam substrate of thickness 1.0 mm. Semi-major and semi-minor axes of the semi-elliptical patch were 23.0 mm and 14.0 mm respectively. Fig. 18 shows the semi-elliptical patch antenna with semi-circular ring slot. Centre of semi-circular ring slot was at 11.5 mm along minor axis from the straight edge of semi-elliptical patch. The inner and outer radii of semi-circular ring slot were 5.1 mm and 6.1 mm respectively.

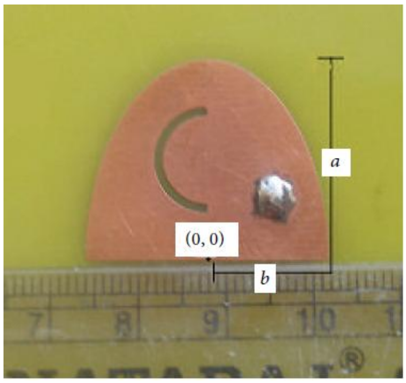


Fig. 18 Top view of semi-elliptical patch antenna structure with semi-circular ring slot [21]

E. Modified Ground Plane Structure

Cutting a slot in the ground plane pattern under the micro-strip line was proved to be a good technique for impedance-matching for a planar elliptical antenna for UWB communications [19]. The elliptical patch antenna was printed on an FR4 substrate of thickness 0.8 mm and relative permittivity of 4.4. The ground plane was of rectangular shape. The geometry of elliptical UWB antenna with a slot in the ground plane is shown in Fig. 19. The width and depth of the slot were varied from 2.5 mm to 4.0 mm and from 0.5 mm to 2.0 mm respectively and their effects were studied. The antenna could provide good broadband characteristics in a planar structure.

Use of trapezoidal ground plane was reported in literature. A trapeziform ground plane, along with an optimum elliptical monopole patch and a tapered Co-Planar Waveguide (CPW) feeder could achieve a ratio impedance bandwidth of 21.6:1 for VSWR $\leq$ 2 [25]. Both the monopole and the ground plane were etched on the same side of the substrate with thickness of 1.524 mm and relative permittivity of 3.48. The elliptical monopole was fed by a tapered CPW feeder in the middle of the ground. It was observed that the use of trapeziform ground plane instead of rectangular one broadened the impedance bandwidth by 1.5 times. Fig. 20 shows the geometry of the elliptical monopole antenna with trapeziform ground plane.

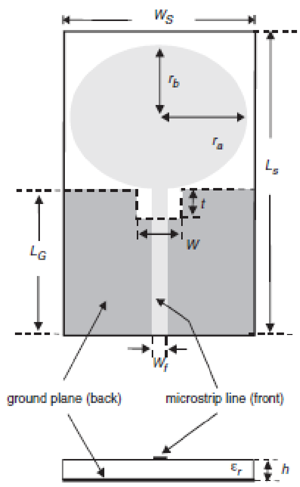


Fig. 19 Geometry of elliptical UWB antenna with a slot in the ground plane [19]

Retrieval Number: L33561081219/2019©BEIESP
DOI: 10.35940/ijitee.L3356.1081219
Journal Website: www.ijitee.org

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

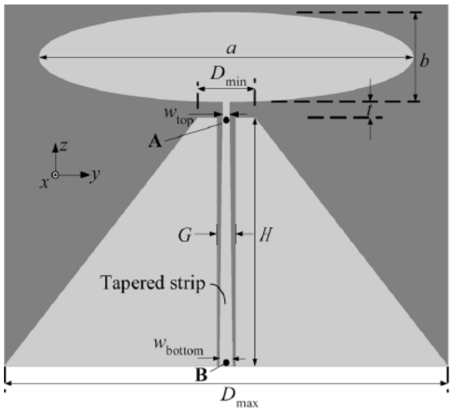


Fig. 20 Geometry of elliptical monopole antenna with the trapeziform ground plane [25]

The same authors proposed a bandwidth enhancement technique by which they made an extremely wideband antenna with a trapezoidal shape ground plane and elliptical monopole patch fed by a modified tapered CPW line [14]. The modification in the feeder line was incorporation of triple-segment feeding arrangement to planar monopole antenna which resulted in improvement of impedance bandwidth. While the modification extended the upper limit of bandwidth substantially, there was no significant change to the lower limit. The antenna could achieve an extremely wide impedance bandwidth of 1.02 GHz - 24.1 GHz with a VSWR $\leq$ 2. This antenna was claimed to be supporting many wireless services such as GPS (1.57-1.58 GHz), GSM1800 (1.71-1.88) GHz, PCS1900 (1.93-1.99) GHz, WLAN (2.5 or 5-6 GHz), Multi-band GNNS and UWB (3.1-10.6 GHz).

Semi-elliptical monopole patch antenna fed by a tapered coplanar waveguide feeder was proposed for SWB applications [26] and this led to reduction in size and weight of antenna in comparison with an elliptical patch antenna. Geometry of the semi-elliptical patch along with feeder is shown in Fig. 21. In the case of an elliptical patch antenna under the same feeder conditions, it was observed that the surface currents of the patch monopole mostly concentrated on the lower portions of the patch close to the feed, at all frequencies of its operating bandwidth. Surface currents around the centre and above of the patch are of low current density. Hence, the upper semi-elliptical part of the patch was discarded from the elliptical patch to reduce the size and weight of antenna, as shown in Fig. 21. There was a spacing ‘t’ between the semi-elliptical monopole and tapered ground plane. CST Microwave Studio was used for simulation and Agilent 8722ES network analyzer was used for taking experimental measurements. The antenna achieved a measured ratio bandwidth of 19.7:1 for VSWR $\leq$ 2 and covered the frequency range from 0.46 to 9.07 GHz.

F. Introduction of Metamaterials

Metamaterials are introduced in patch antennas to reduce its size while retaining the same radiation properties. Metamaterials thus helps to improve performance of miniaturized patch antennas. It was shown analytically that the resonant dimensions of sub-wavelength elliptical patch antenna could be squeezed when the magnetic metamaterials of properly tailored properties were used [35]. The proposed design consisted of an elliptical patch

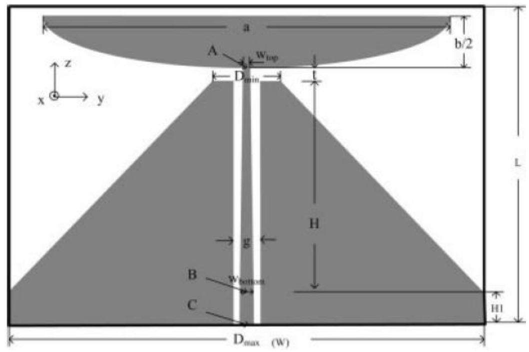


Fig. 21 Geometry of semi-elliptical monopole patch antenna for SWB applications [26]

antenna which was partially loaded by an MNG (μ-Negative) metamaterial core surrounded by a Double-Positive (DPS) dielectric shell, as shown in Fig. 22. It was also observed that, for an elliptical shaped patch, two orthogonal modes might be independently excited within a sub-wavelength volume. The same authors further worked on the dual-mode elliptical patch antenna with MNG metamaterials and proved that by varying the patch eccentricity, the two resonances could be combined and considerable bandwidth enhancement could be attained to overcome the Chu limit on bandwidth for single-mode electrically small antennas [39].

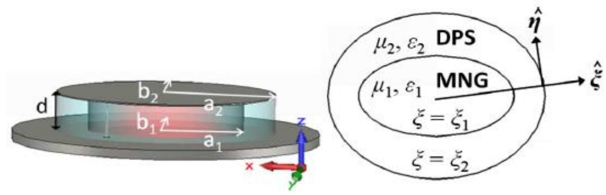


Fig. 22 Geometry of elliptical patch antenna, partially loaded by an MNG metamaterial core surrounded by a DPS shell [35]

G. Elliptical Annular Ring Antennas

A confocal elliptical annular ring micro-strip patch antenna was analysed using the ‘Generalized Transmission Line Model (GTLM)’ and fabricated [40]. It was shown experimentally that the antenna produced a very good quality circularly polarized wave over a wider frequency range in comparison with the rectangular, circular and elliptical patches. Fig. 23 shows the configuration of confocal elliptical annular ring micro-strip patch antenna. It was also found from the experiments that the axial ratio bandwidth of an elliptical ring antenna was larger compared to that of the elliptical patch antenna for the same thickness of 0.02 λ_0, where λ_0 is the free-space wavelength at the resonant frequency.

Mode charts to evaluate the cut off wave-numbers of the Confocal Annular Elliptic Resonator (CAER) were developed and this has made the initial designs of annular elliptical patch antennas easier and quicker [41]. The authors presented the mode cutoffs of the first five modes of the CAER. These mode charts were prepared using a particular normalization technique proposed by the authors.

For Radio Frequency Identification (RFID) and Global System for Mobile Communications (GSM-900) applications, an elliptical shaped annular ring patched planar antenna was developed with a semielliptical partial ground plane at the bottom of the antenna [27]. An FR4 substrate of thickness 1.6 mm and having a dielectric constant of 4.55 was used.

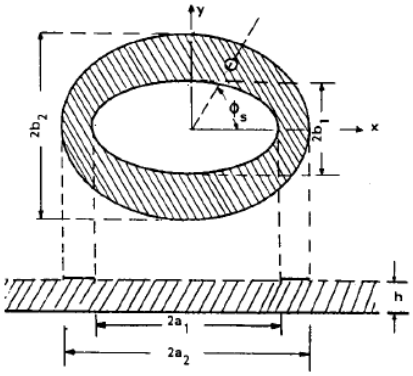
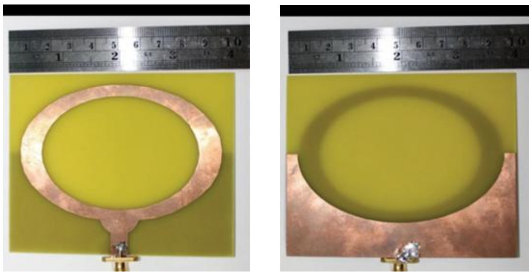


Fig. 23 Configuration of confocal elliptical annular ring micro-strip patch antenna [40]

The antenna had a -10 dB resonance response starting from 0.9 GHz to 1.08 GHz. The measured average gain was 5.5 dBi with a peak gain of 6.5 dBi at 1 GHz. Prototype of the proposed antenna is shown in Fig. 24.



(a) (b)

Fig. 24 Prototype of elliptical annular ring patch antenna (a) patch (b) ground plane [27]

Shorted Annular Elliptical Patch (SAEP) antenna was designed and analysed by some researchers for GPS applications [20]. The inner border of the conducting annular elliptical patch was shorted to the ground. Circular polarization was achieved with a single feed and this led to reduction in overall size of the antenna. The major and minor axes of the ellipses and the position of feed were so designed that even and odd modes were excited with a phase delay of 90^0. The major and minor axes of the outer and inner borders were designated as a_{max}, a_{min}, b_{max} and b_{min}. The antenna was made using a substrate of 3.2 mm thickness and dielectric constant of 2.55. Soldered copper foil helped to achieve the short circuit.

H. Miscellaneous Techniques

For millimeter wave Wireless Personal Area Networks (WPAN) and Wireless HD applications, a 4 x 2 elliptical patch array was designed and fabricated [36]. The array consisted of 8 elements. Each element was made of circular slot loaded with an elliptical patch and fed by a micro-strip line. The elements were implemented with a liquid crystal polymer substrate. A metallic reflecting plate was placed behind the antenna. Measured peak gain of the array was 15.6 dBic. The measured axial ratio was less than 3.3 dB over a bandwidth of 34.6%. Measured gain and impedance bandwidths were 29.1% and 38.9% respectively.

The Genetic Algorithm (GA) along with the Finite-Difference Time-Domain (FDTD) method was employed to generate amorphous shaped micro-strip patch antenna designs from ellipses [37]. This automatic shape creation technique was applied to develop four different designs of tri-band patch antenna, broadband patch antenna, GSM compatible dual-band monopole embedded in a dielectric and broadband monopole. Multiple number of ellipses were arranged to create the shape of antenna in which the optimization of location parameters and geometry parameters of these ellipses were carried out using the GA. The ‘x’ and ‘y’ co-ordinates of centre of ellipse were the location parameters and the radii in ‘x’ and ‘y’ directions were the geometry parameters. The ellipses overlapped to generate amorphous designs. Models were created using the parameter values provided by the GA programme and these models were passed on to the commercial programme QFDTD for simulation. These models were ranked based on their values for the cost function and thus optimized models were developed. The authors have claimed that the design using ellipses was simple to implement and produced wider bandwidths and less reflection loss than many previous methods.

Synthesis of EMPA for any desired gain and at any desired frequency in L-band was made easier and more accurate with the help of Artificial Neural Network (ANN) having Radial Basis Function [24]. For synthesis, the operating frequency and gain were considered as input and size of elliptical patch and height of substrate were taken as the output. Comparison between the values of desired parameters and output parameters of ANN showed that percentage errors were less than 2%. It was pointed out by the authors that the main advantage of this method was the easiness with which the required parameters for designing EMPA could be determined without depending upon the tedious iterative design process using commercial software packages.

Impedance bandwidth of circularly polarized EMPA in free space was increased from 2% to 6.54% when its edges were truncated parallel to the major axis [38]. The radiating patch was kept vertical to the ground plane. Feed location and edge lengths were determined after extensive optimization work. For the best performance of this antenna, the two equal truncated edges were parallel to the major axis of EMPA. The gain of antenna was found to be reduced because of the decrease in effective size of antenna. It could achieve right circular polarization with an axial ratio of 0.9 dB at a frequency of 2.751 GHz.

IV. ECCENTRICITY OF ELLIPSE

The reason for higher design flexibility in EMPA, compared to circular and rectangular shaped antennas, is the presence of an additional design parameter known as eccentricity. For an ellipse, eccentricity is the ratio of its length of semi-minor axis to length of semi-major axis. The eccentricity value for a circle is one and that of ellipse varies between zero and one.

The analytical studies reveal that best circular polarization can be attained when the patch remains only slightly elliptical (eccentricity <10 - 20%) [11]. The approximated Mathieu functions may be applied to the patch when it is slightly elliptical. It shows that eccentricity is an important design parameter for EMPA and we observed that most of the experimental studies were conducted using low value for eccentricity. It is interesting to note that a few researchers have tried to attain circular polarization even with higher values of eccentricity. Table-II given below is a summary of eccentricity values from the literature.

Table-II: Summary of eccentricity values of elliptical patches from literature

Elliptical eccentricity	Remarks
0.976	For the best circular polarization [10]
0.97	Circular slotted elliptical patches were used. For L-band and S-band applications [23]
0.962	Used edge truncated elliptical patch. Resulted circular polarization with improved bandwidth [38]
0.909	Trapezoidal-elliptical hybrid structure for broadband applications [33].
0.8	Stacked EMPA. Dual polarization and multiple resonant bands [11].
0.714	UWB antenna with slots [16].
0.67	Miniaturized crescent shaped antenna for UWB applications [13].

For an elliptically slotted patch, the eccentricity is defined as $e = \sqrt{1 - \left(\frac{b}{a}\right)^2}$, where ‘b’ is the semi-minor axis and ‘a’ is the semi-major axis of the elliptical slot [28][40].

V. FUTURE DIRECTIONS

As already discussed, the design flexibility in the case of elliptical antenna is higher in comparison with more conventional shapes of patches such as square, rectangular and circular. Design of elliptical shaped antenna is a less traversed path and the associated literature available is comparatively less. Some of the possible directions of work in the field of designing elliptical micro-strip patch antenna are given below.

1. Most of the work carried out in the area of EMPA was on enhancement of bandwidth. Very less work has been reported on miniaturization of antenna. More efforts towards reducing the size of antenna are required and the appropriate techniques need to be developed. Reducing the effective patch area by maintaining the same level of radiation properties will lead to large savings. One of the promising, but less tried, techniques is incorporating fractal shapes on elliptical patches. Many of the fractal shapes may be realized using mathematical equations and this makes the technique easier and accurate.

2. Most of the researchers have worked on EMPA with a very low value of eccentricity, usually (<10 – 20 %). EMPA with higher eccentricity values is almost an untouched area where there is a scope for enormous analytical, experimental and computational work.

3. The authors believe that the reason for very less work reported in literature on elliptical and derived shapes is the complexity involved in its design due to the Mathieu and Bessel functions. Apart from circular and rectangular shaped antennas, which produce linearly polarized waves, the design of EMPA requires substantial mathematical analysis and, because of this, the practicing engineers in today’s industry may have hesitations to start working on these types of antennas. A practical solution to suggest is the use of metaheuristic optimization techniques such as Genetic Algorithm (GA), Simulated Annealing (SA), Ant Colony Optimization (ACO), Particle Swarm Optimization (PSO) and Tabu Search (TS). These techniques may be applied to optimize the design parameters either for an individual shape or for a group of such shapes. This is a near-total unexplored area where new researchers can start working.

VI. CONCLUSION

This review paper is an attempt to summarize and critically assess the reported design techniques in literature and understand their effects on performance of elliptical patch antenna for suggesting practical solutions and new research fronts in the field of EMPA. The various design techniques in literature were classified into seven categories – Use of FSS superstrate or parasitic patch, stacked and hybrid structures, fractal techniques, introduction of slots, modified ground plane structure, introduction of metamaterials and elliptical annular ring structures. A few standalone techniques were grouped as miscellaneous techniques. In view of the significance of eccentricity values in the design of EMPA, a short discussion on eccentricity was included. A few directions for the possible future works in the field of EMPA have been suggested. The review reveals that most of the researches led to bandwidth enhancement and very less work was done to improve the gain. Suitable design techniques need to be developed to realize high gain EMPAs and attain higher levels of miniaturization. In order to make these antennas more attractive to engineers in industry, alternate and evolutionary techniques are to be tried, rather than following complex mathematical analysis.

REFERENCES

1. L. Shen, “The elliptical microstrip antenna with circular polarization,” *IEEE Trans. Antennas Propag.*, vol. 29, no. 1, pp. 90–94, Jan. 1981.
2. N. Kumprasert, “Theoretical study of dual-resonant frequency and circular polarization of elliptical microstrip antennas,” in *IEEE Antennas and Propagation Society International Symposium. Transmitting Waves of Progress to the Next Millennium. 2000 Digest. Held in conjunction with: USNC/URSI National Radio Science Meeting (C*, 2000, vol. 2, pp. 1015–1020 vol.2.
3. S. Long and M. McAllister, “The impedance of an elliptical printed-circuit antenna,” *IEEE Trans. Antennas Propag.*, vol. 30, no. 6, pp. 1197–1200, Nov. 1982.
4. S. R. Rengarajan, “Resonance frequency of elliptical microstrip antennas,” *Electron. Lett.*, vol. 29, no. 12, pp. 1066–1067, Jun. 1993.
5. P. Mythili and A. Das, “Simple approach to determine resonant frequencies of microstrip antennas,” *Antennas Propag. IEE Proc. - Microw.*, vol. 145, no. 2, pp. 159–162, Apr. 1998.
6. J. G. Kretzschmar, “Theoretical Results for the Elliptic Microstrip Resonator (Short papers),” *IEEE Trans. Microw. Theory Tech.*, vol. 20, no. 5, pp. 342–343, May 1972.
7. H. Jung and C. Seo, “Analysis of elliptical microstrip patch antenna considering attachment mode,” *IEEE Trans. Antennas Propag.*, vol. 50, no. 6, pp. 888–890, Jun. 2002.

8. R. Bedra, S. Bedra, and T. Fortaki, "Analysis of elliptical-disk microstrip patch printed on isotropic or anisotropic substrate materials," *Int. J. Microw. Wirel. Technol.*, vol. 8, no. 2, pp. 251–255, Mar. 2016.
9. M. Mencagli, E. Martini, and S. Maci, "Surface Wave Dispersion for Anisotropic Metasurfaces Constituted by Elliptical Patches," *IEEE Trans. Antennas Propag.*, vol. 63, no. 7, pp. 2992–3003, Jul. 2015.
10. S. Long, L. Shen, D. Schaubert, and F. Farrar, "An experimental study of the circular-polarized elliptical printed-circuit antenna," *IEEE Trans. Antennas Propag.*, vol. 29, no. 1, pp. 95–99, Jan. 1981.
11. D. K. Raheja, B. K. Kanaujia, and S. Kumar, "A Dual Polarized Triple Band Stacked Elliptical Microstrip Patch Antenna for WLAN Applications," *Wirel. Pers. Commun.*, vol. 100, no. 4, pp. 1585–1599, Jun. 2018.
12. V. Sharma, V. Saxena, K. B Sharma, and D. Bhatnagar, "Radiation Performance of an Elliptical Patch Antenna with Three Orthogonal Sector Slots," *Romanian J. Inf. Sci. Technol.*, vol. 14, Jan. 2011.
13. N. C. Azenui and H. Y. D. Yang, "A Printed Crescent Patch Antenna for Ultrawideband Applications," *IEEE Antennas Wirel. Propag. Lett.*, vol. 6, pp. 113–116, 2007.
14. J. Liu, S. Zhong, and K. P. Esselle, "A Printed Elliptical Monopole Antenna With Modified Feeding Structure for Bandwidth Enhancement," *IEEE Trans. Antennas Propag.*, vol. 59, no. 2, pp. 667–670, Feb. 2011.
15. L. Peng, C. Ruan, and X. Yin, "Analysis of the small slot-loaded elliptical patch antenna with a band-notched for UWB applications," *Microw. Opt. Technol. Lett.*, vol. 51, no. 4, pp. 973–976, 2009.
16. H. Zhang, R. Zhou, Z. Wu, H. Xin, and R. W. Ziolkowski, "Designs of ultra wideband (UWB) printed elliptical monopole antennas with slots," *Microw. Opt. Technol. Lett.*, vol. 52, pp. 466–471, Feb. 2010.
17. R. Eshtiaghi, J. Nourinia, and C. Ghobadi, "Electromagnetically Coupled Band-Notched Elliptical Monopole Antenna for UWB Applications," *IEEE Trans. Antennas Propag.*, vol. 58, no. 4, pp. 1397–1402, Apr. 2010.
18. S. Jiao, N. Ge, J. Lu, and M. Jiang, "Monopole crescent elliptical antenna with band-notched characteristics for UWB applications," *Tsinghua Sci. Technol.*, vol. 14, no. 4, pp. 460–464, Aug. 2009.
19. C.- Huang and W.- Hsia, "Planar elliptical antenna for ultra-wideband communications," *Electron. Lett.*, vol. 41, no. 6, pp. 296–297, Mar. 2005.
20. L. Boccia, G. Amendola, and G. D. Massa, "A shorted elliptical patch antenna for GPS applications," *IEEE Antennas Wirel. Propag. Lett.*, vol. 2, pp. 6–8, 2003.
21. B. Shrama, V. Sharma, K. B. Sharma, and D. Bhatnagar, "Broadband Semielliptical Patch Antenna with Semicircular Ring Slot for WiMax Application," *Chinese Journal of Engineering*, 2014. [Online]. Available: https://www.hindawi.com/journals/cje/2014/379073/. [Accessed: 21-Jan-2019].
22. M. Barbuto, F. Trotta, F. Bilotti, and A. Toscano, "Circular Polarized Patch Antenna Generating Orbital Angular Momentum," *Prog. Electromagn. Res.*, vol. 148, pp. 23–30, 2014.
23. N. Kashyap, "Circular Slotted Elliptical Patch Antenna with Elliptical Notch in Ground," *Prog. Electromagn. Res. C*, vol. Vol. 74, pp. 181–189, Jun. 2017.
24. A. Y. Modi, J. Mehta, and N. Pisharody, "Synthesis of Elliptical Patch Micro-strip Antenna using artificial neural network," in *2013 International Conference on Microwave and Photonics (ICMAP)*, 2013, pp. 1–3.
25. S.-S. Zhong, X.-L. Liang, and W. Wang, "Compact Elliptical Monopole Antenna With Impedance Bandwidth in Excess of 21:1," *Antennas Propag. IEEE Trans. On*, vol. 55, pp. 3082–3085, Dec. 2007.
26. X.-R. Yan, S.-S. Zhong, and X.-L. Liang, "Compact printed semi-elliptical monopole antenna for super-wideband applications," *Microw. Opt. Technol. Lett.*, vol. 49, no. 9, pp. 2061–2063, 2007.
27. M. R. Zaman, R. Azim, N. Misran, M. F. Asillam, and T. Islam, "Development of a Semielliptical Partial Ground Plane Antenna for RFID and GSM-900," *International Journal of Antennas and Propagation*, 2014. [Online]. Available: https://www.hindawi.com/journals/ijap/2014/693412/. [Accessed: 21-Jan-2019].
28. M. Kumar and V. Nath, "Microstrip-line-fed elliptical wide-slot antenna with similar parasitic patch for multiband applications," *IET Microw. Antennas Amp Propag.*, vol. 12, no. 14, pp. 2172–2178, Aug. 2018.
29. Mohammed Younssi, Achraf Jaoujal, Ahmed El Moussaoui, and Noura Aknin, "Miniaturized Probe-Fed Elliptical Microstrip Patch Antenna for Radiolocation Applications," *Int. J. Eng. Technol. IJET*, vol. 4, no. 5, pp. 324–327, Nov. 2012.
30. Amit Agrawal, D.Vakula, and N.V.S.N. Sarma, "Design of elliptical microstrippatch antenna using ANN," in *PIERS Proceedings*, Suzhou, China, 2011, pp. 264–268.
31. S. Peddakrishna and T. Khan, "Performance improvement of slotted elliptical patch antenna using FSS superstrate," *Int. J. RF Microw. Comput.-Aided Eng.*, vol. 28, no. 9, p. e21421, Nov. 2018.
32. S. R. Lee, E. H. Lim, F. L. Lo, and W. H. Ng, "Circularly Polarized Elliptical Microstrip Patch Reflectarray," *IEEE Trans. Antennas Propag.*, vol. 65, no. 8, pp. 4322–4327, Aug. 2017.
33. A. Dastranj, "Very small planar broadband monopole antenna with hybrid trapezoidal–elliptical radiator," *Antennas Propag. IET Microw.*, vol. 11, no. 4, pp. 542–547, 2017.
34. M. Gupta and V. Mathur, "Multiband Multiple Elliptical Microstrip Patch Antenna with Circular Polarization," *Wirel. Pers. Commun.*, vol. 102, no. 1, pp. 355–368, Sep. 2018.
35. P. Y. Chen and A. Alu, "Sub-Wavelength Elliptical Patch Antenna Loaded With μ-Negative Metamaterials," *IEEE Trans. Antennas Propag.*, vol. 58, no. 9, pp. 2909–2919, Sep. 2010.
36. 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, pp. 2862–2870, Oct. 2009.
37. L. A. Griffiths, C. Furse, and Y. C. Chung, "Broadband and Multiband Antenna Design Using the Genetic Algorithm to Create Amorphous Shapes Using Ellipses," *IEEE Trans. Antennas Propag.*, vol. 54, no. 10, pp. 2776–2782, Oct. 2006.
38. P. Sekra, S. Shekhawat, M. Dubey, D. Bhatnagar, V. Saxena, and J. Sainl, "Design of circularly polarized edge truncated elliptical patch antenna with improved performance," vol. 40, pp. 227–233, Jan. 2011.
39. P. Y. Chen and A. Alu, "Dual-Mode Miniaturized Elliptical Patch Antenna With μ-Negative Metamaterials," *IEEE Antennas Wirel. Propag. Lett.*, vol. 9, pp. 351–354, 2010.
40. A. K. Bhattacharyya and L. Shafai, "Theoretical and experimental investigation of the elliptical annular ring antenna," *IEEE Trans. Antennas Propag.*, vol. 36, no. 11, pp. 1526–1530, Nov. 1988.
41. F. A. Alhargan and S. R. Judah, "Mode charts for confocal annular elliptic resonators," *Antennas Propag. IEE Proc. - Microw.*, vol. 143, no. 4, pp. 358–360, Aug. 1996.

AUTHORS PROFILE

Jerry V. Jose - Research Scholar at Department of Electronics & Communication Engineering, Karunya Institute of Technology and Sciences, karunya Nagar, Coimbatore, Tamil nadu, India.

A.Shobha Rekh - Professor in the Department of Electronics & Communication Engineering at Karunya Institute of Technology and Sciences, karunya Nagar, Coimbatore, Tamil nadu, India. Obtained Ph.D in Information & Communication Engineering

Jose M.J. - Presently working as Assistant Professor of Mechanical Engineering in Govt. College of Engineering Kannur, Kerala, India.