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Double-Elliptical Micro-Strip Patch Antenna for Higher Design Flexibility and Miniaturization

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Abstract – Micro-Strip Patch Antenna (MSPA) finds large scale applications in various fields of communication. Elliptical shaped patch antenna is a prominent category among MSPAs. Possibility of circular polarization and dual resonant frequencies makes the Elliptical Micro-strip Patch Antenna (EMPA) widely accepted in modern communication devices. The present work aims to identify the constraints in further advancements in the design of EMPA and propose a novel shape to overcome these constraints. Minimizing the patch area and increasing the number of degrees of freedom in design were found to be the challenges. To overcome these challenges, a newly shaped patch called 'Double-Elliptical Patch (DEP)' is proposed for designing 'Double-Elliptical Micro-strip Patch Antenna (DEMPA)'. A double-ellipse is a combination of two half-ellipses either with the same minor axis and different semi-major axes or with the same major axis and different semi-minor axes. The DEP has an additional degree of freedom in design compared to elliptical patch, which leads to greater design flexibility. In the present work, a DEP with the same horizontal major axis and centrally given feed was designed using Ansoft HFSS software. The semi-minor axis of upper half-ellipse was varied by keeping the semi-minor axis of lower half-ellipse a constant. The radiation properties of DEMPA were found to be similar to that of corresponding EMPA and this was achieved with less patch area. The maximum percentage reduction in patch area was 10.714%. The DEMPA covered the entire frequency range of Ultra Wide Band (UWB).

Keywords: Double-elliptical, Elliptical, Micro-strip patch antenna, UWB, Miniaturization

I. INTRODUCTION

Micro-Strip Patch Antennas (MSPAs) are designed and fabricated in various regular geometric shapes such as rectangular, circular, triangular and elliptical. The possibility of attaining circular polarization with a single feed and dual resonant frequencies makes Elliptical Micro-strip Patch Antenna (EMPA) a prominent category among them [1]. The EMPA was found to have a wider frequency band of operation than the circular one [2]. Also, the eccentricity of elliptical patch was considered to be an additional degree of freedom that provided more design flexibility to antenna. The antenna miniaturization techniques and ways of attaining higher flexibility in antenna design are much needed for the further advancement of research in EMPA.

The geometric shape of patch is highly significant in deciding the design flexibility and achieving miniaturization in the case of MSPA. Hence, several variations of the elliptical shape were tried by the researchers so far. Elliptical patch with circular slots at different locations was designed [3]. An elliptical patch in which two sectors were carved out from its bottom half was used to fabricate a UWB antenna [4]. A hybrid patch antenna was made out of hybrid trapezoidal-elliptical patch [5]. The Lorentz fractal shape was introduced on ellipse to form a compact fractal elliptical patch antenna [6]. Two ellipses were joined at 45^0 to attain such a shape. Performance of EMPA could be improved by inserting slots of different shape and size on elliptical patch. This was proved to be a good approach to minimize the patch area. For L-band and S-band applications, circular slotted elliptical patch antenna with an elliptical notch in ground was fabricated [7]. Inclusion of orthogonal sector slots in elliptical patch was found to be reducing the effective patch area [8]. Two such slots were arranged opposite to each other along the major axis and the third slot was inserted along minor axis. By removing a circular disc from an elliptical patch, a crescent shaped patch antenna was designed and fabricated [9]. Combination of two planar antennas, one was made by creating an elliptical slot within an elliptical patch and the other one was made as an elliptical patch within the space of this elliptical slot, was designed for UWB applications [10]. An elliptical patch in which a narrow slot was introduced along the major axis about half way was developed for UWB applications [11]. A semi-elliptical patch antenna with a semi-circular ring slot was fabricated for WiMax applications [12]. Confocal elliptical annular ring MSPA was also proposed [13]. The above shape variations were proposed with respect to the basic elliptical shape. They were only the modifications of ellipse and hence had limitations to get improved further.

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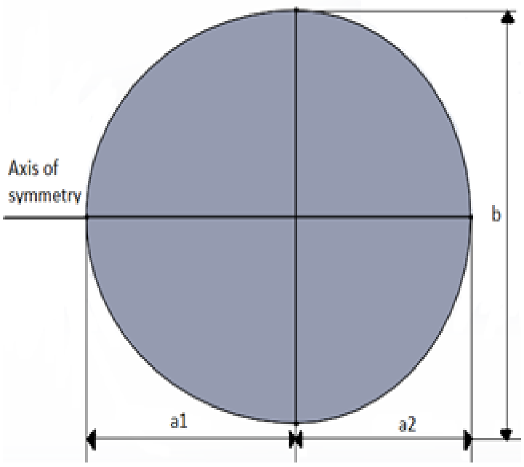
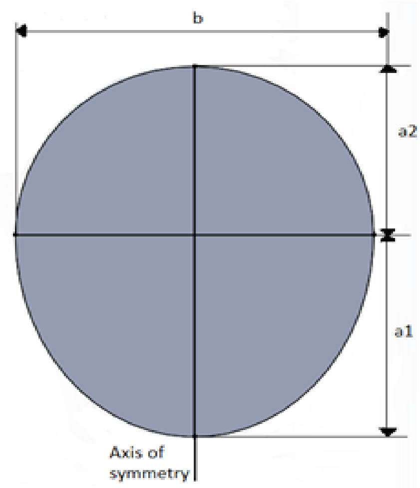
In this background, we explored th possibility of modifying the elliptical shape so as to have more degrees of freedom and less patch area. Our research led to proposing a novel shape for patch called 'Double-Elliptical Patch (DEP)' for MSPA. The DEP is made up of two half-elliptical patches either having the same minor axis and different semi-major axes or the same major axis and different semi-minor axes. The DEP has an additional degree of freedom compared to elliptical patch. In the present work, we designed using Ansoft HFSS, a 'Double-Elliptical Micro-strip Patch Antenna (DEMPA) in which the semi-minor axis of the upper half-ellipse was reduced by keeping the semi-minor axis of lower half-ellipse and major axis fixed. The radiation properties obtained for this DEMPA were similar to the corresponding EMPA and this was achieved for less patch area. This novel shape helped to increase the design flexibility of MSPA as well as attain antenna miniaturization.

II. CONSTRUCTION DETAILS OF DOUBLE-ELLIPTICAL PATCH

A double-ellipse is defined as the combination of two half-ellipses either having the same minor axis and different semi-major axes or the same major axis and different semi-minor axes. The proposed DEP is characterized in terms of its axis of symmetry and the orientation of this axis of symmetry. While an elliptical patch has two axes of symmetry, a DEP has only one. The DEP can have its axis of symmetry oriented along horizontal or vertical directions or inclined at any angle to the horizontal. For a DEP with the same vertical minor axis and different horizontal semi-major axes, the axis of symmetry is in the direction of major axis. In the case of a DEP with the same horizontal major axis and different vertical semi-minor axes, the axis of symmetry lies in the direction of minor axis. Let the DEP with axis of symmetry along the direction of semi-major axes be denoted as DEP_{ma} and the DEP with axis of symmetry along the direction of semi-minor axes be denoted as DEP_{mi}. The DEP_{ma} can be oriented horizontally, vertically or at any angle to horizontal and the radiation properties of resulting DEMPA in each case will be different. The horizontal, vertical and inclined DEP_{ma} may be denoted as DEP_{mah}, DEP_{mav} and $DEP_{ma\theta}$ respectively. Similarly, the horizontal, vertical and inclined DEP_{mi} may be denoted as DEP_{mih}, DEP_{miv} and $DEP_{mi\theta}$ respectively. The Fig. 1 below displays the construction details of DEP by providing the schematic diagrams for DEP_{mah}, DEP_{mav}, DEP_{mih} and DEP_{miv}.



(a) DEP_{mah}



(b) DEP_{mav}

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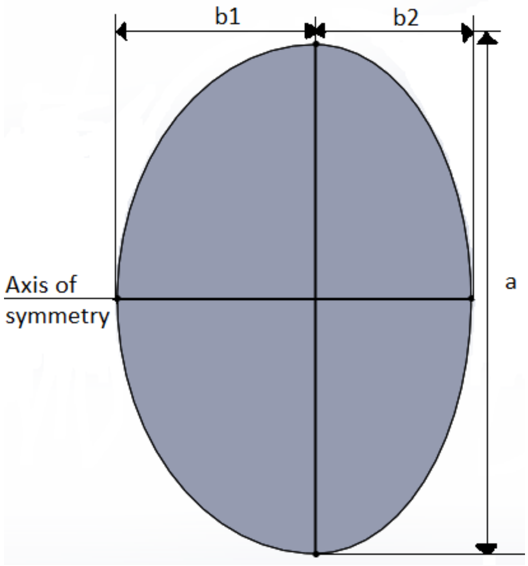
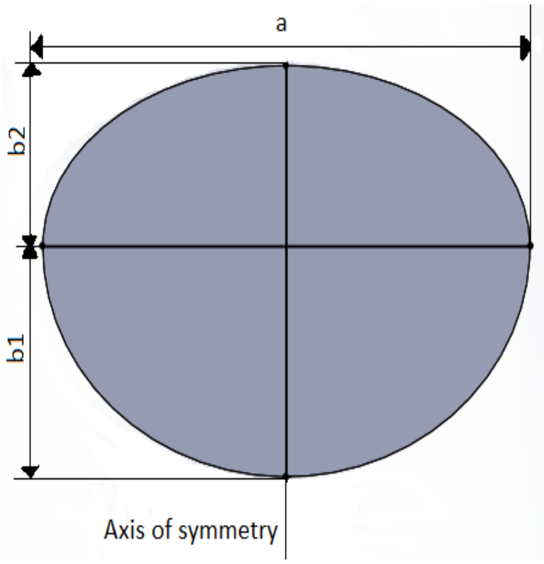


(c) DEP_{mih}



(d) DEP_{miv}

Fig.1 Construction details of Double-Elliptical Patch (a) DEP_{mah} (b) DEP_{mav} (c) DEP_{mih} (d) DEP_{miv}

Effective patch area (A_p) of DEP_{ma} can be expressed as,

$$A_{pma} = \frac{\pi}{2}\, b\,(a_1 + a_2) \qquad (1)$$

Where, $b =$ length of the common semi-minor axis of the two half-elliptical patches, $a_1 =$ length of the semi-major axis of first half-elliptical patch and $a_2 =$ length of the semi-major axis of second half-elliptical patch.

Effective patch area for DEP_{mi} is,

$$A_{pmi} = \frac{\pi}{2}\, a\,(b_1 + b_2) \qquad (2)$$

Where, $a =$ length of the common semi-major axis of the two half-elliptical patches, $b_1 =$ length of the semi-minor axis of first half-elliptical patch and $b_2 =$ length of the semi-minor axis of second half-elliptical patch. The design of DEMPA possesses one additional degree of freedom compared to that of EMPA.

III. ANTENNA DESIGN IN HFSS

A. Antenna Geometry

As the reference for the present work, an EMPA for UWB communications with lengths of semi-major axis and semi-minor axis as 9.0 mm and 7.0 mm respectively was chosen [11]. This elliptical patch with horizontal major axis has been modified to a DEP by changing the length of semi-minor axis b_2, in which the axis of symmetry was along the direction of minor axis. Hence, this DEP was designated as DEP_{miv} and it consisted of a lower half-elliptical patch (first patch) and an upper half-elliptical patch (second patch) with the common horizontal major axis of length 18.0 mm. The b_1 was fixed at 7.0 mm and the b_2 was varied as 6.5 mm, 6.0 mm and 5.5 mm to get different DEPs. For each of these DEPs, the respective DEMP was modeled and analyzed for their radiation performance. The geometry of DEP_{miv} with $b_2 = 5.5\ mm$ is shown in Fig. 2.

B. Design Using HFSS

The High-Frequency Structure Simulator (HFSS), the commercial Finite Element Method (FEM) based solver for electromagnetic structures from Ansoft, was used to design the DEMPA. The parametric study and analysis were conducted by using the Optimetrics capability of HFSS. The material of substrate used was FR-4, with a relative dielectric constant, $\varepsilon_r = 4.4$ and thickness, $h = 1$mm. The length (L) and width (W) of substrate were 40 mm and 38 mm respectively. The micro-strip feed line has a width of 1.6 mm and length of feed was 20.7 mm. The width and length of ground plane were 38 mm and 20 mm respectively. The ground plane and DEP were modeled with the same metallic material. Using HFSS, full wave electromagnetic simulations were carried out to analyze the different performance parameters such as Return Loss, VSWR and Gain. DEMPAs with $b_2 = 6.5\ mm, 6.0\ mm\ and\ 5.5\ mm$ demonstrated similar radiation properties as that of the reference antenna and covered the entire UWB range of frequencies. Hence, DEMPA with $b_2 = 5.5\ mm$ was found to be the most appealing as it had the least patch area.

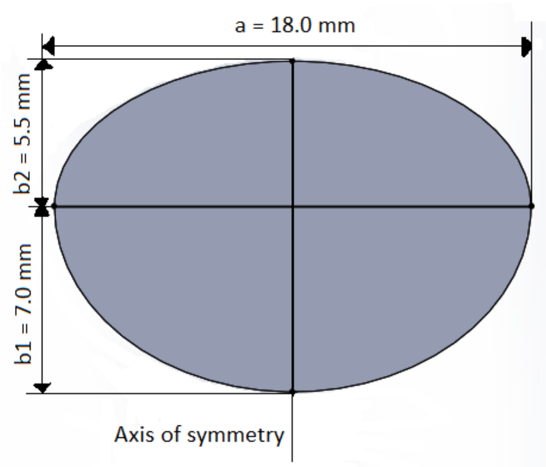


Fig. 2 The geometry of DEP_{miv} for $b_2 = 5.5\ mm$

IV. RESULTS AND DISCUSSIONS

The U.S. Federal Communications Commission (FCC) allotted the frequency band 3.1 – 10.6 GHz for unlicensed commercial UWB communications. Similar to the reference EMPA, all the three DEMPAs covered the entire bandwidth of UWB. The DEMPAs were found to possess similar radiation properties as that of the reference EMPA. The maximum percentage reduction in patch area was 10.714% and it happened for the DEMPA with $b_2 = 5.5\ mm$. Performance comparisons of DEMPAs with reference EMPA in terms of Return Loss, VSWR and Gain are shown below graphically. The DEMPA with $b_2 = 5.5\ mm$ is analyzed particularly and its performance curves are shown separately.

A. Antenna Return Loss

The variation of S_{11} parameter with change in b_2 is shown in Fig. 3. It is evident that the DEMPAs have similar Return Loss characteristics as that of reference EMPA which has $b_2 = 7.0\ mm$. Hence, it is clear that the concept of DEP can be used for antenna miniaturization. The Fractional Bandwidth (FB) of antenna tells us how wideband the antenna is.

$$FB = \left(\frac{Upper\ Frequency - Lower\ Frequency}{Centre\ Frequency}\right) \times 100\% \qquad (3)$$

Where, the $Centre\ Frequency = \left(\frac{Upper\ Frequency + Lower\ Frequency}{2}\right)$ (4)

For the DEMPA with $b_2 = 5.5\ mm$, the lower and upper cut-off frequencies are 3.285 GHz and 17.609 GHz respectively. Hence, the centre frequency is 10.447 GHz and the FB is 137.11%. In other words, the simulation results show that the DEMPA with $b_2 = 5.5\ mm$ covers the bandwidth of 137.11% from 3.285 GHz to 17.609 GHz for $|S_{11}| < -10dB$. For the reference EMPA with $b_2 = 7.0\ mm$, the lower and upper cut-off frequencies are 3.135 GHz and 17.44 GHz respectively and the centre frequency is 10.2875 GHz. So, its FB is 139.05%.

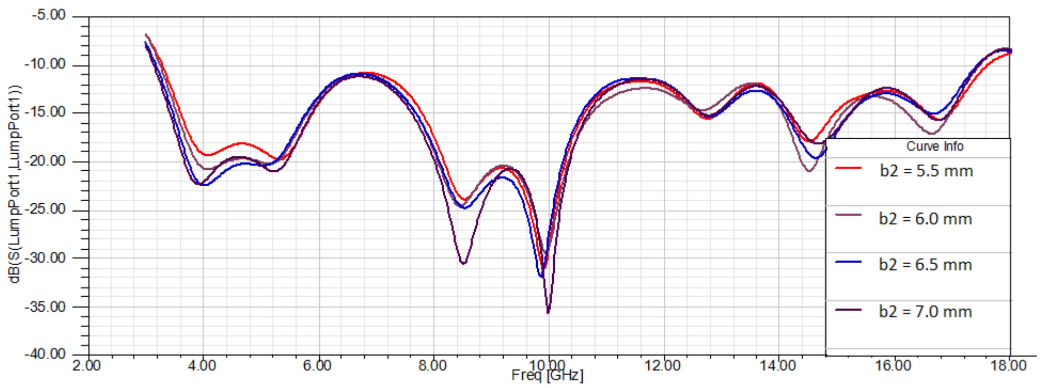


Fig. 3 Comparison of simulated S_{11} parameter values of EMPA and DEMPAs with b_2= 6.5 mm, 6.0 mm and 5.5 mm

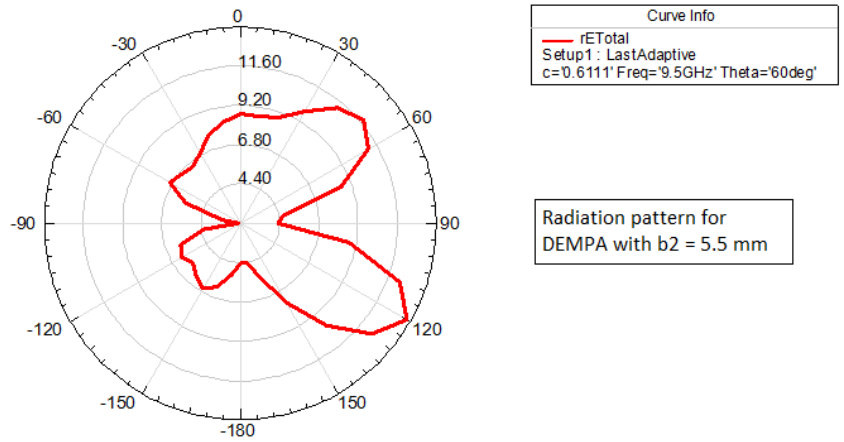


Fig. 4 Radiation pattern of DEMPA with b_2=5.5 mm

B. Radiation Pattern

The radiation pattern for the DEMPA with $b_2 = 5.5\ mm$ as obtained from simulation at 9.5 GHz is shown in Fig. 4. The radiation intensity reaches a maximum of about 14.0 dB at 120^0 and it is 11.6 dB at about 50^0.

C. VSWR Curves

The Fig. 5 shows the comparison of VSWR values obtained from simulations for DEMPAs with b_2= 6.5 mm, 6.0 mm and 5.5 mm and the reference EMPA. Within the UWB range and even up to 17.609 GHz, all are having their VSWR values less than 2. The VSWR values of 1.141 and 1.05 at 8.450 GHz and 9.93 GHz respectively are close to unity. It indicates that there is a good impedance match between the antenna and the feed line connecting to it.

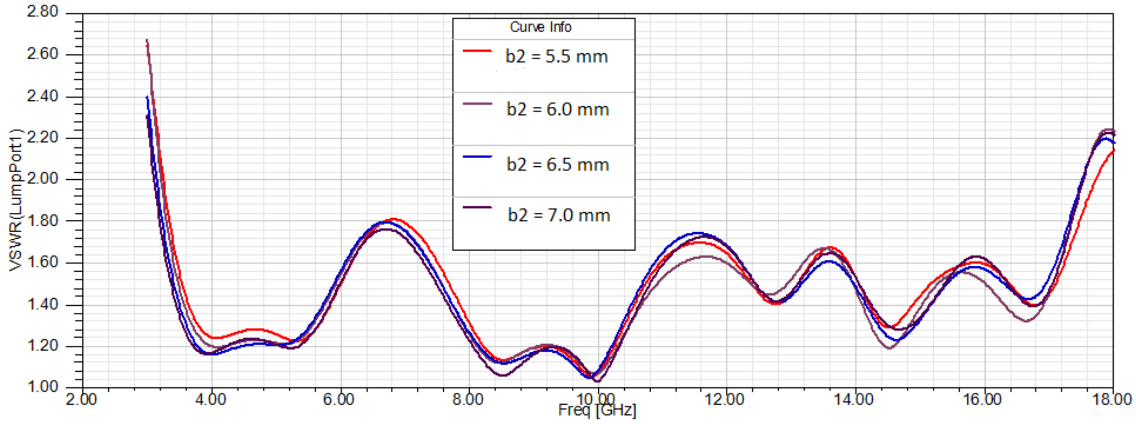


Fig. 5 VSWR curves for DEMPA with b_2= 7.0 mm, 6.5 mm, 6.0 mm and 5.5 mm

D. Axial Ratio

Axial Ratio (AR) is the ratio of orthogonal components of an E-field. Axial ratio expressed in dB is generally used to quantify the quality of circular polarization of antenna. The AR is ideally zero for circular polarization. In practice, AR values up to 3 dB are considered to represent circular polarization. Some researchers even consider the AR values up to 6 dB as that of circular polarization. AR value for linear polarization is infinite. It means that the AR value will be greater than 3 or greater than 6, as the case may be, for linear polarization. In the case of DEMPA with b_2= 5.5 mm, the AR is found to be less than 6 dB within the frequency ranges from 13.810 GHz to 14.03 GHz (close to 4 dB) and from 16.423 GHz to 16.468 GHz (close to 5 dB) which may indicate circular polarization. Hence, it may be stated that this antenna exhibits both linear and circular polarization. The Fig. 6 shows Axial Ratio curve for DEMPA with b_2= 5.5 mm.

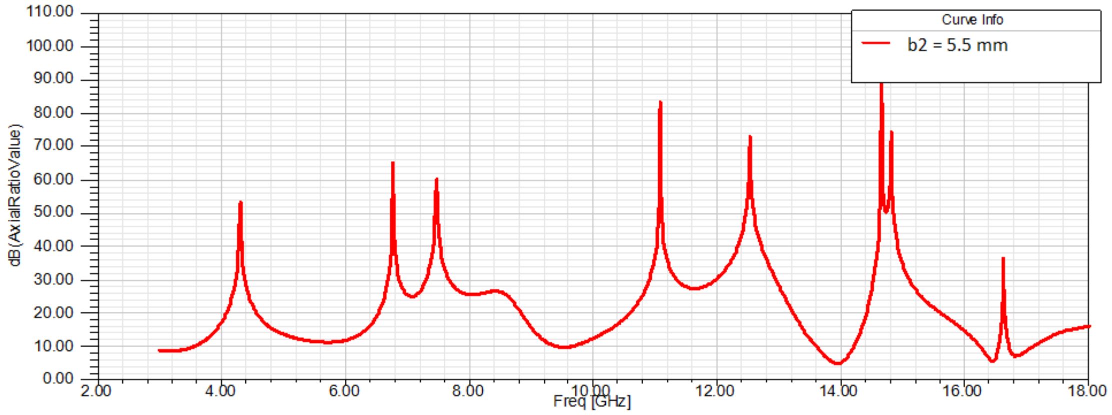


Fig. 6 Axial ratio curve for DEMPA with b_2= 5.5 mm

E. Gain Curve

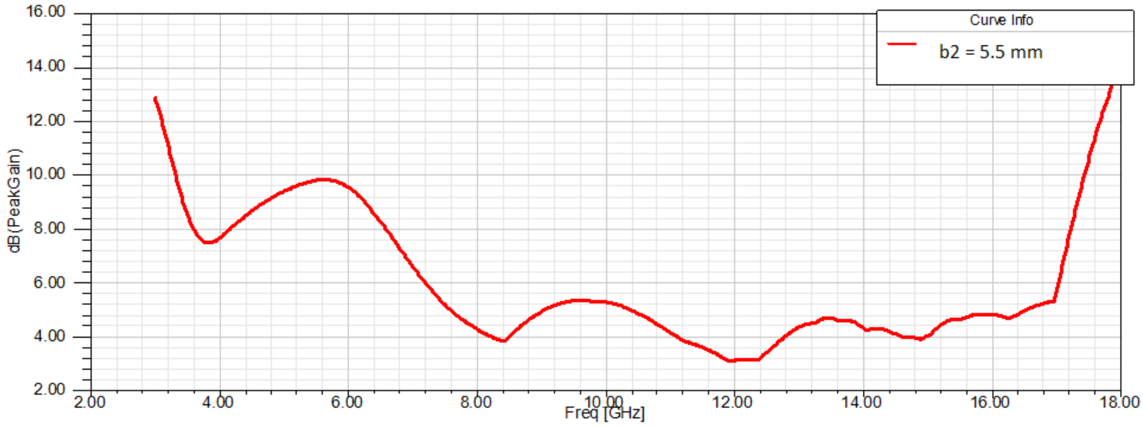


Fig. 7 Peak gain curve for DEMPA with b_2= 5.5 mm

The peak gain is observed to be positive for DEMPA with b_2= 7.0 mm, 6.5 mm, 6.0 mm and 5.5 mm throughout the working band of 3.1 GHz – 17.609 GHz and hence acceptable. The Fig. 7 shows the gain curve for DEMPA with b_2= 5.5 mm. The three dimensional radiation pattern for DEMPA with b_2= 5.5 mm at 9.5 GHz is shown in Fig. 8.

Fig. 8 Three dimensional radiation pattern of gain for DEMPA with b_2= 5.5 mm at 9.5 GHz.

V. CONCLUSION

A novel shaped patch called Double-Elliptical Patch (DEP) has been proposed for Micro-strip Patch Antenna (MSPA) to achieve miniaturization and higher design flexibility. A double-ellipse is a combination of two half-ellipses either with the same minor axis and different semi-major axes or with the same major axis and different semi-minor axes. The DEP has an additional degree of freedom in design compared to elliptical patch, which leads to greater design flexibility. In the present work, a DEMPA with the same horizontal major axis and centrally given feed was designed using Ansoft HFSS software.

The semi-minor axis of upper half-ellipse was varied by keeping the semi-minor axis of lower-half ellipse as constant. The main conclusions are given below.

(a) The DEMPA was found to have similar radiation properties as that of corresponding EMPA. The percentage reduction in patch area obtained for DEMPA with b_2= 5.5 mm was 10.714%. Hence, the DEMPA can be used for antenna miniaturization.

(b) The DEMPA has an additional degree of freedom in design compared to EMPA. This increases its design flexibility.

(c) The proposed DEMPAs were found to be covering the entire frequency range for UWB communications similar to the reference EMPA.

(d) For DEMPA with b_2 = 5.5 mm, circular polarization also appears along with linear polarization.

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