ISSN: 2395-1680 (ONLINE)
DOI: 10.21917/ijme.2020.0173 

# SWASTIK SLOTTED HEXAGONAL PATCH ANTENNA WITH METAMATERIAL-BASED COMPLEMENTARY SPLIT-RING RESONATOR

**K. Lalith Kishore[1], R. Ramana Reddy[2], and Naresh K. Darimireddy[3]**
*[1,2]Department of Electronics and Communication Engineering, JNTUA College of Engineering, Pulivendula, India*
*[3]Department of Electronics and Communication Engineering, Lendi Institute of Engineering and Technology, India*

***Abstract***

***A hexagonal patch antenna with a Swastik slotted design on radiating patch and integration of metamaterial-based Complementary Split Ring Resonator (CSRR) is proposed. The Swastik slot is designed with equal and un-equal arm lengths. Swastik slot with equal arms yields a better result compared to unequal arms. Swastik slot with equal arms results in a bandwidth of 8GHz (12 - 20GHz) with a peak gain of 6.1dBi. For further performance enhancement, the proposed antenna is integrated with metamaterial-based CSRR's. Integration with metamaterial-based 4×4 CSRR's results in a bandwidth of 11.78GHz (8.22GHz to 20GHz) with Circular Polarization (CP). CP is obtained at 9.74GHz with an Axial Ratio (AR) bandwidth of 570 MHz (9.43 - 10GHz). Swastik slotted hexagonal patch antenna works in Ku and K band whereas the same antenna integrated with metamaterial works in X, Ku, and K bands. Simulations are carried out using ANSYS HFSS EM solver.***

***Keywords:***

***Metamaterial, CSRR, Circular Polarization (CP), Swastik Slotted Patch Antenna***

## 1. INTRODUCTION

Advancements and increased applications in wireless communications demanding higher bandwidths with smaller size antennas. Many research works have been reported in the open literature on achieving higher bandwidth, circular polarization, and miniaturization of the antennas. One of the techniques for antenna miniaturization is the usage of the metamaterial. With suitable design and integration of metamaterial, the size of the antenna can be reduced while improving the bandwidth and gain. The materials which exhibit negative permittivity and permeability are called metamaterials. Microstrip fed monopole with a wide hexagonal slot in the ground plane on FR4 substrate for ultra-wideband applications operating from 2.9-18GHz with a peak gain of 4.2dBi and an average gain of 3.7dBi is reported [1]. Utilization of Koch fractal geometry at both patch and ground plane introduces additional resonances thereby increasing the bandwidth up to 122%. The antenna is developed on FR4 with gain varying from 4 to 6dB operating at 5.2GHz WLAN and 5.8GHz WiMAX [2]. A triple-band microstrip fed hexagonal slot patch antenna with additional L-shaped slits is developed on Taconic RF35 operating from 3.22-5.98GHz exhibiting right-hand circular polarization [3]. Printed microstrip antenna with L-strip is developed over FR4 substrate operating in 4.35-9.5GHz frequency range covering 74% bandwidth with a peak gain of 4.09dBi for broadband applications in [4].

The triple-band microstrip antenna centered at 2.7GHz, 3.5GHz, and 5.6GHz is developed on FR4 substrate contains slots etched in ground plane and delivers a gain value varying from 3.5 to 4.32dBi [5]. Swastik slot antenna operating at 2.5GHz is designed which delivers an impedance bandwidth of 43.75% ranging from 1.69GHz to 2.69GHz with a peak gain of 3dB [6]. Hexagonal microstrip antenna is developed on low temperature ceramic FerroA6 substrate operating over 3.5 to 5.2GHz with gain varying from 3.8 to 5.4dBi [7]. Swastik shape microstrip antenna operating in L and S bands delivers a peak gain of 2.7dBi at 1.8GHz and 3.13dBi at 2.5GHz is developed on Glass Epoxy substrate [8]. A circular patch antenna with asymmetric and symmetric bow-tie slots is reported [9]. The asymmetric slot antenna offers a bandwidth of 350MHz with 5dBi gain whereas the symmetric slot antenna offers a bandwidth of 530 MHz with 5.1dBi gain. The design principles and operation of artificial composite structures like metamaterials are presented stating the physical preconditions and properties of different structural geometries like rectangle, circular, swiss roll, etc. [10]. The design of a hepta-band swastika is reported operating over a frequency range of 0.19-6.13GHz with an average gain of 4.625dBi. The successful applications of metamaterial for microwave waveguide and resonators are explained [11].

Deformed Split Ring Resonator antenna with partial ground plane operating over 2.39 to 2.8GHz, 3.92 to 4.09GHz, and 5.43 to 6.13GHz is reported [12]. Metamaterial loaded antenna operating at 2.4GHz with a bandwidth of 200 MHz and gain of 3.23dBi is reported [13]. Multiband monopole antenna is developed initially as rectangle monopole to resonate at 5.2GHz, with the introduction of inverted L-slot the second resonance is at 4.1GHz. When loaded with metamaterial there is a downward shift in frequency to 2.4GHz with a peak gain of 3.2dBi. A dual-band CPW fed antenna loaded with U-shaped metamaterial operating at 2.7GHz and 6.3GHz frequency is reported [15]. Hexagonal Patch antenna is initially developed to operate over a frequency range of 3.20GHz to 3.35GHz with 154 MHz bandwidth. When a split-ring resonator is added in the ground plane the antenna is operating at a second band ranging from 5.14 to 5.32GHz with 180MHz bandwidth and the gain performance of the antenna at first and second bands is observed to be 6.70dB and 5.42dB respectively [16]. The dual MTM layer inspired microstrip patch antenna with single and double meta-screen operating at 9.1GHz with a bandwidth of 14.56% and 22.86%. Peak gain is 0.7dBi and 1.86dBi respectively [17]. Applications of metamaterials to improve antenna parameters are reported [18]. The sides of rings are connected by triangular elements inside a hexagonal metal patch where the iterations are made from hexagonal rings. Transmission line feed is used. A triangular slotted symmetrical DGS with a rectangular slot at the centre is used to obtain an operating bandwidth ranging from 3GHz to 25.2GHz [19].

In this paper, a Swastik slotted hexagonal patch antenna with metamaterial-based complementary split-ring resonators (CSSR) is proposed. The unit cell structure of the CSRR metamaterial antenna is optimized to improve the performance of the antenna in terms of bandwidth, gain, and miniaturization. The proposed antenna exhibits multi-band frequency with compact size and is applicable for Ultra-Wide Band (UWB) applications.

## 2. SWASTIK SLOTTED HEXAGONAL PATCH ANTENNA (SSHPA)

The design of the proposed Swastik slotted hexagonal patch antenna is presented in this section. Simulations are carried out using HFSS software. A hexagonal patch with Swastik shaped slot is designed on an FR4 substrate having a dielectric constant of 4.4 with 1.5mm thickness as shown in Fig.1. The design of the hexagonal Swastik slotted microstrip patch antenna is done in 3 steps. Firstly, a hexagonal patch antenna is considered. In the second step, two rectangular slots are added to form a plus slot on a hexagonal patch. In the third step, four rectangular arms are added to the plus design. The dimensions of the proposed antenna are tabulated in Table.1. The front view and back view of the designed antenna are given in Fig.2(a) and 2(b) respectively.

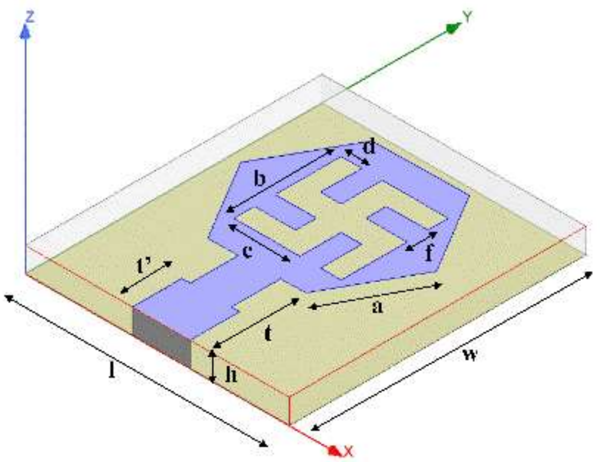



Fig.1. Proposed Swastik Slotted Hexagonal Patch Antenna

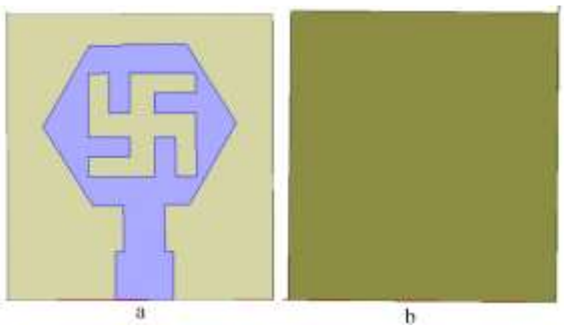



Fig.2. Front view and Back view of SSHPA

Table.1. Dimensions of Swastik Slot

| Parameter | Dimensions (mm) | Parameter | Dimensions (mm) |
|---|---|---|---|
| *l* | 16 | *d* | 1.5 |
| *w* | 18 | *f* | 1.5 |
| *a* | 5.38 | *h* | 1.5 |
| *b* | 6.5 | *t* | 6 |
| *c* | 4 | *t′* | 3 |

The standard equations available in the open literature [19] are used to calculate antenna dimensions. The equations used to obtain antenna dimensions at the desired operating frequency are given below. The effective dielectric constant for $\varepsilon_{ref}$ = 4.3. To find the resonant frequency for Hexagonal strip Patch Antenna (HPA), the equation for the resonant frequency of the Circular strip Patch Antenna (CPA) given in Eq.(1)-Eq.(2) are used.

$$f_{res} = \frac{Y_{mn}C}{5.714R_2\sqrt{\varepsilon_{ref}}} \quad (1)$$

where

$Y_{mn}=Y_{11}$ (for fundamental mode $TM_{11}$) =1.8412

C= Velocity of light in free space

$\varepsilon_{ref}$ = Effective dielectric constant

$R_e$ = Effective radius of CPA and it is given by

$$R_e = R_c\sqrt{\left(1+\frac{2h}{\pi R_c\varepsilon_r}\left[\ln\frac{\pi R_c}{2h}\right]+1.7726\right)} \quad (2)$$

where $R_c$ is the radius of the CPA and $h$ is the thickness of the substrate.

### 2.1 CURRENT DISTRIBUTION OF SSHPA

The proposed antenna with equally spaced rectangular arms of the Swastik slot is shown in Fig.1. The observation of two orthogonal modes with $90^0$ phase shifts and equal magnitude is seen in the Swastik slot which supports Circular Polarization (CP). The Current Distribution of SSHPA given in Fig.3 reflects that current density in the Swastik slot at different phases (0°, 30°, 60°, and 90°). From the anti-clockwise rotation of surface current distribution at different phases it is evident that the proposed antenna supports left-hand circular polarization (LHCP) radiation.

### 2.2 RETURN LOSS, AXIAL RATIO, AND GAIN OF SSHPA

It is evident from the results presented in Fig.4(a) and Fig.4(b) that the bandwidth offered by the hexagonal patch antenna (HPA) is 7.90GHz (12.10-20GHz), the gain is 5dBi and there is no circular polarization (no axial ratio < 3dB in operating frequency range). The bandwidth offered by the HPA with the plus slot is 7.94GHz (12.04-20GHz), the gain is 4dBi and there is no circular polarization (no axial ratio < 3dB in operating frequency range). The bandwidth offered by the SSHPA is 8GHz (12-20GHz), three CP bands with axial ratio bandwidth of 1.70GHz (6.54-8.24GHz), 1.52GHz (12.86-14.38GHz) and 1.09 GHz (14.38-15.47GHz) and gain is 6.1dBi. Gain plots are shown in Fig.4(c) to Fig.4(e) are plotted at frequencies 7.68GHz, 13.46GHz, and 14.95GHz where circular polarization is existing.

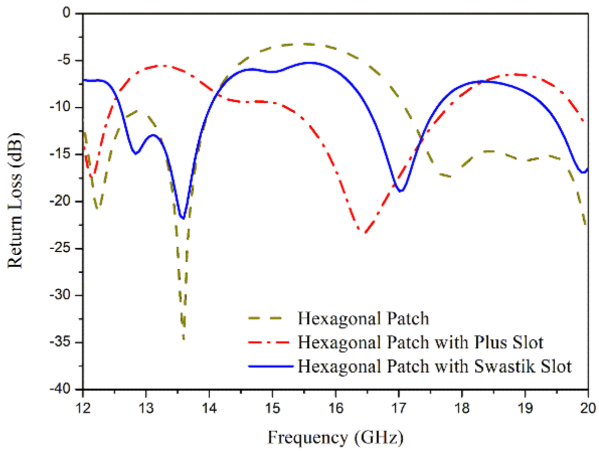
### 2.3 RADIATION PATTERNS FOR SSHPA

Radiation patterns are plotted at frequencies where circular polarization is existing. The E-Plane and H-plane patterns are plotted at frequencies 7.68GHz, 13.46GHz, and 14.95GHz as shown in Fig.5(a)-Fig.(c).

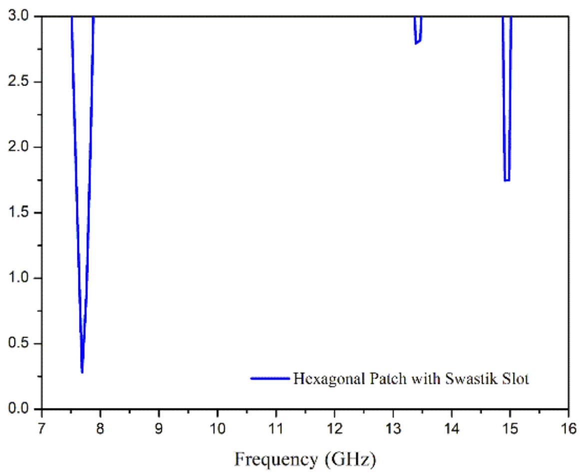
## 3. PARAMETRIC STUDY OF SSHPA

The parametric study is done on the proposed Swastik slotted HPA for different arm lengths of the swastika slot and feed dimensions.

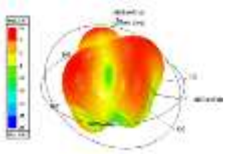
Fig.3. Surface current distribution at 12GHz

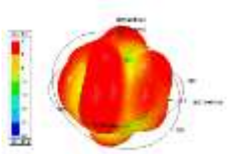


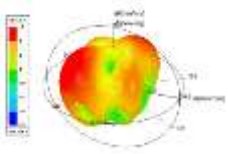

(a)




(b)

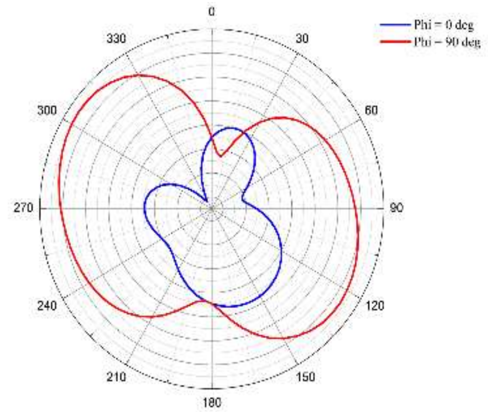




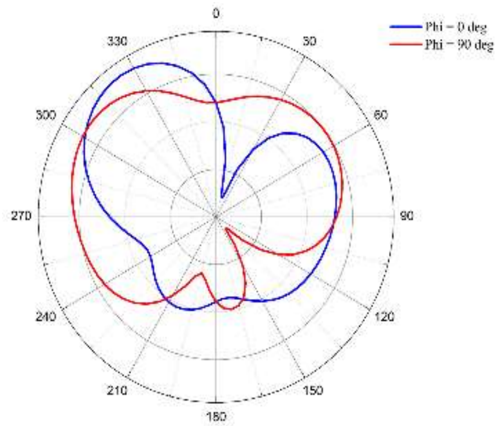


(c) (d) (e)

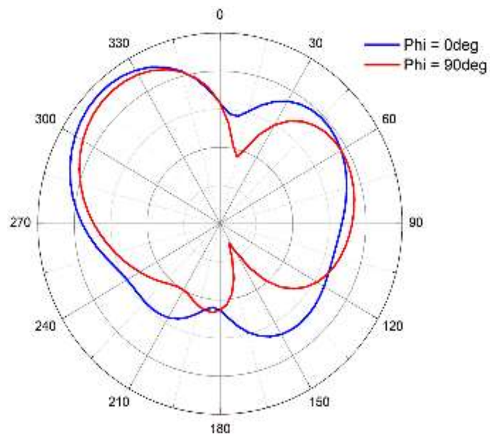
Fig.4. (a) Return Loss (b) Axial Ratio, and 3D gain of SSHPA at (c) 7.68GHz (d) 13.46GHz (e) 14.95GHz




(a)




(b)




(c)

Fig.5. Radiation pattern of SSHPA at CP frequencies (a) 7.68GHz, (b) 13.46GHz, (c) 14.95GHz

### 3.1 UNEQUAL AND EQUAL RECTANGLE ARMS OF SWASTIK SLOT

Swastik slot with unequal arms, diagonally equal arms, and equal arms are considered as presented in Fig.6. Return loss and axial ratio plots are presented in Fig.7. The parametric analysis is conducted by varying the dimensions of the rectangular arms of the proposed Swastik slot. Unequal slotted rectangular arms ($A_1 > A_2 > A_3 > A_4$) presented in Fig.6(a) results in return loss bandwidth of 7.66GHz (12.34 - 20GHz), AR bandwidth of 560 MHz (5.04-5.60GHz) and a gain of 3.6dBi. Diagonally equal arms are shown in Fig.6(b) with $A_1 = A_3$, $A_2 = A_4$ results in RL bandwidth of 7.77GHz (12.23 - 20GHz) with a gain of 5.5 dB and there is no circular polarization (no axial ratio < 3dB in operating frequency range). The proposed antenna with equally slotted shown in Fig.6(c) with rectangular arms ($A_1$=$A_2$=$A_3$=$A_4$) results in RL bandwidth of 8.0GHz (12-20GHz), three CP bands with axial ratio bandwidth of 1.70GHz (6.54-8.24GHz), 1.52GHz (12.86-14.38GHz), and 1.09GHz (14.38-15.47GHz) with a gain of 6.1dBi. Swastik slot with unequal arms results in one CP band, for diagonally equal arms there is no CP band and equal arms design exhibits three CP bands.

### 3.2 FEED DIMENSIONS

Feed dimensions of 3mm×3.5mm results in a wide bandwidth of 8GHz showing good impedance match when compared to other feed dimensions of 3.2mm×3.8 mm and 2.6mm×2.8mm which results in a bandwidth of 7.77GHz and 7.88GHz respectively as shown in Fig.8.

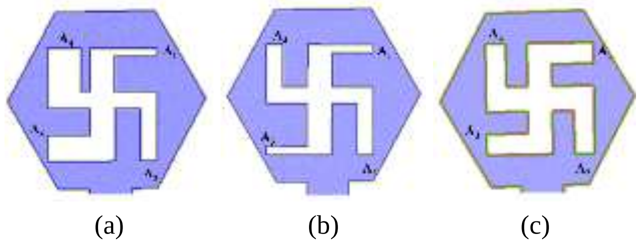



Fig.6. (a) Unequal arms Swastik slot, (b) Diagonally equal arms Swastik slot, (c) Equal arms Swastik slot

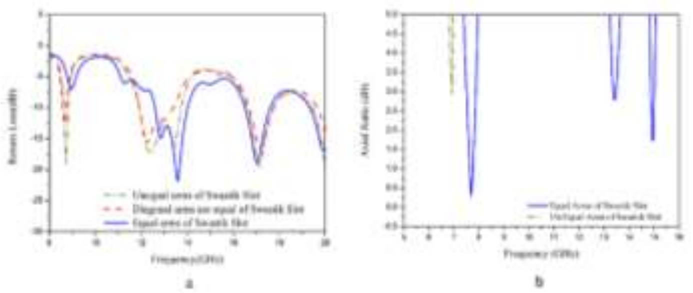


Fig.7. Return Loss and Axial Ratio of unequal, diagonally equal and equal arms Swastik slot

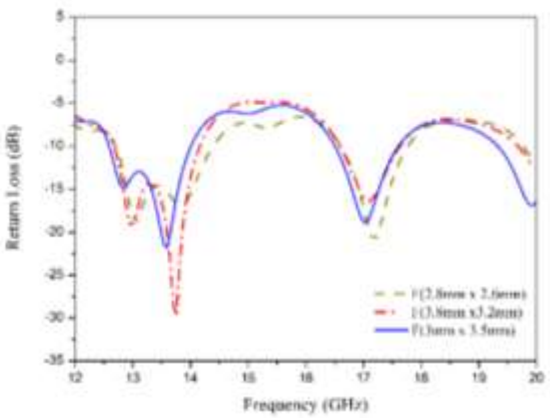



Fig.8. Return Loss observation at various feed dimensions

## 4. LOADING THE ANTENNA WITH METAMATERIAL BASED CSRR UNIT CELL

Metamaterials (MTMs) are artificially developed materials used to enhance bandwidth, multiband operation, and reduce the size of the microstrip patch antenna. The materials which exhibit negative permittivity and permeability are called metamaterials. The loading of metamaterial-based CSRRs unit cell on SSHPA is done in 2 different structural configurations which are a single CSRR unit cell of MTM and 4×4 CSRRs unit cell of MTMs. The dimensions of the different configurations of the CSRRs unit cell are tabulated in Table.2. Different configurations of CSRRs unit cells are given in Fig.9 and Fig.10.

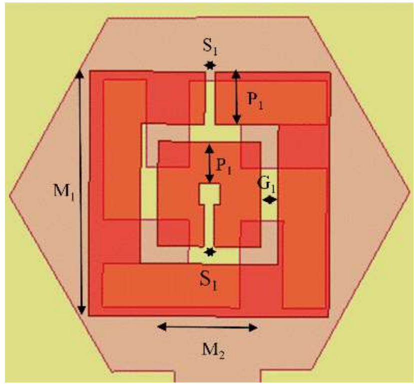



Fig.9. Single unit cell-based CSRR metamaterial

Table.2. Dimensions of single and 4×4 Metamaterial based CSRR

| Parameters/dimensions (mm) | $M_1$ | $M_2$ | $P_1$ | $S_1$ | $G_1$ |
|---|---|---|---|---|---|
| Single CSRR | 7 | 3 | 1.5 | 0.3 | 0.5 |
| 4×4 CSRR | 1.6 | 0.8 | 0.3 | 0.1 | 0.1 |

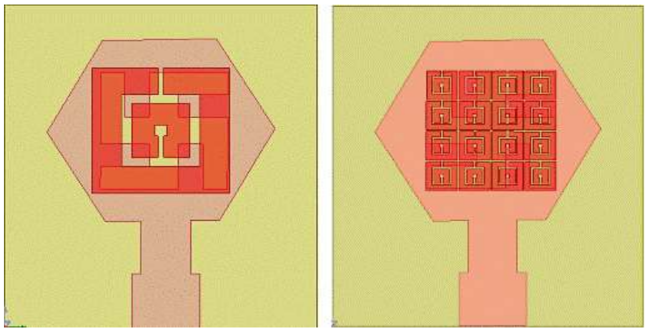


Fig.10. Different configurations of Metamaterial based CSRR

### 4.1 RETURN LOSS, AXIAL RATIO OF SSHPA WITH METAMATERIAL BASED CSRR

The loading of metamaterial-based 4×4 CSRR on SSHPA results in a 10dB RL bandwidth of 11.78GHz (8.22GHz to 20GHz). The 4×4 metamaterial-based CSRRs offer an AR bandwidth of 570MHz (9.43 to 20GHz) whereas, for a single unit cell metamaterial-based CSRR, there is no circular polarization (no axial ratio <3dB in operating frequency range).

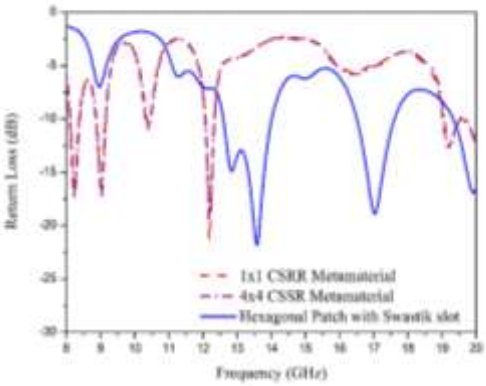
The bandwidth of SSHPA antenna without metamaterial-based CSRR is observed to be 8GHz (12-20GHz) and after loading with metamaterial-based CSRR it got enhanced to 11.78GHz (8.22-20GHz). Before loading metamaterial to SSHPA antenna operates in K and Ku-band and after loading the metamaterial the antenna operates in the X, K, and Ku band. The consequent return loss and axial ratio plots have been presented in Fig.11(a) and Fig.11(b) respectively.

### 4.2 RADIATION PATTERN AND GAIN OF SSHPA WITH METAMATERIAL BASED 4X4 CSRR

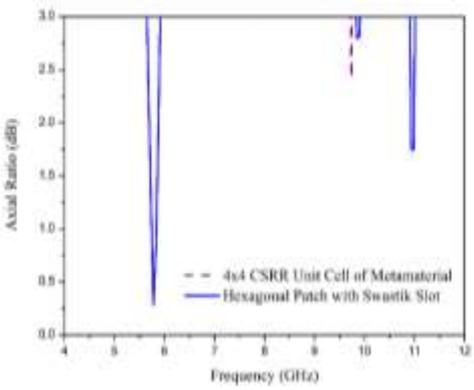
The radiation pattern of SSHPA with metamaterial-based 4×4 CSRR is observed at CP frequency. The E-plane and H-plane patterns obtained are nearly similar indicating the presence of circular polarization frequency at 9.74GHz as shown in Fig.12(a). A gain of 4dBi is obtained for SSHPA with metamaterial-based 4x4 CSRR as shown in Fig.12(b).

### 4.3 CURRENT DISTRIBUTION OF METAMATERIAL BASED CSRRS UNIT CELL

The Current Distribution given in Fig.13 reflects the current density in the material based CSRRs on SSHPA at different phases (0°, 30°, 60°, and 90°). From the anti-clockwise rotation of surface current distribution at different phases it is evident that the proposed antenna supports left-hand circular polarization (LHCP).

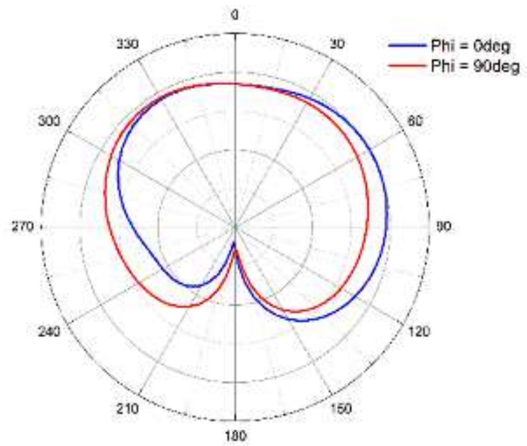



(a)

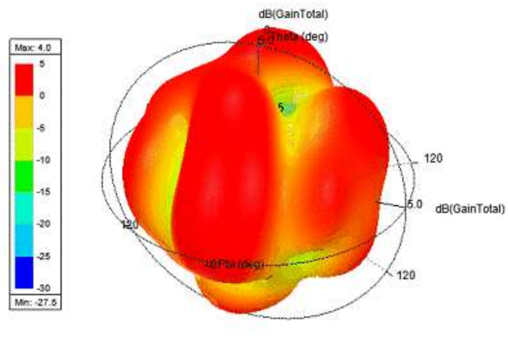



(b)

Fig.11. Return Loss and Axial Ratio of metamaterial-based CSRR on SSHPA




(a)




(b)

Fig.12. (a) Radiation Pattern (b) Gain of SSHPA with metamaterial-based 4×4 CSRR

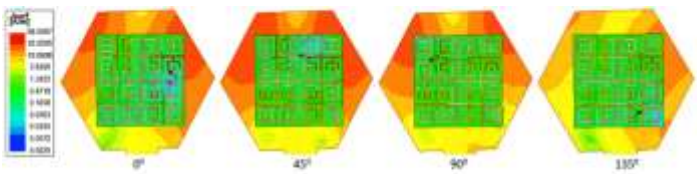


Fig.13. Surface current distribution at 9.74GHz

## 5. CONCLUSIONS

The Swastik slotted hexagonal patch antenna with metamaterial-based complementary split-ring resonators is designed and analyzed. The SSHPA operates over a frequency range of 12GHz -20GHz with an RL bandwidth of 8GHz resulting in three CP bands with AR bandwidth of 1.74GHz (6.54GHz to 8.24GHz), 1.52GHz (12.86GHz to 14.38GHz), and 1.07GHz (14.38GHz to 15.47GHz). The peak gain is 6.1dBi. The integration of metamaterial-based 4×4 CSRR's resulted in RL bandwidth of 11.78GHz (8.22 to 20GHz), AR bandwidth of 570 MHz (9.43 to 10GHz), and gain is 4dBi. The proposed Swastik slotted hexagonal patch antenna works in Ku and K bands whereas the same antenna integrated with metamaterial works in X, Ku, and K bands.

## REFERENCES


[1] M.R. Ghaderi and F. Mohajeri, “A Compact Hexagonal Wide-Slot Antenna With Microstrip-Fed Monopole for UWB Application”, *IEEE Antennas and Wireless Propagation Letters*, Vol. 10, pp. 682-685, 2011.

[2] S. Tripathi, A. Mohan and S. Yadav, “Hexagonal Fractal Ultra-Wideband Antenna using Koch Geometry with Bandwidth Enhancement”, *IET Microwaves, Antennas and Propagation*, Vol. 8, No. 15, pp. 1445-1450, 2014.

[3] J.G. Baek and K.C. Hwang, “Triple-Band Unidirectional Circularly Polarized Hexagonal Slot Antenna With Multiple L-Shaped Slits”, *IEEE Transactions on Antennas and Propagation*, Vol. 61, No. 9, pp. 4831-4835, 2013.

[4] V.P. Sarin, M.S. Nishamol, D. Tony, C.K. Aanandan, P. Mohanan and K. Vasudevan, “A Broadband L -Strip Fed Printed Microstrip Antenna”, *IEEE Transactions on Antennas and Propagation*, Vol. 59, No. 1, pp. 281-284, 2011.

[5] L. Dang, Z.Y. Lei, Y.J. Xie, G.L. Ning, and J. Fan, “A Compact Microstrip Slot Triple-Band Antenna for WLAN/WiMAX Applications”, *IEEE Antennas and Wireless Propagation Letters*, Vol. 9, pp. 1178-1181, 2010.

[6] Vivek Singh Rathor and Jai Prakash Saini, “A Design of Swastika Shaped Wideband Microstrip Patch Antenna for GSM/WLAN Application”, *Journal of Electromagnetic Analysis and Applications*, Vol. 6, No. 3, pp. 31-37, 2014.

[7] K. Qian and X. Tang, “Compact LTCC Dual-Band Circularly Polarized Perturbed Hexagonal Microstrip Antenna”, *IEEE Antennas and Wireless Propagation Letters*, Vol. 10, pp. 1212-1215, 2011.

[8] Avinish Kumar Tripathi, Sumit Srivastava and H.P. Sinha, “Design and Analysis of Swastik Shape Microstrip Patch Antenna at Glass Epoxy Substrate on L-Band and S-Band”, *International Journal of Engineering and Innovative Technology*, Vol. 2, No. 7, pp. 1-12, 2013.

[9] Naresh K. Darimireddy, R. Ramana Reddy and A.M. Prasad, “Asymmetric and Symmetric Modified Bow-Tie Slotted Circular Patch Antennas for Circular Polarization”, *ETRI Journal*, Vol. 40, No. 5, pp. 561-569, 2018.

[10] S. Rajkumar, N. Vivek Sivaraman, S. Murali and K.T. Selvan, “Heptaband Swastik Arm Antenna for MIMO Applications”, *IET Microwaves, Antennas and Propagation*, Vol. 11, No. 9, pp. 1255-1261, 2017.

[11] I.A. Buriak, V.O. Zhurba, G.S. Vorobjov, V.R. Kulizhko, O.K. Kononov and Oleksandr Rybalko, “Metamaterials: Theory, Classification and Application Strategies (Review)”, *Journal of Nano and Electronic Physics*, Vol. 8, No 4, pp. 1-11, 2016.

[12] Z. Yu and Q. Wang, “A Multi-Band Small Antenna Based on Deformed Split Ring Resonators of Left-Handed Meta-Materials”, *Proceedings of International Symposium on Microwave, Antenna, Propagation and EMC Technologies for Wireless Communications*, pp. 531-534, 2007.

[13] G. Geetharamani and T. Aathmanesan, “Design of Metamaterial Antenna for 2.4 GHz WiFi Applications”, *Wireless Personal Communications*, Vol. 113, pp. 2289-2300, 2020.

[14] H. Huang, Y. Liu, S. Zhang and S. Gong, “Multiband Metamaterial-Loaded Monopole Antenna for WLAN/WiMAX Applications”, *IEEE Antennas and Wireless Propagation Letters*, Vol. 14, pp. 662-665, 2015.

[15] S.A.H. Saghanezhad and Z. Atlasbaf, “Miniaturized Dual-Band CPW-Fed Antennas Loaded With U-Shaped Metamaterials”, *IEEE Antennas and Wireless Propagation Letters*, Vol. 14, pp. 658-661, 2015.

[16] Y. Sidana, R.K. Chaudhary and K.V. Srivastava, “A Novel Dual-Band Hexagonal Patch Antenna Coupled with a Complimentary Split Ring Resonator”, *Proceedings of Asia Pacific Conference on Microwave*, pp. 1343-1345, 2012.

[17] Muhammad Tauseef Asim and Mushtaq Ahmed, “Metamaterial Inspired Microstrip Antenna Investigations using Metascreens”, *International Journal of Antennas and Propagation*, Vol. 2015, pp. 1-9, 2015.

[18] Wojciech Jan Krzysztofik and Thanh Nghia Cao, “Metamaterials in Application to Improve Antenna Parameters”, *Metamaterials and Metasurfaces*, Vol. 12, No. 2, pp. 63-85, 2018.

[19] N.K. Darimireddy, R. Ramana Reddy and A. M. Prasad. “A Miniaturized Hexagonal-Triangular Fractal Antenna for Wide-Band Applications”, *IEEE Antennas and Propagation Magazine*, Vol. 60, No. 2, pp. 104-110, 2018.