Slotted E Shaped Patch Antenna Embedded with Split Ring Resonator

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***Abstract*— The evolution in advance technology has been developing rapidly around the world where necessities of satellite and radar communication as well as demand for multiband operating miniature antenna equipments are growing epidemically. Integration of Microstrip Patch Antenna (MPA) in wireless devices, have given the flexibility to fulfill the requirements due to its robustness, minuscule dimension and inexpensive attributes. But for further antenna characteristics enhancement researchers are inaugurating Microstrip Patch Antenna with Metamaterials. It has spectacular features of negative permittivity and permeability. This paper represents different alphabetical slots incorporated on E shaped patch antenna, which is embedded by Split Ring Resonator Metamaterials. The antenna design has been configured on the top FR4 substrate having dielectric constant of 4.2 with thickness of 1.6mm. The proposed scheme and probe feeding technique provides designed antenna to operate in multiband frequencies under X band. The proposed antenna resonates at 9.05 GHz and 9.76 GHz under same bandwidth of 714 MHz. The antenna has return loss of -68.4 dB and -40.4 dB at operating frequencies respectively with reasonable directivity and efficiency. The design concepts of the proposed antenna have been simulated, examined and discussed.**

Keywords—Microstrip Patch Antenna, Metamaterial, X band, Slots, IE3D Software.

I. INTRODUCTION

People always dream of possessing the capability to communicate with each other anytime, anywhere from the birth of human race. Now-a-days, communication becomes the integral part of day to day life of human being. Wireless communication is the fastest growing segment of the communications industry. In addition, wireless local area networks are currently replacing wired networks in many homes, campuses and businesses. Many new applications including wireless sensor networks, smart home and appliances, automated highways and factories, remote telemedicine etc. are already came into service. In wireless communication system**,** microwave with frequencies between 300 MHz and 300 GHz has been hugely popular since they are more easily focused into narrower beams allowing frequency reuse and their comparatively higher frequencies allow huge bandwidth, high data transmission rates & very small size of antenna. For all wireless communication systems, antenna is an essential part. It is mainly used to send or receive a signal. A signal that generates in a transmitter and travel through a transmission line to an antenna. An antenna connected to a transmitter is the device that releases energy in the form of an electromagnetic field to be sent to a distant receiver. The receiving antenna picks up the energy. As the electromagnetic field strikes the receiving antenna, a voltage is induced into the antenna, which serves as a conductor. The induced voltages are then used to recover the transmitted information [1].

Considering the availability of the technology and applications antennas are divided into two categories. They are: - Omni-directional and Directional. Omni-directional antennas are those which radiate or receive signals more or less in every direction. On the contrary, Directional antennas radiate or receive signal in a particular direction. According to the shape and purpose, antennas are divided into several types like: - half wave dipole, quarter wave monopole, loop antenna, helical antenna, horn antenna and micro strip patch antenna etc [2].

The global demand of Microstrip Patch Antenna (MPA) is increasing exaggeratedly. The reasons behind this rapidly growing demand are its amazing features of lightweight, low volume, low profile, simplicity and cheap fabrication cost characteristics. Specially, the Rectangular Microstrip Patch Antenna (RMPA) has some additional advantages like low profile and omni directional radiation pattern [3]. On the contrary, RMPA has some disadvantages like low gain and narrow bandwidth [4].

To overcome these drawbacks different types of method can be introduced such as the bandwidth of MPA can be improved by using air as substrate [5], increasing the substrate height, adding up parasitic patches element in co-planer or stack configuration but slotting the RMPA is prominent technique. This improves the bandwidth and makes the antenna operate at multi bands [6]. By cutting the slots from a patch, gain and return loss of MPA can also be improved [7-8]. Multi-slotted E-shaped patch antenna is investigated for the gain and bandwidth enhancement [9-13]. It gives wideband operating frequency for wireless applications. It will provide the broad bandwidth which is required in various application like remote sensing, biomedical application, mobile radio, satellite communication etc. [14].

For further antenna characteristic enhancement, researchers are introducing Metamaterial structures in designing MPA. Metamaterials are the artificial materials which posses simultaneously negative values of magnetic permeability and dielectric permittivity [15]. Most of the Metamaterial structures consist of Split Ring Resonators (SRRs) to produce negative permeability and thin wire elements to generate negative permittivity. Metamaterial characteristic of different SRR structures have been studied and analyzed [16-21]. It improves the directivity as well as the bandwidth of the antenna by creating resonance [22]. From the above discussion, authors are encouraged to design and simulate slotted E shaped MPA loaded with Metamaterial structure of SRRs.

II. ANTENNA DESIGN

The geometry of the proposed antenna in 3D view is illustrated in Fig. 1. The whole design of the proposed antenna is developed in IE3D software. It has been configured on the top of the RMPA. The RMPA consists of a rectangular conducting patch on one side of a dielectric substrate with a ground plane on the other side. The antenna has been excited by most commonly used coaxial feeding technique. The general structure is evolved on the FR4 substrate having dielectric constant of 4.2 with thickness of 1.6mm from the ground plane. The initial dimensions of the rectangular patch are determined from the following equation.

$$W = \frac{v_o}{2 f_r} \sqrt{\frac{2}{\varepsilon_r + 1}} \tag{1}$$

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-\frac{1}{2}} \tag{2}$$

$$\Delta L = 0.421h \frac{\left(\varepsilon_{eff} + 0.3\right)\left(\frac{W}{h} + 0.264\right)}{\left(\varepsilon_{eff} - 0.258\right)\left(\frac{W}{h} + 0.8\right)} \tag{3}$$

$$L = \frac{1}{2 f_r \sqrt{\varepsilon_{eff}}\sqrt{\mu_o \varepsilon_o}} - 2\Delta L \tag{4}$$

Here W is the width of the patch, v_o is the speed of light in a vacuum, ε_r is the dielectric constant of the substrate, f_r is the target frequency, ε_{eff} is the effective dielectric constant of the material, ΔL represents the extension in length caused by the fringing effect, h is the thickness of the substrate and L is the length of the patch.

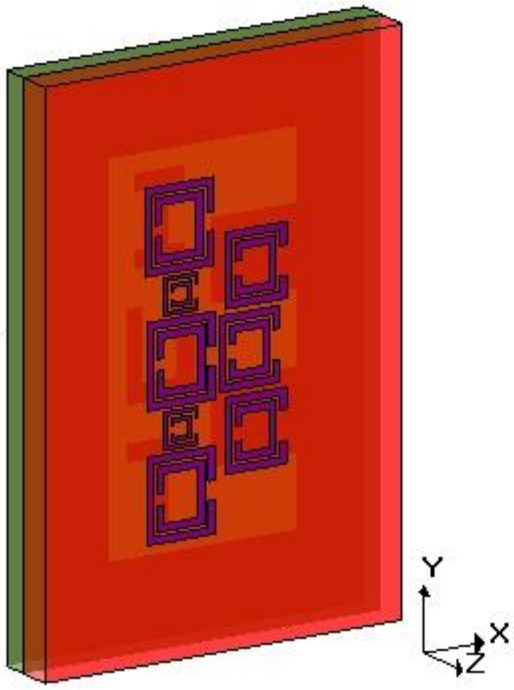

Fig. 1. 3D view of Proposed Antenna

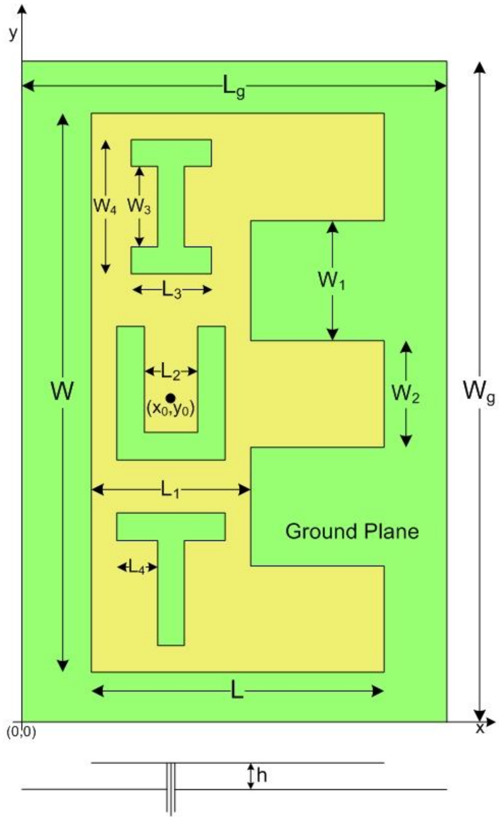

Fig. 2. Dimensions of Slotted E Shaped MPA

The RMPA and proposed antenna both have patch and ground plane dimension of (LxW) 21mm x 11mm and (LgxWg) 31mm x 21mm respectively. For desired proposed antenna two parallel slots are incorporated from rectangular patch to transform into "E" shaped patch. After acquiring E shaped patch more three alphabetic letter of "I", "U" and "T" shapes are trimmed off from the top of the patch accordingly shown in Fig. 2. The slots acquiesce to perturb the surface current path and affect the local inductive effect which is responsible for resonance in antenna. The slot length, slot width of the patch controls the frequency of the fundamental resonant mode and the performance characteristics of the antenna [23-25].

Fig. 2 shows the desired "I", "U", and "T" slotted E shaped patch antenna and corresponding dimensions are given in Table I. A probe with an extension of the inner conductor of the coaxial feed line is attached at the point (x_0,y_0 = 3, 10.4) also shown in the figure.

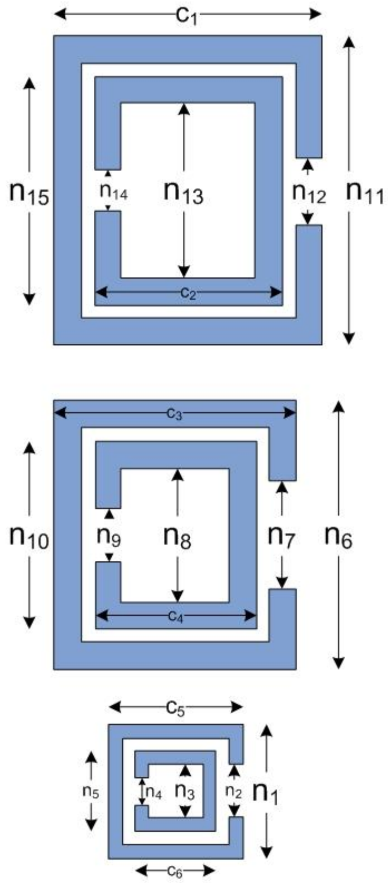

Fig. 3. Dimensions of SRR structure for Proposed Antenna

Fig. 3 depicts the configuration of SRR structure. Three different dimension of same structure shape of SRRs have been designed on same FR4 substrate with relative permittivity of 4.2 used in pervious antenna but thickness is 3.2 above from the ground plane. Total eight numbers of SRRs are used to cover MPA. The whole arrangement has been carried out and loaded on the top of slotted E shaped MPA. Table II shows the dimension of the parameters of SRR structures.

TABLE I. DIMENSIONS OF E SHAPED MPA AND SLOTS

Parameters	***Dimension(mm)***
W_1	4.5
W_2	4
W_3	3
W_4	5
L_1	6
L_2	2
L_3	3
L_4	1.5
L	11
W	21
W_g	31
L_g	21

TABLE II. DIMENSIONS OF SRRS USED OVER E SHAPED MPA

Parameters	***Dimension(mm)***
n_1	2
n_2	0.8
n_3	2.6
n_4	0.4
n_5	1.2
n_6	4
n_7	1.6
n_8	2
n_9	0.8
n_{10}	2.8
n_{11}	4
n_{12}	1
n_{13}	0.8
n_{14}	0.6
n_{15}	3.4
c_1	5
c_2	2.8
c_3	3.6
c_4	2.4
c_5	2
c_6	1.2

III. SIMULATIONS AND RESULTS

The basic design of RMPA and proposed antenna are modeled by using 3D electromagnetic simulator called IE3D from Zeland which has Fast EM Design Kit for real-time full-wave EM tuning, optimization and synthesis. It is one of the most advance software in electromagnetic (EM) simulation and antenna designing. IE3D is a full wave, method of moments (MOM) based electromagnetic simulator for analyzing and optimizing planar and 3D structures in a multi-layer dielectric environment. The simulated result includes S,Y, and Z-parameters, VSWR, RLC equivalent circuits, current field distribution, near and far field estimation, radiation pattern etc [11 & 26]. Dimension of the parameters are transferred in this software for simulation. All the simulations are done in between 8 GHz to 12 GHz frequency range i.e. X band. The probe feeding line is optimized to obtain desired result. Fig. 4 represents the performance characteristic of basic configuration of regular RMPA. The result shows frequency versus return loss curve, where the lower and upper bandwidth has been measured from the edge of less than -10 dB return loss. Probe feeding position provides the antenna to resonant at X band frequency range. The basic structure of RMPA operates at 9.51 GHz with return loss of -15.46 dB. The antenna has bandwidth of 155 MHz which covers only almost 4% of the whole X band. The basic drawback of narrow bandwidth of RMPA has been observed. The antenna has directivity and gain of 8.25 dBi and 1.32 dBi respectively at operating frequency shown in Fig. 9 and Fig. 10.

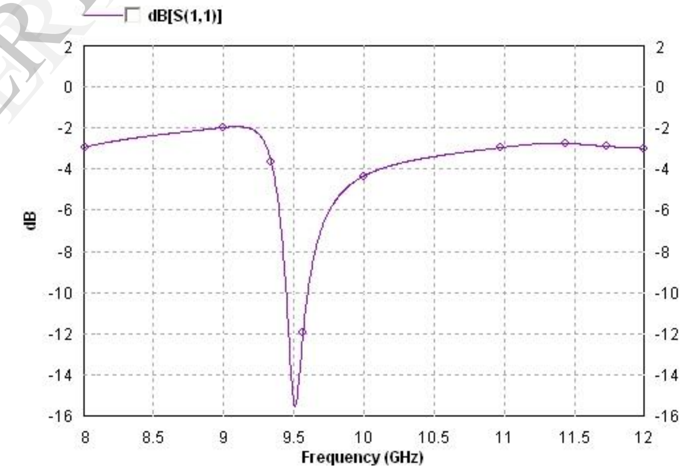

Fig. 4. Reflection Coefficient (S_{11}) of RMPA

Fig. 5 illustrates the variation of return loss versus frequency curve of E shaped MPA with “I”, “U” and “T” alphabet slots on it. The antenna still operates in X band frequency limit at single band, but resonant frequency has been shifted left at 8.38 GHz respect to regular RMPA. The deviation of operating frequency shifting is about 1.13 GHz. The antenna has bandwidth of 176 MHz and return loss of -25.1 dB at operating frequency. For the slots antenna characteristics have been improved where bandwidth improved by 21 MHz and return loss of -9.64 dB compared with RMPA. The slotted has gain and directivity of 2.4 dBi and 8.6 dBi respectively at operating frequency shown in Fig. 11 and Fig. 12.

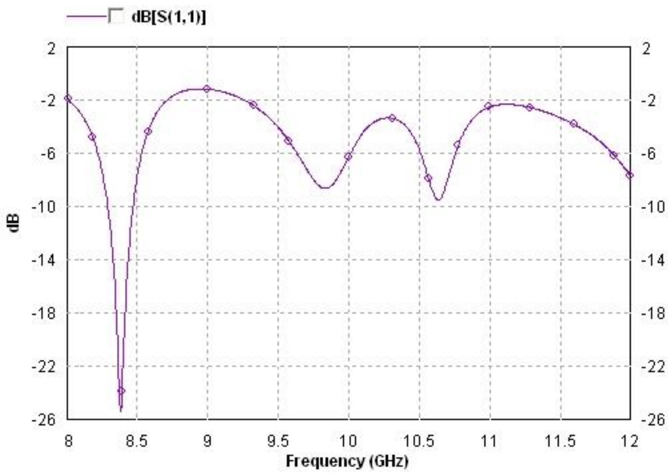

Fig. 5. Reflection Coefficient (S_{11}) of Slotted E Shaped MPA

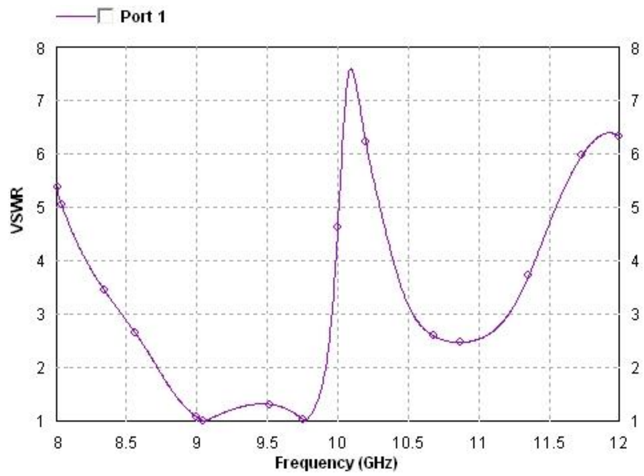

Fig. 7. VSWR of Proposed Antenna

Fig. 6 shows the variation of return loss versus frequency of proposed antenna. It has been observed that, the proposed antenna shows high performance characteristics compare with RMPA. The patch, alphabetic slots and Metamaterial structure provides the proposed antenna to operate under X band with different frequencies. The desired antenna resonates at 9.05 GHz and 9.76 GHz with corresponding return loss of -68.4 dBi and -40.8 dBi respectively. The higher resonant frequency is excited by the patch, and the sub-wavelength resonant is considered as exciting by the SRR structure. Under the sub-wavelength resonance, the effective permittivity of the SRR medium is expected to be negative value. The -10dB bandwidth is 714 MHz for both operating frequencies, which covers almost 22% of X band.

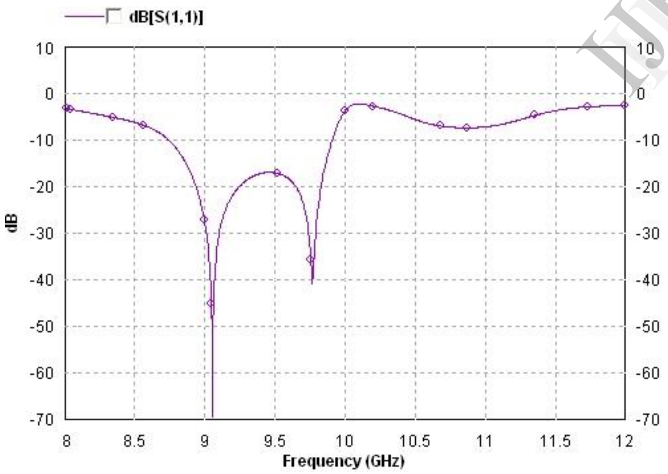

Fig. 6. Reflection Coefficient (S_{11}) of Proposed Antenna

Fig. 7 illustrates the Voltage Standing Wave Ratio (VSWR) of proposed antenna. It is an indication of the quality of the impedance match. A high VSWR is an indication that the signal is reflected prior to being radiated by the antenna. VSWR and reflected power are different ways of measuring and expressing the same thing. Here the ratio of the maximum voltage of a standing wave pattern on a transmission line to the minimum voltage on the line is less than 2 at operating frequencies [11].

Fig. 8 is a combine graph of RMPA, Slotted E Shaped MPA proposed antenna under same frequency range. It is convenient that proposed antenna shows better antenna performances than the other antennas.

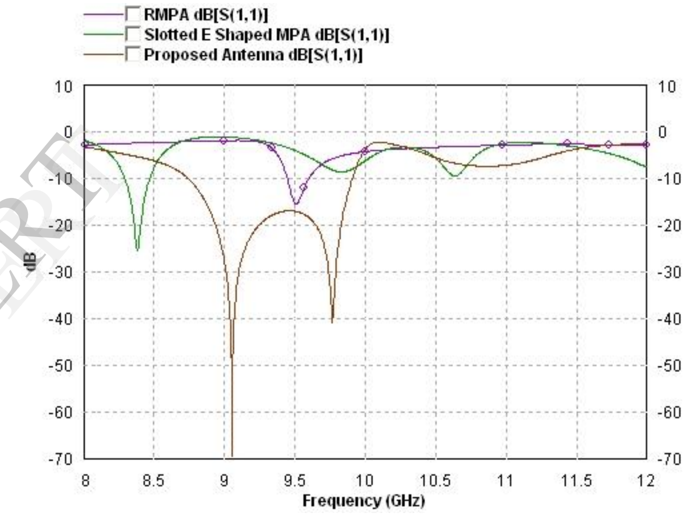

Fig. 8. Reflection Coefficient (S_{11}) of all Antennas under X band range

Directivity is the measure of how much the antenna's radiation is focused respect to isotropic radiation pattern and antenna gain is the measure of energy radiation concentration at a particular direction. The gain and directivity of elevation pattern from φ = 0 and φ = 90 degrees are shown below in the following figures.

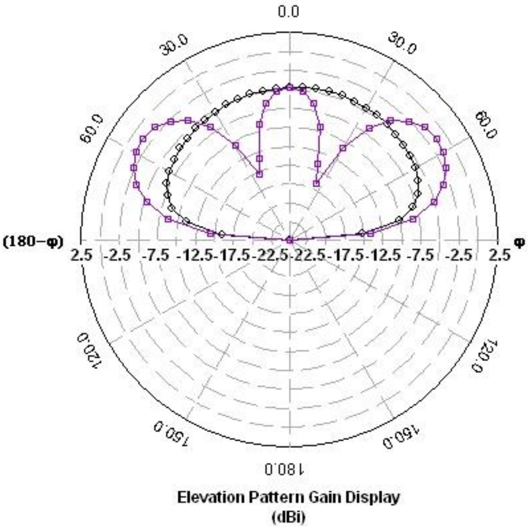

Fig. 9. Gain of RMPA at operating frequency of 9.51 GHz

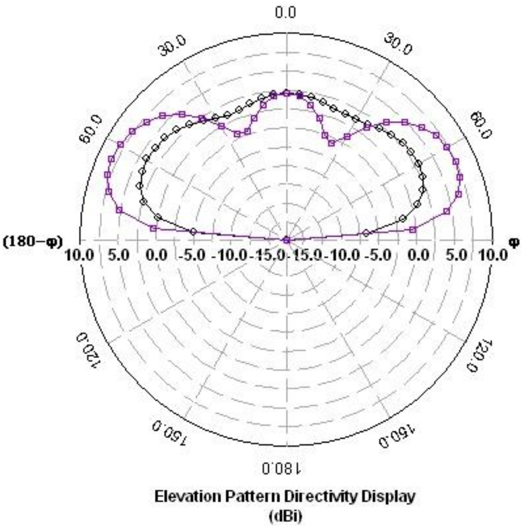

Fig. 10. Directivity of RMPA at operating frequency of 9.51 GHz

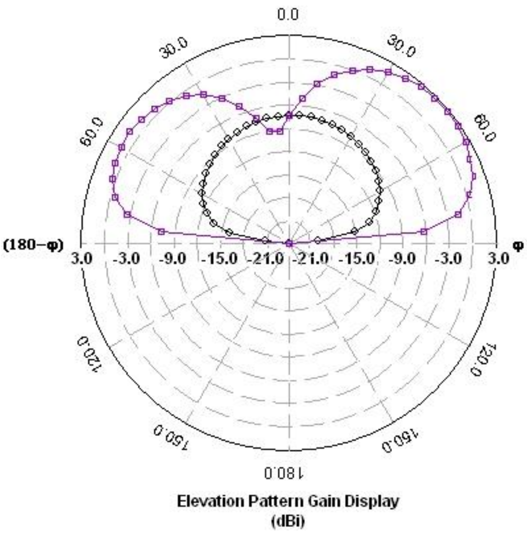

Fig. 11. Gain of Slotted E Shaped MPA at operating frequency of 8.38 GHz

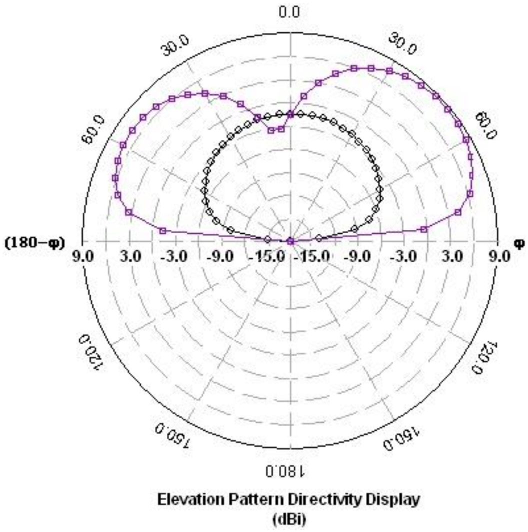

Fig. 12. Directivity of Slotted E Shaped MPA at operating frequency of 8.38 GHz

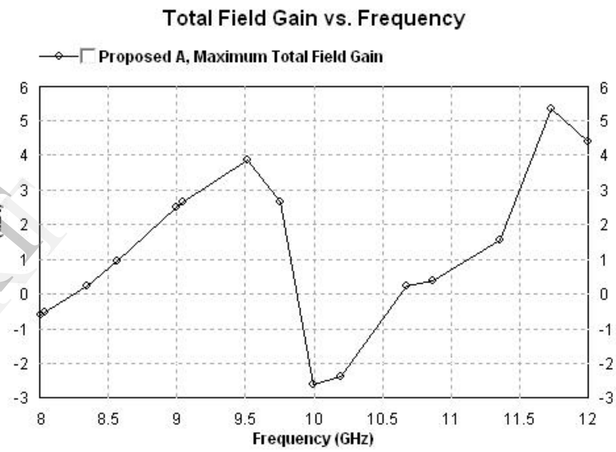

Fig. 13. Total Field Gain of Proposed Antenna

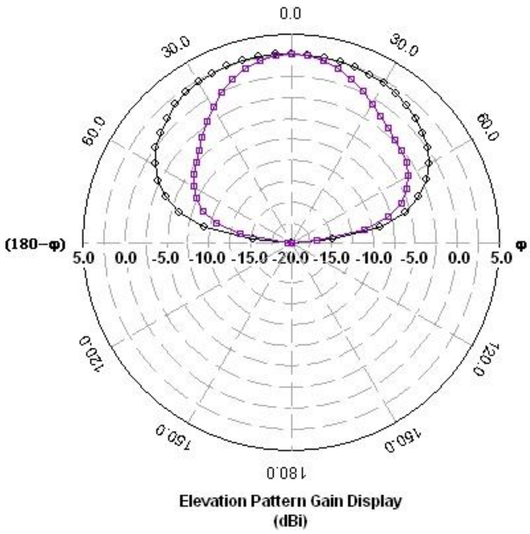

Fig. 14. Gain of Proposed Antenna at operating frequency of 9.05 GHz

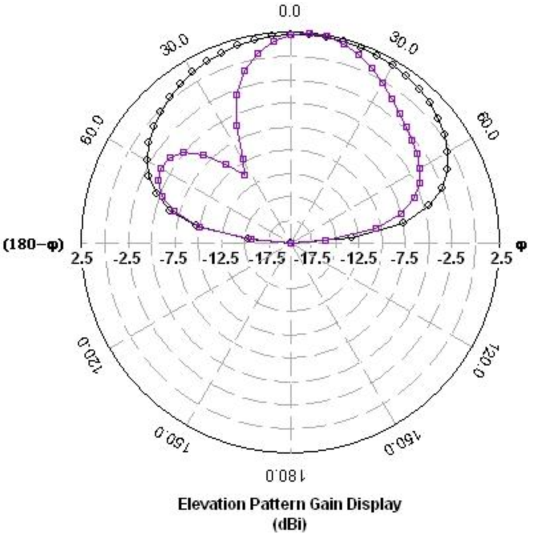

Fig. 15. Gain of Proposed Antenna at operating frequency of 9.76 GHz

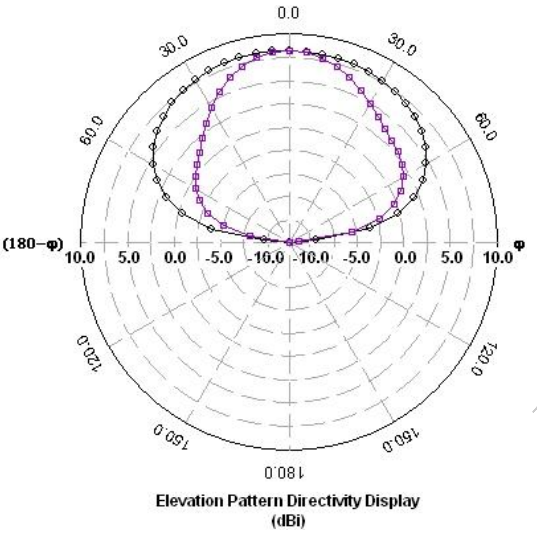

Fig. 16. Directivity of Proposed Antenna at operating frequency of 9.05 GHz

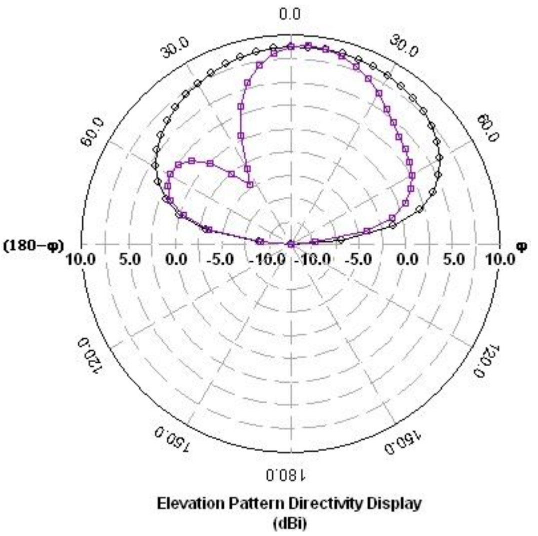

Fig. 17. Directivity of Proposed Antenna at operating frequency of 9.76 GHz

Here, Fig. 13 represents the gain versus frequency graph under X band frequency limit where it has been observed that maximum gain is 4.01 dBi at 9.5 GHz frequency within the operating bandwidth. The antenna gains at centre frequencies are 2.7 dBi and 2.5 dBi respectively shown in Fig. 14 and Fig. 15 as well as 2D directional radiation pattern of proposed antenna illustrated in Fig. 16 and Fig. 17. It can be clearly seen that the proposed antenna embedded with Metamaterial structure produces broadside or omni-directional radiation pattern and almost symmetrical radiation pattern.

IV. CONCLUSION

In this paper, a slotted E shaped MPA loaded with Metamaterial structure of SRRs has been designed and analyzed. As the output results are satisfactory, proposed antenna is suitable for earth exploration satellite, space research, fixed mobile, fixed satellite (earth-to-space), mobile satellite (earth-to-space) and broadcasting satellite. The presence of slots has made the performance of the antenna regarding wide bandwidth (BW), reduced return loss and focused radiation pattern. In order to realize the basic performance variation in the proposed antenna, the physical parameters and the effect of substrate layer are analyzed. From our observation, it is clear that the slots help to agitate the surface current path on the patch which is the reason of local inductive effect. Because of its dimension, the designed antenna can easily be fabricated and placed on small devices.

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