Dual Band Low Profile MPA with I-Shaped MTM Unit Cell for Satellite Communication

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Abstract - *A rectangular MPA having an etched I-shape metamaterial structure with in the ground plane is suggested in this work. The low profile design, having electrical size 0.43λo × 0.54λo × 0.06λo (i.e., 11mm×14mm×1.6mm), is designed to operate at 12.2GHz. The metamaterial unit cell included in the ground plane introduces another resonant peak (at 10.5GHz) to make the antenna dual band. The simulation process is conducted with the help of hfss v.15 simulation software. The outcomes of the simulation show an improvement in the antenna fractional bandwidth and gain. The antenna results in a fractional bandwidth of 6.58% with the central resonant frequency of 10.5GHz and 2.41% with 12.2GHz. The simulated value of peak gain is 4.81dB at 10.5GHz and 1.33dB at 12.2GHz. The proposed antenna also shows good impedance matching condition and results in a return loss of -19.43dB at 10.5GHz and -17.56dB at 12.2GHz. The design also shows an increase in antenna efficiency. The resulted efficiency of the antenna is 80%. I-shaped metamaterial structure created within its bottom surface adds a 46.63% miniaturization in the radiator (patch) area of the proposed antenna. The MTM-antenna designed in the work is suitable for the applications in X-band (e.g. radar communication) and Ku-band (e.g. satellite communication). The antenna also has a notch band between the two bands i.e. 10.8GHz to 12.1 GHz which avoid interference between two resonant regions.*

Keywords*- MTM (metamaterial), MPA (Microstrip Patch Antenna), miniaturization, hfss (high frequency structure simulator).*

1. INTRODUCTION

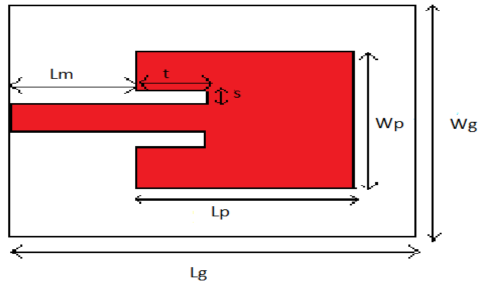
Numerous benefits of patch antennas like compact dimensions, low profile, effective in cost and easy in terms of fabrication make them famous among the researchers[1-2]. These advantages make them most suited antennas for the wireless communication applications.

An artificially created periodic media that finds its characteristic features (in terms of electromagnetic responses) totally different from its base material is famous by the name Metamaterial [3]. The periodic structure, either created by slots in base material or by arranging the similar materials in periodic manner, results in double negative (DNG) metamaterial which has both its permittivity and permeability in the negative region. Such characteristic were first detected and studied by Veselago [4]. A paper by Smith et al had experimentally verified the characterization given by Veselago about DNG material [5]. After this, these metamaterial structures are identified and applied in the antenna application for improving the antenna radiation characteristics. These metamaterials inserted in the antenna structures have not only showed an improvement in antenna parameters like gain, return loss and directivity but also resulted in miniaturization in the antenna dimensions [6-11].

The work in this paper aims to simulate a rectangular microstrip patch antenna having an I-shape metamaterial unit cell created by etching within the ground surface. The structure is modeled to resonate at 10.5GHz and 12.2GHz. The simulation work of the design is conducted using hfss v15 simulation software and the outcomes of the simulation are illustrated in the paper. The proposed antenna shows 46.63% miniaturization with respect to the area of patch in contrast to that of the regular patch area at same resonant frequency. The proposed antenna shows an enhancement with respect to both Gain and fractional bandwidth.

2. DESIGN ASPECTS OF PROPOSED MTM-ANTENNA

The geometrical aspects related to the proposed MTM antenna is depicted in the figure 1 below. The figure demonstrates upper and lower surface of the simulated structure. The lower surface of the designed patch antenna, called as ground plane, is etched with an I-shape metamaterial unit cell placed symmetrically at the center of the ground. The rectangular patch with inset feed using a microstrip line is placed on a FR4 epoxy glass material having 1.6mm of height, relative dielectric permittivity εr =4.4 and the loss-factor $\tan\delta=0.02$. Other geometrical parameters for the simulated structure are illustrated in the table given below.



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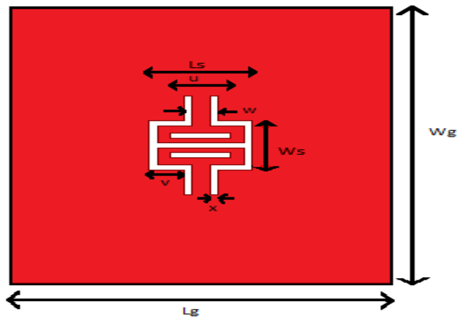

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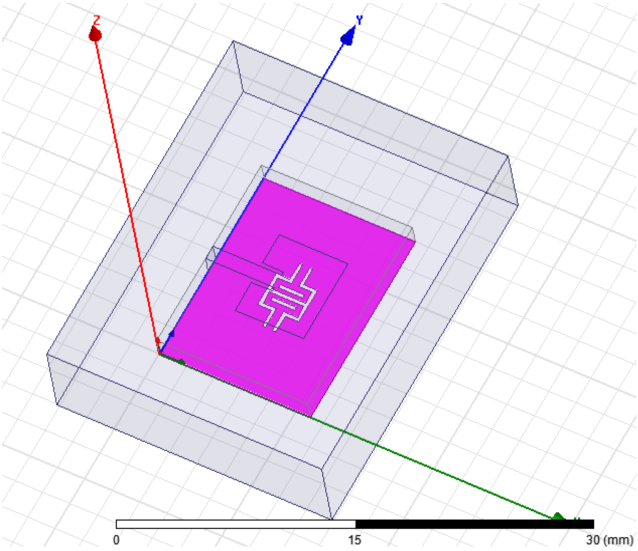


(c)

Figure 1. (a) Upper surface having patch, (b) Ground plane with metamaterial unit cell and (c) overall hfss model of the designed antenna

TABLE I

Proposed Antenna: Dimensions

Facet	Units (mm)	Facet	Units (mm)
L_g	11	s	1
W_g	14	L_s	3
L_p	5	W_s	2.5
W_p	6	u	1.75
L_m	3.5	v	1.25
t	2	w	1
x	0.25		

The microstrip feed line is connected and positioned to result the best possible impedance matching condition for the antenna. The inset feeding is done to reduce the spurious radiation near the feed patch interface.

3. METAMATERIAL UNIT CELL EQUIVALENT CIRCUIT

An unit cell of the metamaterial structure included in the ground plane denotes LC resonant circuit in its equivalent model resonating at particular resonant frequency. The metal strips in the unit cell acts like an inductor whereas the gaps in between acts like capacitors. These unit cells when exposed with the electromagnetic radiation either stores or reflect all the waves passing through them.

The equivalent model of a metamaterial cell is depicted in the fig.2.

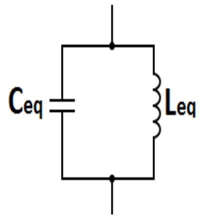


Figure 2. MTM-unit cell equivalent circuit

MTM unit cell's resonant frequency is given as,

$$f = \frac{1}{2\pi\sqrt{L_{eq}.C_{eq}}}$$

Here, L_{eq} and C_{eq} denote the equivalent values of inductance and capacitance for the metamaterial unit cell respectively.

4. SIMULATED ANTENNA PARAMETERS

Return loss (S_{11} dB) - The parameter of reflection (S_{11}) for the simulated resonator is drawn in the fig.3. The designed antenna receives good impedance matching. The simulated value of the parameter S_{11} is -19.43dB at the resonating frequency of 10.5GHz and -17.56dB at 12.2GHz. Around these center frequencies, the resulted fractional BW for the designed antenna is 6.58% and 2.41% respectively. Thus, the antenna shows an improvement in terms of bandwidth.

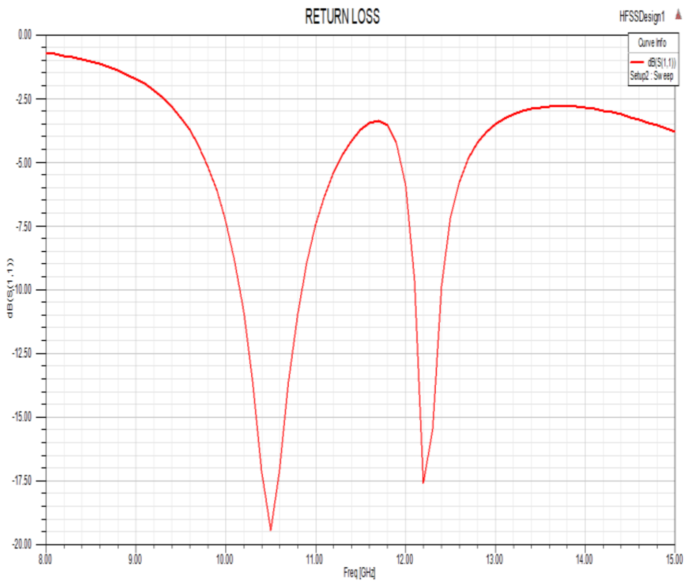


Figure 3. Graph of simulated return loss

Gain and Directivity- An integrated plot of gain and directivity of the suggested antenna is shown in the fig. 4 below. The peak gain resulted at the resonant frequency of 10.5GHz is 4.8dB and 12.2GHz is 1.33dB. The measures of peak directivity are 5.89dB and 4.47dB respectively.

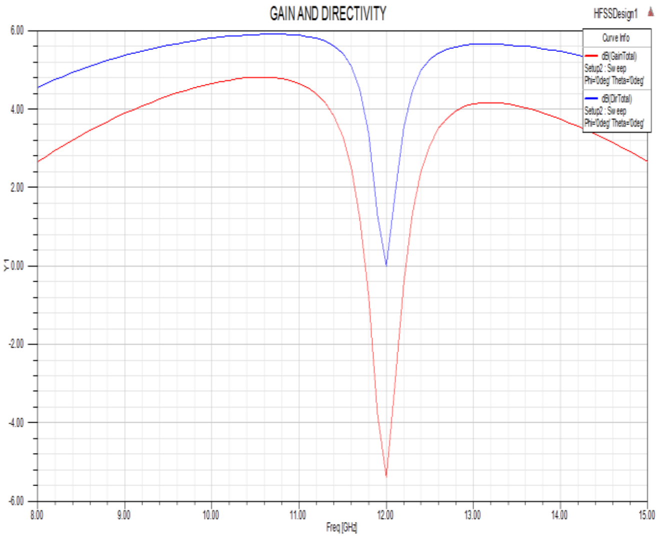
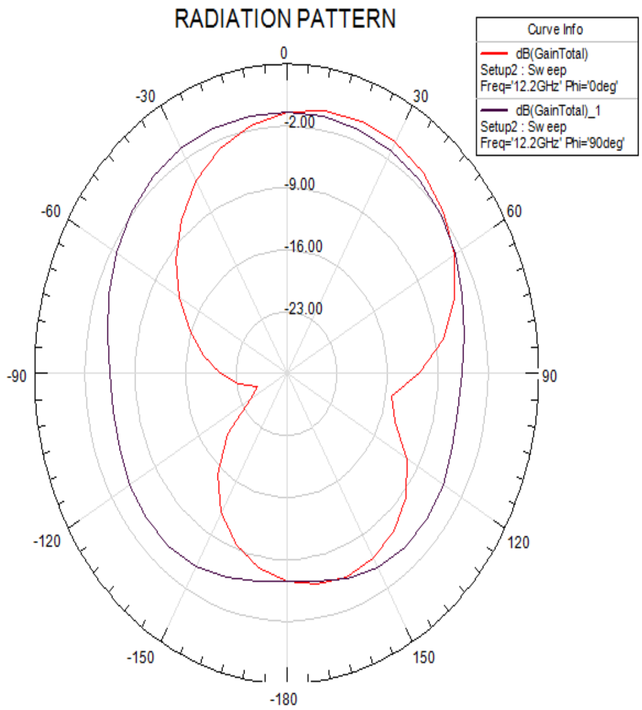


Figure 4. Integrated plot of gain and directivity vs frequency

Antenna Efficiency- The capability of an antenna to generate radiated power from the radio-frequency power is termed as its efficiency. The proposed antenna is 80% efficient.

Radiation Pattern- A semi-omnidirectional radiation pattern depicted in the fig.5(a) is shown by the proposed antenna. The radiation pattern shown is well suited for the satellite and radar communication applications.



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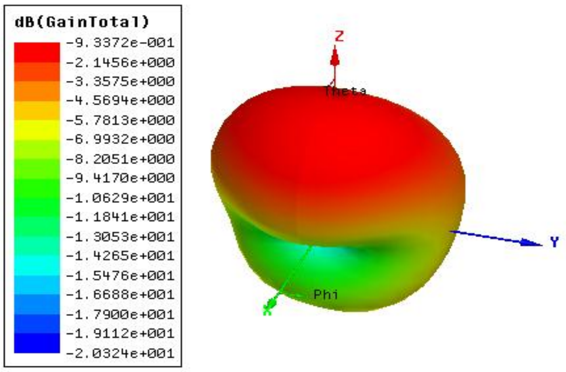


(b)

Figure 5 (a) Pattern of Radiation with varying theta,(b) Polar plot with respect to total gain.

Current distributions- The distributions of current density for the resonating patch surface and the ground suface having metamaterial unit-cell are drawn in the fig.6.

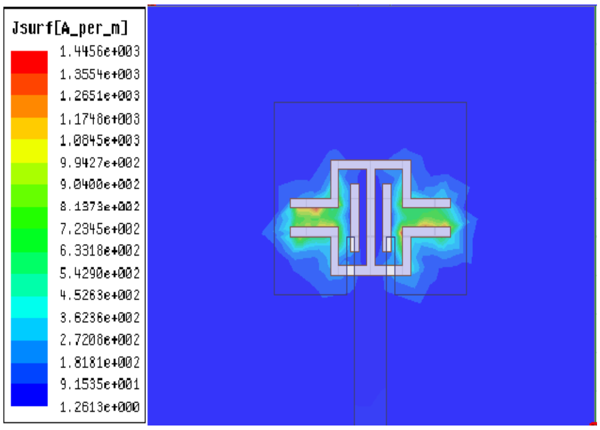
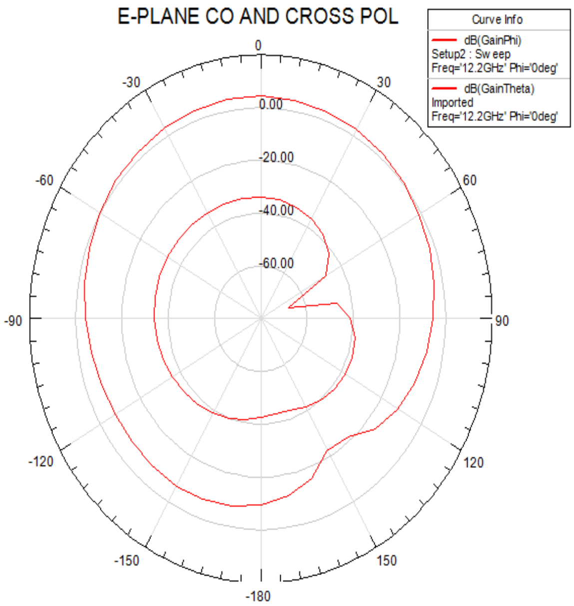
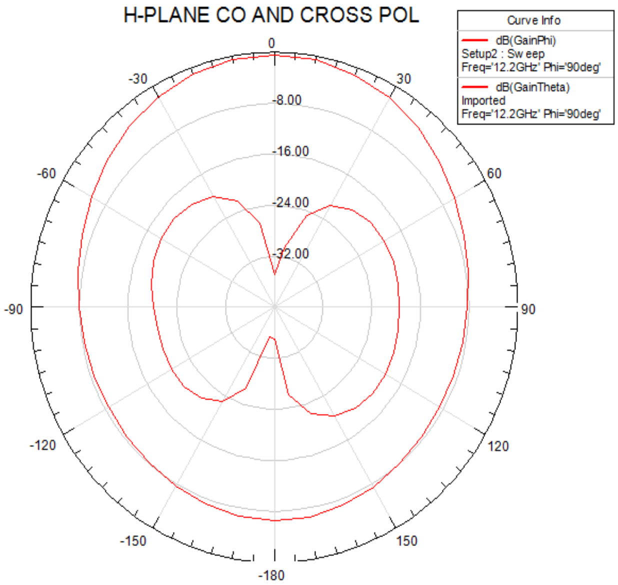


Figure 6. Current distribution across the metamaterial unit cell

Co-Polarization and Cross-Polarization- The E and H plane's Co. and X-polarizations plots are drawn in the fig.7. The measures of both the polarizations for both the planes are also given in the table 2 below.



(a)



(b)

Figure 7. (a) E-Plane's Co. & X-polarization, (b) H-Plane's Co. & X-polarization

TABLE II

Measures of Co. & X-Polarization

Plane	Peak Co-pol.(dB)	Peak Cross-pol.(dB)
E-Plane	4.35	-33.78
H-plane	-0.40	-34.78

Voltage Standing Wave Ratio (VSWR) - The simulated graph for VSWR vs frequency is depicted in the fig.8. The measure of VSWR for the suggested antenna is 1.86dB with the resonant frequency of 10.5GHz and 2.23dB at 12.2GHz.

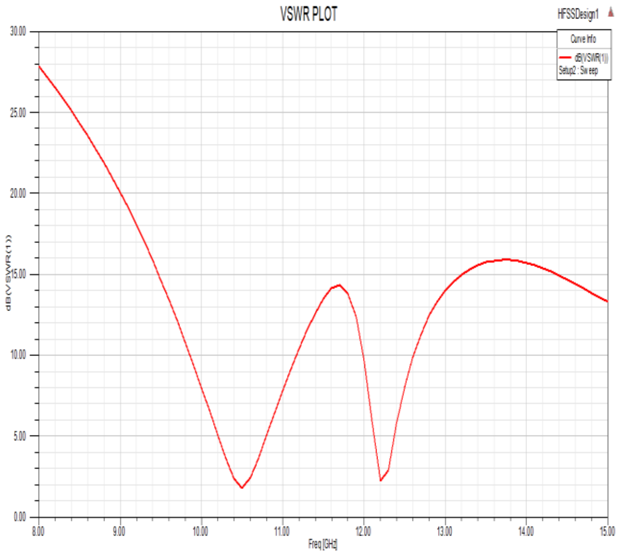


Figure 8. Graph of VSWR vs frequency

Miniaturization- The required patch area for a regular microstrip patch antenna modeled with a 12.2GHz resonating frequency is 38.12 mm^2. The effective patch area for the designed antenna is 26 mm^2. Hence, the proposed antennas results in 46.63% miniaturization in the patch dimensions.

5. CONCLUSION

Metamaterial-inspired rectangular MPA is described and simulated in the paper. All important antenna parameters are calculated and the results obtained are illustrated in the paper. The antenna, designed with the resonant frequencies of 10.5GHz and 12.2GHz, has not only shown an improvement in antenna gain and fractional bandwidth but also added 46.63% miniaturization in antenna's patch area. The design also shows good impedance matching condition as the parameter of reflection (S_{11}) at the resonating frequency is quite low.

The desined antenna finds its application in the X-band and Ku-band of electromagnetic spectrum. The bands are useful for satellite communication and radar applications. The antenna has semi-omnidirectional radiation pattern, so it is well suited for applications in satellite communication.

Table 3 makes a comparison between the previous literatures and antenna proposed in the paper. The antenna shows improvement in terms of gain and fractional bandwidth.

TABLE III

Comparison among Previously Designed Antennas and Proposed Antenna

References	Resonating Frequencies (GHz)	Fractional Bandwidth (%)	Peak Gain (dB)
[12]	1.35 3.75	4.4 2.6	0.4 2.6
[13]	2.49 3.66	3.2 2.74	-0.5 1.27
[14]	3.51 5.76	3.4 2.43	1.3 5
[15]	3.65 5.77	4.33 2.06	3.1 5.8
Suggested Antenna	**10.5** **12.2**	**6.58** **2.41**	**4.81** **1.33**

To get more improvement in the antenna parameters and to get high degree of miniaturization, more number of unit cells can be constructed in place of one. By using the array of unit cells, it is also possible to receive double-band or multi band response.

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