Criss-Cross Metamaterial Based Radiating Structures for C-band Applications

Kirti Inamdar[1], **Y. P. Kosta**[2], **and S. Patnaik**[3]

[1]ECED, SVNIT, Surat, Gujarat, India
[2]MEFGI, Rajkot, Gujarat, India
[3]St. Xavier's Institute of Engineering, Mumbai, India

Abstract— In this paper, we present the design of a metamaterial based microstrip patch antenna, optimized for bandwidth and multiple frequency operations. A Criss-Cross structure has been proposed, this shape has been inspired from the famous Jerusalem Cross. The theory and design formulas to calculate various parameters of the proposed antenna have been presented. Design starts with the analysis of the proposed unit cell structure, and validating the response using software — HFSS Version 13, for obtaining negative response of ε and μ — metamaterial. Following this, a metamaterial-based-microstrip-patch-antenna is designed. A detailed comparative study is conducted exploring the response of the designed patch made of metamaterial and that of the conventional patch. The unique shape proposed in this paper gives improvement in bandwidth without reducing the gain of the antenna. The C-band of the frequency spectrum has been chosen for all the above mentioned exercise as it is the most popular band for commercial, satellite and radar applications. The proposed metamaterial based antenna can be utilized for higher gain and bandwidth requirements in any of these applications.

1. INTRODUCTION

Low gain and narrow bandwidth are the limitations of conventional microstrip antennas (MSA). The urge of having a compact antenna configuration further deteriorates these two parameters as gain and bandwidth both are directly related to the size of the antenna. Therefore, the most recent design consideration for most of the practical wireless communication applications is size reduction together with gain and bandwidth enhancement. In order to increase the gain, techniques like loading of high permittivity dielectric substrate [1], inclusion of an amplifier type active circuitry [2] and stacked configuration [3] are used. Bandwidth improves if the substrate thickness is increased or the dielectric constant is reduced, use of thick substrates with the help of air or foam along with impedance matching technique [4]. Use of metamaterials (MM) for further improving the performance of MSA has been the recent trend in this field. Majid et al. [5] has proved that the gain and bandwidth of MSA can be increased by placing an array of left-handed metamaterials (LHM) in front of patch. This paper lends its contribution for bandwidth enhancement using a unique MM of Criss-Cross shape. The use of this shape for miniaturisation has been reported in [6].

2. DESIGNING OF CRISS-CROSS SHAPE METAMATERIAL

2.1. Mechanical and Material Aspects

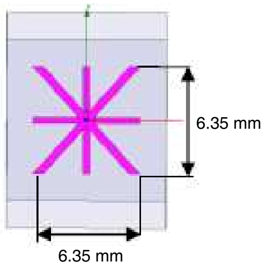
In the Criss-Cross shape [7], there are two cross shapes stacked over each other but electrically separated from each other by 45° as shown in Figure 1(a). The dimension of the unit cell is 6.35×6.35 mm with each of its strip with a width of 1.016 mm made of Copper with a thickness of 0.017 mm. The substrate used is Dupont with $\varepsilon_r = 7.8$.

2.2. Simulations and Response

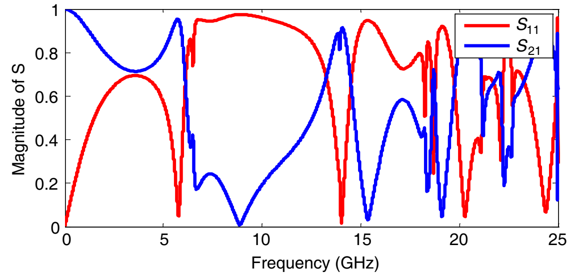
Figure 1(b) shows the results obtained in HFSS. The analysis of the unit cell when made on different substrate material and when its array was designed is presented well in [7]. The proposed signature structure exhibits negative μ & ε in the frequency band of 5 to 9 GHz. As per the thumb rule, the unit cell size less than quarter wavelength behaves like MM therefore, at higher frequency, its behaviour as MM is not effective. Therefore, band 5 to 7 GHz is considered to be the effective negative medium band. The negative parameter bandwidth obtained is thus 33%.

3. DESIGNING OF A CRISS-CROSS METAMATERIAL EMBEDDED MICROSTRIP PATCH ANTENNA

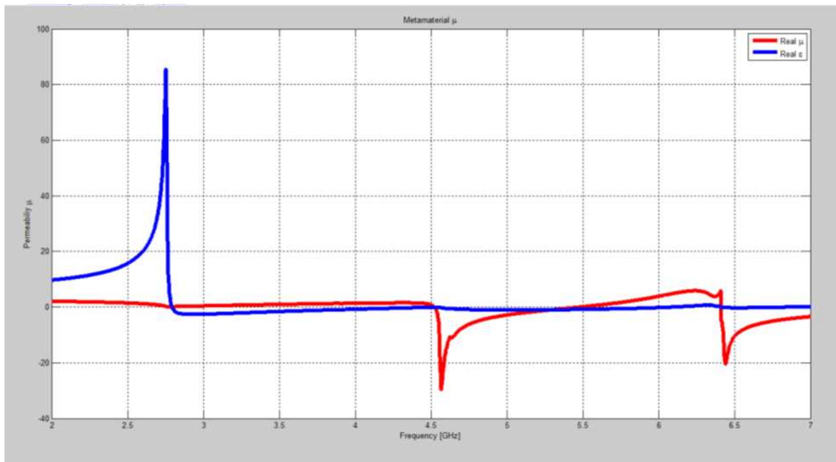
We now present the design aspects related to designing of rectangular microstrip patch antenna embodied on a host substrate — metamaterial (signature criss-cross), this is depicted in Figure 3(a).



(a)



(b)

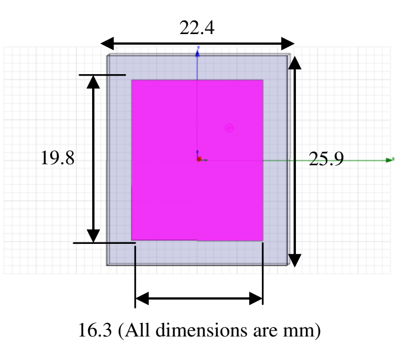


(c)

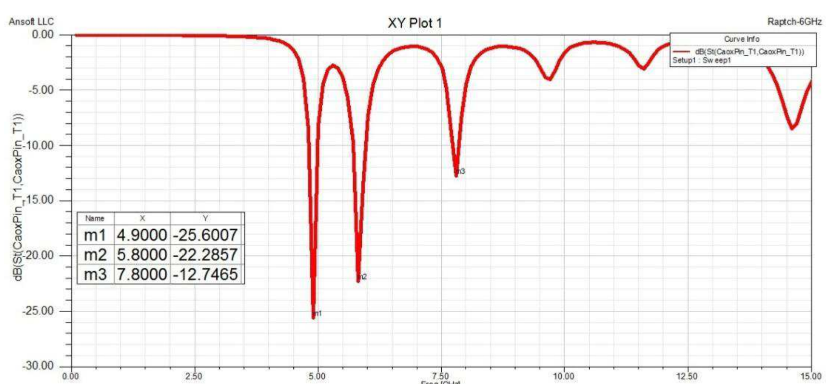
Figure 1: (a) A Criss-Cross shape unit cell with stacked X on both sides of substrate. (b) The S_{11} response of the Criss-Cross unit cell. (c) The extracted parameters of Criss-Cross shape unit cell when made on the substrate of Dupont ($\varepsilon_r = 7.8$).

Comparison of the same is done with the conventional patch antenna that was designed to resonate at 6 GHz, shown in Figure 2(a). The length of the patch is 16.3 mm and its width is 19.8 mm. The substrate dimensions are $l = 22.4$ mm and $w = 25.9$ mm with a thickness of 1.016 mm with $\varepsilon_r = 2.2$. The feed position is $(x, y) = (4, 4)$. The feed position was optimized in an attempt to obtain multi-band response covering a larger frequency bandwidth with a view that the negative medium band after inclusion of MM can be covered by the device. Figure 2(b) shows the return loss response for the conventional patch antenna for $f_0 = 6$ GHz.

In the next step, an array of Criss-Cross metamaterial inclusions was done in the substrate as shown in Figure 3(a). The frequency response of the above patch is changed as shown in

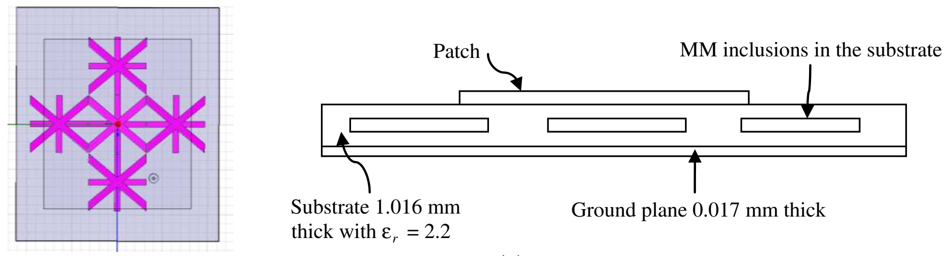


(a)

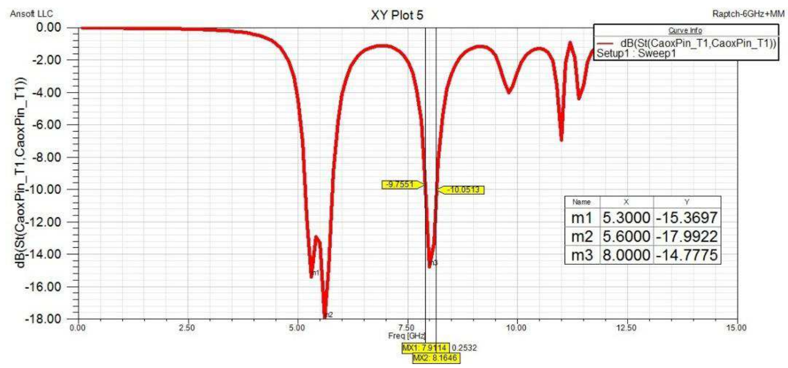


(b)

Figure 2: (a) Design for a conventional patch antenna for $f_0 = 6$ GHz. (b) S_{11} response for the conventional patch antenna.



(a)



(b)

Figure 3: (a) Design of Criss-Cross metamaterial embedded patch antenna (top & front view). (b) S_{11} response for the Criss-Cross metamaterial embedded patch antenna.

Figure 3(b). The left shift in frequency is due to change in the effective impedance of the medium due to metamaterial inclusions. The bandwidth of this antenna configuration is 610 MHz. The bandwidth for simple patch was 300 MHz, so an enhancement of 310 MHz is thus achieved with a gain of 4.45 dB. The metamaterials work on the principle of effective medium theory. The variation in the size of unit cell, no of array elements, arrangement or distribution of unit cells along the structure, material used etc. can generate paths for further improvement in the performance of any model.

4. CONCLUSION

This paper presents the simulation results for a new signature — Criss-Cross shaped metamaterial structure. It has been shown that the proposed structure exhibits negative values of μ and ε in the region of design-interest. The negative parameter bandwidth obtained for this signature shape (criss-cross) is 33.33% which is distinctively higher as compared to Square SRR structure (17–18%) [8] and other reported cross structures (31%) [9]. Our proposed signature — criss-cross metamaterial structure when utilized to design a rectangular microstrip patch antenna multiple band operation was observed with an improvement of bandwidth within the multiple bands along with appreciable improvements in the gain as well, compared to the conventional patch antenna. Thus, inspired from the Jerusalem cross, this novel signature — Criss-Cross shaped metamaterial antenna can be strategically utilized to realized microstrip based radiating antennas.

REFERENCES

1. Habib Ullah, M., M. T. Islam, et al., "A parametric study of high dielectric material substrate for small antenna design," *Int. Jour. of App. EM and Mechanics*, Vol. 41, 2, 2013.
2. Robert, B., T. Razban, and A. Papiernik, "Compact amplifier integration in square patch antenna," *Electronics Letters*, Vol. 28, 1808–1810, Sep. 1992.
3. Lee, R. Q. and K. F. Lee, "Experimental study of the two-layer electromagnetically coupled rectangular patch antenna," *IEEE Trans. Antennas and Propagation*, Vol. 38, 1298–1302, Aug. 1990.
4. Huynh, T. and K. F. Lee, "Single layer single patch wideband microstrip patch antenna," *Electronics Letters*, Vol. 31, 1310–1311, Aug. 1995.

5. Majid, H. A., M. K. Abd Rahim, and T. Masri, "Microstrip antenna's gain enhancement using left-handed metamaterial structure," *Progress In Electromagnetics Research M*, Vol. 8, 235–247, 2009.
6. Inamdar, K., Y. P. Kosta, and S. Patnaik, "A Criss-Cross metamaterial based electrically small antenna," *IJERA*, Vol. 3, No. 3, May–Jun. 2013.
7. Inamdar, K., Y. P. Kosta, and S. Patnaik, "A novel Criss-Cross shaped metamaterial," *IJEAT*, Vol. 2, No. 3, Feb. 2013.
8. Smith, D. R., et al., "Electromagnetic parameter retrieval from inhomogeneous metamaterials," *Physical Review E*, Vol. 71, 036617, 2005.
9. Katko, A. R., "Artificial negative permeability based on a fractal Jerusalem Cross," Undergraduate Honors Thesis, 2009.