INTERNATIONAL JOURNAL OF MICROWAVE AND OPTICAL TECHNOLOGY,
VOL.10, NO.3, MAY 2015

Tunable and directive metamaterial-inspired antennas for 'C' Band Applications

Parul Dawar*, N.S. Raghava and Asok De

Department of Electronics and Communication Engineering ,Guru Tegh Bahadur Institute of Technology, G-8 Area ,Rajouri Garden ,New Delhi-110064, India ,Tel: 011-45599900
Email:paru.dawar@gmail.com

***Abstract*- A new type of metamaterial-inspired monopole antenna designed for satellite transmission communication systems has been elucidated. By adding a 'C' Shaped Pair (CSP) metamaterial into the near field of monopole antenna resonating at 7.5 GHz, a secondary resonance has been created in C-Band which is lower than the monopole's ones. At this new resonance, the directivity of the structure was enhanced and its profile was reduced. Next, the tunability of the structure was observed with respect to the coupling distance between the monopole antenna and the CSP. The directivity of the structure has also been enhanced.**

***Index Terms* -Antenna, metamaterial, HFSS, negative refraction, C-Band.**

I. INTRODUCTION

'Metamaterials' (MTMs) are engineered to modify the bulk permeability and/or permittivity of the medium. It is realized by placing periodically, structures that alter the material parameters, with elements of size less than the wavelength of the incoming electromagnetic wave. It results in "meta" i.e. "altered" behavior or behavior unattainable by natural materials. Slight changes to a repeated unit cell can be used to tune the effective bulk material properties of a MTM, replacing the need to discover suitable materials for an application with the ability to design a structure for the desired effect. Examples of MTMs are single negative materials (SNG) like ε negative (ENG) which have effective negative permittivity and μ negative (MNG) which have effective negative permeability, and double negative materials (DNG).

A fresh approach to microwave and optical devices presented itself with the interesting breakthrough in the area of MTMs at high frequencies. The need of hour is to optimize the antenna parameters (gain, bandwidth , directivity) without altering its dimensions i.e. external control over antenna parameters using MTM . The software tool HFSS is used because it is a high performance full wave electromagnetic (EM) field simulator for arbitrary 3D volumetric passive device modeling. It integrates simulation, visualization, solid modeling, and automation in an easy to learn environment where solutions to 3D EM problems are quickly and accurately obtained [1].

Section 2 abridges the design of 'C' shaped Pair with resonant frequency 55GHz having FR4_epoxy (ε_r=4.4) as substrate material. Section 3 gives the mathematical proof of the designed MTM. Design of monopole antenna resonating at 7.5GHz has been done in section 4.Section 5 shows the parasitic resonance obtained in monopole antenna by insertion of CSP. Section 6 studies the tunability with respect to the coupling distance between the antenna and the CSP. Section 7 concludes the paper.

II. PROPOSED 'C' SHAPED PAIR MTM

A 'C' shaped Pair (CSP) metamaterial has been proposed having negative refractive index [2]. It behaves as DNG i.e. Double Negative Group. Such materials have negative permeability and negative permittivity over same frequency region

INTERNATIONAL JOURNAL OF MICROWAVE AND OPTICAL TECHNOLOGY,
VOL.10, NO.3, MAY 2015

[3],[4]. The parameter retrieval i.e. parameter extraction using S parameters has been followed using NRW approach to observe the negative permeability region of SRR metamaterial. The constructional details along with the curve are as under.

'C' Shaped Pair metamaterial consists of FR4 epoxy as substrate with εr=4.4 [5]. It is designed in such a way that the inclusions are much smaller than the operating wavelength. Such structures can be denoted by quasi-static equivalent LC circuit [6],[7].

The advantage of using C-shaped Pair is that the structure is very simple in construction. Unit cell formed in HFSS is shown in figure 1 where thickness 't' of the conducting metallic inclusions is 0.017mm, height 'h' of the substrate is 0.203mm, bulk conductivity is 38000000Siemens/m ,l=5mm,w=2mm and the spacing and metallic sheet width is 0.1mm each.

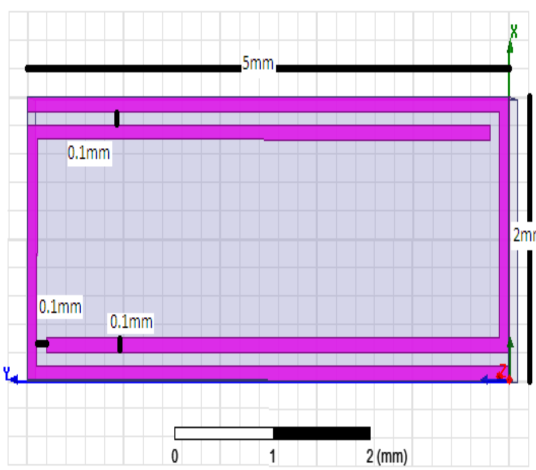


Figure 1:CSP MTM a)unit cell designed in HFSS b)constructional details

Ansoft HFSS has been used to simulate the unit cell designed in figure 2 having metamaterial on the dielectric substrate bounded by box having air as material and radiation boundary.

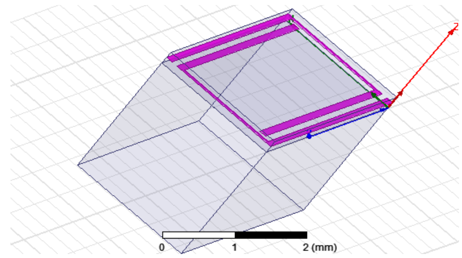


Figure 2:Unit cell for simulation boundary

It can be observed as in figure 3(a) and (b) that negative refraction region exists. Hence this MTM is a DNG metamaterial.

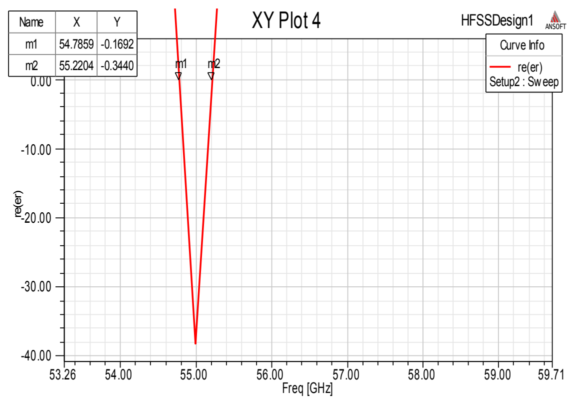


Figure 3(a) Negative permittivity region

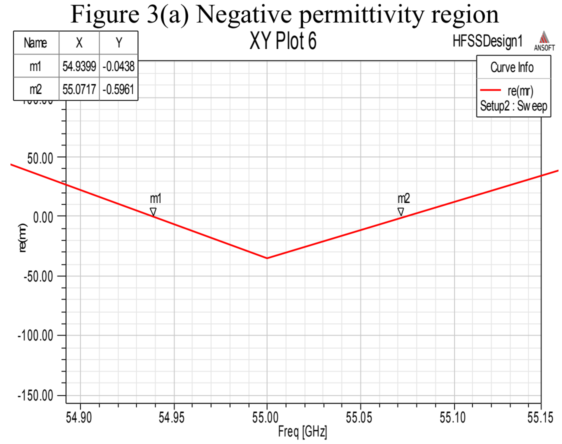


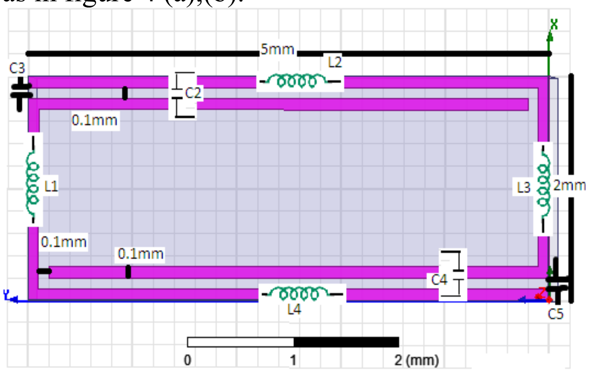
Figure 3(b) Negative permeability region

III . MATHEMATICAL PROOF

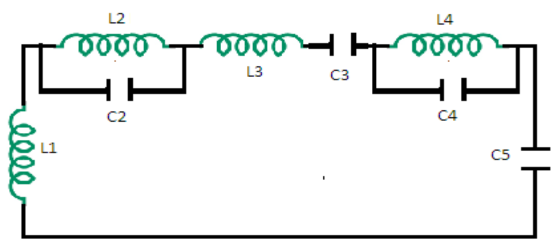
CSP MTM has magnetic and electric properties because of internal inductances and capacitances. It can be simplified in terms of combinations of

INTERNATIONAL JOURNAL OF MICROWAVE AND OPTICAL TECHNOLOGY,
VOL.10, NO.3, MAY 2015

C and L. Using transmission line theory (quasi-static regime), we can draw its equivalent circuit as in figure 4 (a),(b).



(a)



(b)

Figure 4:(a),(b)Equivalent LC circuit of CRP

The Lm is the inductance per unit length of the loop and Cn is the capacitance of the gap, where m is (1,2,3,4) and n is (2,3,4,5) .
The expressions for L and C are given by equation 1 and 2 as below:

$$L_m = \frac{\mu}{2}\frac{hl}{w} \qquad (1)$$

where μ=μo is the vacuum permeability and parameter values can be referred to figure 4(a).
Therefore, the equivalent inductance, Leq, is given by (L2+L3+L4)11L1.Upon calculation, Leq is found out to be 9.82X10^{-8}H.

$$C_m = \varepsilon\frac{w c_1 l}{h} \qquad (2)$$

where ε=4.4εo, Therefore, the equivalent capacitance ,Ceq,is given by (C211C311C4)+C5. Upon calculation ,Ceq is found out to be 9.35X10-11F.

Neglecting high frequency losses, magnetic resonance frequency is given by equation 3.

$$\omega = \sqrt{\frac{1}{L_{eq}C_{eq}}} \qquad (3)$$

Thus, resonant frequency is found out to be 52.5GHz. However, using simulational study of CSP in Ansoft HFSS, resonant frequency has been found out to be 55GHz. The agreement between simulation and theory is very good, with errors of less than 4.5 per cent in the resonant frequency. These errors can be attributed to simulational inaccuracies in terms of definition of mesh size and theoretical inaccuracies in terms of application of Lorentz theory.

IV.ANTENNA DESIGN

Design of monopole antenna has been shown in figure 5 with FR4 (ε_r=4.4) as substrate material with thickness of 0.205mm and having length =7.5 mm and width =0.3mm [8].It has been mounted perpendicularly on ground plane having dimension of 20X20mm^2.

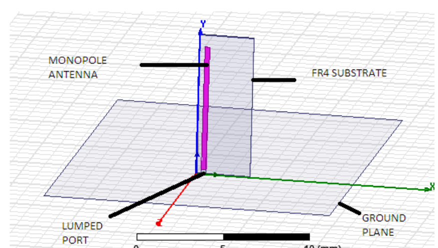


Figure 5:Monopole Antenna

The monopole antenna has resonant frequency of f_r=7.5GHz with resonant length of 5mm (λeff/4) where λeff is effective wavelength in the propagating medium. The optimization procedure has been applied on length of the antenna and it yields optimized length as 7.5mm which givesS11=-29.5dB as shown in figure 6. The absolute value of peak realized gain of monopole antenna is 0.598 as shown in figure 6 (b) and the absolute value of peak directivity is observed as 0.646.

INTERNATIONAL JOURNAL OF MICROWAVE AND OPTICAL TECHNOLOGY,
VOL.10, NO.3, MAY 2015

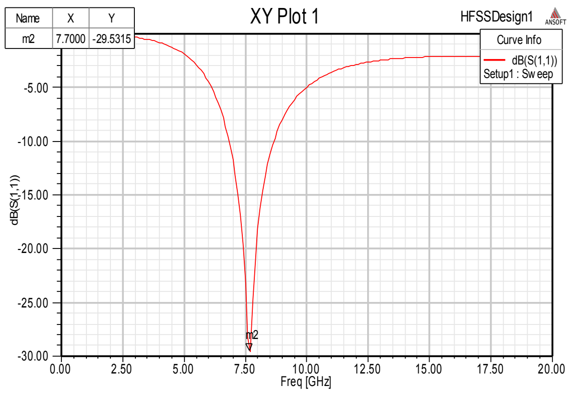


Figure 6(a): Return Loss of Monopole Antenna

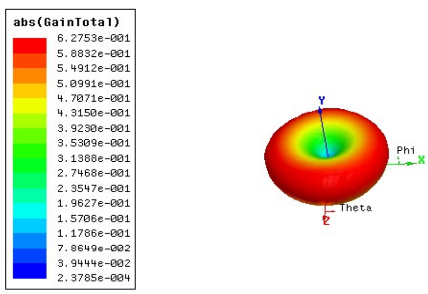


Figure 6(b): Peak realized gain of Monopole Antenna

V.PARASITIC RESONANCE FOR 'C' BAND APPLICATIONS

The miniaturization of the antenna structure can be achieved by placing the 'C' shaped Pair metamaterial in the structure as shown in figure 7.

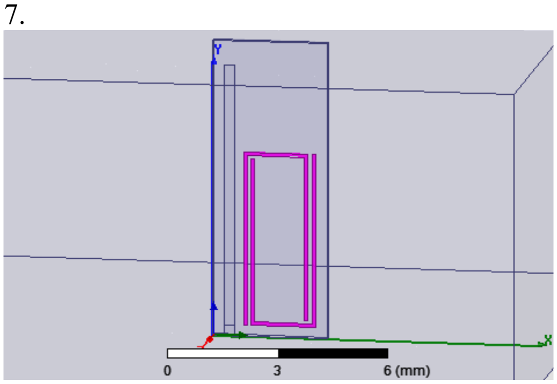


Figure 7: Miniaturization of Monopole Antenna

By placing the CSP metamaterial in the near field of monopole antenna , a parasitic resonance has been obtained at fp=4 GHz as shown in figure 8(a).This frequency corresponds to the IEEE C-band (4 to 8 GHz), that are used for many satellite communications transmissions, some Wi-Fi devices, some cordless telephones, and some weather radar systems.

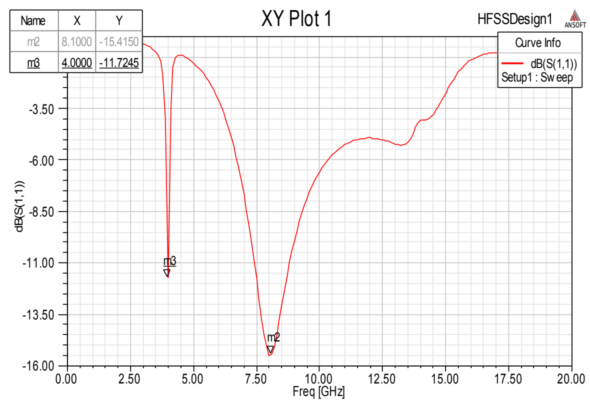


Figure 8 (a): Parasitic resonance in Monopole Antenna

This parasitic resonance is less than the resonant frequency of monopole antenna i.e. fp<fr. This allows for miniaturization of the structure. The coupling distance has been kept as 0.2mm.

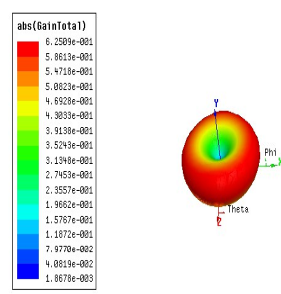


Figure 8(b): Peak realized gain of Monopole Antenna with metamaterial

Also, the peak realized gain has been reduced by 5% (0.57) as shown in figure 8(b) and peak directivity has been improved by 2% (0.657).
The reduction in gain can be explained as the resonant frequency is lowered ,so the effective length of the patch is lowered, thereby lowering gain.

INTERNATIONAL JOURNAL OF MICROWAVE AND OPTICAL TECHNOLOGY,
VOL.10, NO.3, MAY 2015

VI.TUNABILITY

Tunability in parasitic resonance has been observed by following two procedures referring to figure 9:

1. By moving Δx along the coupling distance direction
2. By moving Δy perpendicular to the coupling distance direction

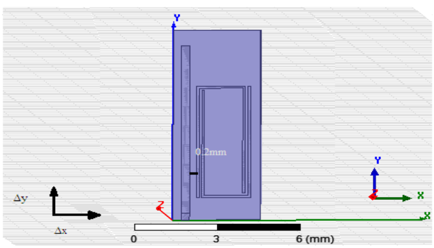
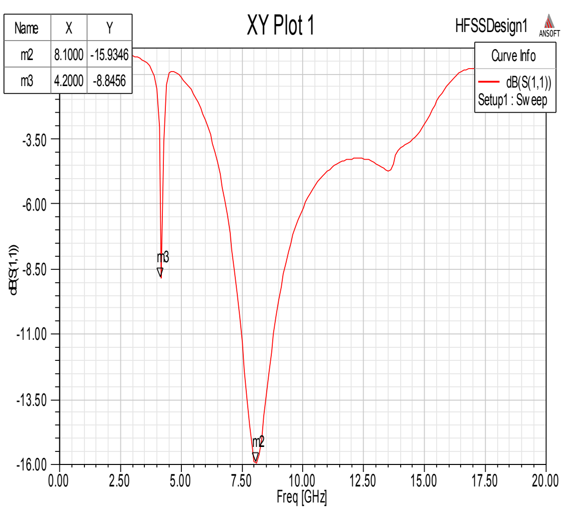


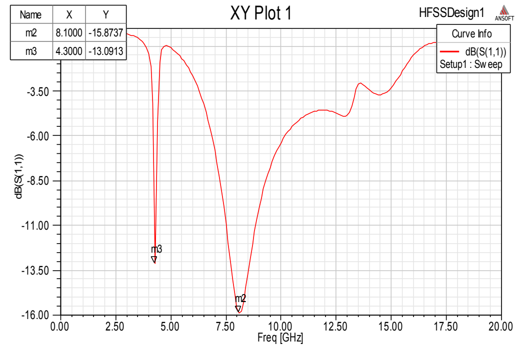
Figure 9: Tunability procedure for Monopole Antenna

A. Movement Δx along the coupling distance

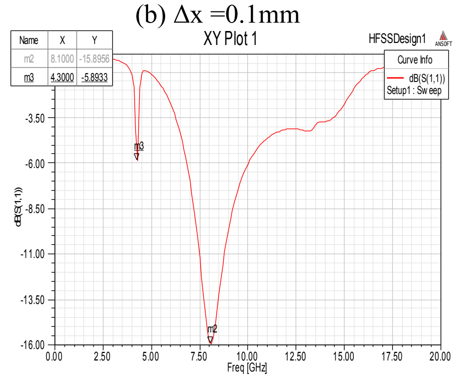
The effect in the fp i.e. parasitic resonance has been observed by moving Δx =0.05mm along the coupling distance direction. The figure 10 a,b,c,d shows the return loss curves for incremental Δx .



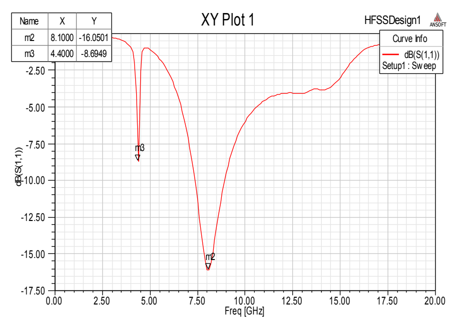
(a) Δx =0.05mm



(b) Δx =0.1mm



(c) Δx =0.15mm



(d) Δx =0.2mm

Figure 10a,b,c,d: Return loss curve wrt the incremental movements in x direction

Table 1 tabulates the findings from Figure 10 a,b,c,d. It concludes the relation between the increments in x direction with the return loss and the parasitic resonance.

INTERNATIONAL JOURNAL OF MICROWAVE AND OPTICAL TECHNOLOGY,
VOL.10, NO.3, MAY 2015

Table 1: Effects of increments in x with fp and S11

+Δx(mm)	fp(GHz)	S11(dB)
0	4	-11.7
0.05	4.2	-8.8
0.1	4.3	-13
0.15	4.3	-5.9
0.2	4.4	-8.7

Thus, with the increase in the distance separating the monopole antenna and the resonator (CSP), the structure size can be reduced .Hence; miniaturization can be obtained with increasing coupling distance. Table 1 shows that at distance =0.2+0.1 i.e. at a distance of 0.3 mm from the monopole antenna ,the best impedance matching for the structure can be obtained. Thus, at this frequency i.e. fp=4.3GHz, the monopole's reactive impedance has been matched with the 'C' shaped Pair metamaterial impedance.

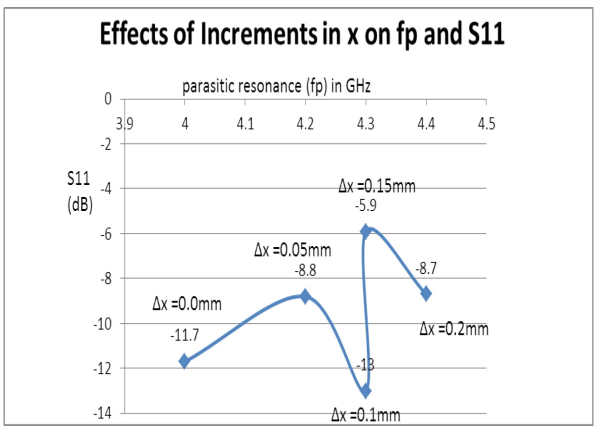
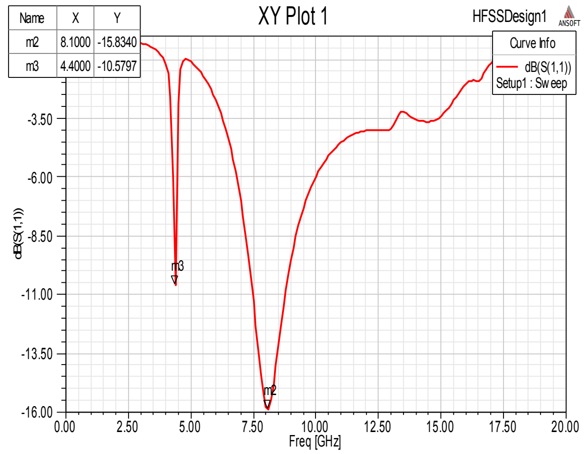


Figure 11: Return loss curve wrt the incremental movements in x direction

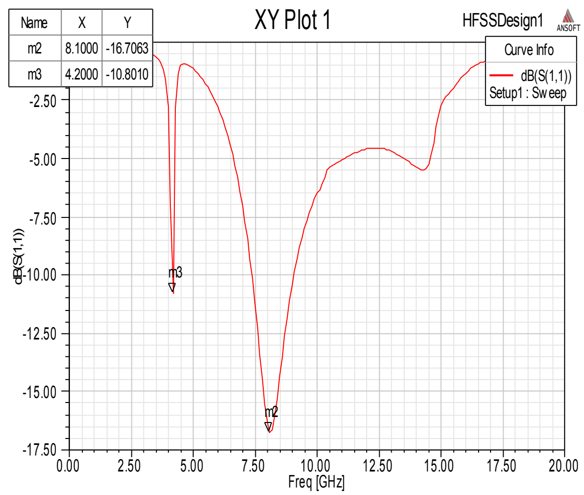
The figure 11 shows the curve of effects of increments in x on parasitic resonance and return loss keeping the coupling distance fix at 0.2mm.

B. Movement Δy perpendicular to the coupling distance direction

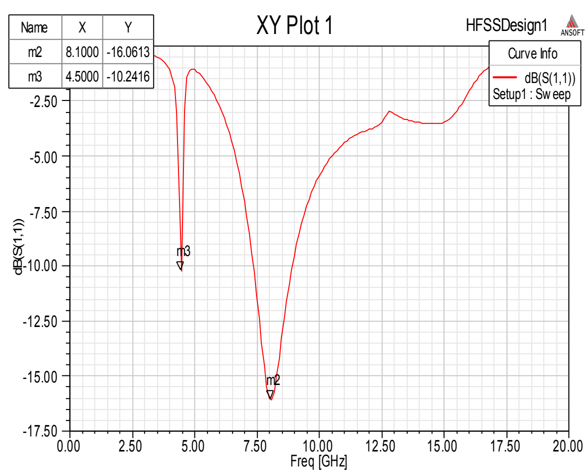
The effect in the fp i.e. parasitic resonance has been observed by moving Δy =0.1mm perpendicular to the coupling distance direction. The figure 12 a, b, c, d shows the return loss curves for incremental Δy.



(a) Δy =0.1mm

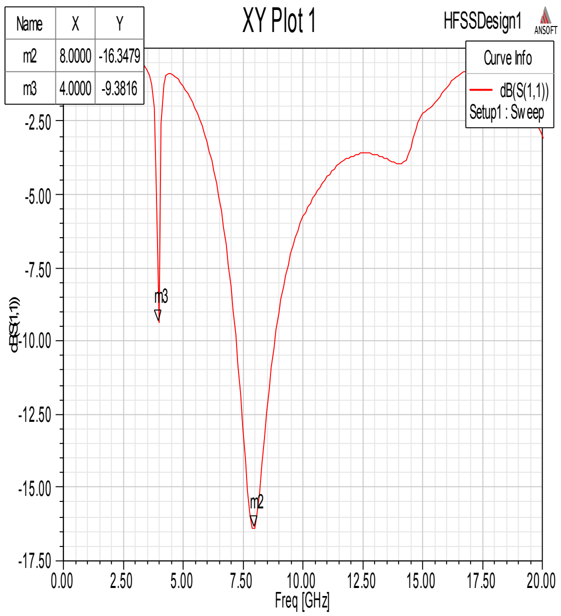


(b) Δy =0.2mm



(c) Δy =0.3mm

INTERNATIONAL JOURNAL OF MICROWAVE AND OPTICAL TECHNOLOGY,
VOL.10, NO.3, MAY 2015



(d) Δy =0.4mm

Figure 12a, b, c, d: Return loss curve vs the incremental movements in y direction

Table 2 tabulates the findings from Figure 12 a, b, c, d. It concludes the relation between the increments in y direction with the return loss and the parasitic resonance.

Table 1: Effects of increments in y with fp and S11

+Δy(mm)	fp(GHz)	S11(dB)
0	4	-11.7
0.1	4.4	-10.6
0.2	4.2	-10.8
0.3	4.5	-10.2
0.4	4	-9.4

Thus, with increments in y (0.1mm) perpendicular to the coupling distance, not much improvement in impedance matching as well as miniaturization can be seen from figure 13.

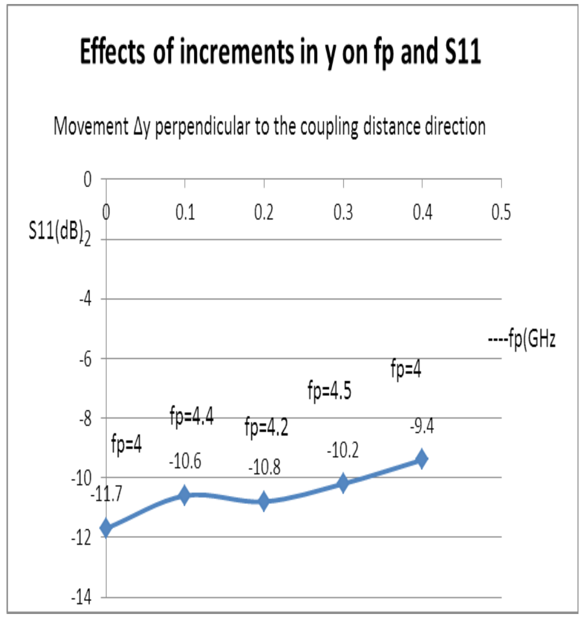


Figure 13: Return loss curve vs the incremental movements in y direction

VII.CONCLUSION

In this paper, novel metamaterial 'C' shaped pair has been designed and implemented using Ansoft HFSS. The mathematical proof of the structure verifies the FEM resonance .Also, a 'C' shaped pair metamaterial inspired monopole antenna has been designed with applications in C-band (4 to 8 GHz) .The composite structure has been studied for tunability by varying the coupling distance between the antenna and the CSP resonator. The miniaturization in the structure has been achieved. The directivity of the structure has been improved by 2%.

REFERENCES

[1] www.docstoc.com/docs/127876758/High-Frequency-Structure-Simulator-_HFSS_-Tutorial

[2] Jianqiang Gu1,Jiaguang Han, Xinchao Lu, Ranjan Singh, Zhen Tian,Qirong Xing, Weili Zhang, "A close-ring pair terahertz metamaterial resonating at normal incidence", Optics Express 20307, October 2009 ,Vol. 17, No. 22

[3] Withawat Withayachumnankul Derek Abbott, "Metamaterials in the Terahertz Regime", IEEE

Photonics Journal, Vol 1, No 2, pp 99-118, Aug 2009.

[4] Hayet Benosman, Nouredine Boukli Hacene , "Design and Simulation of Double "S" Shaped Metamaterial", *International Journal of Computer Science Issues*, Vol. 9, Issue 2, No 1, March 2012 ISSN (Online): 1694-0814pg 534-537

[5] B R Koushik and B Ajeya, " Design of Rectangular Microstrip Antenna with Metamaterial for Increased Bandwidth", *International Journal of Innovation and Applied Studies,* Vol. 3 No. 4, Aug. 2013, pp 1094-1110

[6] Minowa, Y, Nagai, M. Hu Tao , Kebin Fan , Strikwerda, A.C. , Xin Zhang; Averitt, R.D. , Tanaka, K. , "Extremely Thin metamaterial as slab waveguide at Terahertz frequencies" , *IEEE transactions on Terahertz Science and Technology*, Vol 1 No.2, pp. 441-449,Nov 2011.

[7] Filiberto Bilotti, Alessandro Toscano, Lucio Vegni, Member, Koray Aydin, Kamil Boratay Alici, and Ekmel Ozbay, " Equivalent-Circuit Models for the Design of Metamaterials Based on Artificial Magnetic Inclusions", IEEE *Transactions on Microwave Theory and Techniques*, Vol. 55, No. 12, Dec 2007,pp 2865-2873

[8] Saber Dakhli, Hatem Rmili, Kouroch Mahdjoubi , Jean-Marie Floc'h, and Fethi Choubani, "A Family of Directive Metamaterial-Inspired Antennas", *Progress In Electromagnetics Research C*, Vol. 49, 105-113, 2014

[9] V.G. Veselago , " The electrodynamics of subs-tances with simultaneously negative values of ε and μ.", *Soviet Physics-Uspekhi*,Vol 10,No.4,pp 509–514, January-February 1968.

[10] J. B. Pendry, A. J. Holden, W. J. Stewart, and I. Youngs, "Extremely low frequency plasmons in metallic micro structures", *Phys. Rev. Lett*., vol. 76, pp. 4773–4776, 1996.

[11] J. B. Pendry, A. J. Holden, D. J. Robbins and W. J. Stewart, "Magnetism from conductors and enhanced nonlinear phenomena", *IEEE Trans. Microwave Theory Tech.*, vol. 47, pp. 2075-2084, Nov. 1999

[12] D. R. Smith, Willie J. Padilla, D. C. Vier, S. C. Nemat-Nasser, and S. Schultz, " Composite Medium with Simultaneously Negative Permeability and Permittivity", Vol. 84, No. 18, *Physical Review Letters*,pp. 4184-4187,May 2000

[13] C.A.Balanis,"Antenna Theory '', John Wiley & Sons Inc,1999

[14] Ziolkowski,R.W., "Design,fabrication and testing of double negative metamaterials", *IEEE Transactions on Antenna and Propagation*,Vol 51,No.7 (2003),pp. 1516-1529.

[15] Ekmel Ozbay'and Costas M. Soukoulis ," Observation of Negative Refraction and Negative Phase Velocity in True Left-Handed Metamaterials",*Proceedings of the 36th European Microwave Conference (EuMA)*, 2006,pp 959-962.

[16] Daniela Ionescu , Maria Kovac , "About the Negative Permittivity of Some Metamaterial Composites - Simulational Study", *IEEE 17th International Symposium for Design and Technology in Electronic Packaging* ,2011 ,pp 197-200.

[17] Anthony Grbic ," A 2-D Composite Medium Exhibiting Broadband Negative Permittivity and Permeability", *IEEE*,pp 4133-4136, 2006.

[18] H. O. Moser,B . D. F. Casse, O. Wilhelmi, and B. T. Saw, " Terahertz Response of a Microfabricated Rod–Split-Ring-Resonator Electromagnetic Metamaterial", *Physical Review Letters*,PRL 94, 063901 ,Feb 2005.

[19] Hou-Tong Chen, Willie J. Padilla, Richard D. Averitt,Arthur C. Gossard, Clark Highstrete, Mark Lee,John F. O'Hara, and Antoinette J. Taylor, "Electromagnetic Metamaterials for Terahertz Applications", *Terahertz Science and Technology*, Vol.1, No.1, March 2008.

[20] Parul Dawar ,Asok De, "Tunability of Triangular SRR and Wire Strip (TSRR-WS) Metamaterial at THz", *Advances in Optical Technologies,* Volume 2014 (2014), Article ID 405301, 10 pages

[21] Parul Dawar , Asok De, "Bandwidth enhancement of RMPA using ENG metamaterials at THz", *2013 4th International Conference on Computer and Communication Technology (ICCCT)*, 20-22 Sept.,pp 11 – 16

[22] Parul Dawar , Asok De, " Bandwidth Enhancement of RMPA Using 2 Segment Labyrinth Metamaterial at THz", *MSA*,Vol.4 No.10, October 2013

[23] N.S. Raghava, Asok De, "Effect of air gap width on the performance of a stacked square Electronic Band gap Antenna", *International Journal of Microwave and Optical technology*,Vol.4 No.5,Sept2009,pp 315-317..