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Metamaterial Based Electrically Small Dual Band Antenna

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Abstract: **-- This paper proposes an electrically small metamaterial antenna that resonates at two frequency bands 2.9GHz and 9.3GHz.The dimension of this low profile antenna is 10mm×10mm×0.92mm which is printed on a low cost FR4 substrate. By Chu limit the antenna comes under the category of electrically small antennas as ka=0.8(<1).The radiation quality factor for the antenna is 16.66 which is sufficiently higher than the minimum Q of 3.2.The antenna exhibits an impedance bandwidth of 180 MHZ at both the bands.**

Keywords: **Antennas,CRLH transmission line, electrically small antenna, metamaterials**

I. INTRODUCTION

Small antennas have wide range of applications in current wireless communication systems such as RFIDs, biomedical, wearable and sensor networks. But there exist many concerns regarding the design of Electrically Small Antennas (ESA) such as impedance matching, joule heating and reduction in radiation efficiency. Miniaturization of an antenna critically limits its performance as small size, high radiation efficiency and wide bandwidth cannot be achieved simultaneously. The first studies to address the fundamental limits of small antennas; antennas having physical dimension very small compared to the wavelength, was done by wheeler in 1947 [1]. Chu and later McLean presented theories to derive minimum radiation quality factor (Q) for an electrically small antenna [2], [3]. Chu-Wheeler limits of electrically small antennas were studied and experimentally validated by Sievenpiper et al [4].

Electrically small microstrip antennas can be realized by incorporating metamaterials. Recently research in metamaterials has got increased interest because of its unusual properties like negative refractive index [5]. Metamaterials are artificial electromagnetic materials composed of sub wavelength elements. The existence of Left-hand (LH) materials; materials having simultaneous negative permittivity and permeability values were first predicted by V Vaselago [5]. The practical implementation of these materials was done only at the beginning of 21st century using Thin Wires (TW) and Split Ring Resonators (SRR) [6], [7]. Metamaterial realization using periodic arrays of these sub wavelength elements has serious drawbacks due to its resonating nature. Transmission Line (TL) approach of metamaterials was introduced in [8]-[11] by using Composite Right Left hand TL (CRLH TL).Advantages of transmission line metamaterial from TW-SRR type metamaterial include low loss and planar configuration which make it suitable for integrating with Microwave Integrated Circuits (MIC).Electrically small patch antenna loaded with SRR was reported [12] to obtain high gain with sufficient radiation quality factor and good bandwidth. ESA with magneto dielectric substrate is proposed by Tamma et al [13] that have high gain and radiation efficiency as a result of high permittivity of the substrate. ESA with high radiation efficiency using stacked SRR and ka=0.22 is reported [14].

This paper is organized as follows: section II and III discusses fundamental concepts of electrically small antennas and transmission line metamaterials respectively. Design of the proposed antenna is given in section IV. The section V discusses the simulation results and compares them with theoretical limits and similar works. Section VI concludes the paper with remarks on limitations and future work.

II. BACKGROUND OF ELECTRICALLY SMALL ANTENNAS

There exists a fundamental limitation to the performance of an antenna with respect to its size. As we continue to miniaturize the device, performance also degrades as there is a tradeoff between size, bandwidth and efficiency. Wheeler investigated the limitations of electrically small antennas; antennas that are much smaller than the operating wavelength [1].An antenna can be considered electrically small if

$$ka<1 \quad \text{………….(1)}$$

Where „k" is the wavenumber $(k = \frac{2\pi}{\lambda})$, λ, is the wavelength and „a" is the radius of the smallest sphere that can contain the antenna. At this size it behaves as a lumped capacitor or inductor that is finely tuned to deliver its power and limits bandwidth considerably. Reduction in radiation resistance and increased reactance makes matching with 50Ω transmission line difficult and providing external matching circuitry is also challenging as it makes the antenna bulky. Another limitation is the reduced radiation efficiency which is a consequence of poor radiation resistance.

Chu, Harrington and Mclean [1-3] derived a relation for the minimum radiation quality factor for an antenna and are given by (2) and (3) for linear and circular polarized antennas respectively.

$$Q_{min} = \frac{1}{(ka)^3} + \frac{1}{ka} \quad (2)$$

$$Q_{min} = \frac{1}{2(ka)^3} + \frac{1}{ka} \quad (3)$$

A useful parameter for evaluating performance is the product of bandwidth and radiation efficiency whose value cannot exceed a theoretical limit whatever design methodology is being followed for a given value of „ka". For a given dimension if one wants to have higher bandwidth one has to sacrifice the radiation efficiency. Only antennas with low dielectric constant, aspect ratio close to unity and minimum fill ratio w.r.t the enclosing sphere can achieve best performance. The practical values for these limits are further discussed in the section V of this paper.

III. TRANSMISSION LINE THEORY OF METAMATERIALS

Lumped circuit equivalent of left hand transmission line (LH TL) is composed of series capacitance and shunt inductance opposite to the conventional right hand transmission line. But it is practically infeasible to realize a pure LH TL due to right hand parasitic effects and results in composite Left/Right hand transmission line (CRLH TL). Equivalent circuit of CRLH TL unit cell is given in Fig.1 (a).

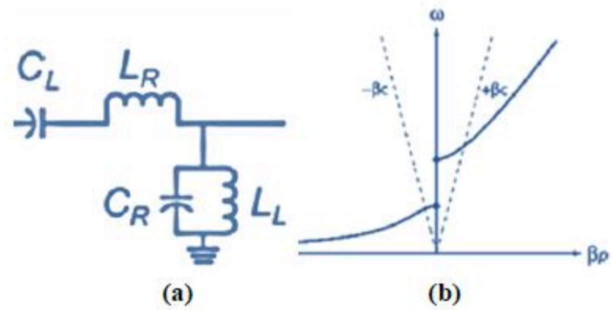

Figure 1 CRLH TL (a) equivalent circuit (b) dispersion diagram

The dispersion diagram that plots a structures propagation constant versus frequency is given in Fig.1.b. It is evident that propagation constant of LH materials is a nonlinear function of frequency converse to the linear relation in RH materials.

An important property of CRLH TL is the Zeroth Order Resonance (ZOR) where the propagation constant becomes zero for a non-zero frequency. With unequal series and shunt resonance there exist two frequencies where the propagation constant can be zero. When the series and shunt resonance becomes equal a balanced configuration will be obtained.

$$\omega_{sh} = 1/\sqrt{C_R L_L} \quad (4)$$

$$\omega_{se} = 1/\sqrt{C_L L_R} \quad (5)$$

Equation (4) & (5) gives the expression for shunt and series resonances respectively. The resonance of CRLH TL occurs at

$$\beta = \frac{n\pi}{l}, n = 0, \pm 1, \pm 2, \dots \pm (N-1) \quad (6)$$

Where l is the length of the line, n mode number and N number of unit cells. It can have positive, negative and Zeroth order resonances.

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Vol 4, Issue 3, March 2017

IV. ANTENNA DESIGN

The design of proposed antenna is given in Fig 2.It is composed of CRLH TL metamaterial unit cell designed using grounded spiral inductor and inters digital capacitor. The overall dimension of the antenna is 10mmx10mmx0.92mm which is very compact. The entire structure was printed on low cost FR4 substrate with dielectric constant 4.4 and loss tangent 0.02. Two metallic via of radius 0.18 mm is provided for grounding the spirals which act as shunt inductors. Microstrip feeding is used and the feed is designed to match with 50Ω TL and no external matching circuitry for the antenna is used.

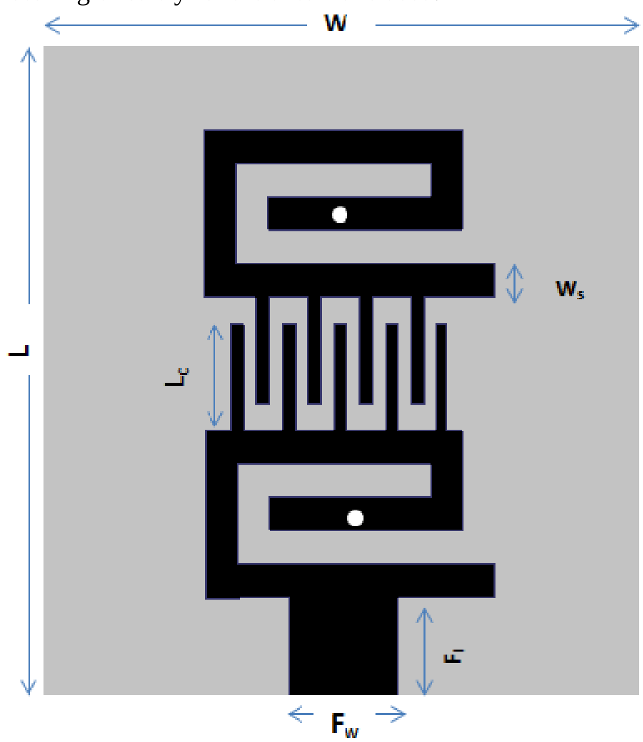

Figure 2 Design of the proposed antenna with grounded spiral and inter digital capacitor

Length and width of the substrate are equal W=L=10mm. The dimensions of the feed line is Fw=1.8mm, Fl=1.5mm. Inter digital capacitor has 9 fingers with length Lc=1.6mm and 0.15mm of width and inter finger spacing. Both the spirals are single turned having width and distance between the turns Ws=0.5mm.

V. RESULTS AND DISCUSSION

The designed antenna was simulated using ANSYS HFSS finite element method. Obtained S parameter and VSWR plots are shown in the Fig 3 and Fig 4 respectively. The result shows dual band response and the resonance occurs at 2.9GHz and 9.3GHz. 2.9GHz band have -30dB return loss and VSWR less than 2 and the high frequency band has -24dB return loss and VSWR less than 2.

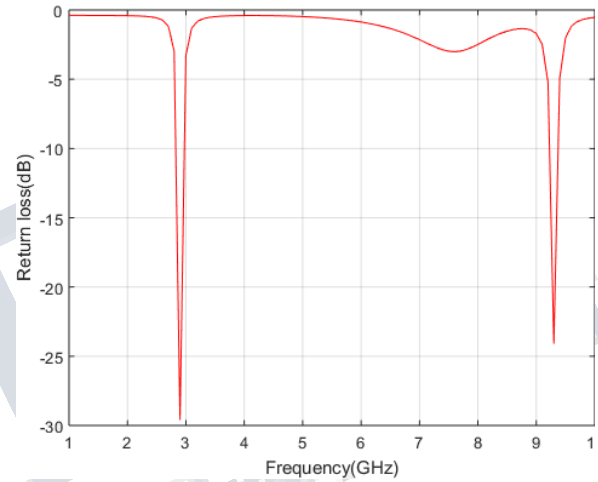

Figure 3 S11 of proposed antenna

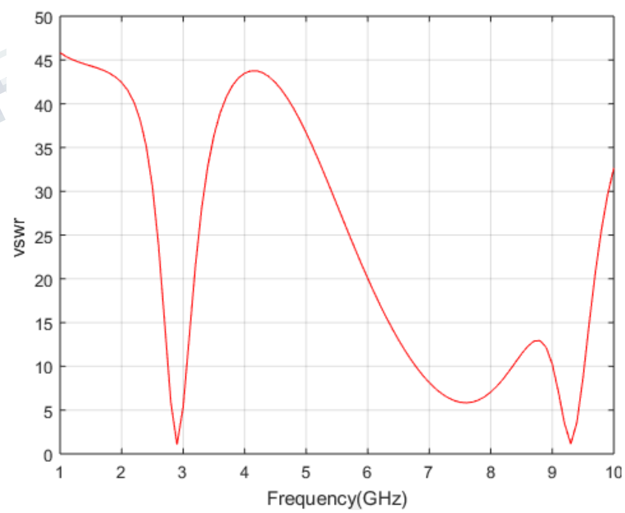

Figure 4 VSWR of proposed antenna

Radiation pattern of the antenna at two operating frequencies are given in Fig 5.It clearly shows directional pattern and as axial ratio is higher than 3dB the antenna is

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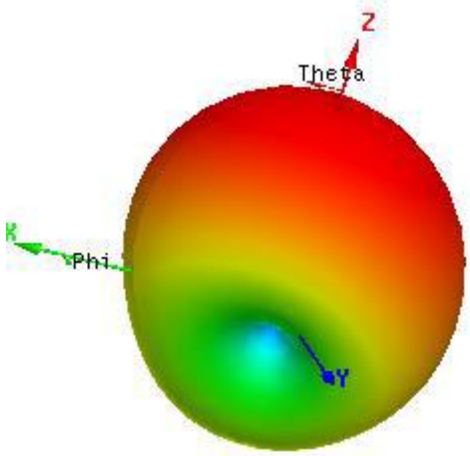
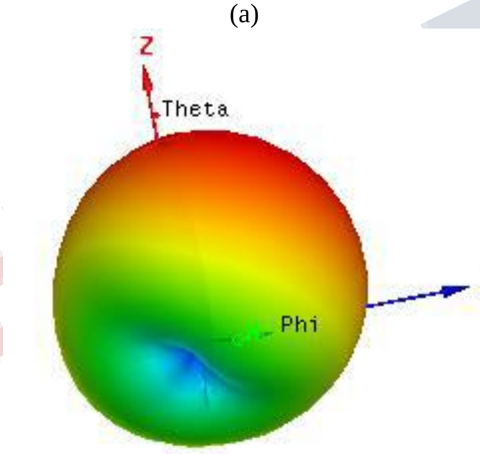
linear polarized. The simulated radiation efficiency is 8.2% and the gain of the antenna is negative which the major drawback of metamaterial based small antennas.



(a)



(b)

Figure 5 Radiation pattern of proposed antenna at (a) 2.9GHz (b) 9.3GHz

Metamaterial behavior of the structure can be verified from plotting dispersion diagram. For obtaining the dispersion characteristics the unit cell is converted in to a two port network and scattering parameters are observed. ABCD matrix can be used for obtaining the propagation constant which describes the properties of the wave in a medium. By directly substituting S parameters to (7) dispersion characteristics can be extracted.

$$\beta p = cos^{-1}\left(\frac{1 - S_{11}S_{22} + S_{12}S_{21}}{2S_{21}}\right) \quad (7)$$

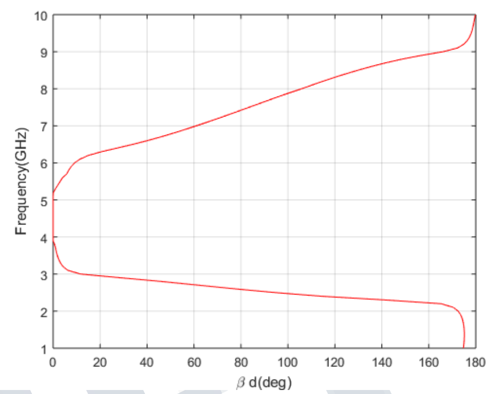


Figure 6 Dispersion diagram

Dispersion diagram for the CRLH unit cell is shown in Fig.6. It shows that the CRLH TL is unbalanced and have a band stop region from 4GHz to 5GHz. Lower resonance of the proposed antenna is of LH (negative order) and higher resonance is RH(positive order).

Fig.7 is the plot of bandwidth efficiency product versus electrical size of the antenna [4]. The proposed antenna is compared with large number of ESA studied. Value of ka=0.8 for the discussed design at 2.9GHz which is less than 1 and hence satisfies the condition for electrically small antenna. Product of bandwidth and efficiency is 0.082×0.18=0.01476.For the 9.3GHz band value of ka=2.7 and bandwidth efficiency product is 0.26×0.18=0.0468.Both the results are highlighted in red color in Fig 7 and is evident that proposed antenna has better performance compared to certain designs with small dimension.

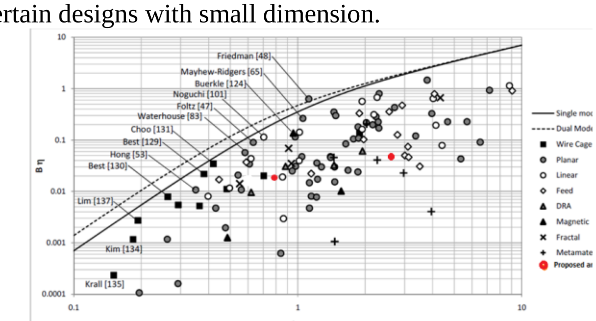


Figure 7 Comparison of βη of proposed antenna with [4]

For 2.9GHz Bη (Theoretical) = 0.2×1=0.2, βη (practical) =0.01476, βη (practical)/ βη (theoretical) = 0.0738. ratio of βη versus relative permittivity is compared

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with wheeler limit in Fig 8.For Fr4 substrate with relative permittivity 4.4 wheeler‟s limit (βη (practical)/ βη theoretical)) is 0.2.The obtained result is better compared to other metamaterial antennas.

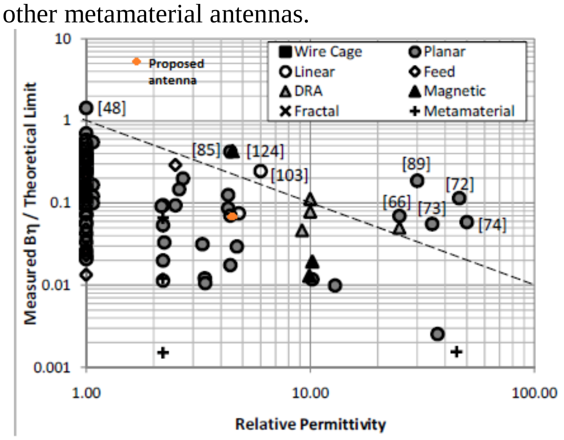

Figure 8 Comparison of the proposed antenna with Wheeler limit [4]

The aspect ratio of the proposed antenna is 5.4 that are comparable with the ideal unity aspect ratio condition. Gustaffson‟s limit for aspect ratio 5.4 is 0.2.The obtained value for the ratio of practical to theoretical bandwidth efficiency product of the proposed antenna is compared with reported antennas [4] and plotted in Fig 9.The dashed line shows the Gustaffson‟s curve for antennae with aspect ratio greater than one.

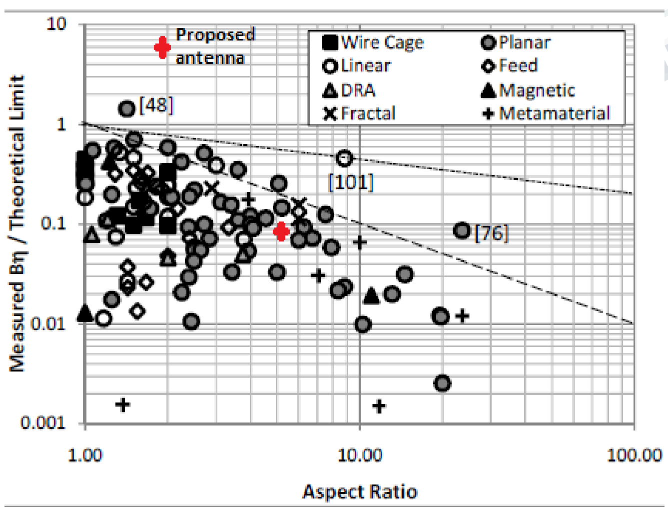

Figure 9 comparison of proposed antenna with [4]

Minimum required radiation quality factor for the proposed antenna is estimated using equation (2) and .Q_{min}=3.2. Radiation quality factor of the antenna was calculated by using Fosters reactance theorem. The Fractal bandwidth of the antenna is 0.06.So Q_{rad}=1/BW=16.66(>10) which is sufficiently greater than the Q_{min} (3.2).

VI. CONCLUSION

Electrically small dual band metamaterial antenna that resonates at 2.9GHz and 9.3GHz is proposed. The CRLH TL is realized using grounded spirals and inter digital capacitors and it is printed on FR4 substrate with dielectric constant 4.4.The antenna is electrically small as it satisfies the condition that ka<1 and Qrad is higher than Qmin. The bandwidth radiation efficiency product of the proposed antenna was compared with other ESAs and has better performance compared to some designs. But the values are less than the wheeler‟s limit. To achieve the best performance radiation efficiency and bandwidth has to be improved. Microstrip feeding without any external matching circuits was provided in this design. As a future work antenna matching can be improved and by optimizing the dimensions of inter-digital capacitors and spirals ZOR can be modeled to achieve best performance.

REFERENCES

[1] H A Wheeler, “Fundamental limitations of small antennas”, IRE Proceedings, Vol. 35, pp. 1479-84, Dec. 1947.
[2] L J Chu, “Physical limitations on omnidirectional antennas”, Journal of Applied Physics, Vol. 19, pp. 1163-75, 1948.
[3] J S McLean, “A re-examination of the fundamental limits on the radiation Q of electrically small antennas”, IEEE Transactions on Antennas and Propagation, Vol. 44, No. 5, pp. 672-6, May. 1996.4.
[4] Daniel Sievenpiper, David Dawson, Minu Jacob, "Experimental Validation of performance Limits and Design Guidelines for Small Antennas, "IEEE Trans. Antennas Propagation., vol.60, no:1, pp.8-19, Jan 2012.
[5] Veselago, Viktor G. "The electrodynamics of substances with simultaneously negative values of ε and μ." Soviet physics uspekhi 10.4 (1968): 509.
[6] Pendry, John B., et al. "Magnetism from conductors and enhanced nonlinear phenomena." IEEE transactions on microwave theory and techniques 47.11 (1999): 2075-2084.

[7] Shelby, Richard A., David R. Smith, and Seldon Schultz. "Experimental verification of a negative index of refraction." science 292.5514 (2001): 77-79.

[8] Caloz, Christophe, and Tatsuo Itoh. "Application of the transmission line theory of left-handed (LH) materials to the realization of a microstrip" LH line"." Antennas and Propagation Society International Symposium, 2002. IEEE. Vol. 2. IEEE, 2002.

[9] Eleftheriades, George V., Omar Siddiqui, and Ashwin K. Iyer. "Transmission line models for negative refractive index media and associated implementations without excess resonators." IEEE Microwave and Wireless Components Letters 13.2 (2003): 51-53.

[10] Caloz, Christophe, and Tatsuo Itoh. "Electromagnetic metamaterials: transmission line theory and microwave applications."John Wiley & Sons,2005

[11] Caloz, Christophe, Tatsuo Itoh, and Andre Rennings. "CRLH metamaterial leaky-wave and resonant antennas." IEEE Antennas and Propagation Magazine 50.5 (2008): 25-39.

[12] Joshi, J. G., et al. "Electrically small patch antenna loaded with metamaterial." IETE Journal of Research 56.6 (2010): 373-379.

[13] Tamma, Venkata A., et al. "Metamaterial inspired electrically small patch antenna." Antennas and Propagation (APSURSI), 2011 IEEE International Symposium on. IEEE, 2011.

[14] Chen, Peiwei, Liang Peng, and Gaofeng Wang. "Electrically small antennas made of multiple Split-Ring Resonators." Progress in Electromagnetic Research Symposium (PIERS). IEEE, 2016.