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A COMPACT METAMATERIAL BASED TRIPLE BAND ANTENNA WITH CRLH TL UNIT CELL

Neethu P S, Sumi M, Harikrishnan A I

Abstract*—This paper presents two multiband compact metamaterial antennas for microwave applications. Inter-digital capacitor and grounded meander- line is used to form a CRLH TL unit cell and act as the radiating element for both the antennas. . First antenna operates at 2.7 GHz and 5.1GHz band with overall dimension of 10mm×18mm×0.8mm and is printed on FR4 substrate of dielectric constant 4.4. A triple band response at 1.1GHz, 3.7GHz and 6.8GHz is achieved by modifying the structure to a smaller dimension of 10mm×10mm×1.6mm.

Keywords—Electrically small antenna, metamaterial, CRLH TL metamaterial, inter digital capacitor, meander-line.

I. Introduction

Antenna miniaturization is one of the most significant areas of research as continuing growth in wireless communication demand small antennas. Small antennas are desirable for applications such as RFID, IoTs, wireless sensor networks and portable communication devices. Recently design of antennas that can operate in multiple standards with low profile and low cost has become a major challenge .An antenna is electrically small if its dimension is less than $\frac{\lambda}{2\pi}$ where λ is the operating wavelength. Wheeler [1] proved that the bandwidth, radiation efficiency and size of an antenna are related. For Electrically small antennas (ESA) the propagating fields are replaced by evanescent fields with high Q (Quality factor) reducing the bandwidth significantly. Chu [2] and McLean [3] derived relations for the minimum attainable radiation quality factor or maximum bandwidth for an electrically small antenna. The performance of a small antenna is limited as the product of bandwidth and efficiency cannot exceed Wheeler-Chu limits.

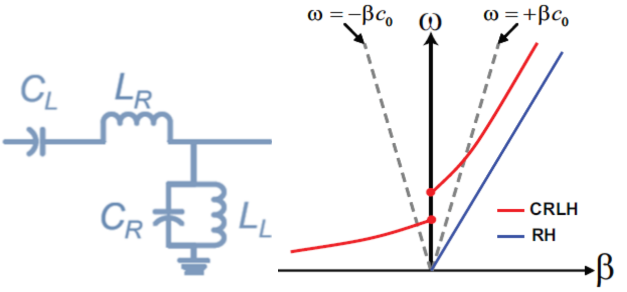
Neethu P S, Department of electronics and communication, NSS College of engineering, Palakkad, India.
Sumi M, Department of electronics and communication, NSS College of engineering, Palakkad, India.
Harikrishnan A I, Department of electronics and communication, NSS College of engineering, Palakkad, India.

Recently metamaterial concept has made it possible to realize small microwave devices with enhanced performance. Metamaterials are artificial electromagnetic materials composed of sub wavelength elements. Electromagnetic response of a material can be summarized by its permeability and permittivity that in turn gives the refractive index. Based on these values V Vaselago classified materials and predicted the existence of materials with simultaneously negative values of permittivity and permeability [5]. This type of material is called as Left Hand (LH) materials as the electric field, magnetic field and wave vector forms a left hand triad. The important properties of metamaterial include negative refractive index, backward wave propagation, frequency dispersion etc. The first practical implementation of metamaterial (MTM) was done by Pendry [6] and Smith [7] by creating a wire mesh and Split Ring Resonator (SRR) structure with negative permittivity and permeability at low frequencies. But the resonant approach of metamaterial realization has major problem as it exhibits negative refractive index only near the resonance frequencies. The transmission line approach of metamaterial was introduced by Caloz [8] and Elfetheriads [9] and it can have wide range of continuous bands with negative refractive index.

This paper is organized as follows: The section II gives a theoretical overview of transmission line metamaterials. Section III and IV discusses the two antenna designs with their simulation results. The performance of ESA is compared with other works. Section V concludes the paper.

II. CRLH TL METAMATERIALS

Lumped circuit equivalent model of a transmission line consist of series inductance and shunt capacitance and it can be called as Right Hand (RH) line as the propagating wave is in the forward direction. So backward wave propagation can be supported by a line if it has series capacitance and shunt inductance. But due to right hand parasitic effects it is impossible to realize pure LH line and the resultant structure is a composition of right and left hand line and is called as Composite Right /Left Hand Transmission Line (CRLH TL). The equivalent circuit of this is shown in Figure1.a.Where C_L, C_R, L_L, L_R are right & left hand capacitance and inductance of a unit cell.



(a) **(b)**

Figure 1 CRLH TL unit cell (a) Equivalent circuit model (b) Dispersion diagram

Transmission line approach of metamaterial realization is possible as the permittivity (ε) and permeability (μ) can be expressed as admittance and impedance respectively (Equation 1&2).

$$\varepsilon = C_R - \frac{1}{\omega^2 L_L} \quad (1)$$

$$\mu = L_R - \frac{1}{\omega^2 C_L} \quad (2)$$

The dispersion diagram shown in Figure 1.b gives the relation between frequency and propagation constant of a structure. For a RH structure the propagation constant has only positive values and it has linear relationship with frequency. But CRLH unit cell have nonlinear relationship showing frequency dispersion. Resonance occurs for a short circuit or open circuit transmission line at

$$\beta = \frac{n\pi}{l} \quad (3)$$

where β is the propagation constant, l length of the line and n=0, ±1, ±2,….When n=0 wavelength becomes infinity and the physical dimension is independent of the resonance frequency and known as Zeroth Order Resonance (ZOR).

III. Antenna Design I

The design of the proposed antenna with dimensions is shown in figure 2. It is composed of inter digital capacitor and grounded meander-line. The overall profile of the antenna is 10mm×18mm×0.8mm.The radius of grounding via is 0.1mm.The design is printed on FR4 substrate with dielectric constant 4.4 and loss tangent 0.02.Microstrip feeding is used with a width of 3mm to match 50Ω. Inter digital capacitor is designed with 20 fingers of width 0.2 mm length 2.2mm and base width of 8mm.

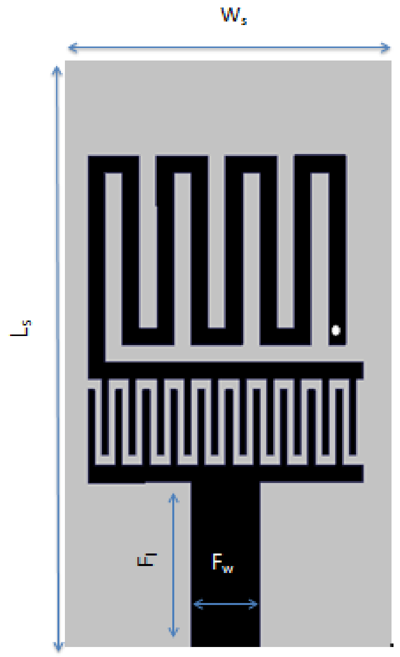


Figure 2 Layout of antenna with inter digital capacitor and grounded meander line-I (L_s=18mm, W_s=10mm, W_b=7mm, F_w=2mm, F_l=5mm**).**

Meander-line is used to reduce the size of an antenna with a lower resonance frequency as it give a resonance of monopole antenna of same height. The proposed antenna has 4 sections of meander-line with a width of 0.5mm and length of the line is 5.5 mm with a space of 1.5mm between two parallel lines. Inductance equivalent circuit of each meander-line was studied in [12] and each section of the meander-line was replaced with a series inductor but the effective capacitance between the lines was not addressed. Another equivalent representation of meander-line is using the parallel RLC circuit [13]. Figure 3&4 shows the simulated return loss and VSWR of the proposed antenna using HFSS finite element method.

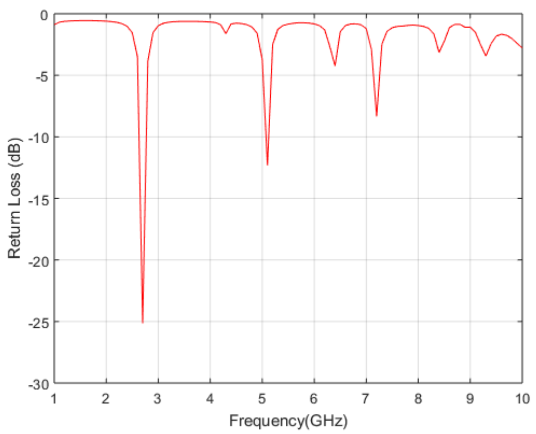


Figure 3 Simulated Return Loss

The reflection coefficient of the structure is less than -10 dB and VSWR is less than 2 at 2.7GHz and 5.1GHz and it has a minor resonance of -8dB at 7.2 GHz.

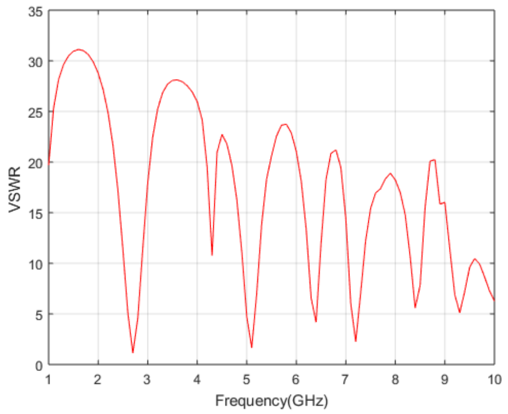
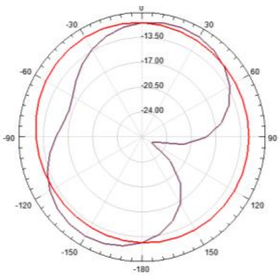
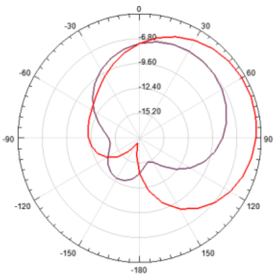


Figure 4 Simulated VSWR

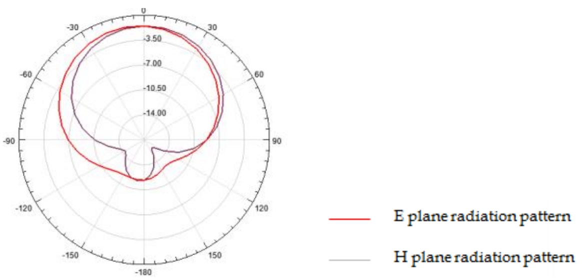
Figure 5 show the two dimensional radiation pattern of the antenna. The pattern is Omnidirectional as E plane has non directional pattern and H plane has directive pattern at 2.7 GHz. Radiation pattern at 5.1GHz and 7.2GHz are directional.



(a)



(b)



(c)

Figure 5 Radiation pattern (a) Azimuth and elevation plane at 2.7 GHz (b) Azimuth and elevation plane at 5.1GHz (c) Azimuth and elevation plane at 7.2GHz

IV. ANTENNA DESIGN II

The design of the proposed antenna II with dimension is shown in Figure 7. The antenna has inter digital capacitor and grounded meander line as in design 1 but with a reduced size compared to design I and its dimension is 10mm×10mm×1.6mm. The radius of grounding via is 0.1mm. Number of fingers of inter digital capacitor is reduced to 15 with a base width of 7mm and finger length of 2mm effectively reducing the capacitance. Number of Meander line sections was increased to obtain an increased self-inductance and a reduced resonance frequency.

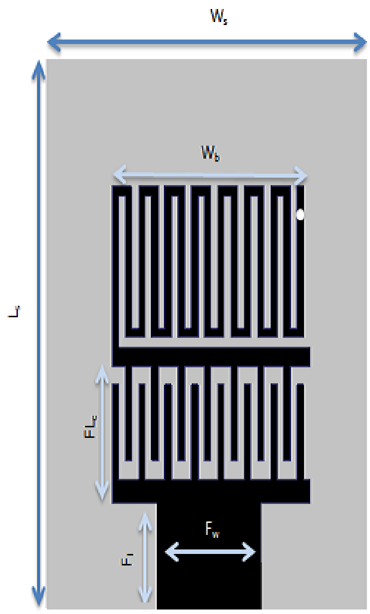


Figure 6 Design of antenna with inter digital capacitor and grounded meander line-II (L_s=10mm, W_s=10mm, W_b=7mm, F_w=3mm, F_l=2.5mm, FL_c=3mm**).**

Reflection coefficient of antenna design II is plotted in Figure 8.The S_{11} is less than -10 dB at 3 bands 1.1GHz, 3.7 GHz and 6.8GHz. VSWR plot shown in Figure 9 is also agreeable with reflection characteristics.

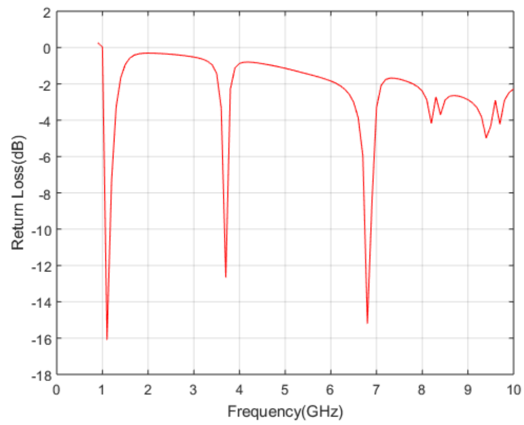


Figure 7 Simulated Return Loss

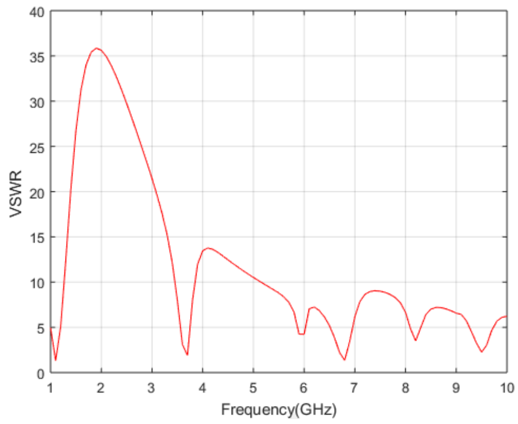
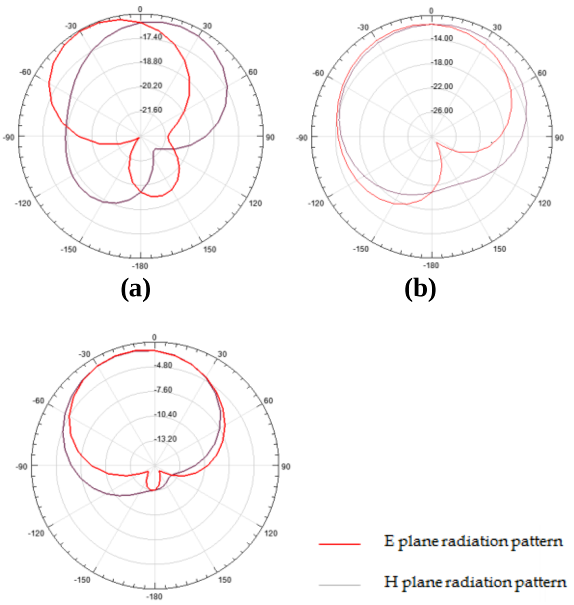


Figure 8 Simulated VSWR

Radiation characteristics of the presented antenna are shown in Figure 10. E plane and H plane pattern at all the resonant frequencies are directive in nature.



(c)

Figure 9 Radiation pattern (a) Azimuth and elevation plane at 1.1 GHz (b) Azimuth and elevation plane at 3.7GHz (c) Azimuth and elevation plane at 6.8GHz

To analyze the performance of an electrically small antenna apart from reflection characteristics product of bandwidth and efficiency is the parameter of interest. For the band 1.1GHz the electrical size of the antenna is calculated and ka= 0.32 which is less than 1 and satisfies the condition for ESA. Product of radiation efficiency and bandwidth is 0.05×0.1=0.005.The antenna is compared with that in [4] based on bandwidth efficiency product and electrical size as shown in figure 11.The proposed antenna is marked in red.

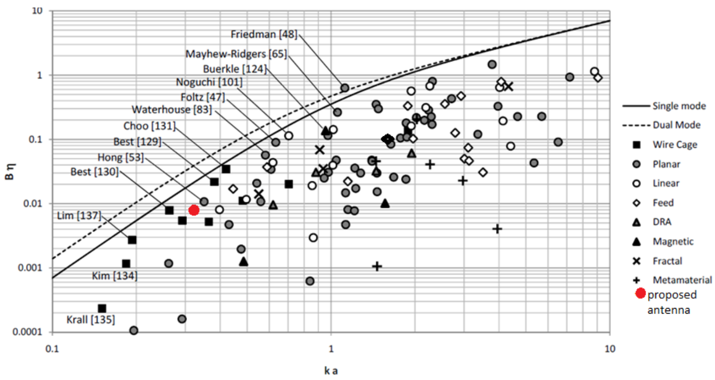


Figure 10 Comparison of performance with [4]

V. CONCLUSION

Two types of low profile antennas with triple band response were proposed. Both the antennas can be used for GPS/WLAN/Bluetooth applications. The antennas are very compact with dimension of 10mm×10mm×1.6 mm and 10mm×18mm×0.8mm. Inter-digital capacitor and grounded meander-line exhibit CRLH TL metamaterial effect. Performance comparison of antenna design II with respect to recent electrically small antennas is also done.

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Neethu P S received B.Tech in Electronics and communication engineering from Calicut university,kerala in 2014. She is currently pursuing her M.Tech in Communication engineering from KTU,kerala. Her area of interest include metamaterials and Antennas

Sumi M received the B.Tech degree in Electronics and Communication from the Cochin University of Science and Technology (CUSAT) in 2003, and the MTech degree in Electronic Design from the Indian Institute of Science (IISc) in 2009. She is currently working towards her Ph.D. degree at School of Engineering, CUSAT. Her research interests are designing of Chipless RFIDs, Microwave Low Pass Filters and multiband antennas.

Harikrishnan A I was born in India. He received the B.Tech degree in Electronics and Communication from Mahatma Gandhi University in 2000 and M.Tech degree in Microelectronics and VLSI in 2009 from Indian Institute of Technology, Kharagpur. His research interest includes reconfigurable microwave circuits and Compact Planar filters.