# A Compact Triple mode Metamaterial Inspired-Monopole Antenna for Wideband Applications

Bashir D. Bala, Mohamad Kamal A. Rahim, and Noor Asniza Murad
Communication Engineering Department,
Faculty of Electrical Engineering,
Universiti Teknologi Malaysia (UTM),81310, Johor Bahru, Malaysia.
bashirdbala@yahoo.com, mkamal@fke.utm.my, asniza@fke.utm.my,

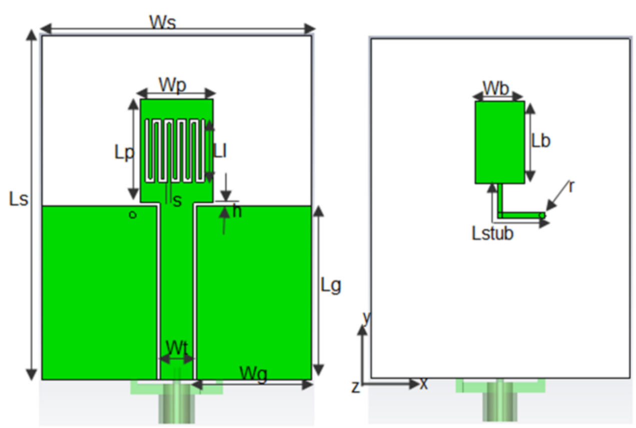
***Abstract*— A compact triple mode metamaterial (MTM) inspired antenna for wideband is presented. The antenna is based on composite right/left handed transmission line (CRLH-TL) which employs MTM loading on a conventional monopole to attain a certain degree of miniaturization. The antenna has triple mode of operations- negative order resonance (NOR), zero order resonance (ZOR) and positive order resonance (POR) modes. Two modes are merged into a single pass band (3.1 - 6.0 GHz) to obtain a dual band. The over size of the antenna is 33 x 26 x 1.6 mm$^3$. A high level of miniaturization is obtained when the return loss of loaded and unloaded metamaterial antenna is compared. Simulated return loss shows that the proposed antenna is suitable for Wi-Fi (2.4 GHz) and WiMAX (3.5, 5.2-5.8 GHz).**

***Index terms* — metamaterial, dual band, Monopole, triple mode.**

## I. INTRODUCTION

In recent years, the concept of composite right/left handed (CRLH) metamaterial design have been widely applied to RF devices [1]. Basically, metamaterials (MTM's) represents novel electromagnetic materials with negative refractive index (NRI) over a specify range of frequency [2–5]. Microwave researchers use these unusual electromagnetic phenomena to design antennas and other RF components for improved performance. [6]. MTM antennas can be designed based on resonant and non-resonant approach [7]; the resonant approach requires resonant elements such as split ring resonators (SRR) and complementary split ring resonators (CSRR). This approach requires a very large number of elements which makes the design bulky [8] and undesirable where miniaturization is a priority. However the non-resonant or transmission line approach offers a greater advantage of miniaturization because of its zeroth-order resonance frequency [9]. Several CRLH transmission line (TL) MTM antennas have been presented in literature which employed MTM loadings. In [10] a triple-band monopole antenna loaded with CRLH unit cell was presented. The first two narrow bands 0.925 and 1.227 GHz which represent the negative and zero order modes occurred due to the loaded unit cell and the third band 2.5 GHz was due to the monopole itself. Because of decrease in the resonance frequency when loaded with MTM unit cell, the design is considered to be compact. In [11] a wideband zero-order MTM antenna was presented. The antenna utilizes mushroom unit cell where the negative and zero order modes are merged to obtain a wider bandwidth although the gain is low. A printed monopole antenna that employed NRI-TL loading was reported in [12]. In the design a single MTM unit cell was integrated directly onto the antenna which transforms it to a folded monopole with resonance frequency around 5.5 GHz and the unit cell contribute the lower frequency bands.

In this paper, a compact, dual band, triple mode MTM antenna is proposed. The design is inspired by [12] with modification on the top monopole patch. An inter-digital capacitor (IDC) is etched on the top patch to create a negative order resonance (NOR) at 2.4 GHz. Hence with proper tuning of the constitutive parameters, the zero order resonance (ZOR) can be merged to the positive order resonance (POR). The antenna resonates at NOR (2.4 GHz) and a single pass band (3.1 to 6.0 GHz) when ZOR and POR are merged. Hence a triple mode and dual band is thus obtained.




(a) (b)

Fig.1. Geometry of the proposed metamaterial antenna. (a) front view (b) back view

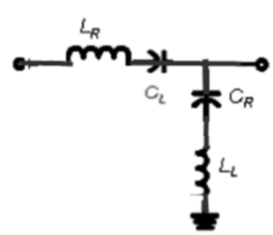



Fig. 2. Equivalent circuit diagram

Table 1. Parameters of the proposed antenna in (mm)

| | | | | | | |
|---|---|---|---|---|---|---|
| Ls | Ws | Lp | Wp | Lg | Wg | h |
| 33 | 26 | 10 | 7 | 16.7 | 11.1 | 0.3 |
| | | | | | | |
| Wt | LI | S | Lb | Wb | Lstub | r |
| 3.2 | 6 | 0.3 | 8 | 5 | 8.1 | 0.5 |

## II. Antenna Design

### A. Analysis of the Loaded Unit Cell

The geometrical configuration of the proposed metamaterial antenna is shown in Fig. 1. The antenna is simulated on FR4 substrate of permittivity 4.3, tangential loss of 0.025 and thickness of 1.6 mm. The antenna is a printed monopole type with loaded MTM unit cell. The idea of loading MTM unit cell onto a conventional monopole is to impose a left handed property onto the antenna so that the overall design will have a reduced form factor. The antenna is coplanar waveguide (CPW) fed by a 50 Ω transmission line. Fig. 2 show the equivalent circuit model of the proposed design, where an inter-digital capacitor is loaded on top of the patch which is responsible for the series capacitance $C_L$. The shunt capacitance $C_R$ was formed between the top monopole and the bottom patch (Lb x Wb). The series inductance $L_R$ is the inductance along the monopole length and the shunt inductance $L_L$ is the inductance of the stub (Lstub) and the via. Table 1 shows the parameters of the antenna. Four resonance frequencies can be determined from the equivalent circuit model [7]:

$$f_{LH} = \frac{1}{4\pi\sqrt{L_L C_L}} \quad (1)$$

$$f_{sh} = \frac{1}{2\pi\sqrt{L_L C_R}} \quad (2)$$

$$f_{se} = \frac{1}{2\pi\sqrt{L_R C_L}} \quad (3)$$

$$f_{RH} = \frac{1}{\pi\sqrt{L_R C_R}} \quad (4)$$

Where $f_{LH}, f_{sh}, f_{se}$ and $f_{RH}$ are left handed, shunt, series and right handed resonance frequencies respectively. $f_{sh}$ *and* $f_{se}$ are the frequencies where ZOR occurs.

### B. Antenna Parameters Tuning

In order to show the effect of the loaded MTM unit cell on the antennas small form factor or miniaturization, a conventional or unloaded monopole antenna is design and simulated. As a control experiment, the unloaded antenna has same dimension and material properties as the loaded antenna. The return loss of loaded and unloaded antennas is compared as shown in Fig 3. Three resonant modes are obtained: first NOR, ZOR and first POR modes. The first NOR resonates at 2.4 GHz for the Wi-Fi and the other two modes are merged at 3.1 GHz and 6.0 GHz which is suitable for WiMAX (3.5, 5.2-5.8 GHz).

Figure 4 shows the effect of increasing the capacitance $C_L$ on the resonance frequency of the first NOR mode. From equation (1), an increase in the length LI of the inter-digital capacitor from 5.2-6.5 mm shifts the resonance frequency from 2.6- 2.2 GHz. While the ZOR is unaffected by $C_L$ but only suppressed. Length of the stub Lsub together with the via accounts for the shunt inductance $L_L$. Equation (2) and (3) gives the resonance frequency of the ZOR mode. Decrease in the length of the stub from 11.1 – 8.1 mm shifts the ZOR mode from 2.8- 3.25 GHz. However, ZOR mode is largely affected by $L_L$. Hence ZOR mode is merged to the POR mode and this result into a wider bandwidth as shown in Fig. 5.

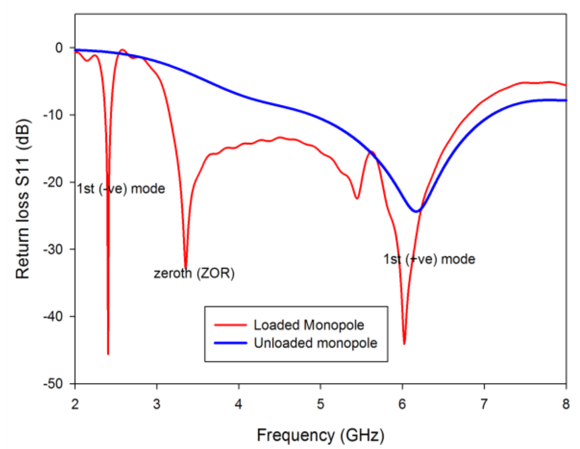



Fig. 3. Simulated return loss of the loaded and unloaded MTM antenna

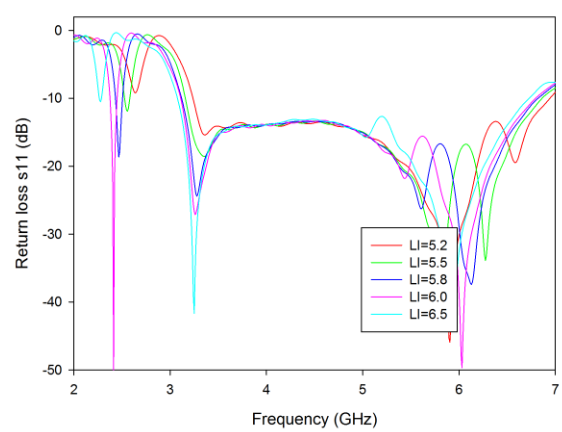



Fig. 4. Effect of $C_L$ of first NOR mode

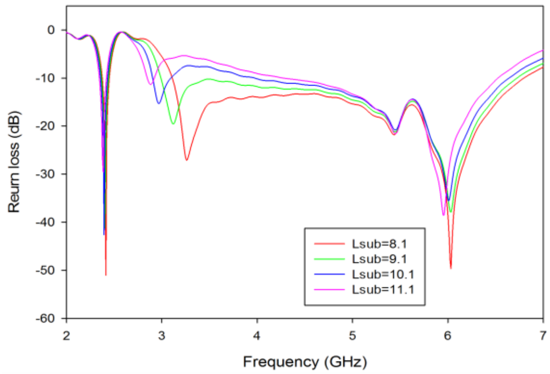



Fig. 5. Effect of the $L_L$ on the ZOR mode

## III. Discussion of the Results

Fig. 6 shows the simulated radiation patterns of the proposed antenna. Patch and monopole-like radiation patterns are obtained as shown in Fig. 6 (a) and (b) for both E and H-plane respectively. Figure 7 shows the surface current distributions of the proposed antenna for different frequency modes. At the first NOR mode (2.4 GHz), high concentration of surface current can be noticed across the inter-digital capacitor as shown in Fig. 7 (a). This shows the dependency of the resonance frequency largely on the length of the IDC. Also at ZOR mode (3.1 GHz), the shunt stub Lsub is responsible for the resonance at that frequency as shown in Fig. 7(b). However, Fig 7(c) shows the first POR mode where the concentration of surface current is along the entire monopole length.

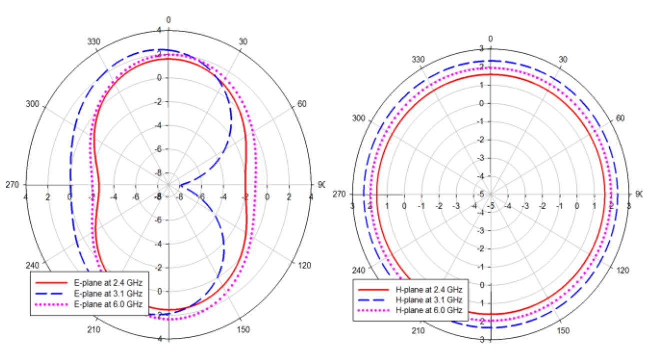



Fig. 6. Simulated radiation patterns

The simulated realized gain according to the operation band is presented in Fig. 8. The antenna gains vary from (-11.42 - 2.53) dBi within the frequency band of 2 - 7 GHz. The peak realized gains of -2.53 and 1.43 dBi are obtained at 2.4 and 3.1 GHz respectively. Low gain at 2.4 GHz is as a result of out of phase current along the inter-digital capacitor which cancels out the radiation in the far field.

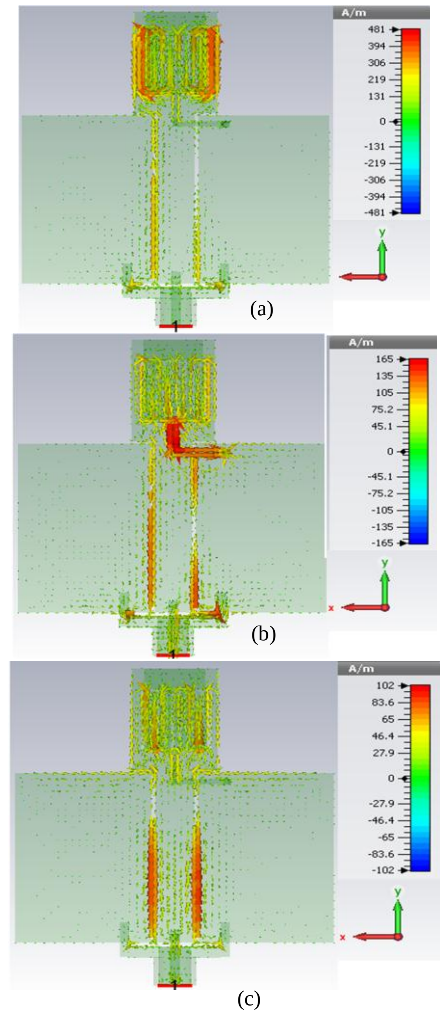



Fig.7. surface current distributions at (a) 2.4 GHz (b) 3.1 GHz (c) 6.0 GHz

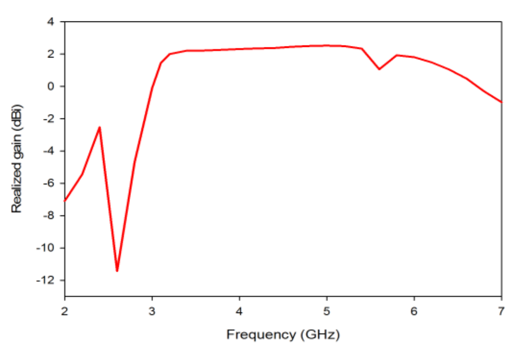



Fig.8. Simulated peak realized gains

## IV. Conclusion

A compact triple mode MTM inspired antenna for wideband is presented. The antenna is based on CRLH-TL which employs MTM loading on a conventional monopole to attain a certain degree of miniaturization. The antenna has triple mode of operations: first NOR, ZOR and first POR modes. Two modes are merged into a single pass band to obtain a dual band. The over size of the antenna is 33 x 26 x 1.6 mm3. Simulated return loss shows that the proposed antenna is suitable for Wi-Fi (2.4 GHz) and WiMAX (3.5, 5.2-5.8 GHz).

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