

## Wideband frequency reconfigurable metamaterial antenna design with double H slots

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### ABSTRACT

This paper presents the design of wideband frequency reconfigurable metamaterial antenna with double H slots. The design is based on the idea of composite right/left-handed transmission line (CRLH-TL) technique. Bandwidth enhancement was achieved by utilizing series left-handed capacitor  $C_L$  transmission line parameter. The design has several outstanding advantages which include efficient bandwidth to cover many lower Application bands with multi frequency operation characteristics. A comprehensive analysis and simulation were done by using computer simulation technology (CST) software to determine the performance and efficiency of the proposed antenna. From the result obtained, the antenna aquired bandwidth range which covered (2.3-5.2) GHz which is equivalent to 77% fractional bandwidth. The wideband antenna was reconfigured by using frequency reconfiguration technique. From the reconfiguration results, the antenna can be switch from wideband to two single bands which resonate at 2.4 GHz and 4.2 GHz and to dual band which resonate at 2.4 GHz and 4.2 GHz. The realized peak gain at 2.4 GHz is 2.28 dBi and 2.58 dBi for E and H field respectively. The maximum efficiency of 96% was obtained. The antenna can be use for WLAN, proposed lower 5G band and cognitive radio system for frequency sensing.

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## 1. INTRODUCTION

Low cost and highly efficient antenna with multi-band characteristics which will provide a solutions of spectrum congestion and interference is highly needed for wireless communication system. This goal can be achieved by utilizing metamaterial unique behavior. Metamaterial antennas are the one that can be improve it without tempering it physical dimension. Russian physicist Victor Veselago pioneer the effect of metamaterial since 1968 [1]. Experimental work was published by Smith in year 2000 [2]. Metamaterials posses negative permittivity  $\epsilon$  and negative permeability  $\mu$  [3]. In fact purely left handed (PLH) material does not exist, but can be generated from combination of transmission line parameters or employment of resonant metamaterial structures like split ring resonator (SRR), complementary split ring resonator (CSRR) [4]. Basic parameters that form (CRLH-TL) are series capacitance  $C_L$ , shunt inductance  $L_L$  which provide left-handed properties and series inductance  $L_R$ , shunt capacitance  $C_R$  to generate right-handed properties [5],

The dispersion behavior for analysis of these parameters can be obtained by using Bloch-Floquet theorem as represent in (1) [4].

$$\beta(\omega) = \frac{1}{d} \cos^{-1} \left( 1 - \frac{1}{2} \left( \frac{\omega_L^2}{\omega^2} + \frac{\omega^2}{\omega_R^2} - \frac{\omega_L^2}{\omega_{se}^2} - \frac{\omega_L^2}{\omega_{sh}^2} \right) \right) \quad (1)$$

where  $\omega_L$  and  $\omega_R$  are left/right-handed resonance and  $\omega_{se}$  and  $\omega_{sh}$  are series and shunt resonance as presented in (2-5).

$$\omega_L = \frac{1}{\sqrt{C_{LL}}} \quad (2)$$

$$\omega_R = \frac{1}{\sqrt{C_{RL}}} \quad (3)$$

$$\omega_{se} = \frac{1}{\sqrt{C_{Lse}}} \quad (4)$$

$$\omega_{sh} = \frac{1}{\sqrt{C_{Rsh}}} \quad (5)$$

CRLH-TL structures can act as resonator when satisfying condition in (6) [6].

$$\beta_n = \frac{n\pi}{L} \quad (6)$$

The relationship between bandwidth and capacitance  $C_L$  of CRLH TL for short-ended antenna is shows in (7). From the equation we observed that, bandwidth has direct proportion relation with left-handed capacitance. Which means that, the high the value of left-handed capacitance  $C_L$  the high the bandwidth of the antenna. Figure 1 represent the circuit of single CRLH-TL unit cell with length  $d$ .

$$BW = R \sqrt{\frac{C_L}{L_R}} \quad (7)$$

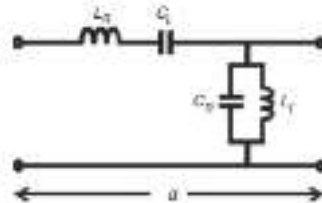


Figure 1. CRLH-TL unit cell [6]

Reconfigurable antennas are considered as antennas with habit of selecting operating parameters such as polarization, frequency, or radiation pattern to rearrange its current distribution to achieve the desired goal [7]. They are classified according to their operating parameters [8]. Previously, various research to improve the performance of antennas have been done. Among the research include utilizing the effect of twice unit cell metamaterial structures by [9, 10] to extend antenna bandwidth. Same objective was achieved in [11, 12] by merging fundamental modes. Substituting interdigital capacitor **IDC** with **H** slot by [13] also result to bandwidth enhancement. Size miniaturization and tunability was achieved by introducing substrate integrated waveguide and **IDC** based on CRLH [14]. Interestingly [15] exploit epsilon negative by using coplanar strip line with meander for reconfiguration purpose. Author [16] modified monopole antenna by activating and deactivating circular split ring resonator and obtained multi bands. Also [17] achieved compound reconfiguration with dual frequency band. Multi band antennas were obtained in [18-22]. From the overview, up to now, there is limited bandwidth of operation from the latest work done in [12, 13, 23, 24]. However, significant results do exist in [25-27], but they exhibit several disadvantages such as large size, insufficient bandwidth to cover many application bands, limited resonating bands. Therefore, more effort needs to be put to design compact antenna with wider bandwidth to cover many application bands.

This paper presents the design of wideband frequency reconfigurable metamaterial antenna with double H slots. The antenna possesses enough bandwidth to cover many application bands. It also reconfigured by frequency reconfiguration technique to obtain multi band. The design procedure is presented and discussed in the subsequent sections.

## 2. RESEARCH METHOD

Figure 2 shows the physical structure and dimension of the antenna proposed in this paper. The antenna is design based on the principles design in [13]. The design started by simulating the antenna with three different value of  $G_2$  and  $G_3$  (0.5mm, 0.7mm and 1.0mm) to explore the effect of series capacitance  $C_L$  for bandwidth enhancement as presented in (7). Two slots with H shape were introduce at the top patch before applying switch operation for further bandwidth enhancement. Low cost FR4 substrate with 1.6 mm thickness and dielectric constant of 4.4 was used in this design. The simulation work was done by using computer simulation technology (CST) Software. After getting the optimized value of  $G_2$  and  $G_3$ , the proposed antenna have the following dimensions in millimeter:  $L=30$ ,  $W=16.8$ ,  $G_1=0.6$ ,  $G_2=G_3=1.0$ ,  $L_1=5.48$ ,  $L_2=10.3$ ,  $L_3=2.7$ ,  $L_4=W_2=9.6$ ,  $W_3=2.6$ ,  $L_5=4.6$ ,  $W_1=6.2$ ,  $W_2=9.6$  and  $T=1.0$ . The wideband antenna was simulated to study the behavior of current distribution at 2.4 GHz. High concentration of current distribution at the edge of shorted strip line and sides of the H slot as observed. Figure 3 shows the behavior of the current distribution at 2.4 GHz.

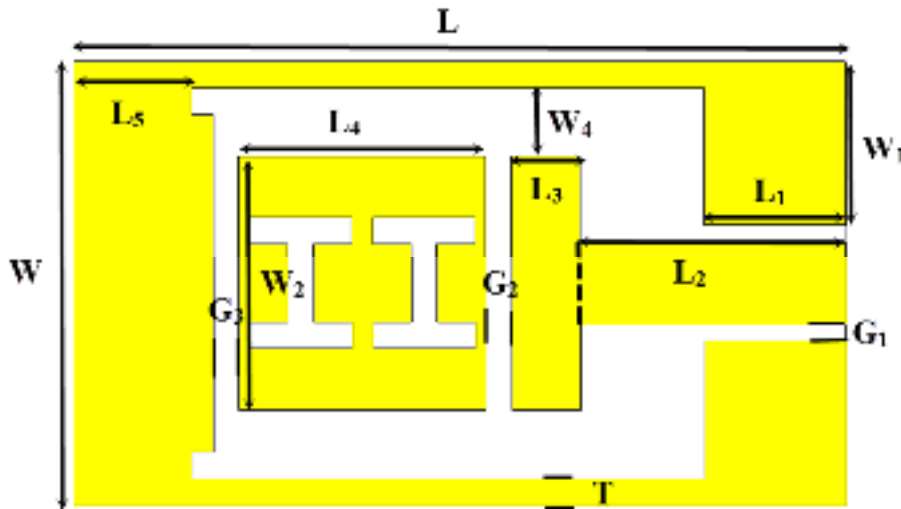


Figure 2. Proposed antenna

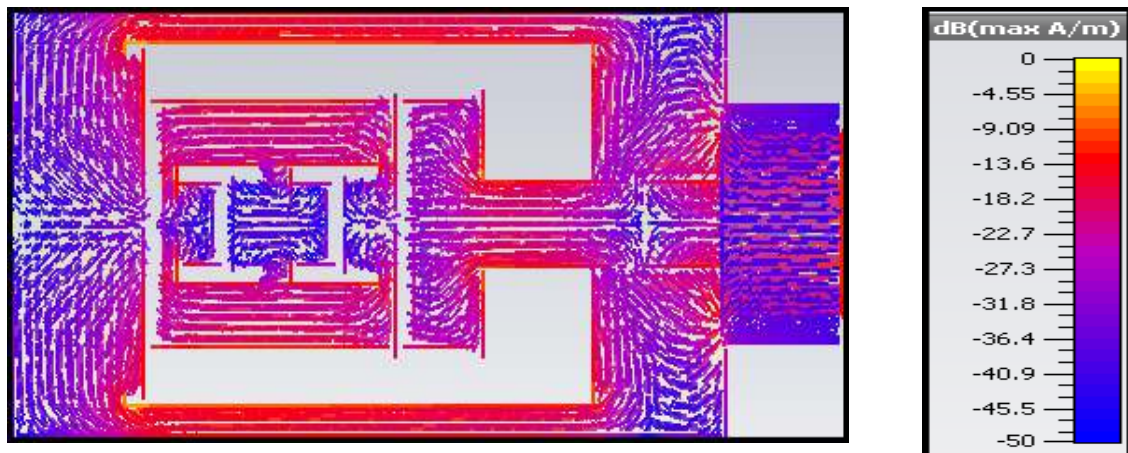


Figure 3. Current distribution at 2.4 GHz

Based on the behavior of current distribution at 2.4 GHz, two slots were created at shorted strip and one side of H slot. Then parametric studies were taken between the three slots for frequency reconfigurable purpose. Three PIN diode switches  $S_2$ ,  $S_3$ , and  $S_4$  are assigned at proper position of the three slots after analysing parametric studies results to achieve the desire goal. Figure 4(a) shows the schematic diagram of the swich configuration and Figure 4(b) shows the proposed antenna with the pin diode switches.

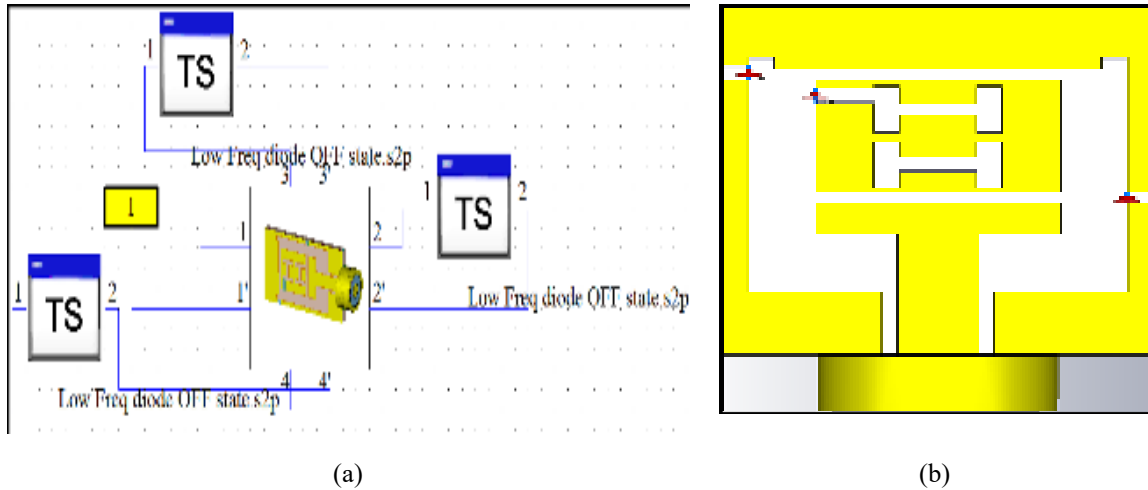


Figure 4. (a) Switching diagram, (b) Proposed antenna with PIN diode switches

### 3. RESULTS AND DISCUSSION

In this section, details of the results obtained in this paper were presented. These results include optimized value of  $G_2$  and  $G_3$  for bandwidth enhancement, effect of H slots and frequency reconfiguration.

#### 3.1. Variation of $G_2$ and $G_3$

By varying the thickness of  $G_2$  and  $G_3$  simultaneously, three different wideband results were obtained, the results show the significant effect at high band. Table 1 presents the summary of the results for the effect of varying  $G_2$  and  $G_3$ . Based on the result, 1.0 mm thickness was selected as optimized value of  $G_2$  and  $G_3$ . These results proved the expression in (7).

Table 1. Effect of thickness  $G_2$  and  $G_3$

$G_2=G_3$ (mm)	0.5	0.7	1.0
Bandwidth (GHz)	2.28-4.55	2.31-4.8	2.34-4.9
Fractional Bandwidth %	66.7	72.12	76.35

#### 3.2. Effect of H slot

Introducing H slots shifted bandwidth at high band to target frequency band. The bandwidth maintained its position at 4.9 GHz with one H slot, while it shifted to 5.2 GHz after introducing the second H slot. Figure 5 shows the effect of introducing H slots.

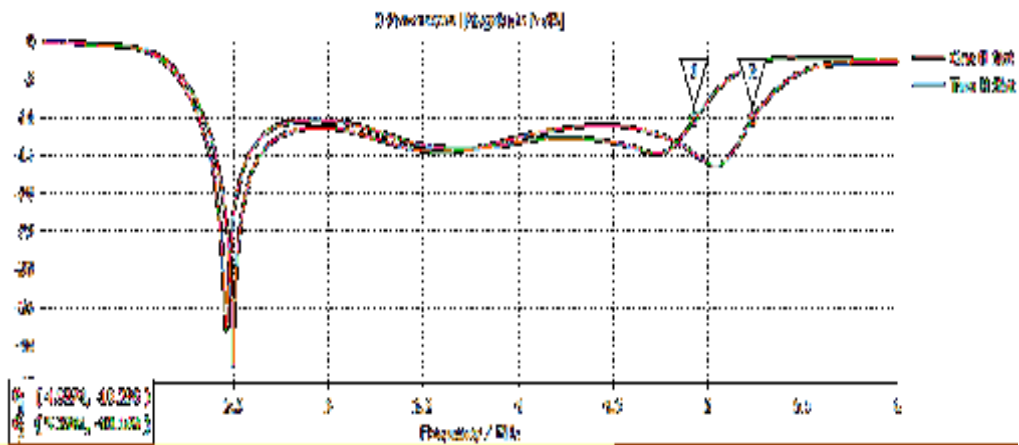


Figure 5. Effect of H slots

**3.3. Reconfiguration results**

The wideband antenna was reconfigured by frequency reconfiguration technique. Three PIN diode switches  $S_2$ ,  $S_3$ , and  $S_4$  are used for reconfiguration purpose. The results obtained by reconfiguration are shown in Figure 6 (a) to (d). The following switch configurations were performed and obtained two single bands and one dual band from the wideband antenna. If all switches are in ON state, the antenna maintained its initial wideband as shown in figure (a). When only switch  $S_3$  is ON, a single band was obtained which resonates at 2.4 GHz as in figure (b). Another single band at 4.2 GHz was obtained when only  $S_4$  is ON. Lastly, a dual band was obtained by switching all the switches OFF as shown in Figure (d). Table 2 summarizes the results of all the switch configurations.

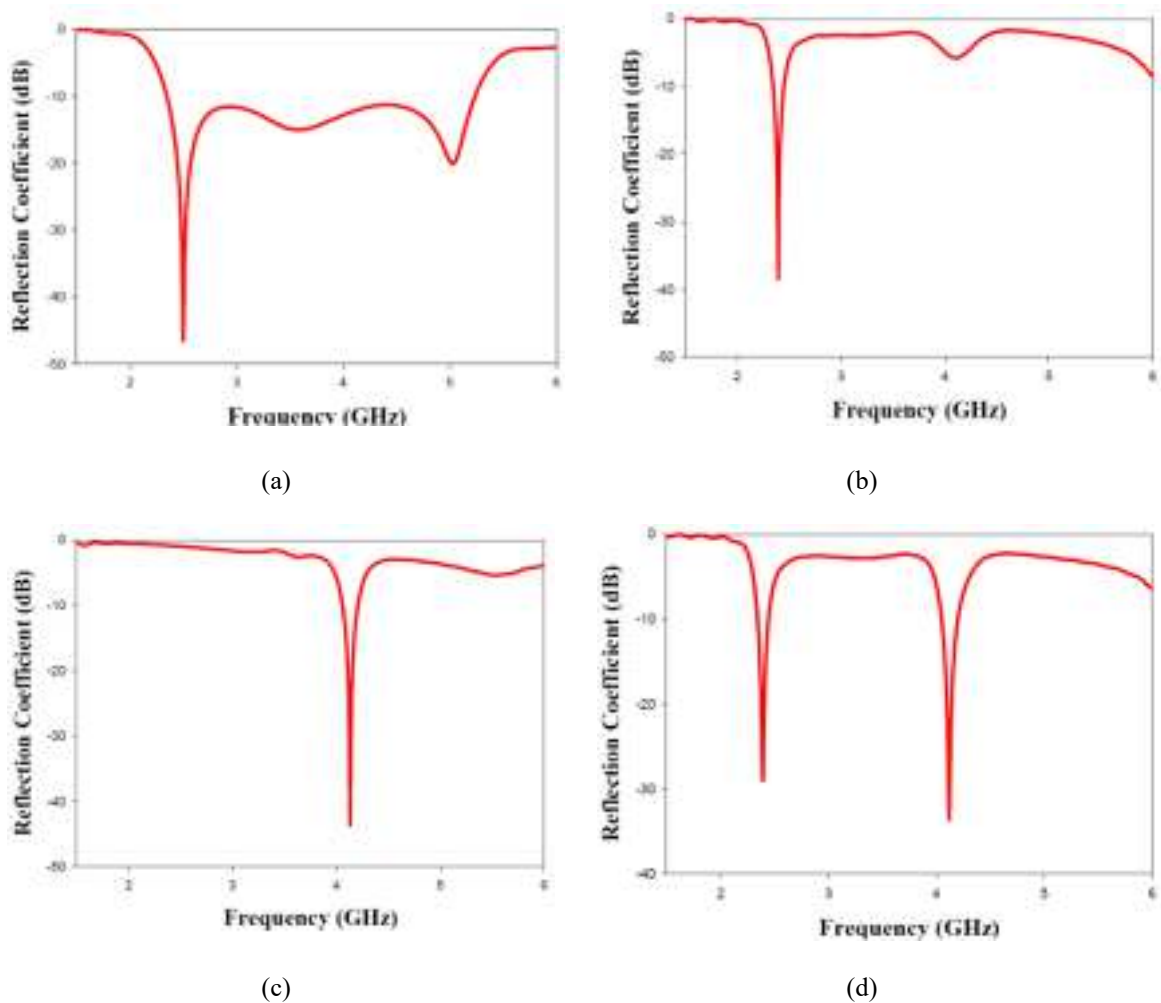


Figure 6. Reconfiguration results, (a) All switches ON, (b) Only  $S_3$  ON, (c) Only  $S_4$  ON, (d) All switches OFF

Table 2. Switch configuration and status

$S_2$	$S_3$	$S_4$	Resonating Band	Status
ON	ON	ON	2.3-5.2	Wideband
OFF	ON	OFF	2.4	Single Band
OFF	OFF	ON	4.2	Single Band
OFF	OFF	OFF	2.4 and 4.2	Dual band

Figure 7 (a) and (b) shows E and H plane radiation pattern at 2.4 GHz while (c) and (d) represent E and H Plane radiation pattern at 4.2 GHz. The E-Plane shows omnidirectional properties at both frequencies while H plane shows dipolar at both frequencies. The realized peak gain at 2.4 GHz and 4.2 GHz are 2.58 dBi and 2.28 dBi respectively. Table 3 presents the summary of the results obtained in this work and compared with the results of the previous similar work.

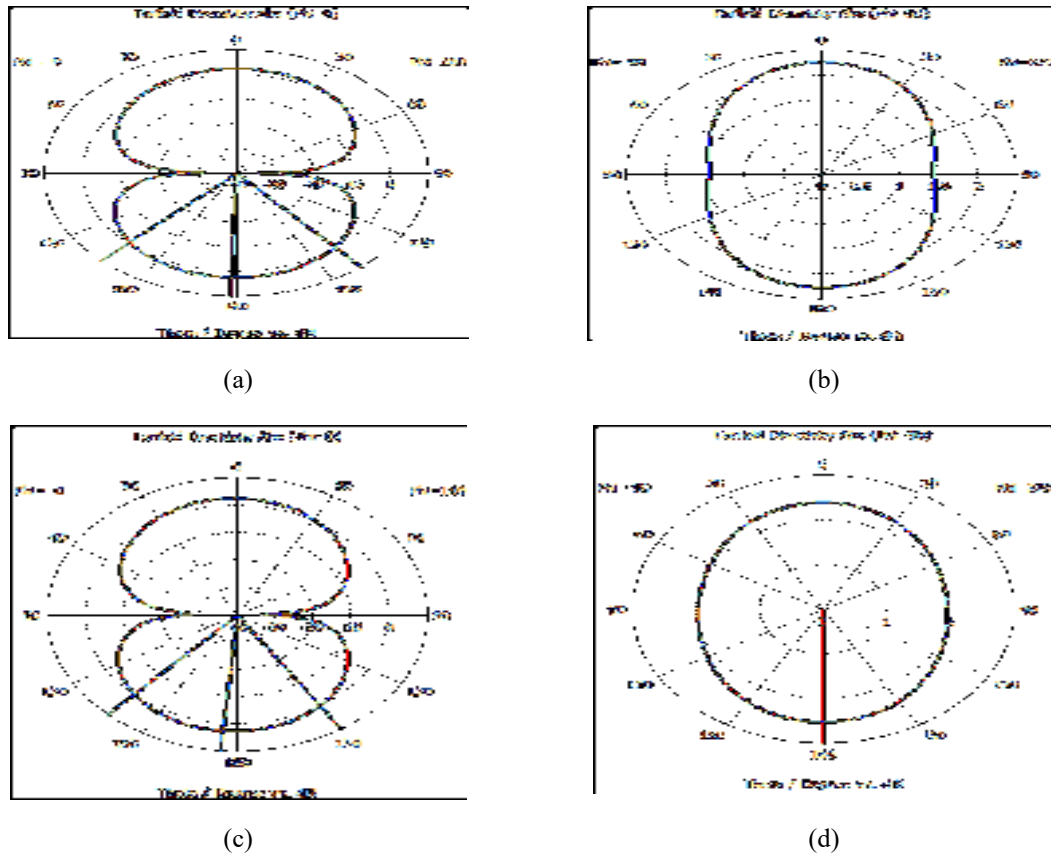


Figure 7. (a) and (b) E and H plane radiation pattern at 2.4 GHz (c) and (d) E and H plane radiation at 4.2 GHz

Table 3. Result comparison

REF	Bandwidth/Bands GHz	Electrical Size	Remark
[16]	2.0-3.4	$0.32 \lambda_0 \times 0.36 \lambda_0$	Large size and bandwidth not cover many application bands
[19]	2.4-4.4	$0.25 \lambda_0 \times 0.14 \lambda_0$	Large size also bandwidth not cover many application bands
[13]	2.23-3.35	$0.36 \lambda_0 \times 0.29 \lambda_0$	Large with narrow bandwidth
[11]	2.4, 3.5 and 5.5	$0.32 \lambda_0 \times 0.36 \lambda_0$	Large size
[13]	2.5, 4.7, 5.3 and 8.2	$0.33 \lambda_0 \times 0.42 \lambda_0$	Large size and less resonating bands
[26]	2.6 and 4.9	$0.27 \lambda_0 \times 0.17 \lambda_0$	Smaal size, wider bandwidth and resonate in many application bands
This Work	2.3-5.3, 2.4, 4.2, 2.4 and 4.2	$0.13 \lambda_0 \times 0.1 \lambda_0$	

#### 4. CONCLUSION

A wideband frequency reconfigurable metamaterial antenna with double H slots has been designed and presented. The fundamental objective is to enhance the bandwidth of the antenna to cover many application bands and then reconfigure for multi frequency operation. Bandwidth enhancement was achieved by using series CRLH-TL parametr  $C_L$ . The result shows direct propotion of  $C_L$  and antenna bandwidth as shows in (7). When the value of  $C_L$  is high, the bandwidth was improved. Finally, the antenna was reconfigured to usefull application bands 2.4 GHz and 4.2 GHz. The overall results make the antenna potential for wireless communication, future proposed 5G lower band and cognitive raidio system.

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