Multi-band Frequency Reconfigurable Metamaterial Antenna Design

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Abstract This paper presents the design of multi-band frequency reconfigurable metamaterial antenna. The design is based on the idea of obtaining multi-band antenna by applying frequency reconfiguration in metamaterial antenna. Some of it advantages include compactness and multi-bands frequency operation. This is achieved by eliminating the horizontal ohm's shape slot from the basic structure and introduction of H slot in the top patch, horizontal and vertical extension *V* and *X* respectively in bottom patch. Frequency reconfiguration was achieved through the operation of three PIN Diode switches at different position. Computer Simulation Technology (CST) software was used to determine the operation and effectiveness of the proposed antenna. From the simulation results, 1.6, 2.6, 3.3, 4.5 and 5.4 GHz operating bands were obtained with realized peak gain 1.94, 2.28, 3.2, 2.9 and 4.25 dBi respectively with average efficiency of 95%. From the results obtained, the bands covered the WLAN and WiMAX band mostly in multi-band form which is suitable for application in cognitive radio to reduce spectrum congestion and interference.

Keywords Metamaterial · Frequency reconfiguration · Multi-bands · Computer simulation technology (CST)

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M. A. Md. Zawawi et al. (eds.), *10th International Conference on Robotics, Vision, Signal Processing and Power Applications*, Lecture Notes in Electrical Engineering 547, https://doi.org/10.1007/978-981-13-6447-1_54

1 Introduction

Recent development in wireless communication encourage researchers to develop a compact, low cost and high efficient antenna which will provide solutions to spectrum congestion and interference. This goal can be achieved with miniaturized, multi-band, metamaterial antenna. The first English seminar paper on metamaterial was written by Russian physicist Victor Veselago in 1968 [1]. But experimental prove was done by Smith in the year 2000 [2]. Metamaterials are unnatural material with properties not available in nature depending on the negative microscopic parameters permittivity $\boldsymbol{\varepsilon}$ and permeability $\boldsymbol{\mu}$ [3]. Purely left handed material does not exist, but composite right/left handed material (CRLH) unit cell which possess double positive, double negative or epsilon/mu negative within a particular frequency range are mostly used for a purpose. Composite Right/Left Handed unit cell are modeled based on it four lump element circuit parameters like series capacitance C_L, shunt inductance L_L which account for left handed propagation and series inductance L_R, shunt capacitance C_R for right handed propagation. From Fig. 1, Eqs. (1), (2), (3) and (4) represent the series resonant frequency, shunt resonant frequency and two cuttoff frequencies for right and left hand respectively [4].

$$\omega_{\text{series}} = \frac{1}{\sqrt{L_R C_L}} \tag{1}$$

$$\omega_{\text{shunt}} = \frac{1}{\sqrt{L_R}} \tag{2}$$

$$\omega_{\text{cutoff,R.H}} = \frac{2}{\sqrt{L_R C_R}} \tag{3}$$

$$\omega_{\text{cutoff.L.H}} = \frac{1}{2\sqrt{L_L C_L}} \tag{4}$$

Reconfigurable antennas are class of antennas that have the ability to select it operating parameters like polarization, frequency, or radiation pattern to redistribute it current for frequency selectivity and reuse [6]. They can be classified based on their operation as either frequency reconfigurable antenna, radiation pattern reconfigurable antennas, Polarization reconfigurable and compound reconfigurable antennas which comprise the combination of any two of the above mentioned three [7]. Recently, researches have been presented to design multi-band antennas by applying

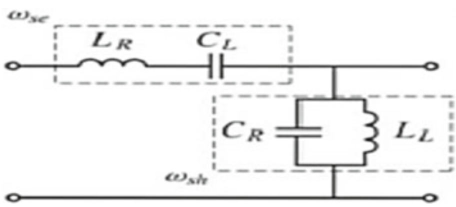

Fig. 1 Equivalent circuit of CRLH [5]

the property of metamaterial for multi frequency operation. This include the idea of multi-band metamaterial loaded antenna by tempering it physical shape and dimension [8]. Similar methodology was used by [9] which utilizes single left handed unit cell and obtained multi-band. This idea was also applied by [10] and achieved miniaturized multi-band antenna by introducing C-Shape slot. Similar method was used by [11] and obtained multi-band frequency reconfigurable antennas by applying switch operation on omega and double split ring resonator. Author in [12] in contrast introduced square split rings in ground plane and achieved multi-bands by frequency reconfiguration. Reconfigurable antenna was designed from the combination of monopole antenna and complementary split ring resonator [13]. In this paper, we proposed to design a compact multi-band frequency reconfigurable metamaterial antenna to provide alternative for multi-bands operation in single antenna to overcome or reduce spectrum congestion and interference. The simulation work was done by using computer simulation technology CST MWS software.

2 Antenna Design

Figure 2 shows the physical geometry of the proposed antenna. As earlier stated, the proposed antenna in this paper was designed based on the basic terminology of [14]. Though, the overall dimension is the same but there are some unique differences between them. The differences include eliminating the horizontal ohm's shaped slot, creating **H** slot in the top patch and extension of the following dimension, **Q** from 1 to 7.0 mm, **U** from 1 to 3.28 mm, horizontal and vertical extension ***V*** and ***X*** in the bottom patch from 3.20 to 5.30 mm, and 3.20 to 5.80 mm respectively. Three PIN Diode switches are placed for reconfiguration purpose. Low cost FR4 substrate with 1.6 mm thickness and dielectric constant of 4.3 ($\varepsilon_r = 4.3,\ \delta = 0.02$) was used. The structure has overall dimension of 16.80 × 30.0 mm^2 with the following parameters in millimeters: **O = 16.8, Z = 30.0 Q = 7.0, P = 3.50 R = 8.50, S = 1.10, T = 1.20, U = 3.28, V = 5.30, W = 6.50, X = 5.80.**

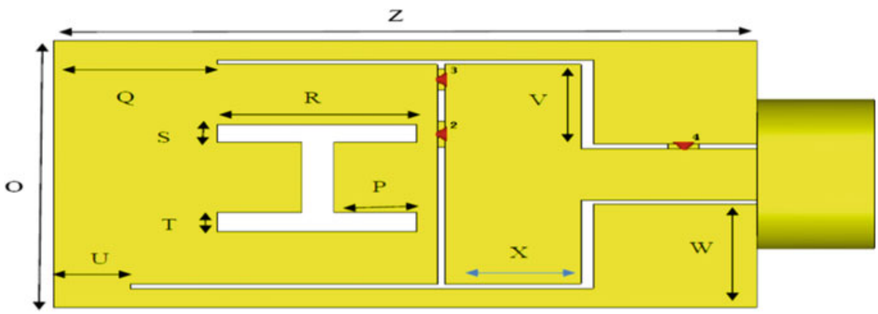

Fig. 2 Proposed antenna

3 Results and Discussion

After simulating the proposed antenna based on the behavior of current distribution at 2.4 GHz, then we introduced PIN Diode switches in appropriate positions. The schematic diagram of the proposed antenna indicating all the switch configuration is shown in Fig. 3 for proper reconfiguration. Table 1 present the summary and status for each configuration of the switches.

The following results are obtained from the configuration of the above switch arrangement as summarize in Table 1. If all the three switches are OFF, we obtained dual-band at 3.3 and 5.4 GHz. For Switch2 ON alone, we also obtained dual-band at 3.3 and 4.5 GHz. If only switch 3 in ON, we got a single band at 3.34 GHz. While for only switch 4 in ON condition, we realized multi-band at 1.67, 2.7, and 5.3 GHz. Combination of switch 2 and 3 in ON state resulted to dual band at 3.35 and 4.5 GHz operating bands. Finally, for switch 2 and 4 in ON condition generate single band at 4.49 GHz operating band. The results of all configuration are shown in the Fig. 4.

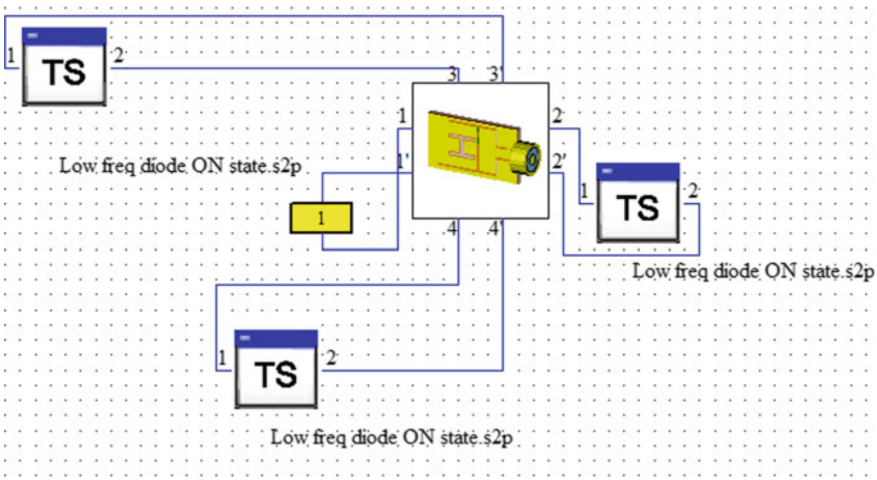

Fig. 3 Schematic diagram of proposed antenna

Table 1 Switch configuration

Switch 2	Switch 3	Switch 4	Operating Bands (GHz)
OFF	OFF	OFF	3.3 and 5.4
ON	OFF	OFF	3.3 and 4.5
OFF	ON	OFF	3.34
OFF	OFF	ON	1.67, 2.7 and 5.3
ON	ON	OFF	3.35 and 4.5
ON	OFF	ON	4.49

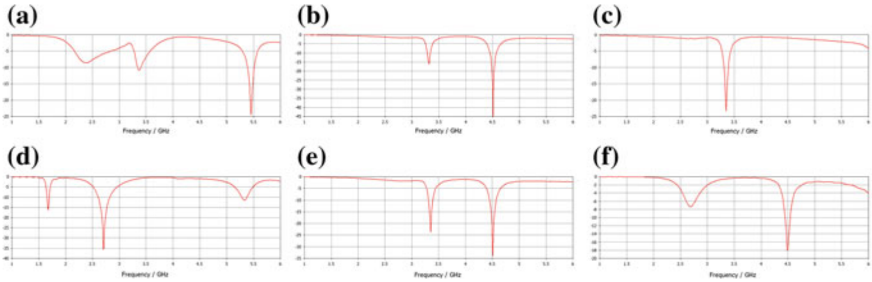

Fig. 4 Simulation RESULTS **a** All Switches OFF **b** Switch 2 ON **c** Switch 3 ON **d** Switch 4 ON **e** Switch 2 and 3 ON **f** Switch 2 and 4 ON

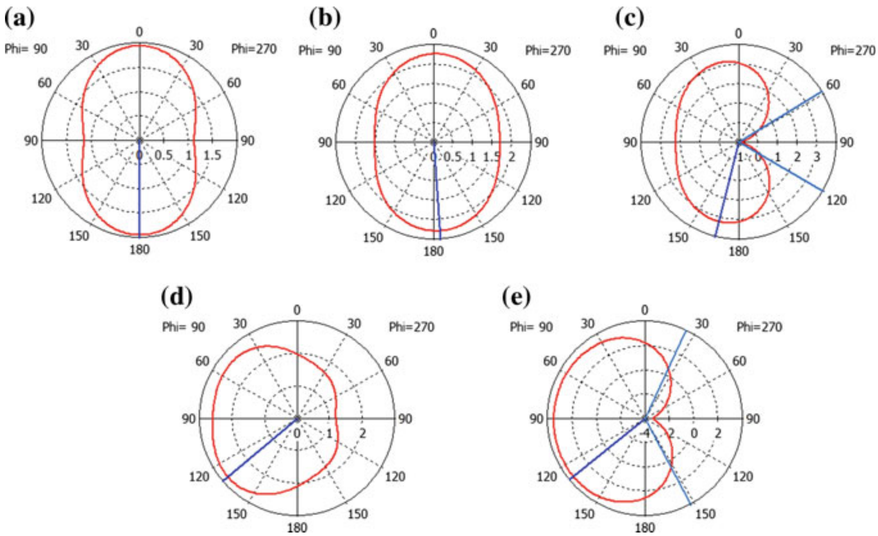

Fig. 5 Radiation Pattern at **a** 1.6 GHz **b** 2.6 GHz **c** 3.3 GHz **d** 4.5 GHz **e** 5.4 GHz

Figure 5 shows the radiation pattern at 1.6 GHz, 2.6 GHz, 3.3 GHz, 4.5 GHz and 5.4 GHz with realize peak gain of 1.94 dBi, 2.28 dBi, 3.2 dBi, 2.9 dBi, and 4.25 dBi respectively (Table 2).

4 Conclusion

The main objective of this work was to design multi-band metamaterial antenna by frequency reconfiguration technique. The design shown the influence of slot here in **H** form at top patch with modification in some dimension and effect of PIN Diode switch in frequency reconfiguration. Five different frequency bands at 1.6, 2.6, 3.3,

Table 2 Results comparison

Parameters	This work	2014	2015	2016	2015
Dimension (mm^2)	30 by 16.80	40 by 45	13.5 by 26.5	40 by 50	30 by 32
Bands (GHz)	1.6, 2.6, 3.3, 4.5 and 5.4	2.4, 3.5 and 5.5	5.0, 5.8 and 6.3	2.45, 4.7, 5.3 and 6.1	2.1, 4.3, 5.3 and 6.9
Peak gain dBi	1.94, 2.28, 3.2, 2.9 and 4.25	3.2, 2.38 and 2.34	3.75, 2.0 and 1.2	5.48, 6.09, 5.77 and 8.4	1.78

4.5 and 5.4 GHz were obtained in single, dual and multi-band form. From the results obtained the antenna can be used for wireless application and reduced the spectrum congestion by utilizing unused bands. The bands show good matching and realized peak gain with average efficiency of 95%. Further work can be done to reduce the number of switches to obtain the same results to minimize the losses associated to switch operation and fabrication work for measurement and validation.

Acknowledgements The authors thank the Ministry of Higher Education (MOHE) for supporting the research work, Research Management Centre (RMC), School of Electrical Engineering, Universiti Teknologi Malaysia (UTM) for the support of the research under grant no. 16H08 and 4F883

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