Wideband frequency reconfigurable metamaterial antenna design with double H slots

Adamu Y. Iliyasu, Mohamad Rijal Hamid, Mohamad Kamal A. Rahim, Mohd Fairus Mohd Yusoff, Murtala Aminu-Baba, Mohammed Mustapha Gajibo
Advanced RF and Microwave Research Group, School of Electrical Engineering, Faculty of Engineering, Universiti Teknoloji Malaysia UTM, Malaysia

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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 sencing.

Corresponding Author:

Adamu Y. Iliyasu,
Advanced RF and Microwave Rearch Group,
School of Electrical Engineering, Faculty of Engineering,
Universiti Teknologi Malaysia UTM, 81310 Skudai, Johor Malaysia.
Email: alhaji080@gmail.com

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 $\boldsymbol{\varepsilon}$ and negative permeability $\boldsymbol{\mu}$ [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 analysys 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 ω_L and ω_R are left/right-handed resonance and ω_{se} and ω_{sh} are series and shunt resonance as presented in (2-5).

$$\omega_L = \frac{1}{\sqrt{C_L L_L}} \quad (2)$$

$$\omega_R = \frac{1}{\sqrt{C_R L_R}} \quad (3)$$

$$\omega_{se} = \frac{1}{\sqrt{C_L L_R}} \quad (4)$$

$$\omega_{sh} = \frac{1}{\sqrt{C_R L_L}} \quad (5)$$

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 propotion relation with left-handed capacitance. Which means that, the high the value of lef-handed capacitance C_L the high the bandwidth of the antenna. Figure 1 represent the circuit of single CRLH-TL unt cell with lenth d.

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

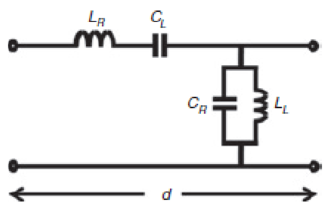


Figure 1. CRLH-TL unit cell [6]

Reconfigurable antennas are considered as antennas with habit of selecting operating parameters such as polariztion, frequency, or radiation pattern to rearrange it current distribution to achieve the desire 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 utilizating the effect of twice unit cell netamaterial structures by [9, 10] to extend antenna bandwidth. Same objective was achieved in [11, 12] by merging fundamental modes. Subtituting 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 result do exist in [25-27], but they exhibit several disadvantages such as large size, insufficient bandwidth to cover many application band, 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.

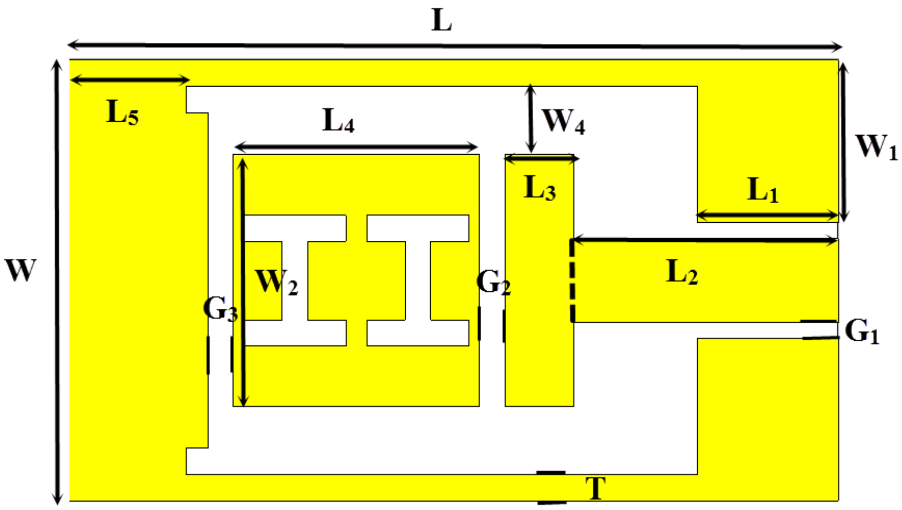


Figure 2. Proposed antenna

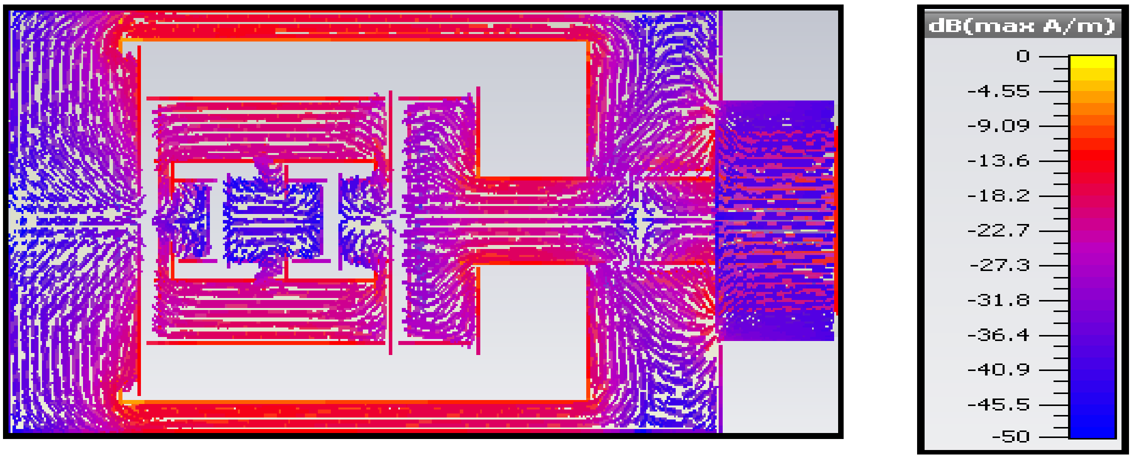
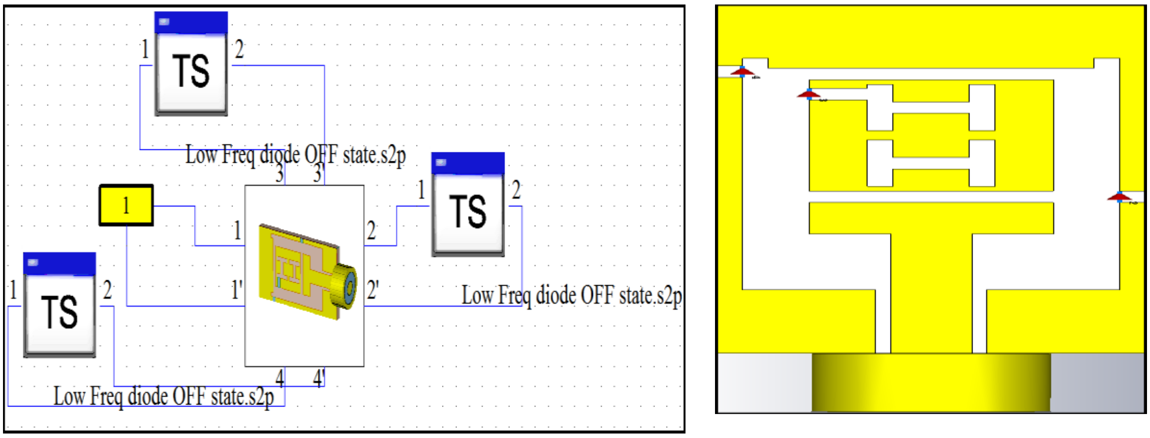


Figure 3. Current distribution at 2.4 GHz

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.



(a) (b)

Figure 4. (a) Switching diagram, (b) Proposed antenna with PIN dide 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 it 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.

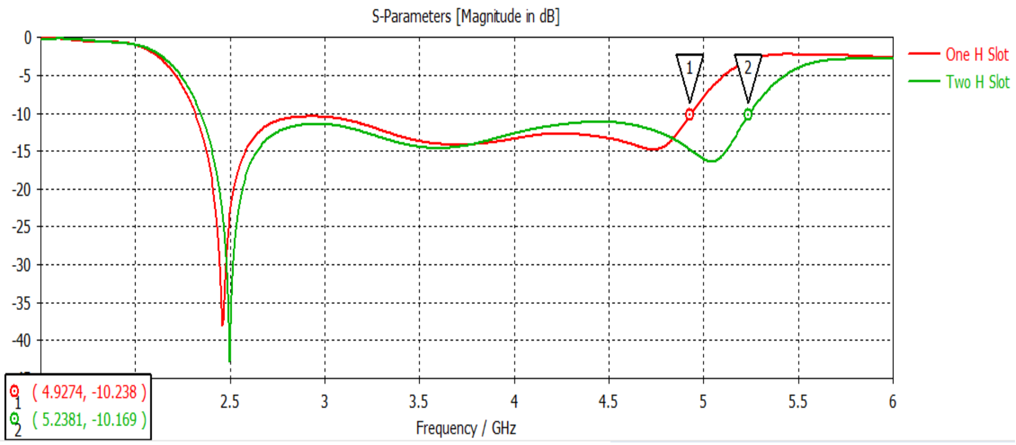
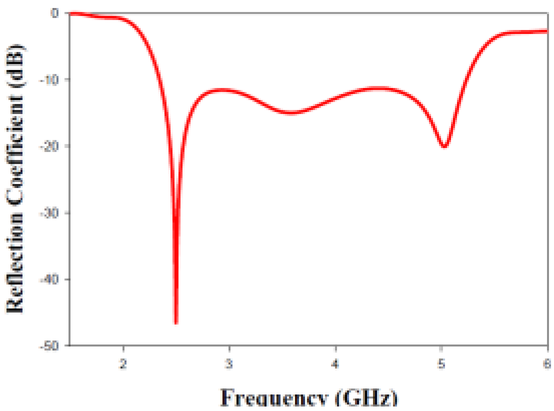


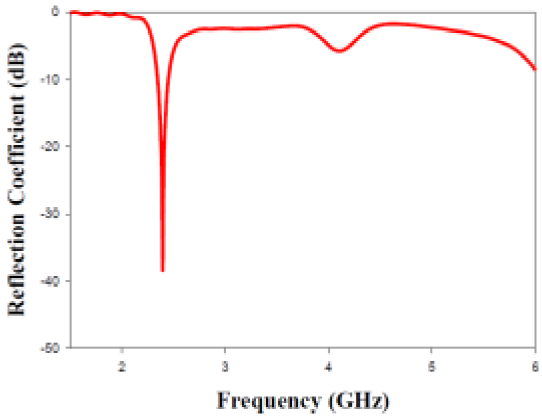
Figure 5. Effect of H slots

3.3. Reconfiguration results

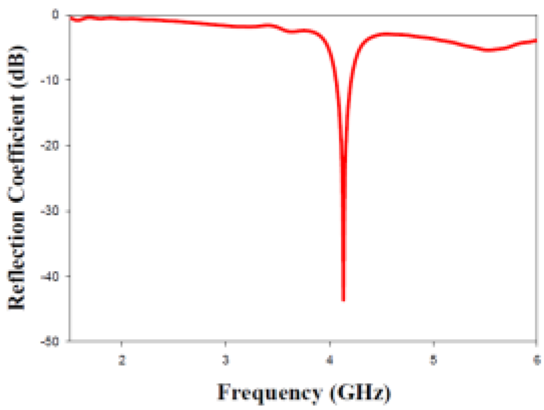
The wideband antenna was reconfigured by frequency reconfiguration technique. Three PIN diode switches S_2, S_3, and S_4 are used for reconfiguration purpose. The results obtained by reconfiguration are shows in Figure 6 (a) to (d). The following switch configuration were perfomed and obtained two single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



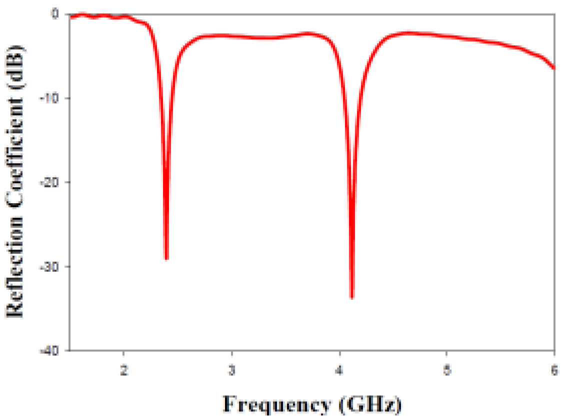
(a)



(b)



(c)



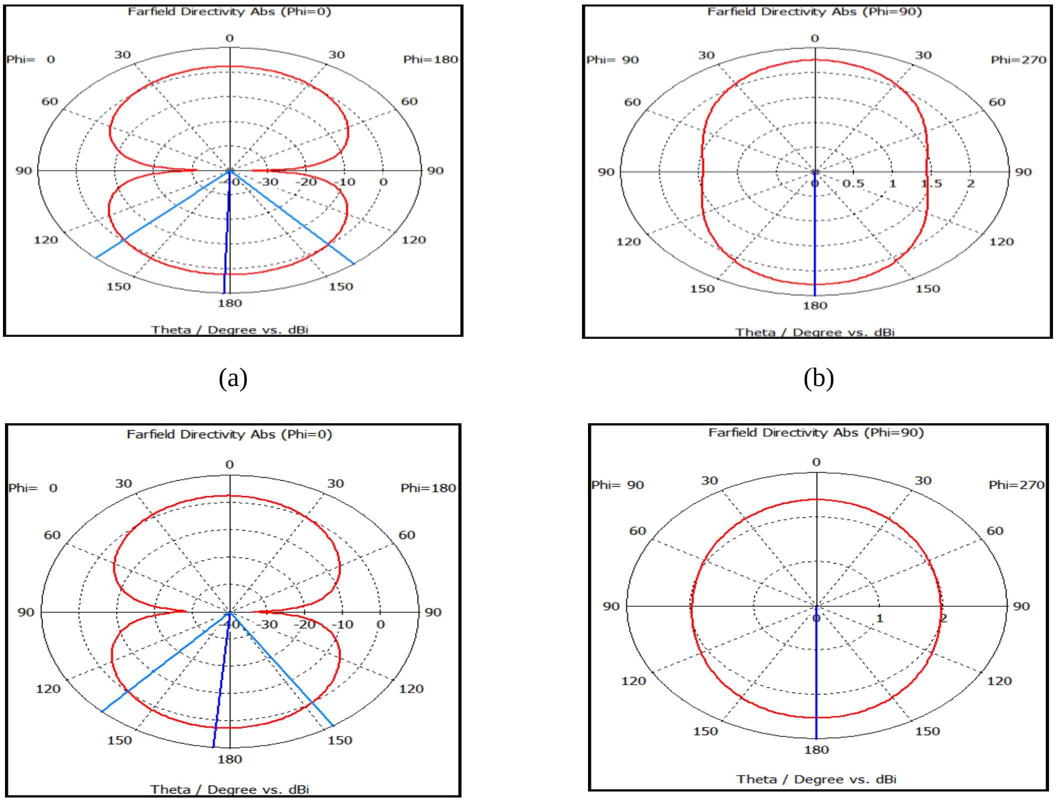
(d)

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

S2	S3	S4	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) represents 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.



(a) (b)

(c) (d)

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	$0.32\,\lambda_O \times 0.36\lambda_O$	Large size and bandwodth not cover many application bands
[19]	2.4-4.4	$0.25\,\lambda_O \times 0.14\lambda_O$	Large size also bandwidth not cover many application bands
[13]	2.23-3.35	$0.36\,\lambda_O \times 0.29\lambda_O$	Large with narrow bandwidth
[11]	2.4, 3.5 and 5.5	$0.32\,\lambda_O \times 0.36\lambda_O$	Large size
[13]	2.5, 4.7, 5.3 and 8.2	$0.33\,\lambda_O \times 0.42\lambda_O$	Large size and less resonating bands
[26]	2.6 and 4.9	$0.27\,\lambda_O \times 0.17\lambda_O$	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	$0.13\,\lambda_O \times 0.1\lambda_O$	

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 achived 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 potenrial for wireless communication, future proposed 5G lower band and cognitive raidio system.

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BIOGRAPHIES OF AUTHORS

Adamu Yau Iliyasu obtaine B. Eng in Electrical Engineering from Kano. University of Science &Technology, Wudi in 2007, Obtained M.Sc in Electrical & Computer Engineering in Meliksah/Erciyes University Turkey 2014. Currently PhD Student in University Technology Malaysia. School of Electrical Engineering. Malaysia. Johor, His research area is Frequency Reconfigurable Metamaterial Antenna Design. Have been with Kano University of Science and Technology Wudil since 2011 as lecturer.

Mohanmad Rijal Hamid received the M.Sc. degrees in communication engineering from the Universiti Teknologi Malaysia, Johor Bahru, Malaysia, in 2001 and the Ph.D Degree at the University of Birmingham, Birmingham, U.K. in 2011. He has been with Universiti Teknologi Malaysia (UTM) at the School of Electrical Engineering, Faculty Of Engineering, UTM, since 1999. Currently his position is a Senior Lecturer. His major research interest is reconfigurable antenna design for multimode wireless applications.

Mohamad Kamal A. Rahim is a Professor at School of Electrical Engineering, UTM Skudai Johor. Graduated with a Bachelor of Electrical Engineering from the University of Strathclyde, UK (1987), a Master of Electrical Engineering (Communication) degree from the University of New South Wales, Australia (1992) and a Doctor of Philosophy (Electrical Engineering) from the University of Birmingham, UK (2003). His research interest includes the areas of design of Dielectric resonator antennas, microstrip antennas, small antennas, microwave sensors, RFID antennas for readers and tags, Multi-function antennas, microwave circuits, EBG, artificial magnetic conductors, metamaterials, array antennas, wearable antennas, textile antenna, smart antennas, computer aided design for antennas and design of millimeter frequency antennas for 5G. He has published over 400 articles. He has supervised more than 20 Phd, 50 Master which includes thesis, project report, dissertation and more than 100 undergraduate students. 10 Phd and 50 Master students have been graduated through his supervision.

Mohd Fairus is a graduate faculty member of the Faculty of Electrical Engineering, University Technology Malaysia (UTM). He joined UTM in 2002 as a Tutor. He received his Bachelor in Engineering (Electrical-Telecommunication) in 2002 and Master of Electrical Engineering (Electrical - Electronics and Telecommunications) in 2005 from University Technology Malaysia. He obtained his Ph.D. in 2012 from University of Rennes 1, France in area of Signal Processing and Telecommunication. His main research interests and areas are antenna design, millimeter waves and microwave devices.

Murtala Aminu-Baba obtained his first degree in 2010 from Abubakar Tafawa Balewa University Bauchi, Nigeria (ATBU) in Electrical/Electronics Engineering. He further received his MSc. Degree in Information Technology from the University of Wolverhampton, U.K, in 2013. He is currently pursuing his PhD in the field of metamaterial antenna design for MIMO applications and have been with Abubakar Tafawa Balewa University Bauchi since 2014 as a lecturer.

Mohammed Gajibo Mustapha obtained his Diploma in telecommunication Engineering at Multimedia University Melaka in 2009. He then obtained his first degree in in Electrical/Electronics Engineering at University of Sunderland U.K in 2013. He further obtained his Masters MEng. In Electrical and Telecommunication engineering at University Technology Malaysia in 2015. He is currently rounding up his PhD in the field of metamaterial absorbers and reflectors at University Technology Malaysia.