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Frequency Reconfigurable Epsilon Negative Metamaterial Antenna

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ABSTRACT

This paper proposes metamaterial (MTM) inspired frequency reconfigurable antenna based on thecircular electric field coupled (ELC) resonator. It is composed of circular shape ELC resonator with the radius size of 7 mm. By inserting two switches between the gaps at both side of the circular ELC resonator, it is possible to switch ON or OFF the unit cell. The antenna has been simulated using CST Microwave Studio software tool. The simulation result shows that the proposed antenna is capable of reconfiguring between two different frequencies which are2.18 GHz and 2.64 GHz. The simulated bandwidth at -10 dB is 4.12 % at resonance frequency of 2.18 GHz and 8.7% at 2.64 GHz.

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1. INTRODUCTION

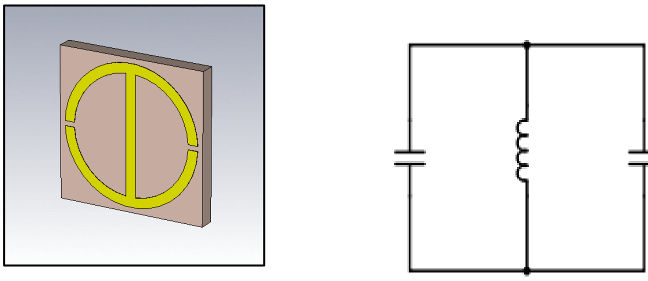
An antenna that possesses the ability to modify its characteristics, such as operating frequency, polarization or radiation pattern, in real time condition is referred to as a reconfigurable antenna. The Reconfigurable antenna can be simply used to reduce the number of antenna necessary for intended system function, but they can also be designed to serve much more complex roles. In addition, reconfigurable antenna can be a cheaper alternative to traditional adaptive arrays or they can be incorporated into adaptive arrays to improve their performance by providing additional degrees of freedom [1]. MTM concept was first conceived by Veslago in 1968 [2]. He revealed the existence of material having both negative permeability and permittivity over a given frequency range.MTM inspired antenna offers a reduction in size because they show anti-parallel phase and group velocities, phase constant is negative and others [3]. The antenna is fundamentally loaded with MTM configuration such as split ring resonator (SRR) complimentary split ring resonator (CSRR) to get dual-band/wideband characteristics with compact size. Resonant structures are the main building block of metamaterials (MTMs) with unusual electromagnetic constitutive parameters [4],[5].

Authors in [6] reviewing the latest advances in reconfigurable metamaterial engineering from the methodological perspective.The choice of the physical mechanism that enables reconfigurability in MTM enhanced devices has a fundamental importance in their design process since it directly impacts the achievable performance, the cost, the fabrication complexity, the scalability, and the flexibility of the resulting architecture.The idea of reconfigurable MTM antenna is supported bystudy in [7], which a printed monopole is loaded with a single unit cell of an NRI-TL. As a result of this loading, another band is added to the antenna.In this paper, circular ELC resonator is used as an antenna and copper strips are use as switches. This reconfigurable MTM inspired antenna can add another frequency band by switching the switch that embedded between the gaps at both sides of the circular ELC resonator

2. RESEARCH METHOD

2.1. Metamaterial Unit Cell

The circular shape ELC resonator unit cell is designed on an FR4 substrate with the dielectric constant of 4.5, the thickness of 1.6 mm and loss tangent of 0.019. Figure 1(a) shows a schematic view of the proposed MTM unit cell named as circular ELC resonator with the radius size of 7mm.The unit cell is designed to have a shared inductive stub at the center, with two capacitive gaps at both sides. Specifically, the unit cell can be modeled by theinductor and a capacitor, therefore forming an LC resonant circuit. The resonance frequency depends largely on the LC element [8]. Figure 1(b) shows the equivalent circuit for the proposed unit cell.



(a) (b)

Figure 1. (a) circular ELC resonator (b) Equivalent circuit

The proposed unit cell structure is simulated in CST microwave Studio. Usually, a resonant structure is simulated by setting Perfect Electric-boundary Condition (PEC) on the y-axis, Perfect Magnetic-boundary Condition (PMC) on the z-axis and open boundary condition on the x-axis where the electromagnetic wave is excited. The simulated S-parameter (S11 and S21) are used in Nicholson-Ross-Weir techniques (NRW) to extract the effective permittivity and permeability. The equation used for calculating permittivity and permeability using NRW [9] approach given below.

The complex S-parameters from the CST software are exported to Mathcad for analysis as follows:

$$V1 = S_{21} + S_{11} \tag{1}$$

$$V2 = S_{21} - S_{11} \tag{2}$$

$$\mu_{eff} = \left[\frac{[2*(1-V1)]*c}{\omega*d(1+V2)}\right] \tag{3}$$

$$\varepsilon_{eff} = (2 * j * S11 * \frac{c}{\omega*d}) + \left[\frac{[2*(1-V1)]*c}{\omega*d(1+V2)}\right] \tag{4}$$

where S11and S21are complex S-parameters and$\omega = 2\pi f$, *c*, and *d*are the angular frequency, thespeed of light and thickness of the substrate respectively. The refractive index (n) and wave impedance in term of S-parameters are given by:

$$n = \frac{1}{k_o d}\cos^{-1}\left[\frac{1}{2S_{21}}(1 - S_{11}^2 + S_{21}^2)\right] \tag{5}$$

$$Z = \sqrt{\frac{(1+S_{11})^2 - S_{21}^2}{(1-S_{11})^2 - S_{21}^2}} \tag{6}$$

Alternatively, the effective permittivity (ε_{eff}) and permeability (μ_{eff}) can retrieved in terms of wave impedance (*Z*) and refractive index (*n)* as follows:

$$\varepsilon_{eff} = \frac{n}{Z} \quad (7)$$

$$\mu_{eff} = n * Z \quad (8)$$

According to the result of Figure 2, it can be seen that the effective permittivity (ε) is negative and spans from 2.12 GHz to 2.85 GHz. The result also shows that the circular ELC resonator is dominated by the electric response. So this MTM also known as epsilon negative material because of having permittivity as negative (ε < 0) and permeability as positive (μ > 0)

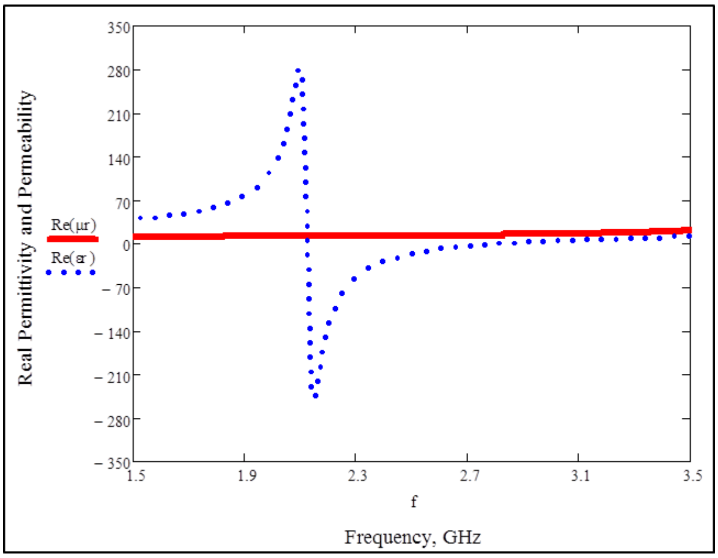
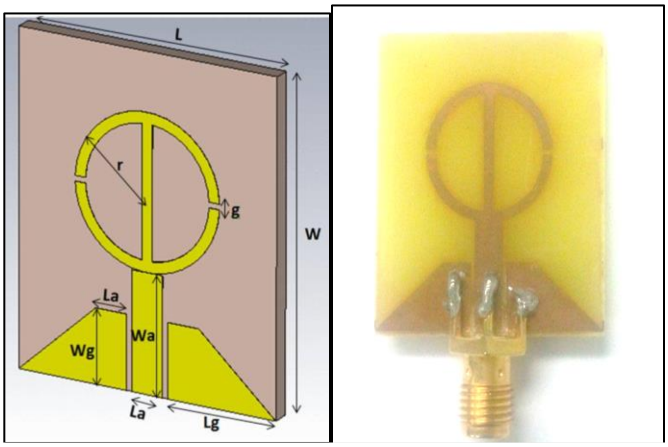


Figure 2. Real Permittivity and Permeability of circular ELC resonator

2.2. Antenna Design

The proposed MTM inspired frequency reconfigurable antenna is designed onFR4 substrate with the dielectric constant of 4.5, the thickness of 1.6 mm and loss tangent of 0.019. The overall antenna size is 25mm x 30mm x 1.6mm. The geometrical structure of proposed antenna is described in Figure 3(a) while the fabricated antenna shows in Figure 3(b). It comprises of CPW feed and circular ELC resonator.All the antenna dimensions are tabulated in Table 1. Figure 4 shows the two switches(D1 and D2) are embedded between the gaps at both sides of the ELC resonator.



(a) (b)

Figure 3. (a)Configuration of the proposed antenna (b) Fabricated antenna

Table 1. Dimensions of proposed antenna

Parameters	Value (mm)
W	30
L	25
r	7
g	0.5
La	3.0
Lg	10.5
Wa	10.7
Wg	6.7

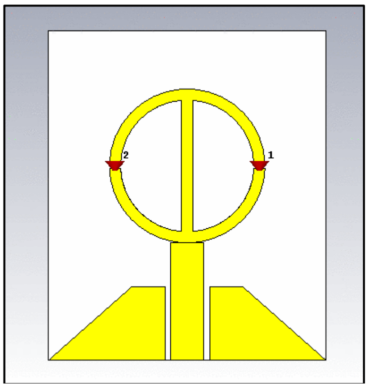


Figure 4. Antenna with the switches

3. RESULTS AND ANALYSIS

The antenna has been simulated using CST Microwave Studio software tool. It is based on finite difference time-domain (FDTD) method fornumerical analysis. Due to fast calculation and memory efficient usage coupled with accurate and fast results delivery, time domain solver is used for the simulation. Figure 5 gives two(2) different antenna operating modes corresponding to the different switch configurations.

When both of the switches are switched OFF, the circular ELC resonator is activated and the antenna is resonating at 2.18 GHz. Both of the switches can't be switch ON togetheratthe same time. It is because the antenna will not act as MTM antenna if both of the switchesare ON. When the switch D1 is switched OFF and switch D2 is switched ON, the antenna resonating at 2.64 GHz. When the switch D2is switched OFF and switch D1 is switched ON, the antenna resonates at the same frequency.The simulated bandwidth at -10 dB is 4.12 % at the resonance frequency of 2.18 GHz and 8.7% at 2.64 GHz. There is 4.6% bandwidth improvement. Table 2 shows the switch configurations.

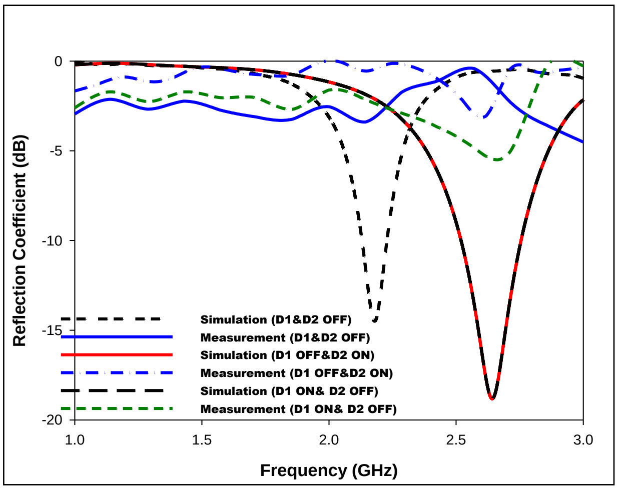
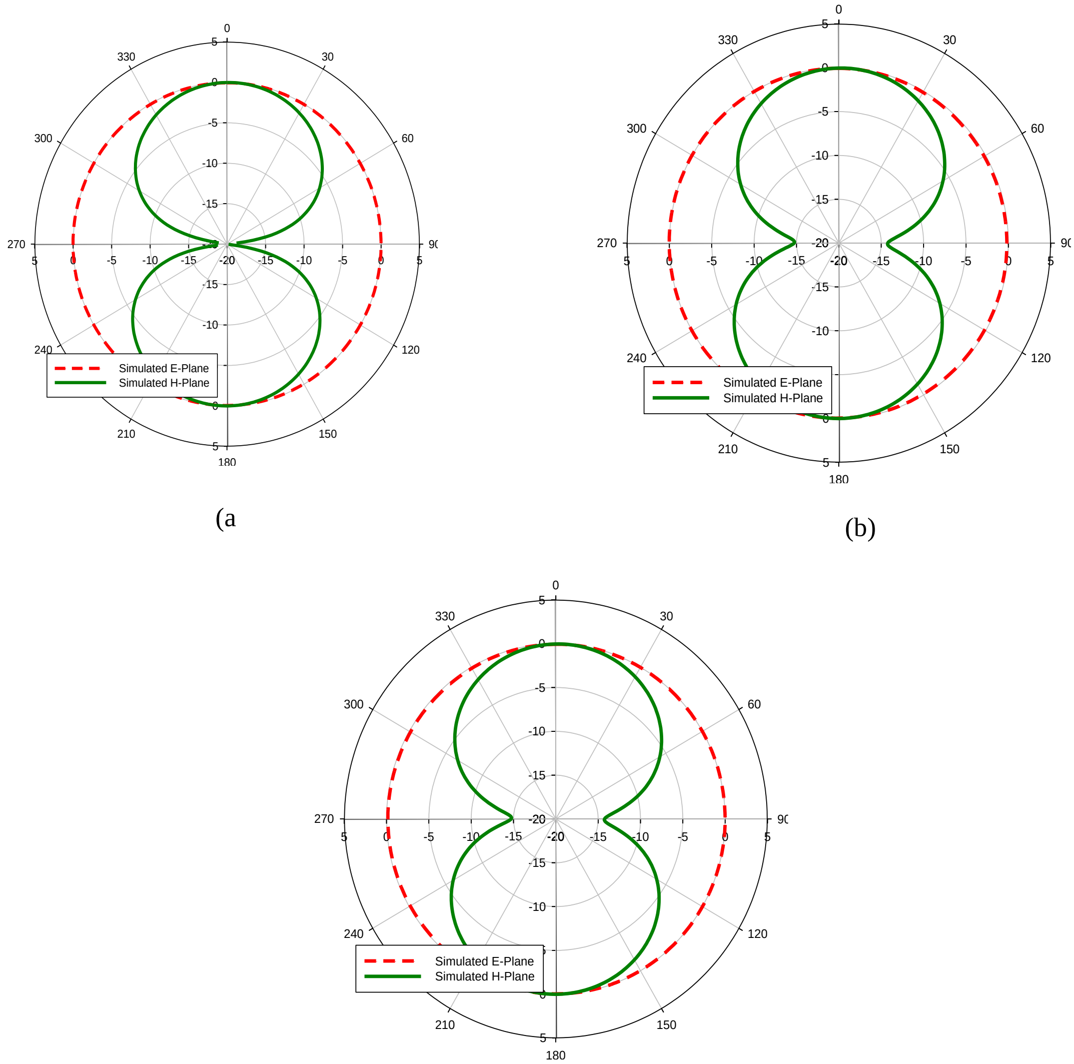


Figure 5. Reflection coefficient

Table 2. Switch configurations

D1	D2	Resonant Frequency (GHz)	Bandwidth (%)
OFF	OFF	2.18	4.12
OFF	ON	2.64	8.17
ON	OFF	2.64	8.17

The radiation pattern is a graphical representation of the radiation properties of an antenna and it is determined in the far field region. From the radiation pattern, other parameters such as radiation intensity, field strength, polarization, and directivity can be determined. Figure 6 shows the simulated radiation pattern at different switch configuration for both E and H-planes. An omnidirectional pattern is obtained in the E-plane and a bi-directional pattern in H-plane for all the switches state.



(a (b)

(c

Figure 6. Simulated radiation pattern. (a) Switch D1 and D2 OFF (b) Switch D1 OFF and D2 ON c) Switch D2 OFF and D1 ON

4. CONCLUSION

A frequencyreconfigurable epsilon negative MTM antenna based on the circular shape electrically coupled resonator has been presented. The proposed antenna is capable of reconfiguring between two different frequencies which are 2.18 GHz and 2.64 GHz. While the bandwidth at -10 dB is 4.12 % at resonance frequency of 2.18 GHz and 8.7% at 2.64 GHz

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Arrauzah Razak received the B Eng. degree in Electrical Engineering with honours from Universiti Tun Hussein Onn Malaysia, in 2011. She then obtained his M.Eng (Electrical-Electronics and Telecommunications) in 2015, at Universiti Teknologi Malaysia. She is currently a on going PhD in Electrical Engineering at Advanced RF & Microwave Research Group,Communication Engineering Department, Faculty of Electrical Engineering Universiti Teknologi Malaysia. Her research interest includes the areas of design of MTM antennas and frequency reconfigurable MTM antenna.

Mohamad Kamal A Rahim received the B Eng. degree in Electrical and Electronic Engineering from University of Strathclyde, UK, in 1987. From 1987 to 1989, he worked as a Management Trainee at Sime Tyres Mergong Alor Star Kedah and Production Supervisor at Sime Shoes in Kulim Kedah. In 1989, he joined the Department of Communication Engineering, Faculty of Electrical Engineering Universiti Teknologi Malaysia Kuala Lumpur as an Assistant Lecturer A. He obtained his M.Eng Science from University of New South Wales Australia in 1992 and PhD degrees in Electrical Engineering from University of Birmingham UK in 2003. After he received his Master he was appointed as a Lecturer at Faculty of Electrical Engineering. In 2005 he was appointed as a senior lecturer and in 2007 he was appointed as Assoc Professor at the faculty. Now he is the Professor in RF and Antenna at Faculty of Electrical Engineering Universiti Teknologi Malaysia. 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 cicuits, EBG, artificial magnetic conductors, metamaterials, phased array antennas, computer aided design for antennas and design of millimeter frequency antennas. He has published over 200 articles in journals and conference papers. He is a co author of a book title basic principle telecommunication and several book chapters and editor of three book chapters. He has been appointed as a reviewer for several journals papers at National and International level. Thus far, he has reviewed and edited more than 100 papers. In year 2012 he was awarded for the highest impact factor journal in Information and Communication Research Alliance (IcRA) during CITRA KARISMA 2012.

Currently he is having two research grant from MOHE (ERGS and PRGS), one from MOSTI which is EScience, three from International Grant which is MOTOROLA , two from Research University Grant which is Tier 1 and Tier 2 and one LRGS collaboration with USM and UNISZAR. He is the project leader for all these grants. The total amount of these research grants are more than RM 2.5 million. One of his research product has been commercialized through UTM Spin off company. This is supported by UTM Symbiosis programme which is the collaboration between UTM and MTDC. The total amount of grant obtained from this programme is nearly RM 2 Million. Through research, which he has conducted throughout the years, he has been honoured with recognition nationally as well as internationally for the products invention. The total awards that he has received through national competition is 5 gold, 5 silver and 3 bronze. This include Malaysia Technology Expo (MTE 2007), International Invention, Innovation and Technology Exhibition (ITEX 2008) and The International Exposition of Research and Invention of Institution of Higher Learning(PECIPTA2009, 2011). For international competition his product manage to secure 4 gold, 4 silver and 3 bronze. The international competition is Seoul International Invention Fair (SIIF - 2008, 2009 and 2011). In addition, he has filed the patent for more than 20 products as a principal inventor. In year 2009 he was awarded as a best fundamental research project in CITRA KARISMA 2009. Meanwhile in 2010 he was the finalist for the best intellectual property award in CITRA KARISMA 2010. MOSTI also has appointed him as an expert assessor to evaluate the proposal application under Research Development and Commercialization He is the chapter chair of IEEE APMTTEMC Malaysian Section for year 2011 and 2012. During his term as a chapter chair, he is continously organised conference under the umbrella of IEEE APMTTEMC. The conferences that chapter organised are IEEE Radio Frequency Microwave (RFM 2011) and IEEE Asia Pacific Conference on Applied Electromagnetic (APACE 2012). He received his excellence service award in 2004 and 2011 for his contribution towards university excellence. He has supervised 10 Phd, 47 Master which includes thesis, project report , dissertation and 100 undergraduate students. 4 Phd and 42 Master students have been graduated through his supervision.

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