TELKOMNIKA, Vol.16, No.4, August 2018, pp. 1535~1541
ISSN: 1693-6930, accredited First Grade by Kemenristekdikti, Decree No: 21/E/KPT/2018
DOI: 10.12928/TELKOMNIKA.v16i4.9065

Switchable Wideband Metamaterial Absorber and AMC reflector for X-band Applications and Operations

M.M. Gajibo*[1], M. K. A. Rahim[2], N. A. Murad[3], O. Ayop[4], H.A. Majid[5]
[1,2,3,4]Advance RF and Microwave Research Group, Department of Communication Engineering, Faculty of Electrical Engineering, Universiti Teknologi Malaysia, 81310 Johor Bahru, Johor, Malaysia
[5]Department of Electrical Engineering Technology, Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia, Parit Raja, 86400, Batu Pahat, Johor, Malaysia
*Corresponding author, e-mail: mmgajibo@yahoo.com[1], mkamal@fke.utm.my[2], asniza@fke.utm.my[3], osman@fke.utm.my[4], mhuda@uthm.edu.my[5]

Abstract

A single layered metamaterial structure with capabilities of switching from a wideband metamaterial absorber to an AMC reflector and vice versa is presented in this paper. A flame retardant 4 substrate with physical thickness of 1.60mm was used. The absorption rate, reflection rate, reflection phase and surface current distribution were studied and discussed. The operational incidental wave angles were varied from 0^o to 65^o. A peak reflection of about 90% was achieved at 11.20 GHz with a usable bandwidth (-90 to +90) of 3.01 GHz by the AMC reflector. The metamaterial absorber demonstrated a wideband performance (from 8.10 GHz to 14.30 GHz). It achieved 100% absorption at 11.20 GHz and not less than 65% absorption across the entire X-band frequencies except for incidental wave angles above 55^o.

Keywords: *metamaterial, reflector, AMC, absorber, reconfigurable, switchable*

1. Introduction

Metamaterials (MTM) are said to be materials or structures that do not exist in nature. They are purposely or artificially engineered to exhibit properties not found in nature. These properties are obtained by manipulating the substances of structures to yield desired outcome [1]. A lot has been said with the emergence MTM and theories and concept behind bizarre properties of metamaterials MTM have long been established [2]. It is evidently proven that manipulating the substances yields unusual properties which are desired for certain applications such as EM filters, cloaking, low profile ground plane, sensing, reflectors, focus antenna beam, phase shifting [3] etc.

In general, Electromagnetic waves (EMW) absorbers are structures that absorbs incidental electromagnetic waves. They are designed to minimize reflection and transmission by maximizing energy loss within the structure [4]. Electromagnetic wave reflectors or Artificial magnetic conductor (AMC)s are structure purposely designed with unusual boundary conditions to be selective in supporting surface wave currents. [5].

Conventional electromagnetic waves absorbers such as Salisbury [6] and Dallenbach absorbers [7] in existence have limitations of being electrically thick, narrowband and can only operate in quarter wavelength [8,9]. similarly, conventional metallic conductors and perfect electric conductor (PEC) used for antenna ground planes have their drawbacks of reversal or out of phase image currents and propagation of surface current which is radiation caused by infinite ground plane. AMCs counter these drawbacks and even exhibit the ability to reduce back-radiation as well as increase gain. [3].

These new MTM based EMW absorbers and reflectors have high potentials for applications such as cloaking [7,8], solar cells [9] thermal emission [10,11], photo detector [12], radar imaging [13], antennas and tagged antenna for RFID [15], etc. AMC or electromagnetic bandgap (EBG) is a structure designed with unusual boundary conditions so as to be selective in supporting surface wave currents. In modern antennas, AMC’s are used to replace the

Received October 15, 2017; Revised February 23, 2018; Accepted March 28, 2018

perfect electric conductor (PEC) ground plane, this is simply because of the AMC's ability to reduce back-radiation as well as increase gain. [3]. One of the most importance things about AMC is its reflection angle, the structure is only considered AMC when its reflection phase is -180^0 to 180^0 and resonates at 0^0. It operates as an AMC at the point where the resonance frequency crosses 0^0. The useful bandwidth of an AMC is at -90 to 90 on either side of the resonance or central frequency.

2. Proposed design and simulation

The proposed MTM structure is patched on an FR4 substrate with a dielectric constant of 4.6, loss tangent of 0.019 and height of 1.60mm as shown in Figure 1. The structure consists of four square patches (P1-P4), two switches (S1 & S2), a long bar patch at the center and is full copper ground plane. The switches are used in selecting operation mode i.e either wideband MTM absorber mode or AMC reflector mode. The unit cell of the proposed structure measures 6.70mm by 5.90mm. The sizes of square shapes are given as P1=P3 measures 2.88mm by 2.60mm and P2=P4 measures 2.68mm by 2.70mm.

When both switches (S1 & S2) are closed, the structure operates as an AMC reflector while when switch S1 is open and S2 closed, it functions as a wideband Absorber. The structure is designed to operate at resonance frequency of 11.20 GHz.

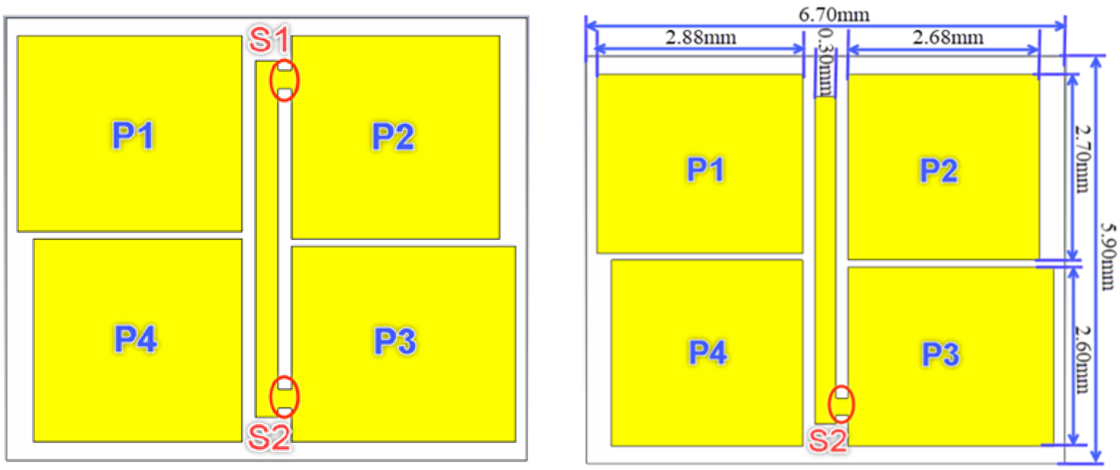


Figure 1. (a) Proposed structure as an AMC reflector (b) Proposed structure as a wideband MTM Absorber

3. Simulation results and discussions

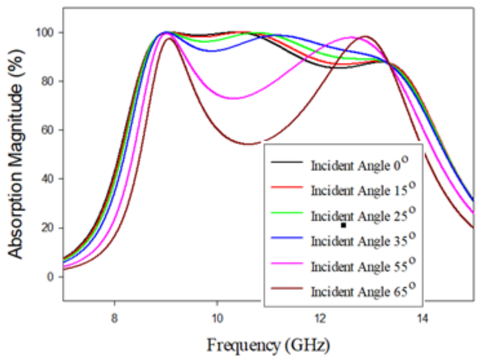
In order to have better understanding of the structure, the structure was simulated in both transverse Electric (TE) and transverse magnetic (TM) mode with various incidental wave angles (IWA) (0^o, 15^o, 25^o, 35^o, 55^o, and 65^o). The performance based on reflection and absorption magnitude, reflection phase and surface current were studied and reported.

3.1. Absorbance Magnitude for Different IWAs (TE and TM Mode)

In this section, the structure was simulated in "wideband absorber" mode. In order to switch to this mode, switch S1 is turned off while switch S2 is turned on. The TE mode simulation demonstrated three jointed resonances at 9.02 GHz, 11.20 GHz and 12.70GHz thus making it a wideband. At these three resonances, it achieved 100% absorbance. It also achieved above 92% absorbance for all frequencies bands within the X-band frequency range (8GHz -12GHz) except for IWA greater than 54^o. It is noted that at larger angles (55^o & 65^o), the absorbance at resonance 11.20 GHz dropped to as low as 73.30% and 55.20% respectively.

On the other side, with respect to the TM mode simulations, similar results were obtained. At the TM mode, the three jointed resonances achieved slightly less than 100%

absorbance when compared to the TE mode results. They achieved 98.83% absorption and for larger angles (55^o & 65^o), the absorbance at resonance 11.20 GHz dropped to as low as 66.70% and 53.60% respectively. The absorber has a total bandwidth of 6.20 GHz. This is shown in Figures 2a and 2b.



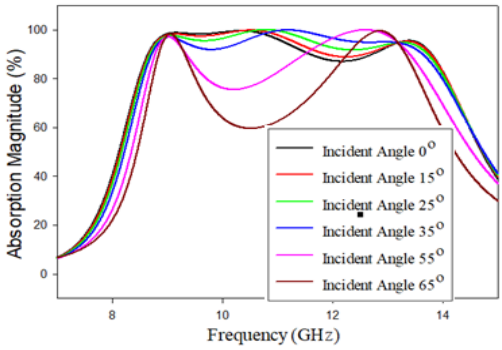
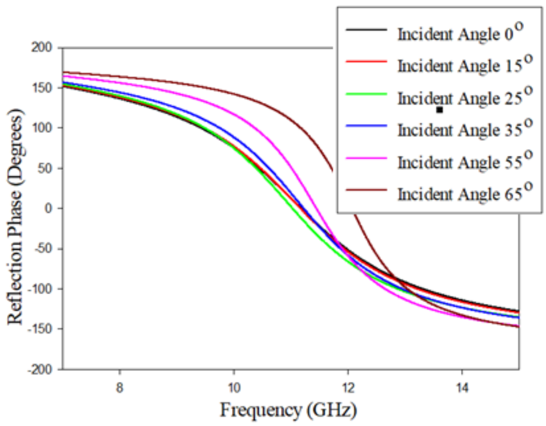


Figure 2. (a) TE mode Absorption rate (b) TM mode Absorption rate

3.2. AMCs reflection phase for Different IWAs (TE and TM Mode)

As stated earlier, for a structure to qualify or perform as an AMC reflector, it must be able to operate zero degrees phase wise. This is because for at zero phase, a constructive interference is established while at other phases a destructive interference is established. Thus, the phase is really important as well as critical. At zero-degree phase it has a periodic repetition of -180^o to 180^o but the usable bandwidth is only take from -90^o to +90. Putting that into consideration, it is safe to state that the reflector has a usable bandwidth of 3.01 GHz.

Here, the structure was simulated for different IWA just like in the absorber's case. For TE mode, it was noted that, for the first four angles (0^o, 15^o, 25^o, 35^o and 55^o) there is no significant phase shift at the "zero degrees. But, for angles greater than 54^o, the results showed significant shift in angles. The mentioned results are shown in Figures 3a and 3b.



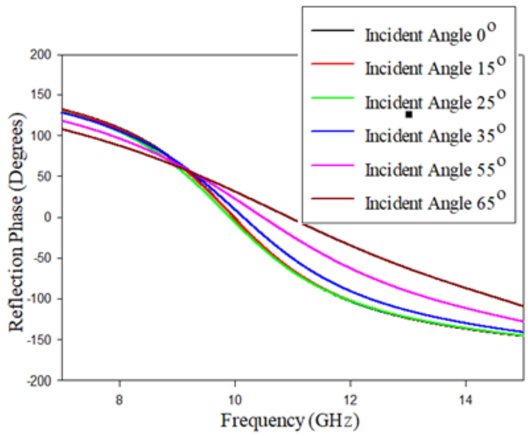


Figure 3. (a) TE mode AMC's reflection Phase (b) TM mode AMC's reflection Phase

3.3. AMCs reflection Magnitude for Different IWAs (TE and TM Mode)

Similar simulation was carried out here but this time, it is for the magnitude of the reflection at various IWA. It was observed that for both TE and TM mode there is shift in the resonance frequency as well as deterioration in reflection magnitude. With respect to TE mode, the shift witnessed in angles (0^0, 15^0, 25^0 and $35^{0)}$ are small and negligible. whereas for IWAs

(55^0 and 65^0) its considerably large as it from 11.20GHz to 11.53GHz and 12.10GHz respectively. It is also noted that as the angle is increased (0^o, 15^o, 25^o, 35^o, 55^o & 65^o) the reflection achieved kept deteriorating from 86.40%, to 85.85%, 84.30%, and 83.21% respectively.

With respect TM mode simulation, the scenario and results looks similar except that, for the shift in resonance frequency is to the left. This is to say as the IWA is increased, there is reduction in resonance frequency as well as reduction in reflection magnitude. This is shown in Figures 4a and 4b.

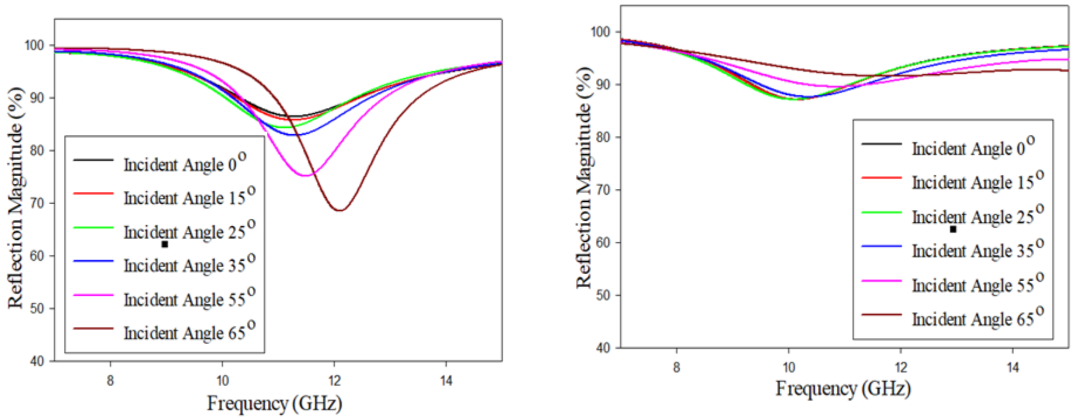


Figure 4. (a) TE mode AMC's reflection magnitude (b) TM mode AMC's reflection magnitude

3.4. Absorber's surface current for different IWAs (TE and TM Mode).

In this section, the surface current of the structure was simulated and the results were reported. For this analysis, 3 out of the 6 IWAs were selected. The selected angles are 0^o, 25^o and 65^o. These three IWAs were simulated for TE and TM mode.

Comparing the TE and TM results obtained at IWA 0^o and IWA 25^o it is noted that there is no difference between the TE and TM surface current. The current flows from the right to the left and there is much or higher concentration across the switch S2 region. In the case of IWA 65^o, it is evidently shown that the current distribution is more widely spread. This can be validated by the shift in resonance frequency and reduction is absorption rate. This is shown in Figure 5a to 5f.

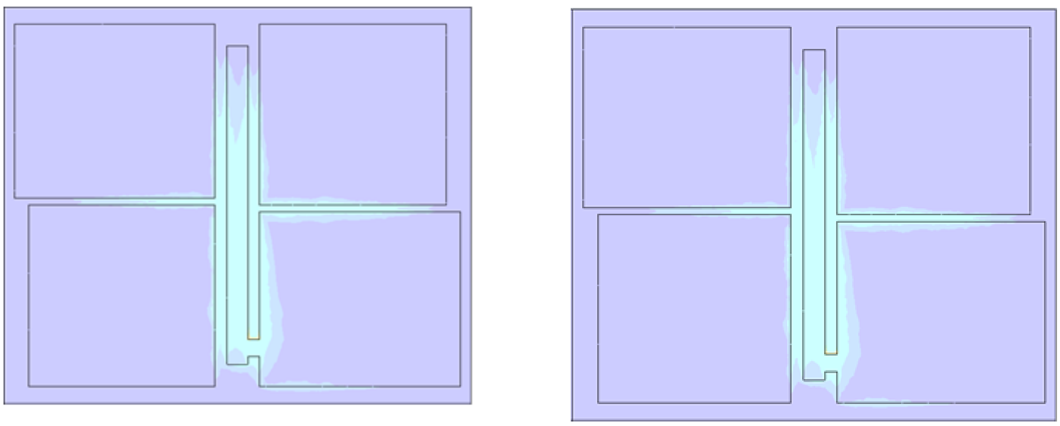


Figure 5. (a) TE surface current at IWA 0^o (b) TM surface current at IWA 0^o

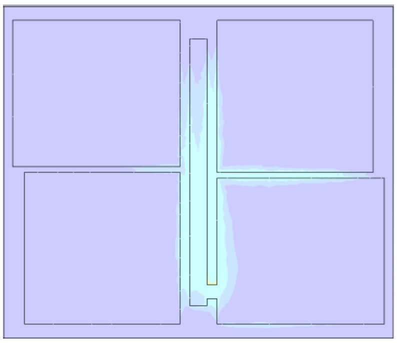
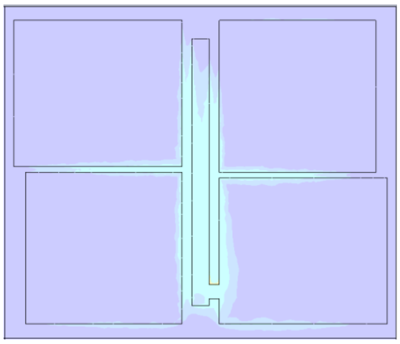


Figure 5. (c) TE surface current at IWA 25^o



(d) TM surface current at IWA 25^o

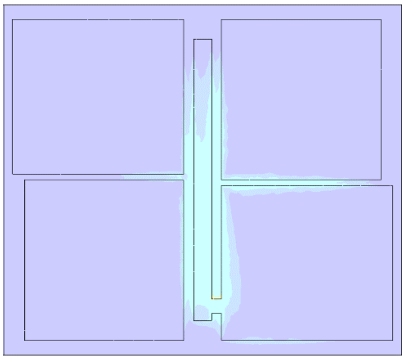
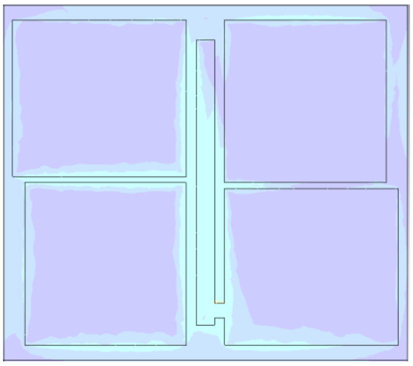


Figure 5. (e) TE surface current at IWA 65^o



(f) TM surface current at IWA 65^o

3.5. AMC's surface current for different IWAs (TE and TM Mode).

In order to have better understanding of the entire structure, the AMC structure was simulated and the current activities/ behavior was observed. The same IWAs were chosen as that of the absorbers surface current. For IWA 0^o and IWA 25^o and it was noted that for the TE mode, the current is concentrated around the two Switches and the center bar. Also, there is concentration in the gap between P1 & P2 and P3 & P4 and very little concentration at the edges.

The scenario is similar for the TM mode also, but this time, there is no current activity or less concentration in between P1 & P2. This is shown in Figures 6a-6d. For IWA 65^o, the surface current distribution is widely spread across the structure but this is expected as there is considerably large shift in the resonance frequency. This is show in Figures 6e and 6f.

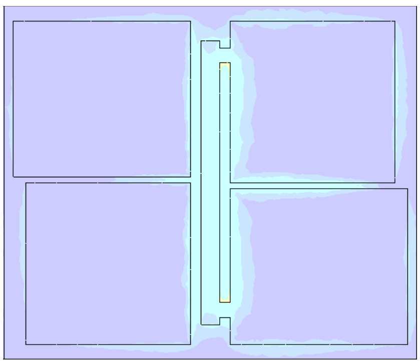
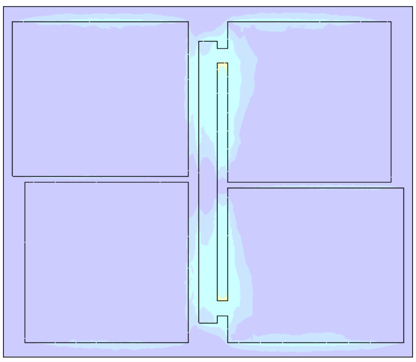


Figure 6. (a) TE surface current at IWA 0^o



(b) TM surface current at IWA 0^o

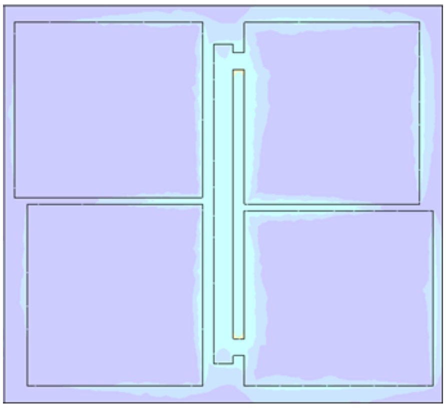
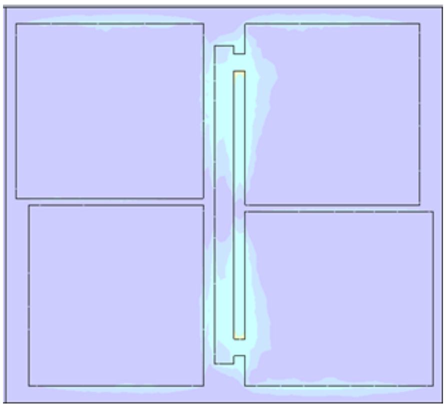


Figure 6. (c) TE surface current at IWA 25^o



(d) TM surface current at IWA 25^o

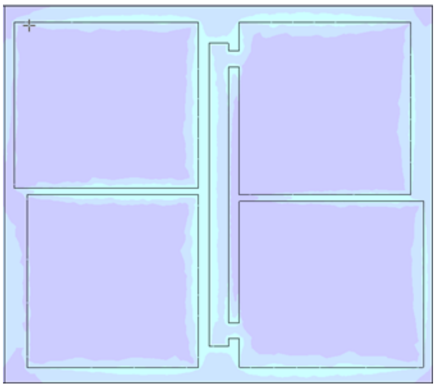
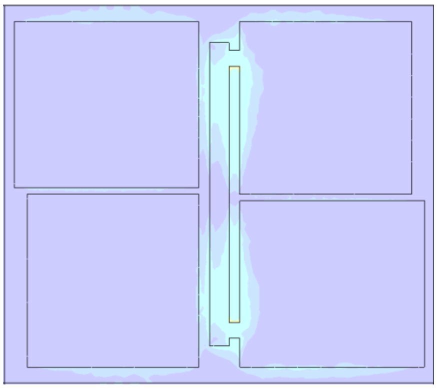


Figure 6. (e) TE surface current at IWA 65^o



(f) TM surface current at IWA 65^o

4. Conclusion

In this report a structure capable of switching between wideband MTM absorber and an AMC reflector was designed and presented. It was simulated for various IWAs (0^0, 15^0, 25^0, 35^0, 55^0 & 65^0) and its performance was tested. Additionally, the surface current and phase were observed. It resonated at 11.20GHz and demonstrated 100% absorption with a bandwidth of 6.20GHz as an absorber. Similarly, the structure demonstrated up to 90% reflection with a usable bandwidth of 3.01GHz as an AMC reflector. Furthermore, as the IWAs are increased to above 54^o, the performance dropped to around 65% and there was significant shift in the resonance frequency.

Acknowledgements

The authors thank the Ministry of Higher Education (MOHE) for supporting the research work, Research Management Centre (RMC), Universiti Teknologi Malaysia (UTM), Faculty of Electrical Engineering and Research Management Centre (RMC), Universiti Tun Hussein Onn Malaysia (UTHM), faculty of Engineering Technology, Research Center of Applied Electromagnetics for the supporting this research under grant no. 12H08, 4F883 and Vote No: GPPS U735 / FRGS 1614 respectively.

References

[1] Bala, Bashir & A Rahim, Mohamad Kamal & Mohd Yusoff, Abdull Rahim & Murad, Noor & Ismail, M. F. & Majid, H. *Design and Analysis of Metamaterial Antenna Using Triangular Resonator*. Proceedings of APMC 2012, Kaohsiung, Taiwan. 2012: 4-7.

[2] Landy, N.I, S. Sajuyigbe, J.J Mock, D. R. Smith and W.J.Padilla. Perfect metamaterial absorber. *Physical Review Letters*. 2008; 100.

[3] Ayop O., M.K.A. Rahim, N.A. Murad and N.A. Samsuri. Dual-resonant polarization-independent and wide-angle metamaterial absorber in X-band frequency. *Journal of Applied Physics*. 2016; 122(4):1-7.

[4] Gajibo M.M, M.K.A. Rahim, N.A. Murad, O. Ayop, B. D. Bala, H. A. Majid. X-band Operations Metamaterial Absorber with Extended Circular Ring Topology for Size Reduction. *Indonesian Journal of Electrical Engineering and Computer Science*. 2017; 6(1):180-184.

[5] Raimi Dewan, M. K. A. Rahim, M. R. Hamid, H.A. Majid, M.F.M. Yusoff, M.E. Jalil. Reconfigurable antenna using capacitive loading to Artificial Magnetic Conductor (AMC). *Microwave and Optical Technology Letters.* 2016; 58(10):2422-2429.

[6] D. Schurig, J.J. Mock, B.J. Justice, S.A. Cummer, J.B. Pendry, A.F. Starr, D.R. Smith. Metamaterial electromagnetic cloak at microwave frequencies. *Science.* 2006; 314(5801): 977–980.

[7] K. Alici, E. Ozbay. Radiation properties of split ring resonator and monopole composites. *Phys. Stat. Sol. B.* 2007; 244(4): 1192–1196.

[8] Ashyap A. Y.I., Z. Z. Abidin, S. H. Dahlan, H. A. Majid, Z. Muhammad, M. R. Kamarudin Parametric Analysis of Wearable Vialess EBG Structures and Its Alication for Low Profile Antennas. *TELKOMNIKA (Telecommunication Computing Electronics and Control).* 2017; 15(2): 718-725.

[9] R. Dewan, S. K. A. Rahim, S. F. Ausordin, and T. Purnamirza. The improvement of array antenna performance with the implementation of an artificial magnetic conductor (AMC) ground plane and in-phase superstrate. *Progress in Electromagnetics Research.* 2013; 140: 147-167.

[10] R. Fante and & M. McCormack. Reflection properties of the Salisbury screen. *IEEE Trans. Antennas Propagat*. 1988; 36:1443–1454.

[11] Du Toit, L. The design of Jauman absorbers. *IEEE Antennas Propagat. Mag*. 1994; 36:17–25.

[12] Raimi Dewan, M. K. A. Rahim. *Antenna performance enhancement with Artificial Magnetic Conductor (AMC).* IEEE Conference on Antenna Measurements & Applications (CAMA), Chiang Mai. 2015: 1-4.

[13] Abu, M. and M.K.A. Rahim. Single-band and dual-band artificial magnetic conductor ground planes for multi-band dipole antenna. *Radio Engineering Journal.* 2012; (4): 999-1006.

[14] R. Dewan, M. K. A. Rahim, M. R. Hamid, H.A. Majid, M.F.M. Yusoff, M.E. Jalil. *Ultra-wide band antenna with tunable Artificial Magnetic Conductor.* International symposium on antennas and propagation, ISAP 2014. 2015: 105-106.

[15] A. Pirhadi, M. Hakkak, F. Keshmiri, and R. Karimzadeh Baee. Design of compact dual band high directive electromagnetic bandgap (EBG) resonator antenna using artificial magnetic conductor. *IEEE Transactions on Antennas and Propagation*. 2007; 55:1682-1690.

[16] Gajibo. M.M, M. K. A. Rahim, N. A. Murad, O. Ayop, M. R. Hamid and H. A. Majid. *10.7 GHz Switchable Metamaterial Absorber/ Reflector for X-band Applications.* The 7th International Conference on Metamaterials, Photonic Crystals and Plasmonics, meta16, ISSN 2429-1390 pp2085-2086.

[17] Abu, M., E.E. Hussin, M.S.M. Isa, Z. Zakaria and Z.A.Baharudin. *Designing artificial magnetic conductor at 2.45 GHz for metallic detection in RFID tag Application.* 2014 International journal and Engineering technology (IJET).