Ultrathin Polarization Insensitive Dual/Triple Band Reconfigurable Metamaterial Microwave Absorber for C, X and Ku Band Applications

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ABSTRACT
A polarization independent dual/triple band metamaterial microwave absorber is designed and characterized. The absorber design comprise two square loop resonators and a circularly slotted square patch resonator designed with 0.03 mm thick copper plate. These resonators are separated by 1.56 mm thick FR4 dielectric from back annealed 0.03mm thick continuous copper plate. The simulated responses derived using HFSS shows that the intended absorber exhibits three absorption peaks at 4.75, 8.52 and 14.16 GHz with an absorption of 94.5%, 97.6% and 98.2%, respectively. The electrical dimensions of the unit cell are 0.158λ × 0.158λ computed at 4.75 GHz. The designed structure is polarization independent due to four-fold symmetric design configuration and therefore exhibit the same absorption response for both TE and TM polarizations for normal incident of the EM wave. The absorption response for oblique incidence angles has also been examined for both polarizations and the absorber exhibit above 80% absorption at oblique angles of incidence. Further, the designed is made frequency reconfigurable by embedding RF switches at circularly slotted square patch resonator. At off conditions of the switches, the design shows dual band behavior (for C, X) which makes it a potential candidate for reconfigurable RF applications such as RCS reduction, energy harvesting, wireless communication and sensors etc.

***Keywords**: metamaterial absorber, reconfigurable, multiband, rf switching*

I. INTRODUCTION

The first metamaterial absorber was developed in 2008 [1]. Metamaterial absorbers provides perfect absorption with ultrathin thickness and becomes alternative to their conventional thick absorbers such as Salisbury and Jaumann absorbers [2-3]. Further, the effective permittivity and permeability can be engineered to control the absorption frequency of the metamaterial based absorbers. The ease of design, ultrathin thickness and perfect absorption makes the metamaterial absorbers a better choice to serve applications from microwaves to optical regime [4-6]. Metamaterials based absorbers operates as periodic array of identical unit cells and can be expanded as per requirement. Despite of these features metamaterial absorbers suffers from narrow absorption bandwidth. Various efforts has been made to design multiband [7-8], broadband [9], switchable [10], tunable [11] and reconfigurable absorbers [12-13] to increase the range of applications of metamaterial absorbers. Frequency reconfigurable absorbers provides flexibility to use absorbers at desired frequencies by use of switches. It is cumbersome to operate at the multiple frequencies simultaneously, and also finds difficult to achieve wide band characteristics. Therefore, in metamaterial based absorbers the electronics devices such as PIN diodes, varactor diodes are most commonly used to change the frequency band [14]. Instantaneous frequency shift is possible through the use of such devices. Here a novel design of triple band metamaterial absorber is proposed and by using diode switches a flexibility to switch its operations from triple band to dual band and vice-versa is achieved.

II. DESIGN & SIMULATION

The design of unit cell of proposed absorber is shown in Fig. 1. The dimensions are as: L_1 = 10 mm, L_2 = 9mm, L_3 = 6 mm L_4 = 4 mm, W_1 = 0.5 mm, W_2 = 0.5 mm and R = 3 mm. The design is simulated using HFSS software. The top and bottom layers of the design are separated by FR4 substrate of dielectric constant 4.4 and thickness (T) 1.56 mm. The top layer is patterned with two square loops and a circularly slotted square patch. The absorption A(ω) is calculated by using the **Eq. 1** where $|S_{11}|^2$ is reflected power and $|S_{21}|^2$ is transmitted power.

$$A(\omega) = 1 - |S_{11}|^2 - |S_{21}|^2 \quad (1)$$

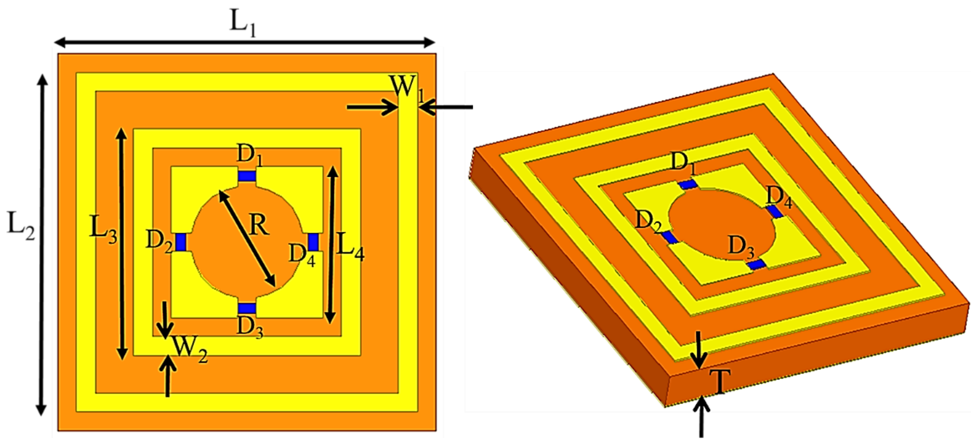

Figure 1: Unit Cell Design of Proposed Reconfigurable Absorber

As the proposed design is backed with a continuous copper plate therefore, the transmitted power will be zero and hence the absorption is evaluated as:

$$A(\omega) = 1 - |S_{11}|^2 \quad (2)$$

The simulated response under normal incidence of EM wave is shown in Fig.2. The three resonator design exhibit three absorption peaks at 4.75 GHz, 8.52 GHz and 14.16 GHz with absorption of 94.48%, 97.64% and 98.21 % respectively. The design exhibit absorption peaks in C, X and Ku bands which makes it suitable for respective band applications such RCS reduction etc.

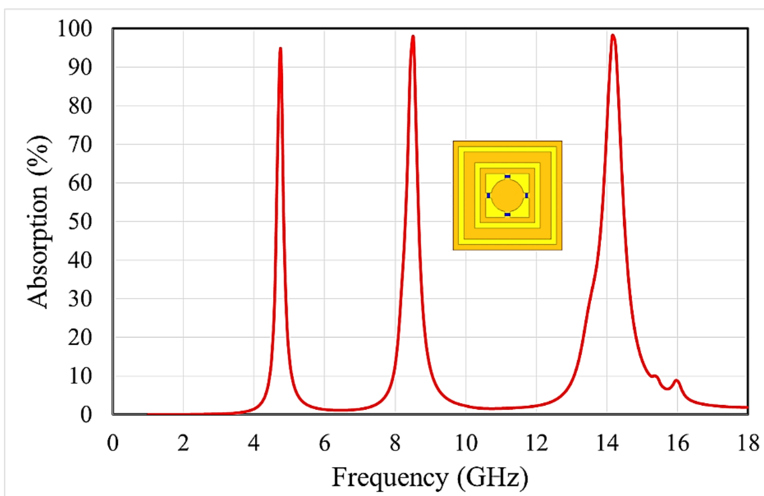

Figure 2: Simulated Absorption response of Proposed Absorber under normal incidence of EM wave under ON condition of switches

Due to the fourfold symmetric configuration of the design the absorber exhibit polarization insensitivity as shown in Fig. 3. The designed absorber exhibit same absorption for varying angle of polarization under normal incidence of the EM wave. Further, the absorption performance of the design is also verified for varying angles of oblique incidence of EM wave as shown in Fig. 4.

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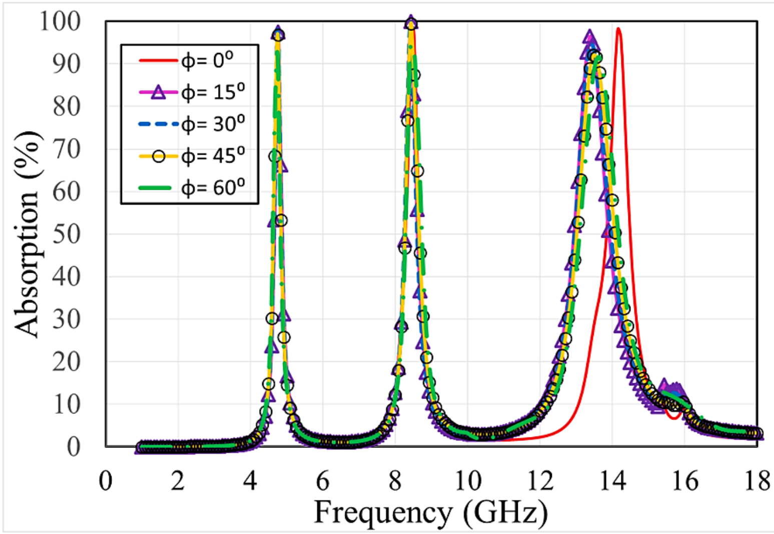

Figure 3: Simulated Absorption response under normal incidence for different polarization angles

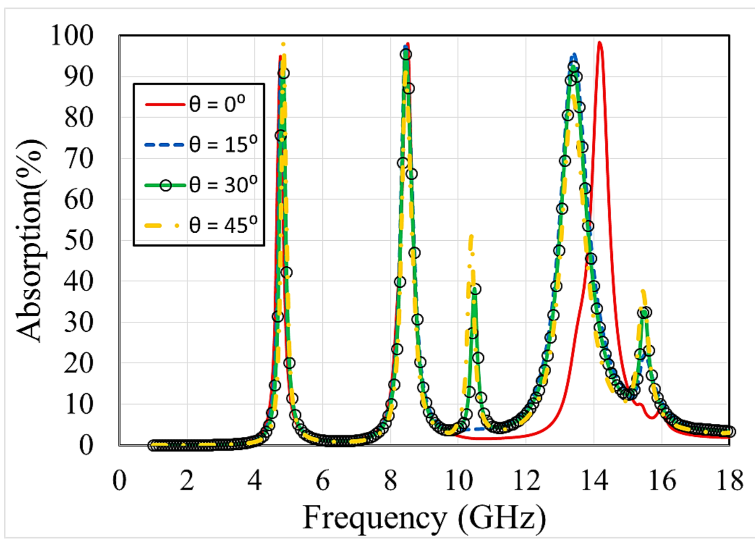

Figure 4: Simulated Absorption response under Oblique incidence for TE polarization angles

In order to understand the physical mechanism of absorption the electric and magnetic field distributions are studied at three absorption peaks as shown in Fig.5. It is observed that the fields are highly accumulated around outermost loop at 4.75 GHz as shown in Fig. 5 (a) & (b) which signifies that the outermost square loop contributes this first absorption peak. As observed from the Fig. 5 (c) & (d) that fields are highly concentrated near second square loop resonator at 8.52 GHz. Circularly slotted square patch contributes third absorption peak as electric and magnetic fields are highly accumulated around it at 14.16 GHz.

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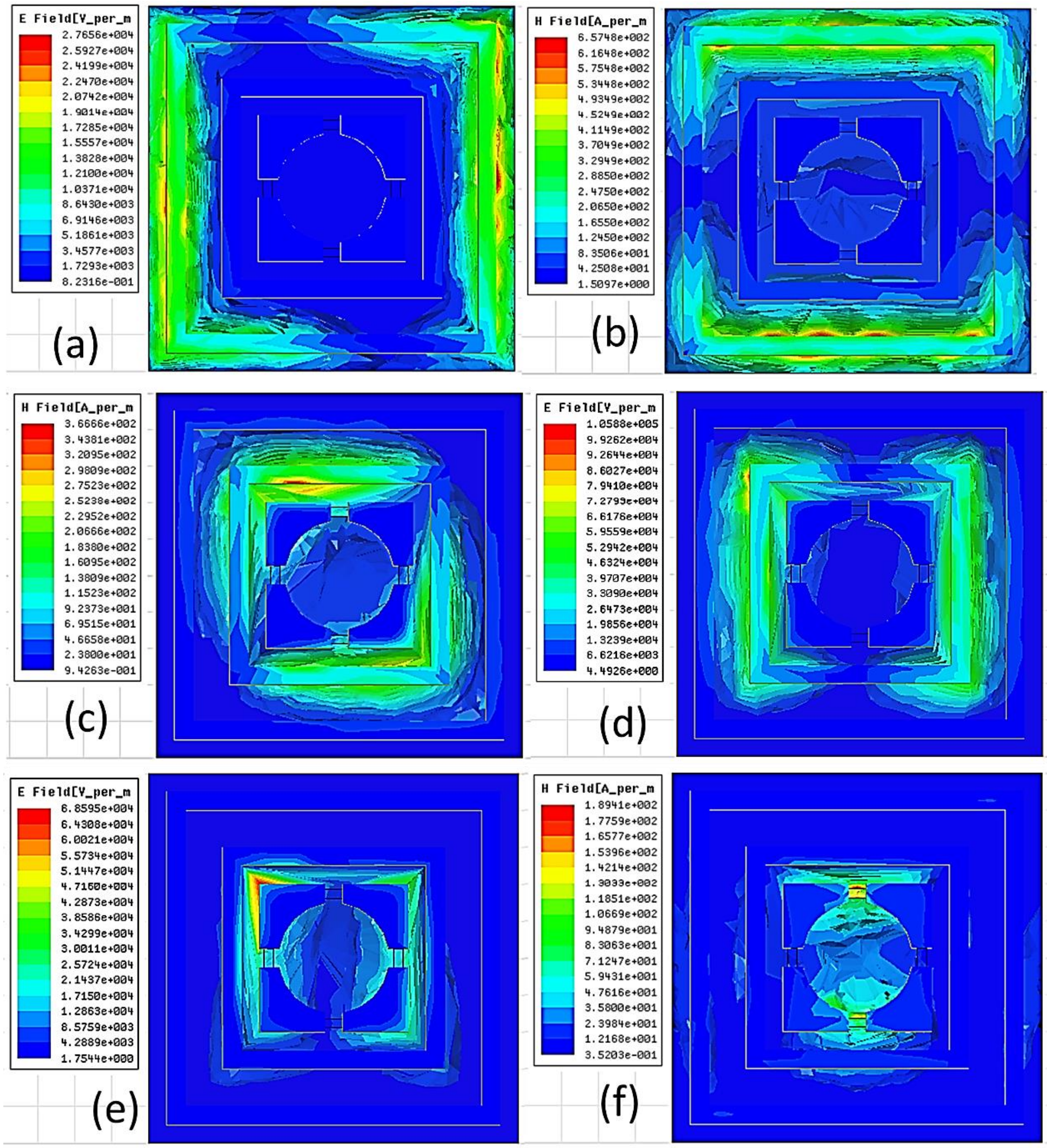

Figure 5: Field distribution at (a) (b) 4.75 GHz (c) (d) 8.51 GHz (e)(f) 14.16GHz

In order to make the design frequency reconfigurable a combination of four diode switches D1 to D4 have been installed symmetrically at the circularly slotted square patch. Under the ON conditions of diode switches the design exhibit triple band absorption but when switches gets OFF the third absorption peaks goes off and the design exhibit dual band absorption as shown in Fig.6. This feature enable the proposed absorber to be useful for switchable dual/triple band microwave absorber applications.

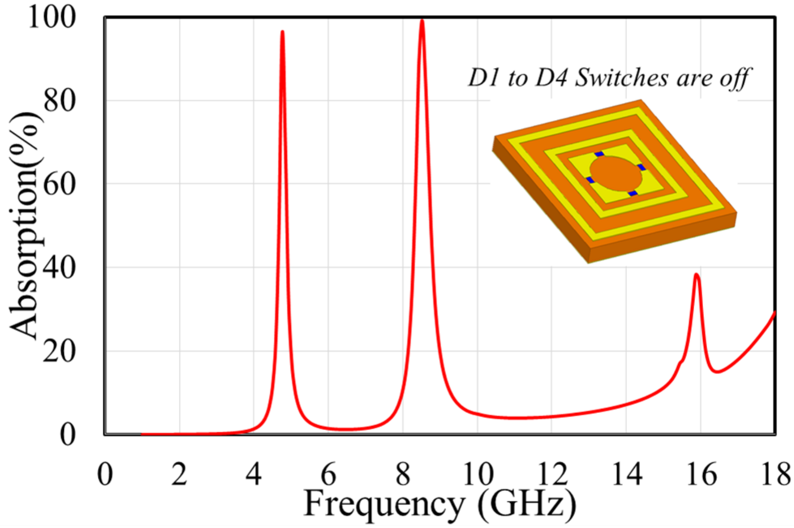

Figure 6: Simulated Absorption response of Proposed Absorber under normal incidence of EM wave under off condition of switches

III. CONCLUSION

A dual/triple band reconfigurable metamaterial microwave absorber is proposed. The absorber exhibits above 90% absorption at 4.75GHz, 8.52 GHz and 14.16 GHz at C, X and Ku microwave bands respectively. The designed absorber exhibits polarization-insensitivity and give above 90% absorption at all three absorption frequencies for varying incidence angle up to 45°. In order to get physical insight of absorption the electric and magnetic field distributions are studied at all three absorption frequencies. Frequency re-configurability is achieved by using diode switches at the third resonator thereby the design can switch its operation between dual/triple band that makes the design useful for switchable RF applications such as sensors, emitters, RCS reduction etc.

REFERENCES

1. N. I. Landy, S. Sajuyigbe, J. J. Mock, D. R. Smith, & W. J. Padilla. (2008). Perfect metamaterial absorber. *Physical Review Letters, 100,* 207402.
2. R. L. Fante, & M. T. Mccormack. (1988). Reflection properties of the salisbury screen. *IEEE Transactions on Antennas and Propagation, 36*, pp. 1443–1454.
3. L. J. Du Toit. (1994). The design of Jauman absorbers. in *IEEE Antennas and Propagation Magazine, 36*(6), pp. 17-25.
4. X. Zhao, K. Fan, J. Zhang, H.R. Seren, G. D. Metcalfe, M. Wraback, R. D. Averitt, & X. Zhang. (2015). Optically tunable metamaterial perfect absorber on highly flexible substrate. *Sensors and Actuators A: Physical, 231*, 74-80.
5. P.K. Singh, K. A. Korolev, M. N. Afsar, & S. Sonkusale. (2011). Single and dual band 77/95/110 GHz metamaterial absorbers on flexible polyimide substrate. *Applied Physics Letters*, *99*, 1–5.
6. C.M. Watts, X. Liu, & W.J. Padilla. (2012). Metamaterial electromagnetic wave absorbers. *Advanced Materials*, *24*, 98–120.
7. B. Zhu, C. Huang, Y. Feng, J. Zhao, & T. Jiang. (2010). Dual band switchable metamaterial electromagnetic absorber. *Progress in Electromagnetics Research B, 24*, 121-129.
8. J. Park, P. Van Tuong, J. Rhee, K. Kim, W. Jang, E. Choi, L. Chen, & Y. Lee. (2013). Multi-band metamaterial absorber based on the arrangement of donut-type resonators. *Opt. Express, 21*, 9691-9702.
9. D. Lee, H. Jeong, & S. Lim. (2017). Electronically switchable broadband metamaterial absorber. *Scientific Reports 7*, No. 4891.
10. R. Zhao, L. Shao, & W. Zhu. (2019). Switchable metamaterial absorber and reflector using PIN diodes. *International Conference on Microwave and Millimeter Wave Technology (ICMMT), Guangzhou, China*, pp. 1-3.
11. L. Lei, F. Lou, K. Tao, H. Huang, X. Cheng, & P. Xu. (2019). Tunable and scalable broadband metamaterial absorber involving VO2-based phase transition. *Photonics Research, 7*, 734-741.

12. J. Shabanpour, S. Beyraghi, & H. Oraizi. (2020). Reconfigurable honeycomb metamaterial absorber having incident angular stability. *Scientific Reports 10*, No. 14920.
13. R. Yang, J. Xu, J. Wang, R. Ma, & W. Zhang. (2019). Frequency-reconfigurable metamaterial absorber/reflector with eight operating modes. *Optics Express, 27*, 16550-16559.
14. X. Shen, T. Cui, J. Zhao, H. Ma, W. Jiang, & H. Li. (2011). Polarization-independent wide-angle triple-band metamaterial absorber. *Optics Express, 19*, 9401–9407.
15. L. Liu, S. Matitsine, R.F. Huang, & C.B. Tang. (2011). Electromagnetic smart screen with extended absorption band at microwave frequency. *Metamaterials, 5*, 36-41.
16. H. Kim, D. Lee, & S. Lim. (2016). Frequency-tunable metamaterial absorber using a varactor-loaded fishnet-like resonator. *Applied Optics, 55*, 4113-4118.