A Multiple-Bands Metamaterial Absorber Based in X, Ku and K-Band

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Abstract

Developing a highly efficient and multiple-bands metamaterial absorber is a hot issue in recent era. In this paper, A multiple-bands metamaterial absorber has been presented which is based in X, Ku and K-band. Firstly, we have designed two single layer basic unit cell of X-shape and cross-shape, then they are arranged in the multi-layers structure form for the purpose of obtaining multiple- bands and wide band absorption. The proposed absorber is able to work in multiple bands because it has six peaks in the frequency range of 8-24 GHz with having near perfect absorption. Moreover, the sixth peak has a wideband absorption which is 2.93 GHz. Furthermore, the proposed absorber is also tested for polarization insensitivity and also for oblique incidence. Absorption was found polarization insensitive with almost perfect absorption.

Key Terms: Metamaterial, Multiple-Bands, Polarization Insensitive, Oblique Incidence.

1. Introduction

Metamaterials are new forms of compounds that show incomparable electromagnetic properties. It is one of the main features which has been observed in recent times that it can perform as a perfect absorber for the incident EM wave. Metamaterials have numerous applications one of them is that it can be utilized in the stealth technology in the direction of remote sensing for a wide range of spectrums. Moreover, it has enormous characteristics like simple design, easy fabrication method, tunability, and broadband absorption.

Probably, the most acknowledged description of the metamaterials is that, a material which is composed of both metal and dielectric material and shows at the same time negative Dielectric constant (ε_r) and Magnetic Permeability (μ_r) [1]. When the negative Dielectric Constant and Magnetic Permeability have been attained then the other properties in the material will also change such as negative refractive index, phase velocity, and backward wave propagation. Due to their exceptional properties, they can be utilized in numerous fields such as in cloaking [2], filters [3], lens with perfect focusing [4], and electromagnetic wave absorption [5]. In the field of electromagnetic absorber, they can also be utilized as Radar Cross Section (RCS) lessening [6], reducing sidelobe radiation in the antennas and minimization of electromagnetic interference [7].

Victor G. Veselago firstly started to study the metamaterial on the property of a negative index of refraction in 1968 [8]. Sir John B. Pendry et al. had done the first experimental verification on the property of a negative index of refraction in 1999 [9]. Metamaterials have been utilized for the first time in 2008 as an Absorber which has perfect absorption by Landy et al [10]. From that point forward, various kinds of Single-Band [11-15] and Multiple-Band [16-20] MA contemplates were designed. Moreover, polarization-independent [21-25] and Tunable Perfect Metamaterial Absorbers (PMA) [26-30] were structured in the Gigahertz, Megahertz, and also in Terahertz.

Mehmat et al. [31] have proposed an Absorber which consists of a split ring resonator (SRR) and it has the perfect absorption between 4 and 16 GHz. As it has high absorption so it tends to be employed in wireless power transfer applications. In [32], they have proposed an ultra-thin triple-band metamaterial resonant structure. The unit cell has an absorption spectrum of 3-12 GHz having three absorption peaks at 3.44 GHz, 6.36 GHz, and 11.51 GHz with more than 90% absorption. The proposed unit cell has additionally demonstrated for polarization insensitivity and for oblique incidence for both Transverse Electric and Transverse Magnetic modes of propagation. The proposed unit cell is appropriate for potential microwave frequency applications. In [33], they have proposed a broadband absorber in which eight square patches were loaded on the double ring structure. They have used two layers of resistance film for the purpose of achieving better absorption. They have achieved the absorption of more than 90% at 0.95 GHz and at 18.4 GHz. It has also the characteristic of polarization insensitivity. In [34], they have used the finite integration technique (FIT) to design the metamaterial absorber based on a multi-layer resonance structure. The proposed unit cell works in the frequency regime of 5 to 8.9 GHz. Moreover, the four-layer unit cell allows absorption peaks with an intensity of over 90%. It also works for oblique incidence and polarization insensitivity. The proposed unit cell has applications in the design of radar shield or military devices.

In this article, we have proposed a multi-layers and multiple-bands metamaterial absorber which works efficiently in X, Ku, and K-band. Firstly, we have proposed the two single-unit cells of X-shaped and Cross-shaped structures. X-shaped structure has five absorption peaks in the frequency regime of 12-24 GHz and a Cross-shaped structure has three absorption peaks in the frequency regime of 10-24 GHz. Then we have put these designs in multi-layers form for the purpose of obtaining multiple frequency bands and wide bandwidth. We have utilized two cross-shaped structures and one X-shaped structure in the multi-layers form. The best Multi-layers structure has six absorption peaks with above 80% absorption at the frequency of 9 GHz, 9.7 GHz, 11.2 GHz, 13.2 GHz, 15.3 GHz, and at 20.7 GHz. Moreover, the sixth peak has wideband absorption of 2.93 GHz. Furthermore, the proposed design is also tested for the Polarization insensitivity and for oblique incidence. The proposed design was found polarization-insensitive with perfect absorption.

This paper is divided into four sections, after the introduction the second section includes design details of the proposed absorber. In the third section, results are discussed. In the end conclusion of the proposed design has been discussed.

2. Design and Theory

We have designed two different unit cells structure for the purpose of obtaining multi-bands absorption. The first design is X-shaped structure and the second design is cross-shaped structure. The copper has been utilized for top and bottom layer whose thickness is chosen of 0.035 mm. Furthermore, fr-4 substrate has been used as a dielectric material whose relative permittivity is chosen to be 4.4, thickness of 1.6mm and loss tangent is 0.02. As can be seen from the Fig.1 that the first basic unit cell is modeled using X-shaped structure, and the second basic unit cell is made using Cross-shaped structure. The dimension of the both proposed unit cell are as follows P=24 mm, W=1.5 mm, L=18 mm, L1=5 mm, L2=6 mm.
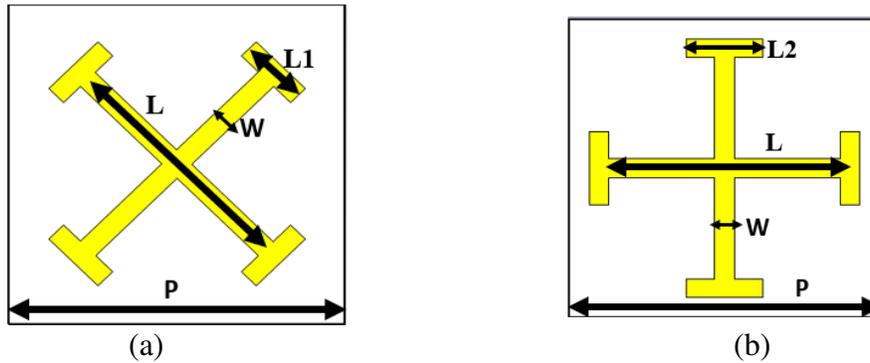

Fig.1. Schematic design of unit cell (a) Proposed basic unit cell of X-shape (b) Proposed basic unit cell of Cross-shape.

We have used these basic unit cells in the multi-layers form. We have designed three multi-layers structures. It has to be remembered that the di-electric layer of same thickness which is applied on the basic unit cells is also applied in multi-layers design between each periodic structure design layer and bottom layer is grounded with copper metal which can be seen in the Fig.2.

In the first design, we have kept an X-shaped structure on top and the Cross-shaped structure in the second and third layer. In the second design, we have kept a X-shaped structure in between the two Cross-shaped structures. In the third design, we have kept a X-shaped structure in the third layer and both Cross-shaped structures in the first and second layers which can be seen from the Fig.3
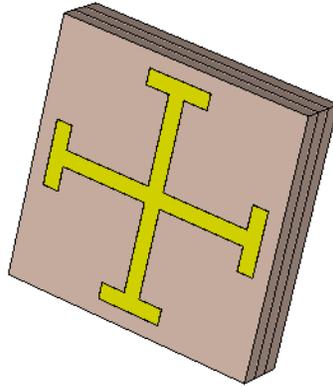
Fig.2. Prospective view of the multi-layer design structure.

Layer 1 (Bottom)   Layer 2   Layer 3 (Top)

(a)

Layer 1 (bottom)   Layer 2   Layer 3 (top)

(b)

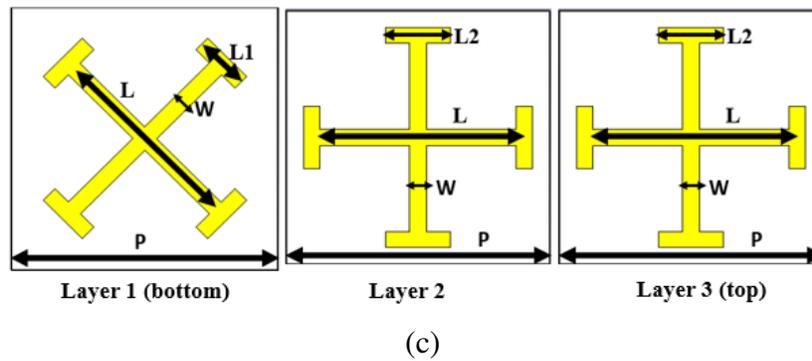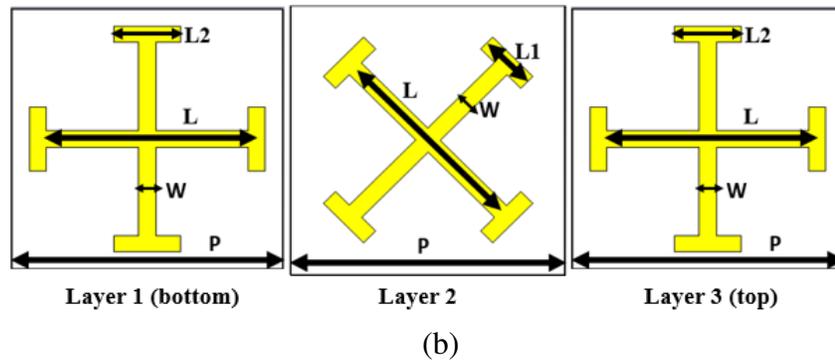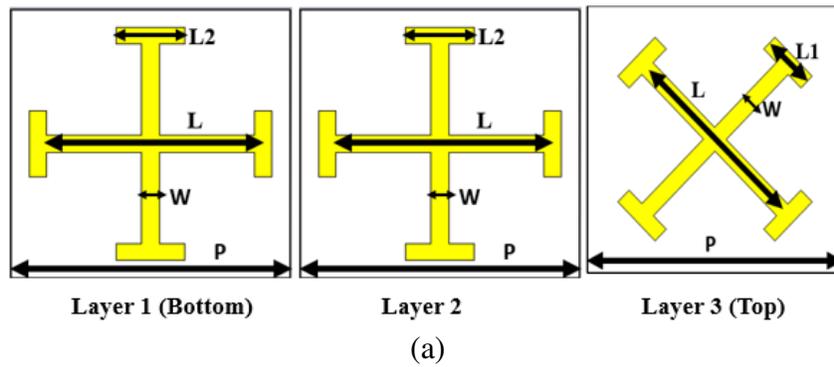Layer 1 (bottom)   Layer 2   Layer 3 (top)

(c)

Fig.3. Multi-layer proposed Structure with (a) X-shaped structure on top layer (b) X-shaped structure in middle layer (c) X-shaped structure in the bottom layer.

We have used commercially available software Computer Simulation Technology (CST) Studio Suite 2017 [35] for the simulation purposes of the design. We have chosen the unit cell boundaries along the x and y axis and open boundaries along the z-axis.

## 3. Simulated Results sand Discussions

For the purpose of designing a well-organized and consistent absorber, it is very essential that the reflection and transmission must be minimum. The absorption can be calculated from equation (1) where $\mathcal{A}(f)$ is absorption, $\mathcal{R}(f)$ is reflection and $\mathcal{T}(f)$ is transmission of the wave and in terms of S-parameter $\mathcal{R}(f) = |S_{11}(f)|^2$, $\mathcal{T}(f) = |S_{21}(f)|^2$.

$$\mathcal{A}(f) = 1 - \mathcal{R}(f) - \mathcal{T}(f) \quad = 1 - |S_{11}(f)|^2 - |S_{21}(f)|^2 \tag{1}$$

As the unit cell is grounded with copper metal so the transmission will be zero and the modified form of Equation (1) will be as

$$\mathcal{A}(f) = 1 - |S_{11}(f)|^2 \tag{2}$$

Fig.4 represents the simulated absorption of the X-shaped structure and Cross-shaped structure. According to the Fig.4. there are five absorption peaks for the X-shaped structure in the frequency from 12 GHz to 23 GHz. There are three absorption peaks for the Cross-shaped structure from the frequency 10 GHz to 24 GHz. This is obvious from the Fig.4 that the cross-shaped structure has absorption peaks at 10.8GHz, 15.7GHz, and 23.7GHz with the absorption of approximately 90%. This design works in three frequency bands of X, Ku and K-band. The X-shaped structure has five absorption peaks at 13GHz, 16.7GHz, 18.2GHz, 20.4GHz and at 22.5GHz with an absorption of 90% except one absorption peak which is at 20.4GHz has an absorption of 80%. This design mainly works in two different frequency bands of Ku and K-band.
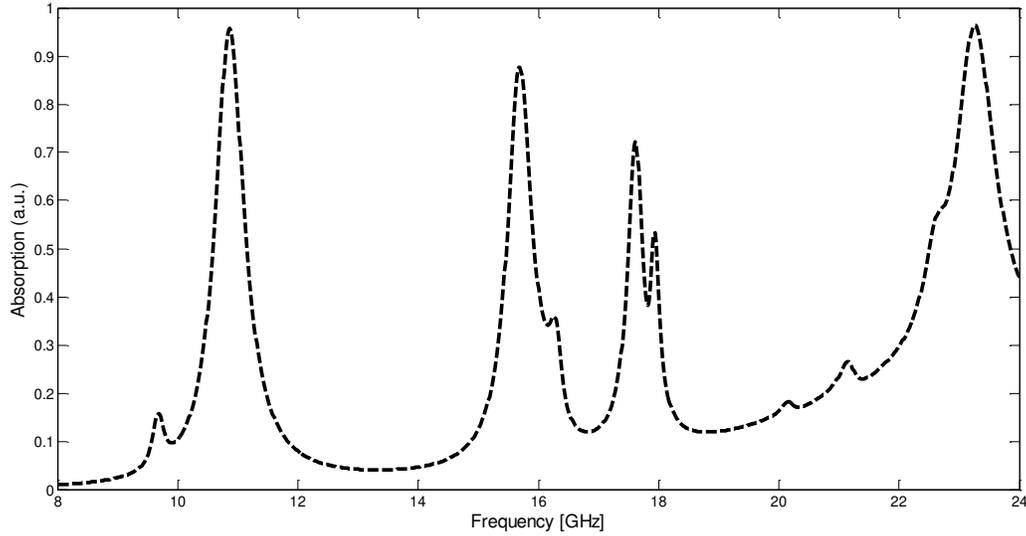
(a)
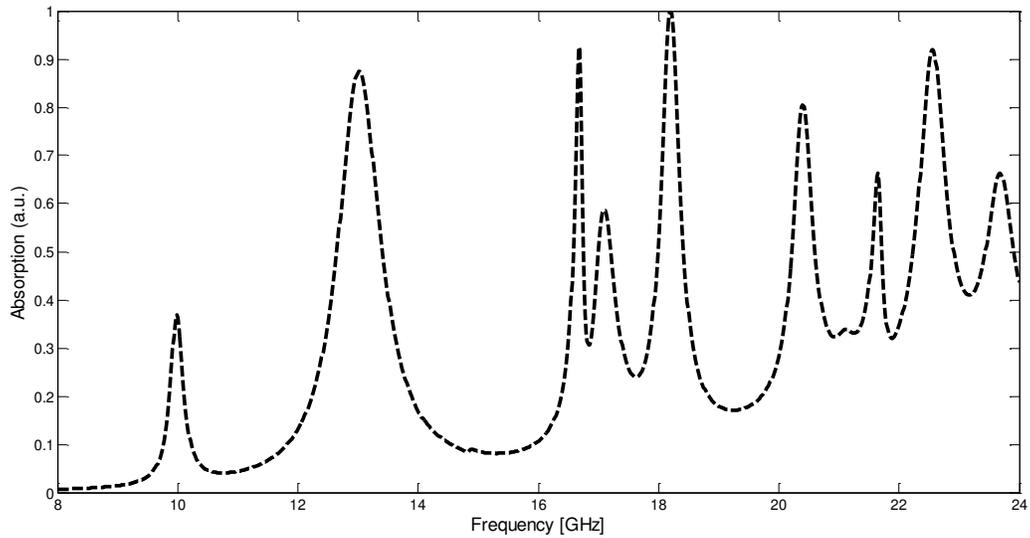
(b)

Fig.4. Absorption results for single layer design (a) Absorption results for the Cross-shaped Structure (b) Absorption results for the X-shaped structure.

We have combined these both designs in the three-layers form in three patterns to obtain the wideband absorption and multiple bands. As it is obvious from the Fig.3 that the Cross-shaped structure works in three different frequency bands of X, Ku and K-band. X-shaped structure works in two frequency bands of Ku and K-band so for the purpose of obtaining multiple frequency bands we have used Cross-shaped structure in two layers. The absorption results for all three designs are shown in Fig.5.

The Fig.6 shows the best absorbance result of the multi-layers structure and according to the Fig.5 the 1st pattern has the best absorption so that is why we have chosen it as our final design because it has six absorption peaks at 9 GHz, 9.7 GHz, 11.2 GHz, 13.2 GHz, 15.3 GHz and at 20.7 GHz in the X, Ku and K-band. Moreover, the sixth peak has 2.93 GHz bandwidth from the frequency 20.74 GHz to 23.67 GHz and with the absorption of above 80%. These are the best results so far research has been done in Giga Hertz frequency regime. Cheng et al. [36] have achieved seven peaks but they are not wideband similarly Xu et al. [37] and Ranjan et al. [38] have achieved six peaks but they are also not wideband as compared to our results.
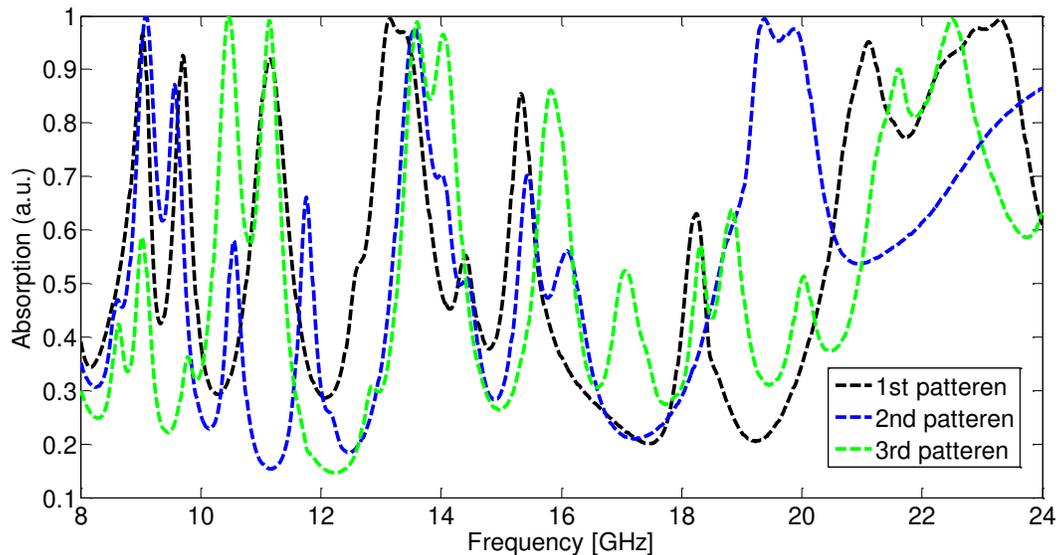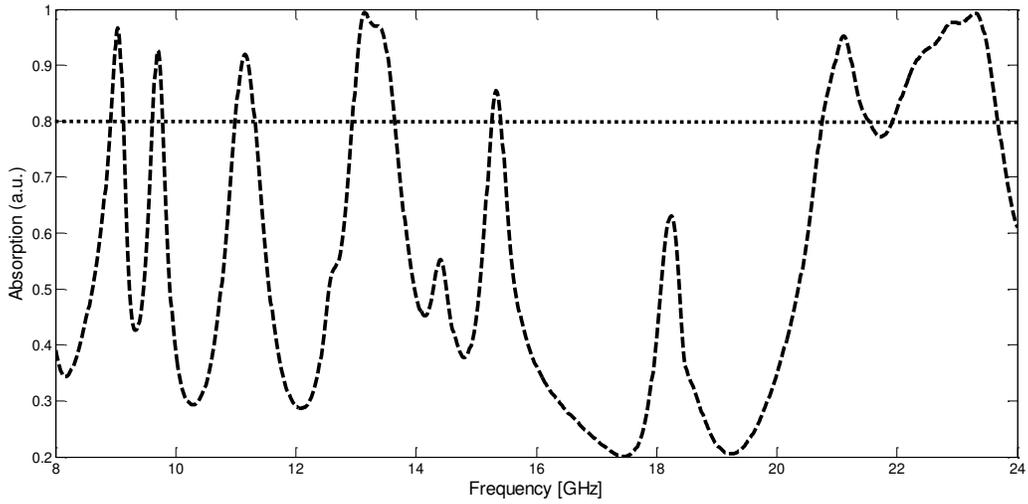
Fig.6. Best Absorption results of the multi-layer structure.

The effect of polarization insensitiveness has been examined in the Fig.7 for the different values of polarization angles (Phi=0-60). As the proposed absorber has a symmetrical shape that is why it has been observed that it shows stable absorption towards the changing polarization. The effect of Oblique Incidence has been examined in the Fig.8 for the different angles in the range between Theta=0-60. The resonant frequency and the absorption have been reduced by changing the oblique incidence, although the proposed structure is not extremely influenced by the changing oblique incidence.
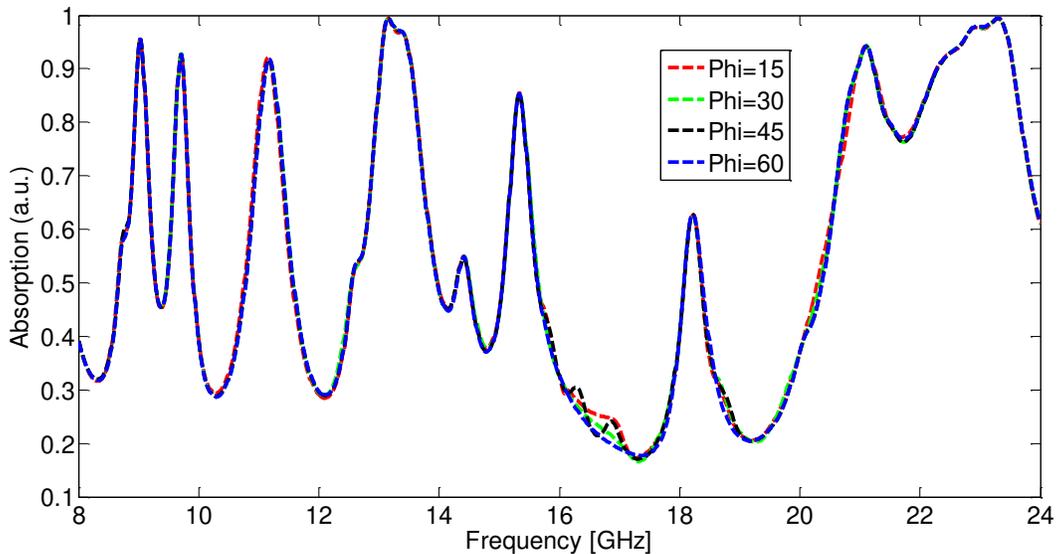

Fig.7. The incident wave polarization effect for Phi=0-60 with step size 15.
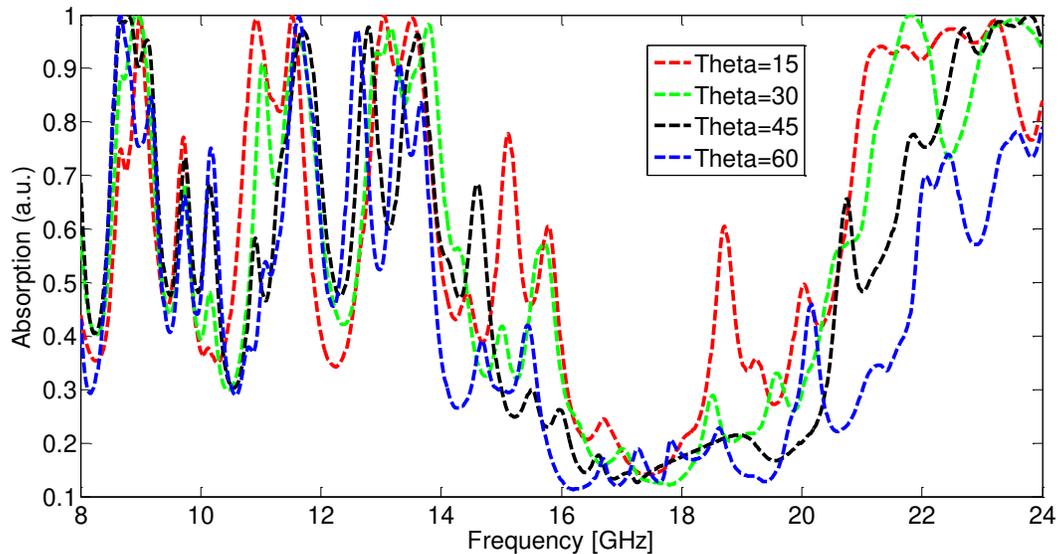
Fig.8. The oblique incident angle effect for Theta=0-60 with step size 15.

4. Conclusion

In this article, we have presented a multi-layer absorber structure which works in the X, Ku, and K-band. We have shown that the proposed absorber is able to work in multiple bands and it has six peaks in the frequency range of 8-24 GHz with the absorption above 80%. Moreover, the sixth peak has a wideband absorption which is 2.93 GHz. These are the so far best result achieved in the Giga Hertz frequency regime. Furthermore, the proposed absorber is also tested for polarization insensitivity and also for oblique incidence, though it does not strictly work for oblique incidence. As the proposed absorber works in X, Ku and K-band so it has numerous applications like in satellite communication, terrestrial microwave communication and radar communication.

Conflict of Interest:

The authors declare that they have no conflict of interest.

References

[1] Bilotti F, Sevgi L. "Metamaterials: definitions, properties, applications, and FDTD-based modeling and simulation (Invited Paper)". Int J RF Microwave Computer Aided Engineering 2012, 22(4):422–38 DOI: 10.1002/mmce.20634
[2] Hongsheng Chen, Bae-Ian Wu, Baile Zhang, and Jin Au Kong, "Electromagnetic Wave Interactions with a Metamaterial Cloak", Phys. Rev. Lett. 99, 149901 (2007), DOI: https://doi.org/10.1103/PhysRevLett.99.063903.
[3] Y.H. Zhu, S. Vegesna, Y. Zhao, V. Kuryatkov, M. Holtz, Z.Y. Fan, M. Saed, and A.A. Bernussi," Tunable dual-band terahertz metamaterial bandpass filters" Opt. Lett. 38, 2382 (2013).
[4] Pendry JB. "Negative refraction makes a perfect lens". Physical Review Lett 2000, 85 (18):3966–9 DOI: https://doi.org/10.1103/PhysRevLett.85.3966.
[5] Wang B, Koschny T, Soukoulis CM. "Wide-angle and polarization-independent chiral metamaterial absorber". Physical Review B 2009, 80(3):0331081–83 DOI: https://doi.org/10.1103/PhysRevB.80.033108.
[6] Munk BA. Frequency selective surfaces: theory and design. Wiley-Interscience: New York; 2000 ISBN: 978-0-471-37047-5.
[7] Emerson WH. "Electromagnetic wave absorbers and anechoic chambers through the years". IEEE Transaction Antennas Propagation 1973, 21(4):484–90.

[8] Veselago VG. "The electrodynamics of substances with simultaneously negative values of e and l". Soviet Physics Solid State 1968, 10(4):509–14.

[9] Pendry JB, Holden AJ, Robbins DJ, Stewart WJ. "Magnetism from conductors and enhanced nonlinear phenomena". IEEE Transaction Microwave Theory Technol 1999;47 (11):2075–84.

[10] Landy NI, Sajuyigbe S, Mock JJ, Smith DR, Padilla WJ. "Perfect metamaterial absorber". Phys Rev Lett 2008;100(20):2074021–24, DOI: https://doi.org/10.1103/PhysRevLett.100.207402.

[11] Ramya Sekar, Srinivasa Rao Inabathini, "An Ultra-thin Compact Wideband Metamaterial Absorber" Electromagnetics Radio Engineering, Vol. 27, NO. 2, June 2018, DOI: 10.13164/re.2018.0364.

[12] D. Sood, Chandra C. Tripathi, "A Compact Ultrathin Ultra-Wideband Metamaterial Microwave Absorber" Journal of Microwaves, Optoelectronics and Electromagnetic Applications, Vol. 16, No. 2, June 2017 DOI: http://dx.doi.org/10.1590/2179-10742017v16i2797

[13] Xiangkun KONG, Junyi XU, Jin-jun MO and Shaobin LIU, "Broadband and conformal metamaterial absorber" Front. Optoelectronics. 2017, 10(2): 124–131 DOI 10.1007/s12200-017-0682-z.

[14] Thtreswar Beeharry, Riad Yahiaoui , Kamardine Selemani and Habiba Hafdallah Ouslimani, "A Co-Polarization Broadband Radar Absorber for RCS Reduction", Materials 2018, 11, 1668; doi:10.3390/ma11091668.

[15] Quanlong Yang, Xieyu Chen, Yanfeng Li, Xueqian Zhang, Yuehong Xu, Zhen Tian, Chunmei Ouyang, Jianqiang Gu, Jiaguang Han, and Weili Zhang, "Aperiodic-metamaterial-based absorber" APL Materials 5, 096107 (2017), https://doi.org/10.1063/1.4996112.

[16] Gobinda Sen, Sk. Nurul Islam, Amartya Banerjee, and Santanu Das, "Broadband Perfect Metamaterial Absorber on Thin Substrate for X-Band and Ku-Band Applications" Progress in Electromagnetics Research C, Vol. 73, 9–16, 2017 DOI: 10.2528/PIERC17011101

[17] Mohammad Jakir Hossain, Mohammad Rashed Iqbal Faruque, Mohammad Tariqul Islam and Kamarulzaman bin Mat, "A New Compact Octagonal Shape Perfect Metamaterial Absorber for Microwave Applications" Appl. Sci. 2017, 7, 1263; doi:10.3390/app7121263.

[18] Young Ju Kim, Ji Sub Hwang, Young Joon Yoo, Bui Xuan Khuyen, Joo Yull Rhee, Xianfeng Chen, and YoungPak Lee, "Ultrathin microwave metamaterial absorber utilizing embedded resistors", 2017, J. Phys. D: Appl. Phys., at press: https://doi.org/10.1088/1361-6463/aa82f4.

[19] Han Xiong, Jin-Song Hong, Chao-Ming Luo, and Lin-Lin Zhong, "An ultrathin and broadband metamaterial absorber using multi-layer structures", Journal of Applied Physics 114, 064109 (2013), Doi: 10.1063/1.4818318.

[20] Kavitha Muthukrishnan & Venkateswaran Narasimhan, "An Ultra-Thin Triple-Band Polarization-Independent Wide-Angle Microwave Metamaterial Absorber" Plasmonics https://doi.org/10.1007/s11468-019-00985-y.

[21] Xiqiao Chen, Zhuang Wu, Zilong Zhang, Liuyang Heng, Shuai Wang, Yanhong Zou "Impedance matching for omnidirectional and polarization insensitive broadband absorber based on carbonyl iron powders" Journal of Magnetism and Magnetic Materials 476 (2019) 349–354, https://doi.org/10.1016/j.jmmm.2018.12.054.

[22] Peng Zhou, Gaige Zheng, Fenglin Xian, Linhua Xu, "Dynamically switchable polarization-independent and broadband metasurface perfect absorber in the visible and near-infrared spectra regime" Results in Physics 11 (2018) 278–282, https://doi.org/10.1016/j.rinp.2018.09.022.

[23] Saptarshi Ghosh, Somak Bhattacharyya, Yadunath Kaiprath, and Kumar Vaibhav Srivastava, "Bandwidth-enhanced polarization-insensitive microwave metamaterial absorber and its equivalent circuit model", Journal of Applied Physics 115, 104503 (2014); doi: 10.1063/1.4868577.

[24] Sachin Kalraiya, Raghvendra Kumar Chaudhary, and Mahmoud A. Abdalla, "Design and analysis of polarization independent conformal wideband metamaterial absorber using resistor loaded sector shaped resonators", J. Appl. Phys. 125, 134904 (2019); Doi: 10.1063/1.5085253.

[25] ZhiHui Yang, YongXing Che, Xin Sun, JiuLin Zhang, JiangXiao Tian, HaiTao Yu, and Qi Huang, "Broadband polarization-insensitive microwave-absorbing composite material based on carbon nanotube film metamaterial and ferrite", J. Appl. Phys. 125, 185103 (2019); https://doi.org/10.1063/1.5086315.

[26] Gwanho Yoon, Sunae So, Minkyung Kim, Jungho Mun, Renmin Ma and Junsuk Rho, "Electrically tunable metasurface perfect absorber for infrared frequencies" Nano Convergence (2017) 4:36, https://doi.org/10.1186/s40580-017-0131-0.

[27] Ahmmed A. Rifat Mohsen Rahmani, Lei Xu and Andrey E. Miroshnichenko, "Hybrid Metasurface Based Tunable Near-Perfect Absorber and Plasmonic Sensor", Materials 2018, 11, 1091; https:// doi:10.3390/ma11071091.

[28] GuoWen Zhang, Jun Gao, Xiangyu Cao, HuanHuan Yand, Liaori Jidi, "An Ultra-Thin Low-Frequency Tunable Metamaterial Absorber Based on Lumped Element" Radio Engineering, VOL. 28, NO. 3, September 2019, DOI: 10.13164/re.2019.0579.

[29] Jiakun Song, Cheng Huang, Jianing Yang, Xu Zhang, Jinqiang Peng, and Xiangang Luo, "Broadband and Tunable Radar Absorber Based on Graphene Capacitor Integrated with Resistive Frequency Selective Surface" DOI 10.1109/TAP.2019.2943419, IEEE Transactions on Antennas and Propagation.

[30] Xin-Ru Kong , Hai-Feng Zhang , Ri-Na Dao , Guo-Biao Liu, "A tunable polarization insensitive ultra-broadband absorber based on the plasma metamaterial", Optics Communications 453 (2019) 124435, https://doi.org/10.1016/j.optcom.2019.124435.

[31] Mehmet Ba gmancı, O guzhan Akgöl, Meliks ,ah Özaktürk, Muharrem Karaaslan, Emin Ünal, Mehmet Bakır, Polarization independent broadband metamaterial absorber for microwave applications2019, https://doi.org/10.1002/mmce.21630.

[32] Kavitha Muthukrishnan1 & Venkateswaran Narasimhan, An Ultra-Thin Triple-Band Polarization-Independent Wide-Angle Microwave Metamaterial Absorber, Plasmonics 2019, https://doi.org/10.1007/s11468-019-00985-y

[33] Xiaoqi Shao, Jiahui Fu, Bo Lv, Wan Chen, Ultrathin broadband absorber based on metamaterials 2019, DOI: 10.1109/CSQRWC.2019.8799270

[34] Jiakun Song, Cheng Huang, Jianing Yang, Xu Zhang, Jinqiang Peng, and Xiangang Luo, Broadband and Tunable Radar Absorber Based on Graphene Capacitor Integrated with Resistive Frequency Selective Surface, DOI 10.1109/TAP.2019.2943419, IEEE Transactions on Antennas and Propagation 2019.

[35] https://www.cst.com/2017.

[36] Yongzhi Cheng, Yao Zou, Hui Luo, Fu Chen, and Xuesong Mao, "Compact Ultra-Thin Seven-Band Microwave Metamaterial Absorber Based on a Single Resonator Structure", Journal of Electronic Materials https://doi.org/10.1007/s11664-019-07156-z.

[37] Guo-Qing Xu, Zong-De Ju, Zhi-Hua Wei1, Jing Li, Qian Zhao, and Jie Huang, "A Novel Six-Band Polarization-Insensitive Metamaterial Absorber with Four Multiple-Mode Resonators" Progress in Electromagnetics Research C, Vol. 77, 133–144, 2017.

[38] Prakash Ranjan, Arvind Choubey, Santosh Kumar Mahto & Rashmi Sinha, "A six-band ultra-thin polarization-insensitive pixelated metamaterial absorber using a novel binary wind driven optimization algorithm" Journal of Electromagnetic Waves and Applications, DOI: 10.1080/09205071.2018.1510344