Three band absorber design and optimization by neural network algorithm

Shihab A. Shawkat¹, Khalid Saeed Lateef Al-badri²,³*, Israa Al_Barazanchi⁴

¹Directorate of education, Salah al-din, Iraq. ²Physics Dept., University of Samarra, Iraq. ³Computer Centre, University of Samarra, Iraq. saaedkhalid@gmail.com

Abstract. In this study, multi band absorber design based on signal absorbing metamaterial. After the metamaterial structure has been designed, the split gap is optimized by the neural network algorithm to get optimum absorption. By this way, metamaterial MTM absorber for stealth applications design has been created. In the simulation, the MTM signal absorbing was found to have three excellent absorption bands at x-band 8.41 GHz, 9.73 GHz, and 12.1 GHz with absorption level 91.65%, 99.35%, and 96.6% respectively. When the increasing the split gap diminution lead to nonlinear change in absorption level additionally resonance frequency. This proposed structure can be used as a multi band absorber application, stealth applications, and energy harvesting.

1. Introduction

Metamaterial are defined as an artificial electromagnetic (EM) structures that are periodically designed with unusual features not found in natural material. The first theoretical studies on electromagnetic metamaterial were done by Veselago [1] in 1968. In the Veselago study, the theory that the relative dielectric constant $\varepsilon_r$ and magnetic permeability $\mu_r$ parameters indicating the EM property of the materials were negative in a certain frequency range revealed the theory that the medium might have a negative refractive index. Later, in 1996 and 1999, Pendry et al. [2] presented an experimental study to confirm the theoretical study of Veselago and showed that these parameters could be simultaneously negative. In the years that followed, researchers began to focus on metamaterial-based fabrication methods and applications needed in science and technology [3]. The popularity of MTMs has increased rapidly due to their unique properties such as negative refractive index, group velocity and sensor [4] has been the subject of research in many applications such as signal absorption [5], antenna [6], superconductor [7], energy harvesting [5,8], and clocking [9]. In addition, MTMs have excellent electromagnetic signal absorbing properties that have been investigated in many studies [10,11].

Most of the MTM studies focused on the real part of $\varepsilon (\omega) = \varepsilon_1 + i\varepsilon$ and $\mu (\omega) = \mu_1 + i\mu_2$ values to produce the material with negative refractive index. However, the missing components of optical constants ($\varepsilon_2$ and $\mu_2$) have considerable potential for forming unusual and useful materials. For example, these materials can be constructed to form structures with perfect electromagnetic absorption properties. The concept of signal-absorbing MTM (SAMTM) has been widely discussed in recent years by Landy et al. In 2008 [12]. There are many studies on microwave, terahertz, infra-red and optical frequency areas with SAMTMs [13-22]. SAMTMS are usually generated using metallic
electrical resonators to absorb the incoming electric field. Metallic split ring layers are used to absorb the incoming magnetic field. In general, it is necessary to provide some special requirements to form SAMTMs such as many SAMTMs consisting of three layers. In this context, the large dielectric loss tangent $\delta\varepsilon$, large magnetic loss tangent $\delta\mu$, $\varepsilon(\omega)$ and $\mu(\omega)$, taking into consideration the parameters, the distance between the plates with the electric resonator and the dimensions of the metallic electric resonator are adjusted. Thus, the generated SAMTM can absorb the entire EM wave. This mechanism is explained by several models, mainly impedance matching. In the impedance matching mechanism, the three-layer structure is considered to be a thin plate made from a homogeneous medium with its frequency-dependent effective dielectric constant $\varepsilon_{\text{eff}}(\omega)$ and effective magnetic permeability $\mu_{\text{eff}}(\omega)$. In perfect absorption frequency, $\varepsilon_{\text{eff}}(\omega)$ and $\mu_{\text{eff}}(\omega)$ reach the same value $\varepsilon(\omega) = \mu(\omega)$ \[4,17\].

As a result, materials with excellent absorption capacity are obtained. SAMTMs offer a very suitable infrastructure for applications where wireless detection techniques are required in the desired frequency ranges. These sensing techniques can be effectively used as sensor and multi-sensor applications in many areas such as ground observation and air traffic control systems \[4,16-18\]. Using MTM extraordinary features with stealth has become an important research area. Microwave-based MTM stealth react to many communication applications on radar, mobile, and satellite. With simple changes made in the geometry of MTMs with simple design, adjustments can be made in the desired frequency ranges. In this study, using the designed MTM with perfect absorption, SAMTM with perfect absorption in the x-band frequency range.

2. Design procedure
The main objective of the study is to design structures with multiband absorption features using MTM structures with a simple design. Changes in structure parameters lead to the electrical absorption properties of the recommended material. In this manuscript, the design of the proposed structure and the linearity of the absorption results serve as the basis for further studies in this area and provide the basis for further research such as the sensor, multiband absorber and energy harvesting. The architecture of the proposed structure is defined as a sandwich structure. The back surface of the dielectric layer is covered with a metal layer to prevent electromagnetic wave transmission and to obtain the maximum absorption value. The front face of the structure designed in Figure 1 (a) is shown. Figure 1 (b) shows the CST set-up.

![Figure 1. (a) perspective view of the proposed structure, (b) the left side view and (c) CST setup.](image)

The entire metal plate and resonators used in the designed structures are composed of copper conductors with electrical conductivity of $5.8 \times 10^7$ S/m and 0.035 mm thickness. The dielectric layer
consists of FR-4 type materials and has 1.48 mm thickness, 4.3 dielectric permeability, 1 magnetic permeability and 0.025 loss tangent. The entire MTM structure has a size of 22.86 mm, 10.16 mm. The resonator consists of two connected circles with radius 2.8 mm and 4.8 mm and the ring width 0.5 mm finally the resonator gap is 0.25 mm see figure 1(a).

3. Numerical analysis

When EM wave hits an object, it can be absorbed, reflected and transmitted according to the structure and design of the object. The frequency of this wave in the frequency range shows whether it is absorbed or reflected. In this context, absorption can be calculated using the formula:

\[ A(\omega) = 1 - |S_{11}|^2 - |S_{12}|^2, \]

which is a function of angular (frequency). frequency which is related to direct reflection (S_{11}) and transmission (S_{12}) coefficients. Since the metal plate at the rear of the structure prevents all transmission, the absorption value is only dependent on the reflection coefficient. In this case, the absorption formula can be written as:

\[ A(\omega) = 1 - |S_{11}|^2 \]

and it is understood that the reflection coefficient should be minimized to obtain maximum absorption from this equation. This condition is only possible by matching the impedance of the designed structure with the impedance of the incoming signal in the empty space. In this way, excellent absorption can be achieved by ensuring the impedance matching and by fulfilling the requirements of the metal plate and the transmission inhibition.

![Figure 2. electromagnetic absorption response of the proposed structure.](image)

The design, calculations and analysis of the structure were performed using the CST Microwave Studio program. In the simulation study, x and y direction is chosen as perfect electrical conductor (PEC) boundary condition and z direction as open boundary condition. These boundary conditions require that the applied wave be TE polarized wave. The
dimensions of the proposed structure are determined by a parametric study and optimized by using neural network algorithm, to obtain the best absorption value in the communication band. Frequency-related absorption values of the structure obtained according to the optimization results are given in Figure 2.

In Figure 2, it is seen that they are four absorption bands 8.41 GHz, 9.73 GHz, 11.31 GHz and 12.1 GHz with absorption level 91.65%, 99.35%, 70.8% and 96.6% respectively. Three of them are perfect absorption bands 8.41 GHz, 9.73 GHz, and 12.1 GHz. According to this result, the proposed structure can be defined as MTM with excellent absorption. In the next step, the effect of the wave on the absorption characteristic of the structure was analyzed numerically.

Figure 3 shows the surfaces current distribution. The result refers to three absorption bands at different parts of resonator.

![Surface current distribution](image)

Figure 3. Surface current distribution at perfect absorption band. (a) at resonance frequency 8.41 GHz, (b) at resonance frequency 9.73 GHz, (c) at resonance frequency 12.1 GHz.

Additionally, in order to grasp the effect of the substrate (FR4) and copper on the absorption the simulation of power losses figure 4 present that the main power loses at the substrate and which is represented an ohmic losses [4].
Finally, Figure 5 plots the absorption spectra for different values of gap size at normal incidence. The physical origin of the near perfect absorption is the localization of electric and magnetic dipole resonances LC resonance, where L and C are the effective inductance and capacitance [10], respectively. When the gap size changes from 0.1 mm to 0.55 mm, the absorption peaks nonlinear a resonance shift and the absorption level.

4. Conclusion

In this study, MTM based multi band signal absorbing design in the x-band frequency was investigated. Excellent absorption was observed at absorption level 91.65%, 99.35%, and 96.6% of the proposed structure. According to the results, as the gap increased, nonlinear shifts in the resonance frequency and absorption level of the structure occurred. This metamaterial absorber can be used in multi band absorption applications, stealth applications, radar cross section redaction and energy harvesting.

References

[1]. Veselago, V.G., 1968. Electrodynamics of Media with Simultaneously Negative Electric Permittivity and Magnetic Permeability, Physics-Uspekhi 10(4), 509–14.
[2]. Pendry, J.B., 2000. Negative Refraction Makes a Perfect Lens, Phys. Rev. Lett. 85(18), 3966–9.

[3]. Smith, D.R., Padilla, W.J., Vier, D.C., NematNasser, S.C., Schultz, S., 2000. Composite Medium with Simultaneously Negative Permeability and Permittivity, Phys. Rev. Lett. 84(18), 4184–7.

[4]. Al-Badri, K. S., Cinar, A., Kose, U., Ertan, O., & Ekmecki, E., 2016. Monochromatic tuning of absorption strength based on angle-dependent closed-ring resonator-type metamaterial absorber. IEEE Antennas and Wireless Propagation Letters, 16, 1060-1063.

[5]. Al-badri, K. S. L. 2018. Electromagnetic broad band absorber based on metamaterial and lumped resistance. Journal of King Saud University-Science, doi:10.1016/j.jksus.2018.07.013.

[6]. Tetik, E., Tetik, G.D., 2017. The Effect of a Metamaterial Based Wearable Microstrip Patch Antenna on Human Body, Can. J. Phys. cjp2017-0755.

[7]. Aydin, K., Bulu, I., Ozbay, E., 2007. Subwavelength Resolution with a NegativeIndex Metamaterial Superlens, Appl. Phys. Lett. 90(25).

[8]. Unal, E., Dincer, F., Tetik, E., Karaaslan, M., Bakir, M., Sabah, C., 2015. Tunable Perfect Metamaterial Absorber Design using the Golden Ratio and Energy Harvesting and Sensor Applications, J. Mater. Sci. Mater. Electron. 26(12), 9735-40.

[9]. Schurig, D., Mock, J.J., Justice, B.J., Cummer, S.A., Pendry, J.B., Starr, A.F., Smith, D.R., 2006. Metamaterial Electromagnetic Cloak at Microwave Frequencies, Science 314(5801), 977-980.

[10]. Al-Badri, K. S. L., Karacan, N., Kucukoner, E. M., & Ekmecki, E., 2018. Sliding planar conjoined cut-wire-pairs: A novel approach for splitting and controlling the absorption spectra. Journal of Applied Physics, 124(10), 105103..

[11]. Al-badri, K. S. L., 2019. Multi Band Metamaterials Absorber for Stealth Applications. Law, State and Telecommunications Review, 11(1), 133-144..

[12]. Landy, N.I., Sajuyigbe, S., Mock, J.J., Smith, D.R., Padilla, W.J., 2008. Perfect Metamaterial Absorber, Phys. Rev. Lett. 100(20).

[13]. Xu, W., Sonkusale, S., 2013. Microwave Diode Switchable Metamaterial Reflector/absorber, Appl. Phys. Lett. 103(3).

[14]. Chen, H.T., Padilla, W.J., Cich, M.J., Azad, A.K., Averitt, R.D., Taylor, A.J., 2009. A Metamaterial Solid-state Terahertz Phase Modulator, Nat. Photonics 3(3), 148–51.

[15]. Ginn, J., Shelton, D., Krenz, P., Lail, B., Boreman, G., 2009. Altering Infrared Metamaterial Performance Through Metal Resonance Damping, J. Appl. Phys. 105(7).

[16]. Al-Badri, K. S. L., 2018. Very High Q-Factor Based On G-Shaped Resonator Type Metamaterial Absorber. Ibn AL-Haitham Journal For Pure and Applied Science, 159-166.

[17]. Tetik, E., 2017. An Overview of Metamaterial Researches, Researches on Science and Art in 21St Century Turkey, Gece Publishing 2, 1817–25.

[18]. Boopathi, Rani, R., Pandey, S.K., 2017. Metamaterial-inspired Printed UWB Antenna for Short Range RADAR Applications, Microw. Opt. Technol. Lett. 59(7), 1600–4.

[19]. Abdalla, M.A., Hu, Z., 2012. On the Study of Development of X Band Metamaterial Radar Absorber, Adv. Electromagn. 1(3), 94-98.
[20]. Bagmanci, M., Karaaslan, M., Altintas, O., Karadag, F., Tetik, E., Bakir, M., 2018. Wideband Metamaterial Absorber Based on CRRs with Lumped Elements for Microwave Energy Harvesting, 52(1), 45-59.

[21]. Al-Badri, K., & Ekmekçi, E. 2016. A Numerical Study with Various Intersecting Twin Structures on Tuning the Absorption Spectra in S-Band.

[22]. Al-badri, Khalid Saeed Lateef, Omar Fadhil Abdullah, and Ahmed Ibrahim Turki. "Penta-Perfect Metamaterial Absorber for Microwave Applications." In IOP Conference Series: Materials Science and Engineering, vol. 454, no. 1, p. 012075. IOP Publishing, 2018.