

Multi Band Metamaterials Absorber for Stealth Applications

Submitted: 14/02/2019

Revised: 03/04/2019

Accepted: 07/04/2019

Khalid Saeed Lateef Al-badri*

Abstract

Purpose – This paper presents a simulation study using CST microwave studio computer software.

Methodology/approach/design – A simple structure based on metamaterial are used to construct a perfect metamaterial absorber. It is made of just one uncompleted square patch copper placed on top of dielectric layer to separate it from a copper ground plate.

Findings – This design provides four perfect absorption regions with absorption peaks of an average of 93%. The characteristic study of parameters such as copper dimensions and dielectric properties led to an expected result in the synthesis of resonant frequency.

Practical implications – The multi-band absorption can be used in energy harvesting applications, protection from the effects of electromagnetic waves, radar stealth technology and thermal imaging. Moreover, the experimental results show good agreement with CST simulation.

Keywords: metamaterial, perfect absorber, radar stealth, microwave.

Introduction

Metamaterials are materials with ideal characteristics in the spectrum of electromagnetic waves and in the size of micro cell compared with the wavelength. They have attracted significant attention due to their exotic properties that are unavailable in nature such as invisibility cloaking (Schurig et al., 2006), radar stealth (Ji et al., 2019), sensor (Al-Badri et al., 2017), negative index of refraction (Smith et al. 2004), split-ring resonator (Pendry et al. 1999; Wang et al. 2013; Al-Badri, 2018), fishing net structure (Faruk et al., 2019), conductive rings separate from each other (Dolling et al., 2005). Stunning structures have been proposed to achieve the amazing properties of electromagnetic metamaterials (Yu et al., 2018). Most proposed metamaterials have inevitable energy losses which reflect negatively on their performance. On the other hand, these losses play a fundamental role in photonics applications.

*Master of Electronics and Communication Engineering at Süleyman Demirel University, Turkey. Member of the Iraqi Engineers Union. Instructor and researcher at the College of Engineering (Electromechanics Department) and College of Education (Physics Department) at University of Samarra, Iraq. Director of Computer and Information Center at University of Samarra. Member of the Committee for the Development of Computer and Informatics Curricula in the Iraqi Ministry of Higher Education. E-mail: khalidsaeed@uosamarra.edu.iq.

The first perfect metamaterial absorber PMMA was proposed by in 2002 by Landy et al. (2008), having the measured absorptivity of around 88%. It was composed of metallic split-ring SRR and wire separated by a dielectric layer. From that, metamaterial perfect absorber has gotten significant attention, and a great number of them have been proposed since (Shchegolkov et al. 2010; Huang et al. 2012) with the ability to achieve unity absorption of electromagnetic waves (*i.e.*, 100% absorption) suitable to several applications such as spectroscopic detection, phase imaging, micro-bolometers, cell thickness meter and solar cell applications. As a matter of fact, the improvement of the ideal perfect metamaterials absorber is particularly alluring at terahertz administration where it is hard to discover natural materials that could be utilized in airport security for detection purposes, imaging system and thermal detectors. Absorbers working in microwave band are equally important, as they play a decisive role in reducing noise interference in radars, assembling power and making use of it in wireless charging, military industries, sensors and stealth technology (Cao et al. 2019; Singh et al. 2019). Several efforts have been made to achieve perfect absorption for the electromagnetic waves. For example, Fernández Álvarez et al. (2015) achieved one band with absorptivity of around 98%. Landy et al. (2009) obtained a polarization insensitivity absorber with an absorptivity of 77%. Shchegolkov et al. (2010) demonstrated a wide- angle one band perfect absorber. Tragically, every one of these endeavors share the regular inadequacy of limited absorption band, *i.e.* narrow absorption bandwidth, which hampers their functional applications. Further studies tackled that problema with double band (Al-Badri et al. 2019) and triple-band absorption (Wang et al. 2014; Cao et al. 2019; Singh et al. 2019). Also, a few endeavors have been made toward the advancement of wide band metamaterial perfect absorber by stacking numerous layers of metallic resonators in a unit cell (Grant et al. 2011; Wang et al. 2014; Al-Badri, 2018; Hu et al. 2013).

This study presents a four-band absorber in a microwave frequency band 9-15 GHz due to its importance for several applications such as radar, satellite communication, and wireless computer networks (Dong et al. 2012; Selvanayagam et al. 2010). In most structures, a three-layered structure is adopted: Two metallic layers separated from each other by an electrical insulator. The shape and dimensions of the first metallic layer are selected as specified below and the last layer often has a flat surface and works to prevent any transition of the electromagnetic wave also acts as a reflecting mirror. Additionally, we present a four-band 60° polarization-insensitive for microwave region. The polarization angle was studied numerically.

Design

Many studies in the past focus into symmetric metamaterial resonator to obtain high absorption. Interesting results will appear when the symmetry of the metamaterial resonator is broken. For example, multi-band absorber and wideband absorption. In this research, an uncompleted squared UCS-shaped perfect metamaterials absorber has been designed. UCS is carried on top of a FR4 dielectric layer with thickness ($h = 1\text{ mm}$), relative permittivity ($\epsilon_r = 4.3$) and tangent loss ($\tan \delta = 0.025$). Figure 1 shows the perspective view of single cell of the suggested design. The dimensions details are in Table 1. The metal components are made from copper with electric conductivity $5.8 \times 10^7 \text{ s/m}$.

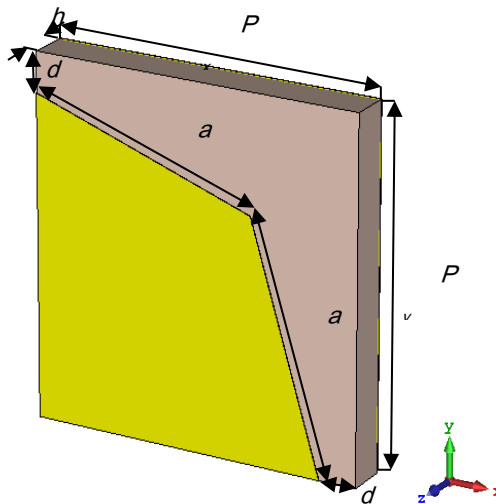


Figure 1- perspective view of UCS-shaped structure

variable	Value
P_x	20 mm
P_y	20 mm
a	13.5 mm
d	2.25 mm
h	2.5 mm

Table 1- Structure parameters value

The design has been analyzed by using CST Microwave studio MWS program in a frequency range of 9 GHz to 15 GHz in TE₁₀ mode when the

direction of propagation vector \mathbf{k} along z-axis, and the electric field vector \mathbf{E} is parallel to the direction of the \mathbf{y} -axis, and the magnetic field vector \mathbf{H} is parallel to the \mathbf{x} -axis.

Results

After the extraction of S values from CST program, the absorption values of the frequency are calculated by the equation:

$$A = 1 - R - T \dots \dots \dots (1)$$

where A is the value of the absorption, R is the reflection $R = |S_{11}|^2$, T is the transition $T = |S_{21}|^2$ (Al-Badri, 2018; Hu et al. 2013), almost above 90% although with shifting in resonance frequency.

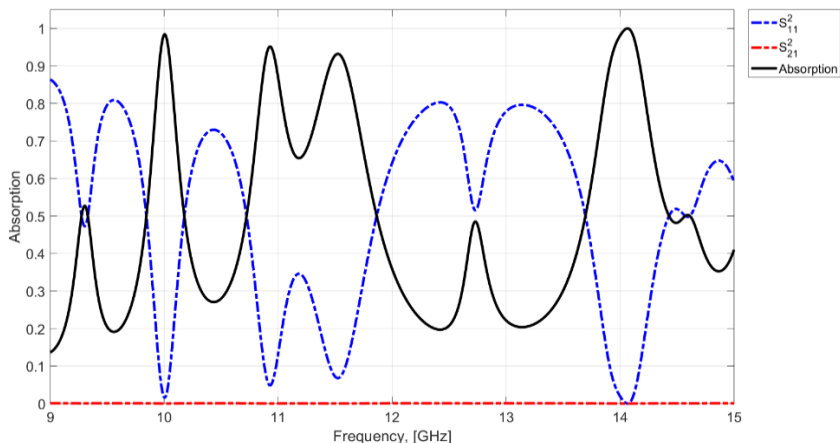


Figure 2- Absorption spectrum

Additionally, the other two peaks nonlinearly change with electric polarization angle change (Figure 4). Polarization insensitiveness is desirable for electromagnetic energy harvesting, radar cross section applications and stealth technology (Cao et al. 2019; Singh et al. 2019). The design provides four absorption bands at 10 GHz, 10.93 GHz, 11.53 GHz and 14.06 GHz. We also study the effect of change in the propagation polarization. The result showed increase in the ϕ angle; all absorption peaks accepted 3rd and 4th peaks (i.e. 11.53 GHz and 14.06 GHz respectively) are almost above 90% but with shifting in resonance frequency.

The surface current analysis was carried out as in Figure 3. The surface current at 10 GHz and 14.06 GHz is mainly responsible for the surface current coupling between adjacent resonators whereas most of the surface currents have been distributed within the nearest outer edge of UCS-shaped resonator. The two other resonance mainly come from the surface current coupling between opposite surface currents within the resonator and ground plate, *i.e.* dipole resonance.

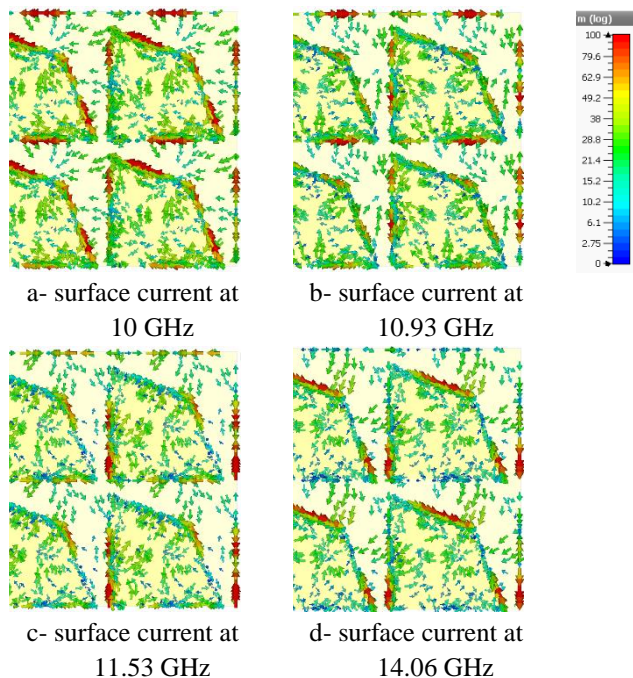


Figure 3- The surface current distribution at resonance frequencies.

There are many ways to control the number of absorption peaks and absorption bandwidth by controlling the properties of the materials used or by controlling the engineering characteristics of the design. Figure 5 shows the effect of change in length of a on the absorption level and resonance frequency. On the other hand, an increase in substrate thicknesses leads to an increase in absorption level and blue shift in absorption frequency (Figure 6). The best thickness is achieved when $h=2.5$ mm. Meanwhile, Figure 7 shows the effect of change in the substrate dielectric constant on the absorption level and resonance frequency.

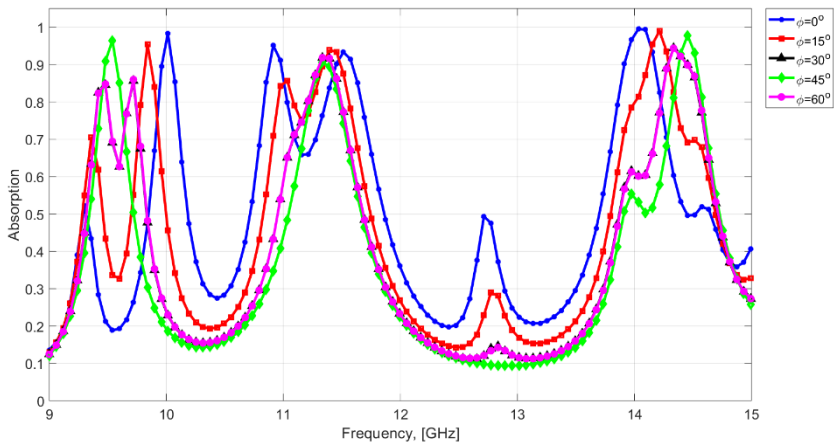
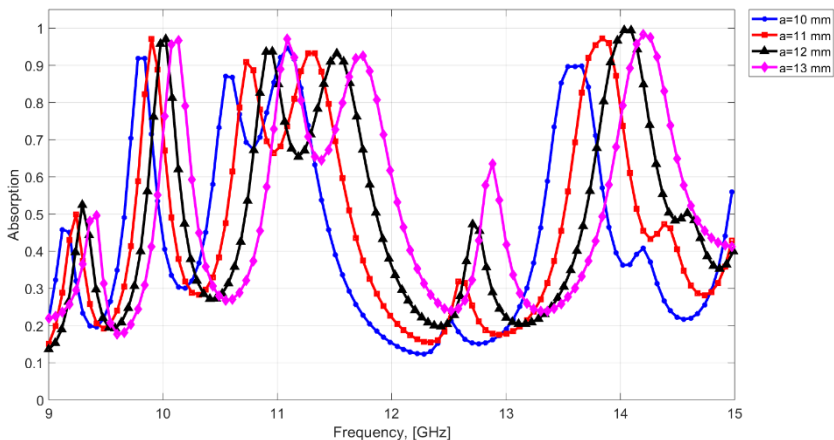


Figure 4- Effect of change in electric polarization.

Figure 5- Effect of change in a length.

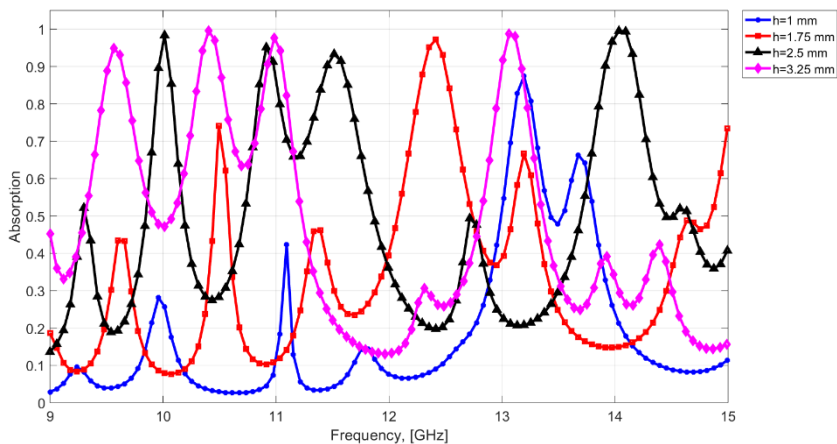
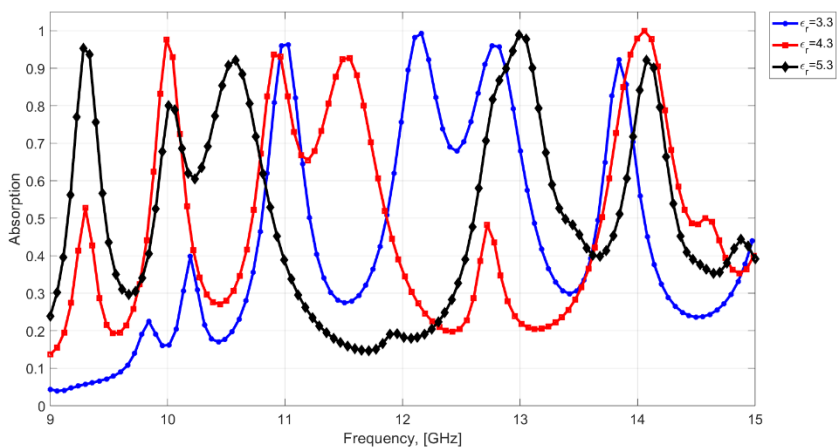
Figure 6- effect of change in h thicknesses.

Figure 7- effect of change in dielectric constant.

Experimental Verification

The 10×10 unit cell prototype of the proposed UCS-shaped absorber was manually fabricated using a standard print circuit board (PCB), as presented in Figure 8(a). The experimental sample dimensions are $200\text{mm} \times 200\text{mm}$ (10×10 unit cell). The UCS-shaped is printed on an FR-4 dielectric substrate with a thickness of 2.5mm, relative dielectric constant $\epsilon_r = 4.3$, tangential losses 0.025, with the back made entirely of copper. The experimental measurement setup was applied in a microwave anechoic chamber. Transmitter

and receiver standard-gain broadband horn antennas were connected to an Agilent HP-8757C vector network analyzer used as presented in figure 8(b) (AL-Badri 2018; Fernández Álvarez et al. 2015). A 5° separation angle was preferred between the two horn antennas (transmitter and receiver). The port-1 of a VNA was connected through a coaxial cable with low loss to transmitted horn antenna and the second port-2 of VNA was connected to a receiver horn. A 10 cm distance is placed between the two horn antennas and 5° angle between them in order to prevent near field effects between the transmitter and the receiver.

The absorption of UCS-shaped was determined by find the reflection wave from proposed fabricated prototype. The experimentally conducted absorptivity of the presented MM absorber at normal incidence compared with the simulated absorptivity is shown in Figure 9. Clearly, there were three distinct absorption frequencies of 8.72, 11.48 and 14.74 GHz, and the corresponding absorption efficiencies were 96.72%, 98.28% and 95.17%, respectively. In comparison, the experimental results are on par with the simulation results. The measured resonance has slight deviations from simulated frequency and the related absorptivity values. The difference may be due to finite size of the fabricated structure, and the metal fabrication tolerances.

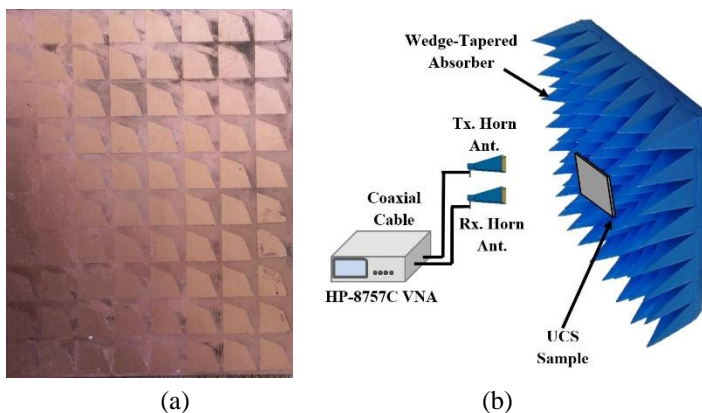


Figure 8- Experimental variation of UCS-shaped: (a) Fabricated MM absorber prototype; (b) Block-diagram for practical for Measurement setup.

The proposed UCS-shaped absorber is compared in table 2 with several literature absorbers reported earlier in terms of number of absorptive bands and absorber thickness. As observed, the proposed absorber has better absorption characteristics.

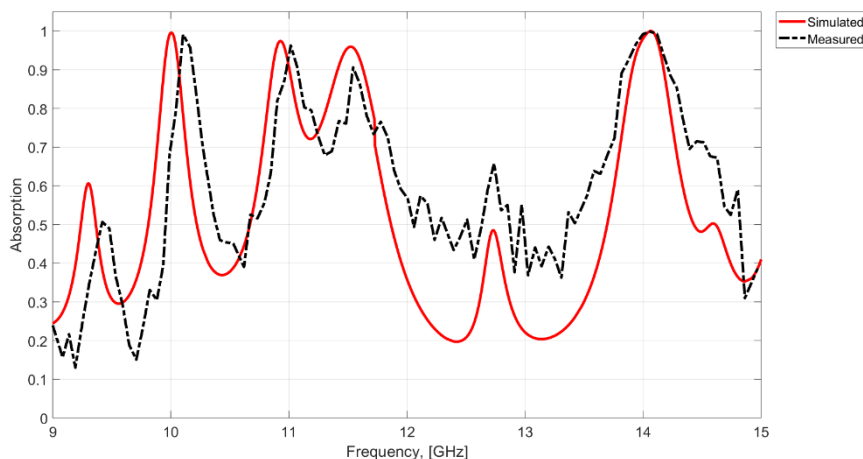


Figure 9- Simulated and measured absorptivity of the proposed metamaterial absorber.

References	No. Absorption bands	Thickness
Fernández Álvarez et al. 2015	1	1 mm
Landy et al. 2008	1	0.8 mm
Xu et al. 2018	2	0.8 mm
Al-Badri et al. 2019	2	1.5 mm
Jafari et al. 2019	3	1.6 mm
Al-Badri 2018	3	1.5 mm
Yoo et al. 2015	3	2.4 mm
Proposed structure	4	2.5 mm

Conclusion

The analysis reveals the ability of making a four perfect electromagnetic absorber based on single metamaterials structure. It can be used in several applications such as satellites, weather satellite, solar cells and on reducing the effects of the electromagnetic waves. The results also showed that the structure can be used as a multi-absorption device serving in several applications such as energy harvesting, electromagnetic waves detector and stealth technology.

References

- JI, S.; Jiang, C.; Zhao, J.; Zhang, X.; He, Q. Design of a polarization-insensitive triple-band metamaterial absorber. **Optics Communications**, v. 432, p. 65-70, 2019.
- SCHURIG, D.; Mock, J. J.; Justice, B. J.; Cummer, S. A.; Pendry, J. B.; Starr, A. F.; Smith, D. R. Metamaterial electromagnetic cloak at microwave frequencies. **Science**, v. 314, n. 5801, p. 977-980, 2006.
- AL-BADRI, K. S.; Cinar, A.; Kose, U.; Ertan, O.; & Ekmekci, E. Monochromatic Tuning of Absorption Strength Based on Angle-Dependent Closed-Ring Resonator-Type Metamaterial Absorber. **IEEE Antennas and Wireless Propagation Letters**, v. 16, p. 1060-1063, 2017.
- SMITH, D. R.; Pendry, J. B.; M. Wiltshire, C. K. Metamaterials and negative refractive index. **Science**, v. 305 n. 5685, p. 788–792, 2004.
- PENDRY, J. B.; Holden, A. J.; Robbins, D. J.; Stewart, W. J. Magnetism from conductors and enhanced nonlinear phenomena. **IEEE Trans. Microw. Theory Techn.**, v. 47, n. 11, p. 2075–2084, 1999.
- WANG, B. X.; Wang, L. L.; Wang, G. Z.; Wang, L.; Zhai, X.; Li, X. F.; Huang, W. Q. A simple nested metamaterial structure with enhanced bandwidth performance. **Optics Communications**, v. 303, p. 13-14, 2013.
- FARUK, A.; Sabah, C. Absorber and sensor applications of complimentary H-shaped fishnet metamaterial for sub-terahertz frequency region. **Optik**, 177, 64-70, 2019.
- DOLLING, G.; Enkrich, C.; Wegener, M.; Zhou, J. F.; Soukoulis, C. M.; Linden, S. Cut-wire pairs and plate pairs as magnetic atoms for optical metamaterials. **Optics letters**, v. 30, n. 23, p. 3198-3200, 2005.
- YU, P.; Besteiro, L. V.; Huang, Y.; Wu, J.; Fu, L.; Tan, H. H.; Wang, Z. Broadband metamaterial absorbers. **Advanced Optical Materials**. v. 1800995, p. 1-32, 2018.
- LANDY, N. I.; Sajuyigbe, S. J.; Mock, J.; Smith, D. R.; Padilla, W. J. Perfect metamaterial absorber. **Physical review letters**., v. 100, n. 20, 2008.
- SHCHEGOLKOV, D. Y.; Azad, A. K.; Ohara, J. F.; Simakov, E. I. Perfect subwavelength fishnetlike metamaterialbased film terahertz absorbers. **Physical review B**, v. 82, n. 20, 2010.

- HUANG, L.; Chowdhury, D. R.; Ramani, S.; Reiten, M. T.; Luo, S. N.; Azad, A. K.; Chen, H. T. Impact of resonator geometry and its coupling with ground plane on ultrathin metamaterial perfect absorbers. **Applied Physics Letters**, v. 101, n. 10, 2012.
- CAO, H.; Shan, M.; Chen, T.; Lei, J.; Yang, L.; Tan, X. Triple-Band Polarization-Independent Ultrathin Metamaterial Absorber. **Progress In Electromagnetics Research**, v. 77, p. 93-102, 2019.
- SINGH, A. K.; Abegaonkar, M. P.; Koul, S. K. (). A Triple Band Polarization Insensitive Ultrathin Metamaterial Absorber for S-C-and X-Bands. **Progress In Electromagnetics Research**, v. 77, p. 187-194, 2019.
- FERNÁNDEZ ÁLVAREZ, H.; de Cos Gómez, M. E.; Las-Heras, F. A thin c-band polarization and incidence angle-insensitive metamaterial perfect absorber. **Materials**, v. 8, n. 4, p. 1666-1681, 2015.
- LANDY, N. I.; Bingham, C. M.; Tyler, T.; Jokerst, N.; Smith, D. R.; Padilla, W. J. Design, theory, and measurement of a polarization-insensitive absorber for terahertz imaging. **physical review B**, v. 79, n. 12, 2009.
- AL-BADRI, K. S. L.; Karacan, N.; Kucukoner, E. M.; Ekmekci, E. Sliding planar conjoined cut-wire-pairs: A novel approach for splitting and controlling the absorption spectra. **Journal of Applied Physics**, v. 124, n. 10, 2018.
- WANG, B. X.; Wang, L. L.; Wang, G. Z.; Huang, W. Q.; Li, X. F.; Zhai, X. A simple design of a broadband, polarization-insensitive, and low-conductivity alloy metamaterial absorber. **Applied Physics Express**, v. 7, n. 8, 2014.
- GRANT J.; Ma, Y.; Saha, S.; Khalid, A.; Cumming, D. R. S. Polarization insensitive, broadband terahertz metamaterial absorber. **Optics letters**, v. 36, n. 17, p. 3476–3478, 2011.
- WANG, B. X.; Wang, L. L.; Wang, G. Z.; Huang, W. Q.; Li, X. F.; Zhai, X. Theoretical investigation of broadband and wide-angle terahertz metamaterial absorber. **IEEE Photon. Technol. Lett.**, v. 26, n. 2, p. 111–114, 2014.
- AL-BADRI, K. S. L. Very High Q-Factor Based On G-Shaped Resonator Type Metamaterial Absorber. **Ibn AL-Haitham Journal For Pure and Applied Science**, p. 160-167. 2018.
- HU, F.; Wang, L.; Quan, B.; Xu, X.; Li, Z.; Wu, Z.; Pan, X. Design of polarization insensitive multiband terahertz metamaterial absorber. **Journal of Physics D: Applied Physics**, v. 46, n. 19, p. 195103, 2013.

- AL-BADRI, K. S. L. Electromagnetic broad band absorber based on metamaterial and lumped resistance. **Journal of King Saud University-Science** 2018.
- DONG, Y.; Itoh, T. Metamaterial-based antennas. **Proceedings of the IEEE**, v. 100, n. 7, p. 2271-2285. 2012.
- SELVANAYAGAM, M.; Eleftheriades, G. V. A compact printed antenna with an embedded double-tuned metamaterial matching network. **IEEE Transactions on Antennas and Propagation**, v. 58, n. 7, p. 2354-2361, 2010.
- SEN, G.; Islam, S. N.; Banerjee, A.; Das, S. Broadband perfect metamaterial absorber on thin substrate for X-band and Ku-band applications. **Progress In Electromagnetics Research**, v. 73, p. 9-16, 2017.
- LUO, H.; Cheng, Y. Z. Ultra-Thin Dual-Band Polarization-Insensitive and Wide-Angle Perfect Metamaterial Absorber Based on a Single Circular Sector Resonator Structure. **Journal of Electronic Materials**, v. 47, n. 1, p. 323-328, 2018.
- LIU, Z.; Li, H.; Zhan, S.; Cao, G.; Xu, H.; Yang, H.; Xu, X. PIT-like effect in asymmetric and symmetric C-shaped metamaterials. **Optical Materials**, v. 35, n. 5, p. 948-953, 2013.
- Jafari, F. S.; Naderi, M.; Hatami, A.; Zarrabi, F. B.; Microwave Jerusalem cross absorber by metamaterial split ring resonator load to obtain polarization independence with Triple band application. **AEU-International Journal of Electronics and Communications**, v. 101, p. 138–144, 2019.
- YOO, Y. J.; Kim, Y. J.; Hwang, J. S.; Rhee, J. Y.; Kim, K. W.; Kim, Y. H.; Lee, Y. P. Triple-band perfect metamaterial absorption, based on single cut-wire bar. **Applied Physics Letters**, v. 106, no. 7, 2015.
- XU, J. P.; Wang, J. Y.; Yang, R. C.; Zhang, W. M. Switchable and Flexible Single-I Dual-Band Metamaterial Absorber. In **2018 International Conference on Microwave and Millimeter Wave Technology (ICMMT)**, IEEE. p. 1-3, May, 2018.