Menoufia J. of Electronic Engineering Research (MJEER), Vol. 30, No. 1, Jan.2021

Electromagnetic Absorbing Materials

1st Fatma S. Saeed
Faculty of Electronic Engineering, Menoufia University,
Egypt
Eng_fatmasamy66@yahoo.com

2nd Ahmed S. Elkorany
Faculty of Electronic Engineering, Menoufia University,
Egypt
elkoranyahmed@yahoo.com

3rd Adel A. Saleeb
Faculty of Electronic Engineering, Menoufia University,
Egypt
aasaleeb@hotmail.com

4th Elsayed E. Rabaie
Faculty of Electronic Engineering, Menoufia University,
Menouf,Egypt
elsayedelrabaie@gmail.com

***Abstract*—Electromagnetic absorbing materials can be classified into: conventional absorbers, metamaterial absorbers, and reconfigurable absorbers. This paper includes a short survey on these types and there applications. It also includes the design of a thin electromagnetic absorber. The absorber is based on mushroom-like electromagnetic band gap structure with square patches. A simple procedure is developed to design the absorber. The design is checked by simulation using HFSS package. The effect of changing dimensions of the structure on absorption is evaluated. The results of the parametric study were used to trim the design and get more accurate dimensions of the structure.**

Keywords—Absorbing materials, Metamaterial absorbers, Reconfigurable absorbers, Mushroom-like absorbers.

I. INTRODUCTION

Absorbing materials are found in different areas of applications. In this paper a survey of types of electromagnetic absorbers and applications is given in section II.

The design of absorbers made of metamaterials in the literature gives the dimensions of their structures without referring to the method they obtained them. If it is required to design the same structure at a different frequency or with different characteristics there is no way to get the required dimensions.

In section III, a simple procedure is developed to design EBG absorbers based on mushroom square patches. The condition for zero reflection is derived, and the procedure to design absorbers is developed. The effect of changing the dimensions of the structure upon absorbing properties is evaluated. Results and discussions are presented. Section IV includes conclusions.

II. TYPES OF ELECTROMAGNETIC ABSORBERS

The energy in an electromagnetic wave can be attenuated by passing the wave through an absorbing material. Absorbers are used to create a region of uniform plane wave in anechoic chambers. When an EM wave strikes an absorbing material, the electromagnetic energy is transformed into thermal energy [1].

The major types of absorbers are: (1) Conventional absorbers, (2) Metamaterials absorbers, and (3) Reconfigurable absorbers.

A. Conventional absorbers

Conventional absorbers include Jaumann, Salisbury, and Dallenbach [2,3]. Salisbury absorbers use a ground plane over which resistive sheets are located at a distance of $\lambda/4$ to attenuate the incident field. Jaumann absorbers use stacked resistive sheets and have band width wider than Salisbury absorber. Dallenbach absorbers do not use resistive sheets but lossy homogenous dielectric materials over a ground plane.

The absorption and bandwidth can be enhanced by including chiral inclusions [4], or using complex fractal geometries [5]. The bandwidth can also be increased by using frequency selective surfaces [6,7]. But the absorbers still have large thickness.

B. Metamaterials absorbers

Metamaterials have interesting properties, ordinary materials do not have. In this sub section we review some papers about the use of metamaterials electromagnetic absorbers. Billotti [8] designed a metamaterial resonator using split ring resonator. This was of limited practical application because the incident wave had to travel through the bulk of the resonator. Wen [9], Tao [10], Bhattacharyya [11], and Li [12], designed electric-field driven LC resonator-based metamaterial absorbers. But those absorbers suffer from polarization sensitivity due to their asymmetric design. Bhattacharyya [13] designed polarization insensitive triple band absorber. Due to its complicated design، it required rigorous parametric optimization to control the absorption frequencies. Zheng [14] and Soheilifar [15] designed polarization insensitive absorber. But those suffer from large unit cell size and thicker design configuration. Ren [16] designed a quad band wide angle absorber, but it was polarization sensitive. Huang, et. al. [17] used a planar lossy material over a ground plane covered by periodic microstrip lines to create absorbing materials.

The black hole in the microwave frequencies was realized by Cheng et. al., [18]. They used non-resonant and resonant metamaterial structures. The EM black hole can absorb EM waves efficiently with an absorption rate of 99% independent of the incident angle. An absorber with fan-shaped slotted ring resonator and modified mushroom-like EBG with horizontal and vertical slots in the rectangular patches was reported, [19]. The structure worked in dual bands.

Sood and Tripath, [20], demonstrated an absorber which worked in the C, X and Ku bands. The structure worked well for incident angles up to 60o. Jha et.al. [21] designed an absorber to work in the frequency band 1.8 – 2.1 GHz to isolate among various components of MIMO and massive MIMO antennas. Deng et.al.[22] reported an absorber to work in the millimeter wave range. It resonates at three frequencies 92.5, 94.9, and 129 GHz.

C. Reconfigurable absorbers.

The tunable metamaterial is a structure whose electromagnetic properties are modified as part of the ordinary operation of the device [23]. This can be done through the change of the unit cell structure, material properties, or geometry, using chemically, thermally, or optically sensitive materials. Zheng et.al. [24] designed a tunable dual-band perfect absorber. The structure can switch the absorber from single-band to dual-band. Zhao et.al. [25] used varactor diodes to control the absorption frequency.

III. Development of a Simple Design Procedure

A. Condition for zero reflection

Figure (1) shows the absorbing structure. The dimensions of the structure relative to wavelength must be small (less than 0.2λ).

To derive the condition for zero reflection, the input impedance of the structure should be considered first. The input impedance is given by, [26]:

$$Z_{inp}^{TE} = \frac{j\omega\mu_o d}{1-2k_{eff}\alpha d\left(1-\frac{\sin^2\theta}{\varepsilon_r+1}\right)} \text{............}(1)$$

$$Z_{inp}^{TM} = \frac{j\omega\mu_o d\left(1-\frac{\sin^2\theta}{\varepsilon_r}\right)}{1-2k_{eff}\alpha d\left(1-\frac{\sin^2\theta}{\varepsilon_r}\right)} \text{............}(2)$$

$$k_{eff} = k_o\sqrt{\varepsilon_{eff}} \text{...................}(3)$$

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} \text{.......................}(4)$$

$$\alpha = \frac{k_{eff}D}{\pi}\ln\left(\frac{2D}{\pi\omega}\right) \text{..............}(5)$$

The substrate is a dielectric material with losses, the dielectric constant given by:

$$\varepsilon_r = \varepsilon_r' - j\varepsilon_r'' \text{................}(6)$$

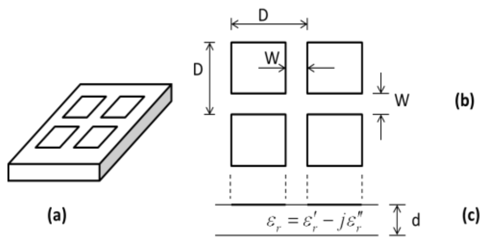

Fig. 1. The thin absorber (a), Top view (b), Side view (c).

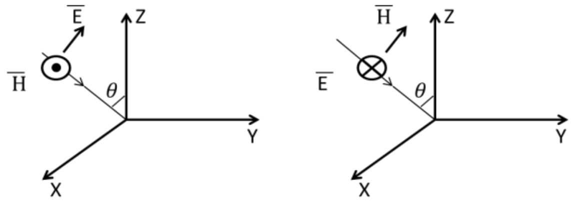

Fig. 2. θ is the incident angle.

The incident wave. If the dielectric constant εr is chosen to be large, the impedance of Eqs. (1) and (2) will be independent of θ. This is an advantage for the absorbing material. The input impedance becomes:

$$Z_{inp}^{TE} = Z_{inp}^{TM} = \frac{j\omega\mu_o d}{1-2k_{eff}\alpha d} \text{..............}(7)$$

Equation (7) can be put in the form:

$$Z_{inp} = \frac{j\omega L}{1-\omega^2 LC'} \text{.................}(8)$$

Where

$$L = \mu_o d \text{.......}(9)$$

$$C' = \varepsilon_o(\varepsilon_r+1)\frac{D}{\pi}\ln\left(\frac{2D}{\pi\omega}\right) \text{........}(10)$$

If εr in Eq. (10) is replaced by its value in (6), after some manipulation we have:

$$C' = \varepsilon_o(\varepsilon_r'+1)\frac{D}{\pi}\left(\frac{2D}{\pi\omega}\right) - j\varepsilon_o\varepsilon_r''\frac{D}{\pi}\ln\left(\frac{2D}{\pi\omega}\right) \text{.....}(11)$$

The susceptance of the capacitance of Eq. (11) becomes:

$$j\omega C' = j\omega\varepsilon_o(\varepsilon_r'+1)\frac{D}{\pi}\ln\left(\frac{2D}{\pi\omega}\right) - \omega\varepsilon_o\varepsilon_r''\frac{D}{\pi}\ln\left(\frac{2D}{\pi\omega}\right) \text{....}(12)$$

Eq. (12) represents an admittance with real part conductance (g) given by:

$$g = \omega\varepsilon_o\varepsilon_r''\frac{D}{\pi}\ln\left(\frac{2D}{\pi\omega}\right) \text{.........}(13)$$

The rest of Eq. (12) represents a capacitance C given by:

$$C = \varepsilon_o \left(\varepsilon_r' + 1 \right) \frac{D}{\pi} \ln\left(\frac{2D}{\pi \omega} \right) \text{............(14)}$$

The model of the structure is shown in Fig.(3).

The components of the resonant circuit of Figure 3 are given by Eqs. (9), (13) and (14). The impedance of the parallel resonant circuit is given by:

$$Z = \frac{1}{j\omega C + g + \frac{1}{j\omega L}} = \frac{j\omega L}{1 - \omega^2 LC + j\omega g L} \text{.....(15)}$$

The reflection coefficient is given by:

$$R = \frac{Z_{inp} - \eta}{Z_{inp} + \eta} \text{..................(16)}$$

where η is equal to 120 π.

For the structure to work as an absorbing material R must be zero. From Eq. (16) , omitting details we get:

$$\omega = \frac{1}{\sqrt{LC}} \text{......(17)}$$

$$g = \frac{1}{\eta} \text{........(18)}$$

The impedance of the circuit at resonance is:

$$Z=\eta \text{............ (19)}$$

The bandwidth is obtained from:

$$|Z| = \frac{\eta}{\sqrt{2}} \text{........(20)}$$

From which the bandwidth is given by:

$$bw = \frac{1}{\eta} \sqrt{\frac{L}{C}} \text{.............(21)}$$

B. design procedure

The data available is the operating frequency and bandwidth. The dimensions of the structure can be found by:

(a) From Eqs. (17), (18) and (21) the components of the resonant circuit L, C, and g are obtained

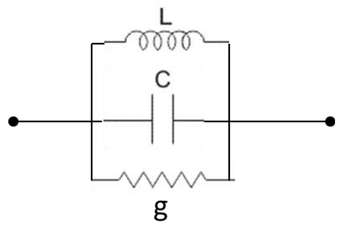

Fig. 3. Equivalent circuit.

$$g = \frac{1}{\eta} \text{.......(22)}$$

$$L = \frac{\eta bw}{2\pi f} \text{......(23)}$$

$$C = \frac{1}{2\pi f \eta bw} \text{..........(24)}$$

(b) Using the values of g, L, and C together with Eqns. (9), (13), and (14) we get the dimensions of the structure d, D, w, εr', and εr''.

Simplifying assumptions are made: w/D was taken to be 0.1, and εr' to be large, 10.

(c) There are three unknowns: d, D, and εr'' and three equations (9), (13) and (14). Thus, all the dimensions can be found.

C. Parametric Study

Effect of Periodicity D

The reflectivity was calculated for the following dimensions:

TABLE I. DIMENSIONS OF THE STRUCTURE

Parameter	D	W	D
mm	3.672	0.3672	0.9549

The parameter D was given another two values (3 and 4 mm) keeping (w) and (d) fixed. The reflectivity for the three cases is plotted in Figure 4. It is clear from the figure that, as D increases the curves shift to the left. This means that the frequency of operation decreases.

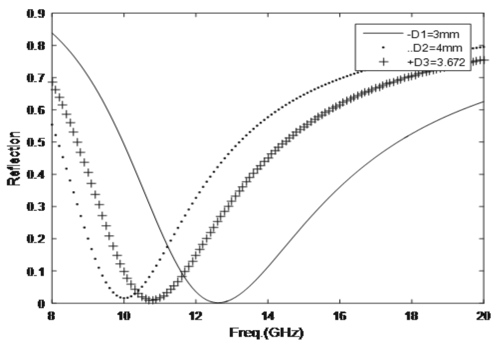

Fig. 4. Effect of changing periodicity D.

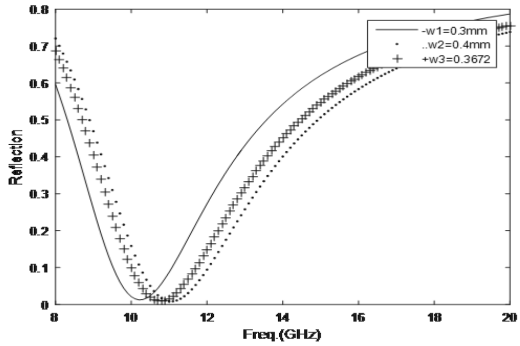

Fig. 5. Effect of changing gap between patches w

Effect of Gap Between Patches w

Keeping (D) and (d) fixed and changing w to take the values 0.3, 0.3672, and 0.4 mm, the reflectivity is plotted in Figure 5. As (w) increases, the curves shift right. Increasing separation between patches (w) causes the equivalent capacitance to decrease. Thus, the frequency of operation is increased.

Effect of Substrate Thickness d

Keeping (D) and (w) fixed and changing (d) to take the values 0.7, 0.5949, and 1.1 mm, the reflectivity is plotted in Figure 6. As (d) increases, the curves shift left. Increasing substrate thickness (d) causes the equivalent inductance (Eqn.9) increase which means decreasing the frequency of operation.

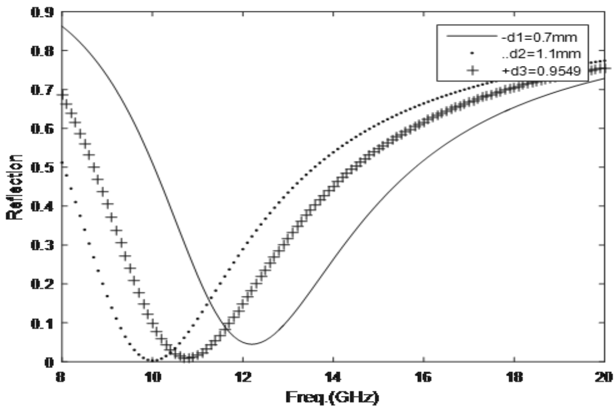

Fig. 6. Effect of changing substrate thickness d

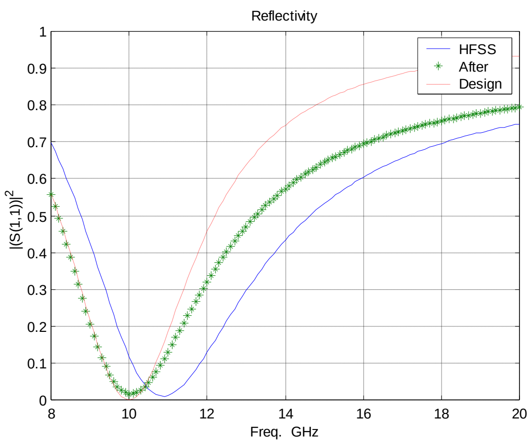

Fig. 7. Reflectivity of the designed structure

D. Results

An absorbing structure was designed to work at 10 GHz and 20% bandwidth. The dimensions of the structure are shown in table (1) above. The permittivity has real part (εr' = 10) and imaginary part (εr''=2.2). The reflectivity was calculated using HFSS and shown in Figure 7, (blue curve). There is a difference between this curve and the required one (dotted red). According to the parametric study conducted above, the periodicity of the structure (D) was increased to be 4 mm. All other dimensions were kept constant. The reflectivity new dimensions of the structure was computed using HFSS and shown in Figure 7, (green curve). Excellent agreement can be observed between desired and computed reflectivity.

IV. Conclusions

A brief survey of types of electromagnetic absorbers is presented. A simple procedure to design an absorber based on EBG was developed. The condition for zero reflection (perfect absorption) was derived. A parametric study to see the effect of changing the dimensions of the structure upon reflectivity was conducted. An absorbing structure was designed to work at 10 GHz and 20% bandwidth. The rules derived from the parametric study were used to trim the design. HFSS was used for the computations.

References

[1] H. Kaur, G. Aul, "A Review Based on Effects of Change in Thickness and Number of Layers on Microwave Absorbing Materials,"IJSR, Vol.3,ISSN(on line):2319-7064,pp.1141-1145,2014.

[2] E. F. Knott, J. F. Shaeffer, and M. T. Tuley, Radar Cross Section. London, U.K.: Artech House, 1993.

[3] B. A. Munk, Frequency Selective Surfaces: Theory and Design. New York: Wiley, 2000.

[4] J. Reinert, J. Psilopoulos, J. Grubert, and A. F. Jacob, "On the potential of graded-chiral Dallenbach absorbers," Microw. Opt. Technol. Lett., Vol. 30, No. 4, pp. 254–257, 2001.

[5] A. R. Chandran, T. Mathew, C. K. Aanandan, P. Mohanan, and K. Va-sudevan, "Frequency tunable metallo-dielectric structure for backscat-tering reduction," Electron. Lett., Vol. 40, No. 20, pp. 1245–1246, 2004.

[6] F. Terracher and G. Berginc, "A broadband dielectric microwave absorber with periodic metallizations," J. Electromagn. Waves Appl., vol.13‹ pp. 1725–1741, 1999.

[7] Marker, B. (n.d.). Use of Radar-Absorbing Material to Resolve U.S. Navy Electromagnetic Interference Problems. Retrieved April Monday, 2014, fromhttp://www.navsea.navy.mil/nswc/dahlgren/Leading%20Edge/E3/05_Solving_the_E3_Challenge_continued. pdf

[8] F.Billotti, L.Nucci, L.Vegni, "An SRR-based microwave absorber," Microw. Opt. Technol. Lett., Vol. 48, pp. 2171–2175, 2006

[9] Q. Y.Wen, H. W.Zhang, Y. S.Xie, "Dual band terahertz metamaterialabsorber: design, fabrication, and characterization," Appl. Phys. Lett., 95, 2009.

[10] H.Tao, C.M.Bingham, D.Pilon, et al., "A dual band terahertz metamaterialabsorber," J. Appl. Phys. D, 2010, 43.

[11] S.Bhattacharyya, K.V.Srivastava, "An ultra-thin electric field driven LCresonator structure as metamaterial absorber for dual band applications," Proc.URSI Int. Symp.Electromagnetic Theory, Hiroshima, Japan, 20–24 May 2013.

[12] M.H.Li, L.H.Yuan, B.Zhou, et. al., "Ultrathin multiband gigahertzmetamaterial absorbers," J. Appl. Phys., 2011, 110.

[13] S.Bhattacharyya, K. V.Srivastava, "Triple band polarization-independentultrathin metamaterial absorber using electric field-driven LC resonator," J.Appl. Phys., 2014, 115.

[14] D. Zheng, Y. Cheng, D. Cheng, et. al., "Four-band polarization-insensitivemetamaterialabsorber based on flower-shaped structures," Prog.Electromagn.Res., 2013, 142.

[15] M.R.Soheilifar,R.A.Sadeghzadeh, "Design, fabrication and measurementof two layered quadruple-band microwave metamaterial absorber," J.Commun. Eng., 2014, 3.

[16] Y. H.Ren, J. Ding, C. J. Guo, et. al., "Design of a quad-band wide-anglemicrowave metamaterial absorber," J. Electron. Mater., 2016, 46.

[17] R. F. Huang, Z. W. Li, L. B. Kong, L. Liu, and S. Matitsine, "Analysis and Design of an Ultra-ThinMetamaterial Absorber," Progress in Electromagnetics Research, B, Vol.14, 407-429, 2009.

[18] Q. Cheng, T. J. Cui, W. X. Jiang and B. G. Cai, "An Electromagnetic Black Hole Made of Metamaterials," New Journal of Phys. 2010.

[19] M. Abdalla and Z. Hu, "On the Study of Development of X-band Metamaterial Radar Absorber," Advanced Electromagnetics, Vol.1, No. 3, PP94-98, Oct. 2012.

[20] D. Sood, C. C. Tripath, "Quad Band Electric Field –Driven LC –Resonator based Polarization Insensitive Metamaterial Absorber," IET Microwaves, Antennas and Propagation, 2018, Vol.12, Iss. 4, pp. 977-985.

[21] K. R. Jha, G. Mishra, S. K. Sharma, "Design of a Compact Microwave Absorber Using a Parameter Retrieval Method for Wireless Communications Applications," IET Microwaves, Antennas and Propagation, 2018, Vol.12, Iss 6, PP 977-985.

[22] G. Deng T. Xia, J. yang, Z. Yin, "Triple-band Polarization-independent Metamaterial Absorber at mm Wave Frequency Band," IET Microwaves, Antennas and Propagation, 2018, Vol.12, Iss7, PP 1120-1125.

[23] Jeremiah P. Turpin, Jeremy A. Bossard, Kenneth L. Morgan, Douglas H. Werner, and Pingjuan L. Werner, "Reconfigurable and Tunable Metamaterials: A Review of the Theory and Applications," International Journal of Antennas and Propagation,Vol. 2014 (11), PP.1-18.

[24] H. Y. Zheng,1 X. R. Jin, J. W. Park, Y. H. Lu, Joo Yull Rhee, W. H. Jang, H. Cheong, and Y. P. Lee, "Tunable dual-band perfect absorbers based on extraordinary optical transmission and Fabry-Perot cavity resonance," Optics Express, Vol. 20, No. 21, 2012

[25] Jie Zhao, Qiang Cheng, Jie Chen, Mei Qing Qi, Wei Xiang Jiang and Tie Jun Cui, "A tunable metamaterial absorber using varactor diodes," New Journal of Physics 15 (2013) 043049 (11pp).

[26] Olli Luukkonen, Filippo Costa, Constantin R. Simovsk‹ Agostino Monorchio, and Sergei A. Tretyakov, "A Thin Electromagnetic Absorber for Wide Incidence Angles and Both Polarizations," IEEE Transactions on Antennas and Propagation, Vol. 57, No. 10, PP. 1-6, Oct. 2009.