Design Double Layers Structure Based Dual Band Metamaterial Absorbers for Stealth Applications

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Abstract: This study presents a new design for a two-layer insensitive of electromagnetic polarization for dual-band based metamaterial absorber at X bands. The electromagnetic absorber proposed her consists of a periodic unit cell of two circular ring resonator arrangement in a double layer. The proposed structure resonates at two frequencies 2.62 and 2.82 GHz with absorptivity level 97.2 and 99.3%, respectively. It displays insensitive of EM polarization performance for TE and TM polarization under oblique wave incidence. The electric field and surface current distributions have been contemplated for improved comprehension mechanism of the dual-band absorption. The manufactured of proposed absorber has been examined, the simulated results and the experimental results are good agreement. This insensitive metamaterial absorber of electromagnetic polarization with its simple of implementation and almost absorption can be utilized for radar applications.

Key words: Electromagnetic, polarization, metamaterial, resonator, electric field, radar applications

INTRODUCTION

The last two-decade Electromagnetic Metamaterial (EMM) gate emergent interest because of (LHB) Left-Handed Behavior (Veselago, 1968; Smith *et al.*, 2000; Caloz and Itoh, 2005; Capolino, 2009 and Smith *et al.*, 2005) LHP materials or metamaterials have many applications in numerous applications, for example: microstrip antenna (Majedi and Attari, 2013; Li *et al.*, 2010), filter of microwave (Mandal *et al.*, 2006), absorber electromagnetic signal (Landy *et al.*, 2008; Bilotti *et al.*, 2006), object hiding (Cai *et al.*, 2007; Alu and Engheta, 2005). The application of Electromagnetic-Absorber EMA based on metamaterial is important in radar technology, like stealth effects, decrease in SAR in medical and wireless devices (Hwang and Chen, 2006; Faruque and Islam, 2013). The reason behind absorption of EM wave based on artificial MMA is the noxious EM interference of the waves and the omich losses (Sun *et al.*, 2011). The stand-out properties of an EMMA have contributed many regards included properties such as: perfect EM absorber, flexible design and polarization unaffected. These points of interest have prompted the quick development of MMA in microwave and terahertz (Al-Badri, 2018a-c; Wang *et al.*, 2015 and Tao *et al.*, 2010) recurrence routines as well. Different MMA with various properties, for example, single band (Dincer *et al.*, 2014;

Soheilifar *et al.*, 2014 and Al-Badri *et al.*, 2017), double band (Zhu *et al.*, 2010; Lee and Lim, 2011; Tuong *et al.*, 2013; Chaurasiya *et al.*, 2014; Li *et al.*, 2013; Al-Badri *et al.*, 2018a-c; Min-Hua *et al.*, 2013; Ghosh *et al.*, 2014; Bhattacharyya *et al.*, 2014), triple band (Bhattacharyya *et al.*, 2013, 2014; Yoo *et al.*, 2015 and Bian *et al.*, 2013), quad band (Chaurasiya *et al.*, 2005), penta-band (Bhattacharya *et al.*, 2015a) and wide band (Al-Badri, 2018a-c) ingestion have been created and considered.

Numerous investigate has been achieved on double band EMPMA Electromagnetic Perfect Metamaterial-Absorber. The double-band EMPMA presented by Zhu *et al.* (2010) at 2.56 and 2.94 GHz showed high absorptions level 99.3 and 99%. Lee and Lim (2011) gave EMPMA resonators working at 9.8 and 10.3 GHz with absorption peaks of 98 and 98.6%, individually. In 2013, a two unequaling width circular was utilized to structure for double band EMPMA which was polarization sensitive (Tuong *et al.*, 2013). The absorption level are 95.9 and 98% was accomplished at 8.55 and 11.75 Ghz. Chaurasiya *et al.* (2014) showed a double absorption structure at 7.38 and 13.14 GHz with estimated electromagnetic absorption level at 99.2 and 99.6% at lower and higher frequencies, separately. In the other study Li *et al.* (2013) changed the electric spacer in order

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to acquire assimilation tow absorption band above 99% level. Al-Badri *et al.* (2018a-c) utilized conjoined two cut wires resonators for planning a double EMPMA which works at 3.24 and 3.64 GHz with absorptive above 93%. Min-Hua *et al.* (2013) presented planned a double absorption region based on metamaterial structure with left-hand properties appropriate for applications, for example, communication antenna, filter, absorber and so, forth (Ghosh *et al.*, 2014) executed a polarization-harsh and ultra-thin EMPMA. Bhattacharyya *et al.* (2014) proposed a double band data transmission improved EMPMA utilizing two layers of dielectric material.

In this research, an original resonator for a two-layer insensitive for electromagnetic wave polarization for dual absorption bands perfect MM absorber. The proposed structure resonates at dual frequencies 2.62 and 2.82 GHz with absorptivity level 97.2 and 99.3%, respectively. This study displays insensitive for electromagnetic wave polarization performance for TE and TM polarization under oblique wave incidence. The manufactured structure has been examined and the laboratory results are good agreement with the simulated results. This polarization-insensitive metamaterial absorber can be utilized for radar applications.

MATERIALS AND METHODS

Design and simulation: Figure 1a presents the top view of the proposed DCDL (Double Circle Double Layer) EMPMA. The unit cell design is selected such that it is simpler perfumed and easy construction. To achieve high absorption performance, the structure optimized to provide negative refractive index (i.e., negative permittivity and permeability) these leading to less reflection. The DCDL structure involves substrate FR4 with dimension along z-axis h = 1.45 mm (relative permittivity ε_r = 4.3, dielectric loss tangent tan δ = 0.025). The substrate is used to separate each two metallic layers where the bottom layer is ground. The first top layer includes circularring resonators and the second top layer also include circular ring resonators. The dimensions were

L = 33 mm, r_1 = 12 mm, r_2 = 5 mm and w = 3 mm. The conductivity of copper (σ = 5.8×10^7 sec/m) with thickness t = 0.035 mm was used for all copper layers. Using CST microwave studio, the DCDL proposed design was simulated based onunit cell Periodic-Boundary-Conditions (PBC). For an Electromagnetic (EM) wave is incident perpendicular on the DCDL proposed structure, the EM transmission wave $S_{21}(\omega)$ is blocked by the entire copper, so, the $S_{21}(\omega)$ = 0. Therefore, the tuning of impedance matching can be leads to zero reflection. Hence, the EM waves are totally absorbed by the DCDL absorber. The absorptivity is given as Al-Badri *et al.* (2017):

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

$$z(\omega) = \frac{\left(1 + S_{11}(\omega)\right)}{\left(1 - S_{11}(\omega)\right)} \qquad (2)$$

Where:
A (ω) = Represent the absorptivity
Z (ω) = Represented normalized input impedance
$S_{11}(\omega)$ = Reflection coefficient, at the angular frequency ω (Al-Badri *et al.*, 2017)

Firstly, the EMPMA based on DCDL resonator with two layers was intended as performed in Fig. 1a and simulated results Fig. 1b. Depicts the DCDL structure resonated at two b and 2.62 and 2.82 GHz with absorptivity of 97.2 and 99.3%, respectively.

Figure 2 shows the density of surface current distribution of the designed DCDL metamaterial at resonance frequency of dual bands. The distribution of electric surface current refers to antiparallel direction at the two-resonance frequency. A great part of the surface current distribution was inside the outer ring in this manner provide the absorption at the lower resonance frequency 2.62 GHz as appeared in Fig. 2a. The distributions of surface current in Fig. 2b demonstrate that the absorption at resonance frequency 2.82 GHz is because of the resonate of inner resonator. The simulated
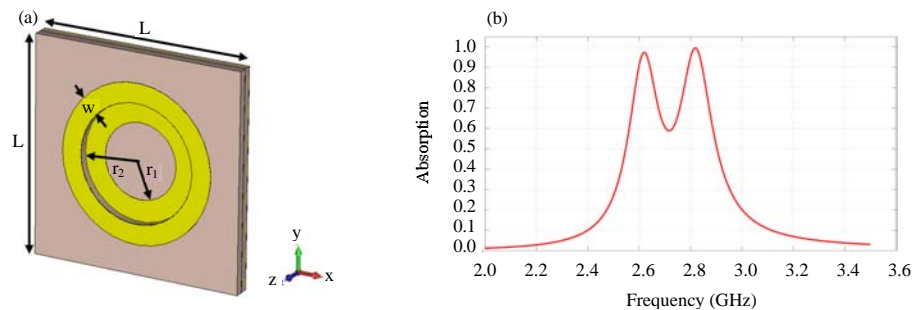

Fig. 1: a) Perspective view of the proposed DCDL unit cell and b) Simulated absorptivity
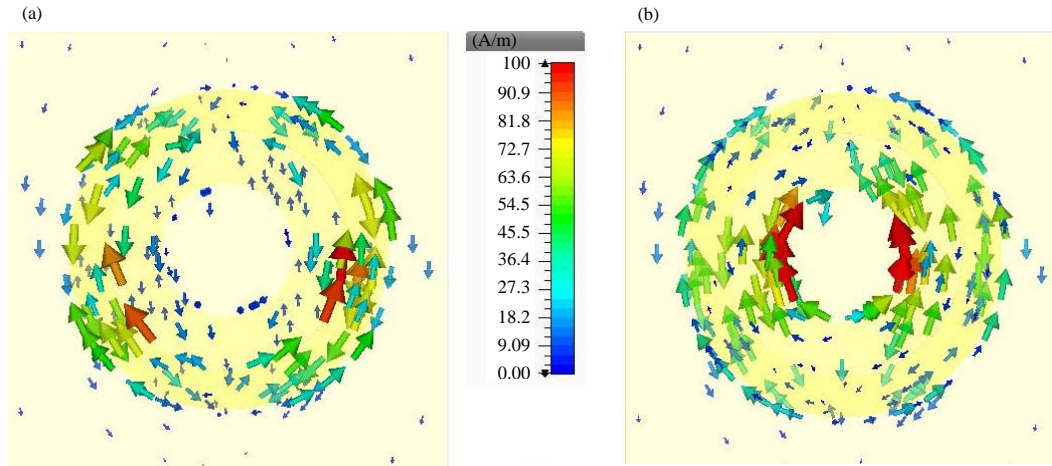
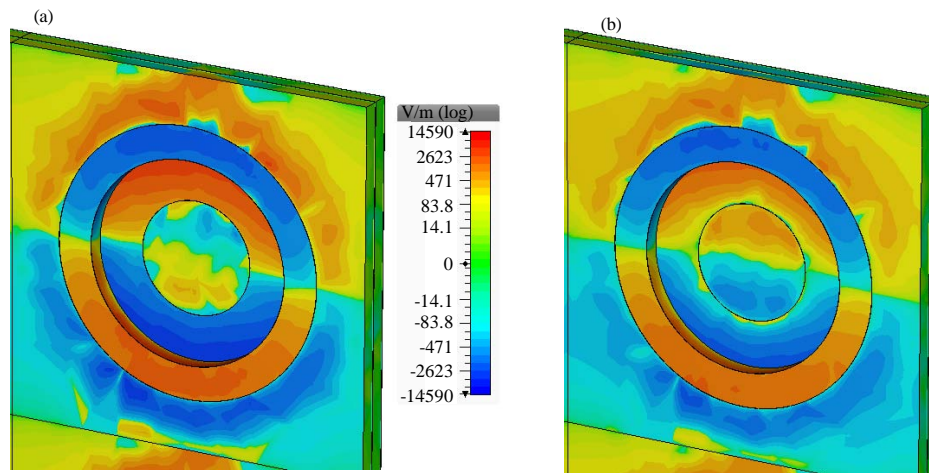Fig. 2: Surface current distributions: a) 2.82 and b) 2.62 GHz

Fig. 3: Electric field distributions: a) 2.82 and b) 2.62 GHz

distributions of Electric field (E-field) at resonance frequencies are shown in Fig. 3a and b. The E-field is incident top layer of resonator (i.e., metallic rings) where the Magnetic field (M-field) is perpendicular to the E-field. The E-field and M-field become distinguished at perfect absorption frequencies this led to high absorption.

Effect of incident wave polarization: In this investigation, TE and TM polarizations consideration are simulation studied under oblique angles of incidence. The CST results demonstrate that the proposed DCDL metamaterial structure at specific angles of EM incidence wave is polarization insensitive because of the symmetry of ring resonator. With constant E-field propagation vector. The propagation vector and M-field are changed to analyze the oblique incidence in TE polarization and in the reverse

condition for TM polarization. The proposed DCDL metamaterial absorber is polarization insensitive for oblique wave from 0-60° for TE mode and TM mode as displayed in Fig. 4 and 5a, b.

Finally, we studied the effect of two types of displacement of the lower copper ring. First the shift of ring (δ_x) along the x-axis, second: the shift of ring (δ_y) along the y-axis. In order to give a more comprehensive study of the proposed structure DCDL and give a more accurate clarification of the physical behavior, for the purpose of the possibility of using the electromagnetic metamaterial absorber in sensors applications. Results showed that shift (δ_x) along the x-axis did not cause a clear change in results. As for the shift towards y (δ_y), the simulation results were very sensitive to the displacement value. This also, explains that the main cause of absorption is the electric dipole resonance.
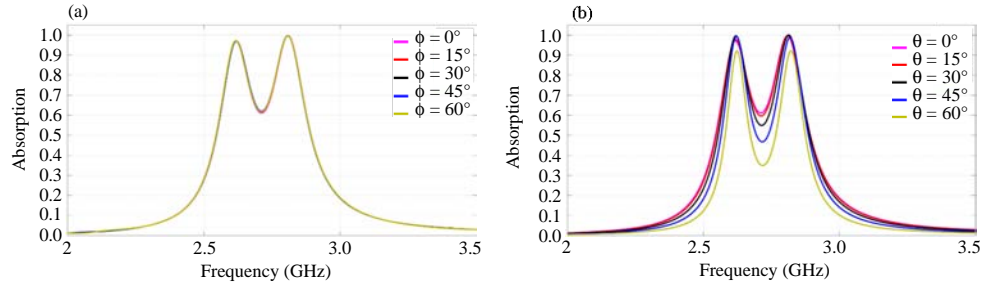
Fig. 4: a) CST simulated results for incidence wave (TE-mode) and b) CST simulated results for incidence wave (TM-mode)
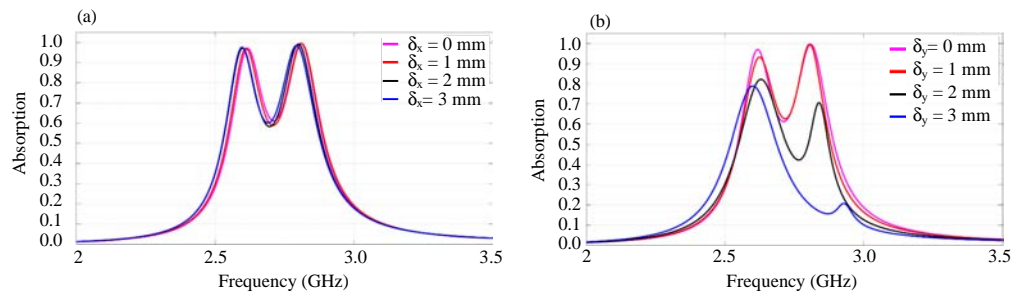

Fig. 5: a) CST simulated results for δ_x and b) CST simulated results for δ_y
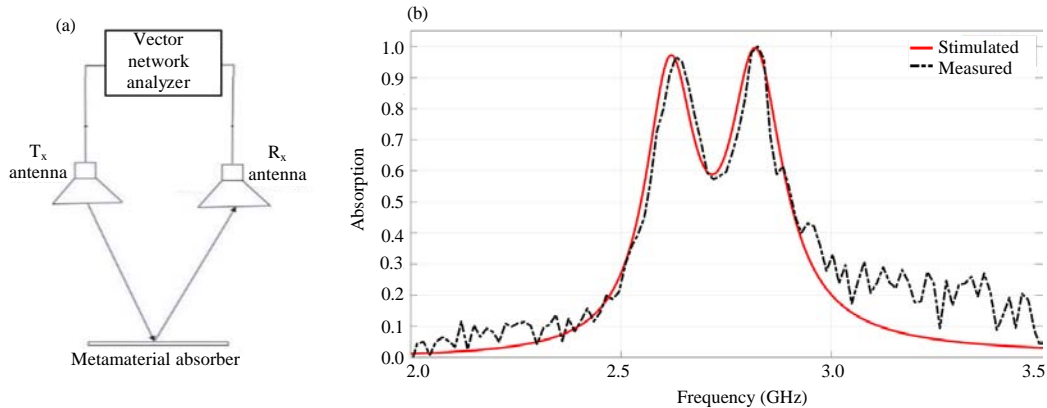

Fig. 6: a) Measurement set up diagram and b) The comparison between measured and CST simulated responses of DCDL

RESULTS AND DISCUSSION

The DCDL structure electromagnetic metamaterial absorber was printed on an electric substrate (FR4 of thickness 1.45 mm) as dielectric substrate through regular circuit board implementation technology. In this experiment a 20×20 mm absorber size was fabricated. The experimental setup diagram is shown in Fig. 6a. Two broad band horn antennas were connected to vector network analyzer with the help of coaxial cable, in order to measure

the electromagnetic wave which are reflected from the fabricated structure. In the beginning, a 20×20 mm dimension sheet of copper was placed to measure a reference reflected power. After that, replaced the test sheet by the fabricated DCDL metamaterial absorber and the power reflected from the structure was measured. The actual reflection from the fabricated MMA was the difference between the reflection measured from the structure and the reference measurement.

Table 1: Comparison between DCDL among metamaterial absorbers

References	No. bands	Design size (mm)	Frequencies	A (w) (%)	Polarization
Landy *et al.* (2008)	1	4.2×12	11.5 GHz	96	Dependent
Al-Badri *et al.* (2017)	1	72.136×34.036	2.82 GHz	95.7	Dependent
Dincer *et al.* (2014)	1	44	5.48 GHz	99.99	Independent
Zhu *et al.* (2010)	2	36×72	2.6 and 2.9 GHz	99.5 and 98	Dependent
Li *et al.* (2013)	2	12×6	9.02 and 11.8 GHz	99 and 98	NA
Al-Badri *et al.* (2018 a-c)	2	72.136×34.036	3.24 and 3.26 GHz	93 and 92.5	Dependent
DCDL	2	33	2.62 and 2.82	97.2 and 99.3	Independent

The experimental result shows good agree with simulation results. There are two peaks at 2.64 and 2.821 GHz with peak level of absorptivity 96.3 and 99.2%, respectively. Meanwhile, experimental results show a small change comparing with simulation may be due to the fabrication tolerance limitations. Therefore, there is a minor difference in level of absorption and resonance frequencies compared to the CST results Fig. 6b.

Table 1 focuses on several literature that studied EM metamaterial absorption. Especially, in the matters related to the level of absorption, resonance frequency, number of absorption band, unit cell size. However, as mention above the DCDL proposed structure obtained double absorption band 2.62 and 2.82 GHz. Where second peak is very high nearly unity absorption.

CONCLUSION

This manu script shows a new design for insensitive EM metamaterial absorber of electromagnetic polarization with its simple of implementation and almost absorption can be utilized for radar applications. The results present dual-band at microwave regime based on metamaterial absorber. The proposed design consists of a periodic unit cell of two circular ring resonator. Which is arrangement in a double layer. The proposed electromagnetic absorber resonates at two band frequencies 2.62 and 2.82 GHz with absorptivity level 97.2 and 99.3%, respectively. The simulated and experimental results are displayed insensitive of EM polarization performance for TE and TM polarization under oblique wave incidence. In order to improve comprehension mechanism of the dual-band absorption, the electric field and surface current distributions have been contemplated.

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