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Design and Analysis of Microwave Absorbers using Metamaterials

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ABSTRACT

This paper presents an ultra-thin polarization independent metamaterial microwave absorber comprising of three concentric closed ring resonators (CRR). The unit cell sizes as well as the other geometrical dimensions like radii and widths of the rings are optimized so that absorptions take place at three distinct frequencies near to the middle of the FCC radar frequency spectrum. The structure shows absorptivity's of 94.1%, 99.6% and 99.4% at 5.5 GHz, 9.52 GHz and 13.8 GHz respectively. The structure has been studied under oblique incidence, both for TE and TM polarization where it behaves as absorber up to 60º incident angles in both the cases. Due to the geometrical symmetry, the structure is found to be polarization independent absorber. S_{11} parameters (reflected power) for Single layer wide band and Multilayer broad band structures were also analyzed

KEYWORDS—Metamaterials, Microwave Absorber, ClosedRing Resonator (CRR) Structure, FSS.

1. INTRODUCTION

Researches on metamaterials [1] have been found to be of potential interest in recent years due to its unusual electromagnetic properties having applications in antenna system [2], cloaking [3], perfect lens [4] etc. Metamaterials based absorbers have recently been developed ranging from microwave to infrared frequency range [5-7]. Electric Field Driven LC (ELC) resonator based structures [8] are preferred over split ring resonator (SRR) based structures [9] as absorbers. Closed ring resonator (CRR) based structures [10] have also been used as absorbers as they are geometrically symmetric in nature and easy to fabricate.

In this paper, three concentric circular-shaped CRR structures in a single unit cell have been proposed which can be used for triple band absorber applications. The radius and width of the individual circles along with the size of the unit cell have been optimized accordingly so that there are three distinct absorption peaks are observed at the specified radar spectrum for air defence applications [11]. The proposed structure has been studied under oblique incidence, where it shows more than 80% absorbance at all the designed frequencies upto 60° TE and TM incidence. The structure is studied under variation of polarization angle, showing identical absorption due to the structural symmetry.

2. DESIGN OF THE STRUCTURE - 1

The front view of the proposed structure is shown in Fig. 1(a) where the directions of electric field, magnetic field and incident electromagnetic wave are also shown. The structure is completely copper laminated at the back and separated by

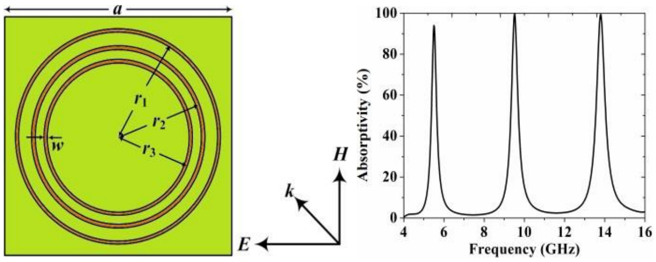


Fig. 1(a) Front view and (b) absorptivity of the proposed CRR structure (a = 10 mm, w = 0.2 mm, $r1$ = 4.625 mm, $r2$ = 3.075 mm, $r3$ = 2.15 mm).

1 mm thick dielectric substrate of FR-4 (ε_r = 4.25 and $tan\delta$ = 0.02). Both the copper films are 0.035 mm thick and other dimensions are as shown in Fig. 1(a). Due to complete copper backing, there is no transmission of the incident electromagnetic wave and hence by minimizing the reflection from the structure, the absorption at the frequencies can be maximized.

2. DESIGN OF THE STRUCTURE – 2

The unit cell geometry of the broadband absorber, which comprises of a top metallic patch imprinted over a thin grounded dielectric substrate. The top frequency selective surface (FSS) is built of a single circle loop which has splits at the centre of each of the four sides of the circle

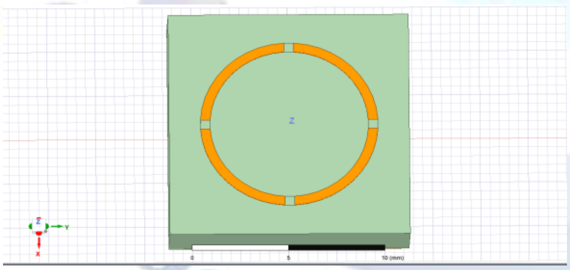


Fig. 2 Front view of single layer wide band metamaterial absorber

The lumped resistors (RC) are inserted at the split positions of the square loop. FR4 has been used as dielectric with relative permittivity (εr) of 4.4 and loss tangent (tanδ) of 0.02. Both the top metal patch and bottom ground plane are made of copper with conductivity of 5.8 × 107 S/m and thickness of 0.035 mm

4. DESIGN OF THE STRUCTURE – 3

This design proposes a dual layered broad band metamaterial absorber for broad band applications. The single unit cell consists of two circular ring resonators backed by metallic plane separated by a dielectric layer.

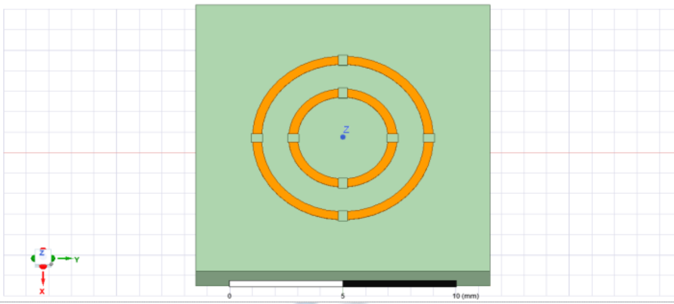


Fig. 3 Top view of Dual Layer Broad band absorber

Figure 3 shows the schematic design of the unit cell of the proposed structure. Two cave metallic resonators have been imprinted on the 0.8mm thick FR-4 dielectric substrate whose relative permittivity and loss tangent are εr= 4.4 and tan δ= 0.02 respectively. The metallic parts, having thickness 0.035mm, are made of copper. The dimensions of the proposed structure as well as the propagation field components of the incident electromagnetic (EM) wave have shown in Fig. 3.: (a) Proposed Unit Cell Structure; a = 10 mm, n = 2.75 mm, m = 1.5 mm, d = 3.25 mm, w = 0.625 mm

5. DESIGN OF THE STRUCTURE – 4

Fig. 4 shows the unit cell geometry of the proposed broadband absorber, which comprises of two metal printed dielectric layers stacked through spacer. The top and bottom metal patches are built of DSL and single-square-loop (SSL), respectively, each loaded with lumped resistors at the centre of each of the four arms of the squares. FR4 has been used as dielectric with relative permittivity (εr) of 4.4 and loss tangent (tanδ) of 0.02. An air spacer has been used between the two layers, and the overall structure has been terminated by a metal ground. All the conducting metal patches and the bottom ground plane are made of copper with conductivity σ = 5.8 × 107 S/m and thickness of 0.017 mm. The optimised geometrical dimensions are: p = 13 mm, d1 = 9 mm, d2 = 4.8 mm, d3 = 10 mm, w1 = w2 = w3 = 0.4 mm, g = 0.5 mm, h1 = h3 = 0.8 mm, h2 = 3 mm, R1 = 120 Ω, and R2 = R3 = 100 Ω.

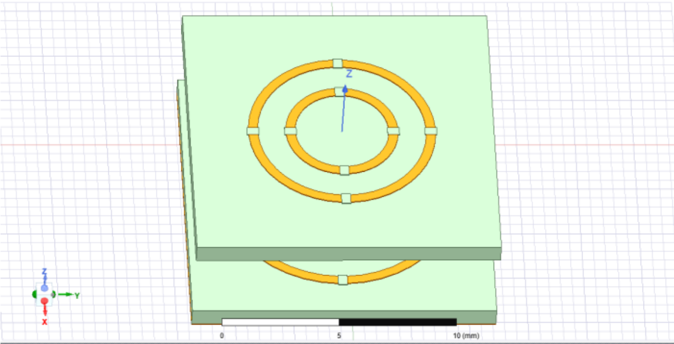


Fig. 4. Top view of multi-layer broad band absorber

The equivalent circuit model of the proposed broadband absorber is illustrated which consists of series resistor inductor capacitor (RLC) circuits in parallel connection with the transmission line terminated by the metal ground. The SSL absorber can be represented by a series R3–L3–C3 circuit connected across a terminated transmission line (of length h3) and this part has been connected in parallel with two series RLC circuits (R1–L1–C1 and R2–L2–C2) through another transmission line (of length h1 + h2) as shown in Fig. 2. Here R1, R2, L1, L2, C1, and C2 represent the equivalent circuit parameters of the outer and inner loop, respectively, of the top FSS whereas R3, L3, and C3 denote the parameters of the square loop of the bottom FSS. The short-circuited transmission line section of length h3 represents the conductor-backed dielectric, while the transmission line sections of lengths h1 and h2 depict the top dielectric substrate and intermediate air spacer, respectively. The reflection coefficient of the proposed absorber (Γ) is expressed as

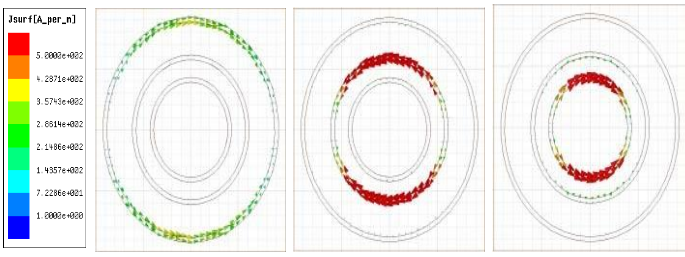
$G = Z_{in} - Z_0 / Z_{in} + Z_0$ (1)

where Z_0 and Z_{in} are the intrinsic impedance of air and the input impedance of the proposed absorber, respectively

6. SIMULATED RESULTS

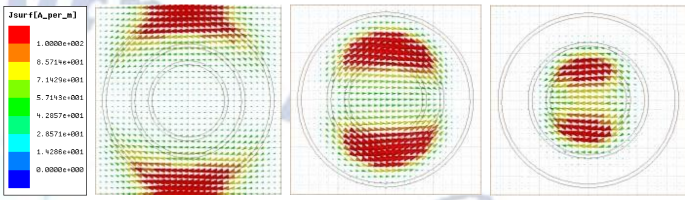
The proposed concentric circular CRR structure has been simulated using periodic boundary conditions in Ansys HFSS showing three distinct peaks at 5.5 GHz, 9.52 GHz and 13.8 GHz with absorptivities of 94.1%, 99.6% and 99.4%respectively as shown in Fig. 1(b).

The surface currents at the top and bottom metallic surfaces are anti-parallel at all frequencies of absorption as evident from Fig. 4 and Fig. 5. This implies a circular current loop formed within the dielectric, which is supportedby the magnetic excitation.



(a) 5.5 GHz (b) 9.52 GHz (c) 13.8 GHz

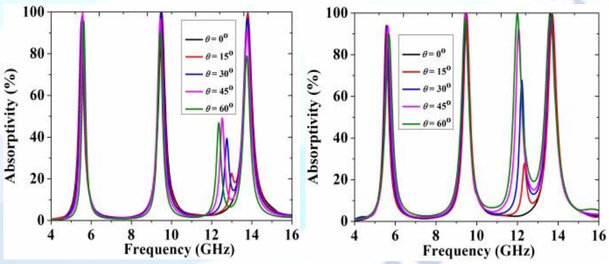
Fig. 5. Surface current density distribution at the top surface.



(a) 5.5 GHz (b) 9.52 GHz (c) 13.8 GHz

Fig. 6. Surface current density distribution at the bottom surface

The triple band absorber structure has also been studied for different angles of polarization (ϕ) as shown in Fig. 7(a), where the wave propagation direction remains parallel to *z*-direction while both the electric and magnetic field make an angle Θ with *x*-direction and *y*-direction respectively. The response is shown in Fig. 7(b). Due to the symmetry of the structure in *xy*- plane, the structure exhibits polarization insensitive absorption phenomenon.



(a) TE Incidence (b) TM Incidence

Fig. 7: Absorptivity variation with oblique incidence of the proposed structure.

The proposed concentric circular CRR structure has been simulated using periodic boundary conditions in Ansys HFSS showing three distinct peaks at 5.43 GHz, 9.47GHz, and 13.99 GHz with absorptivities of 94.1%, 99.6% and 99.4% respectively.

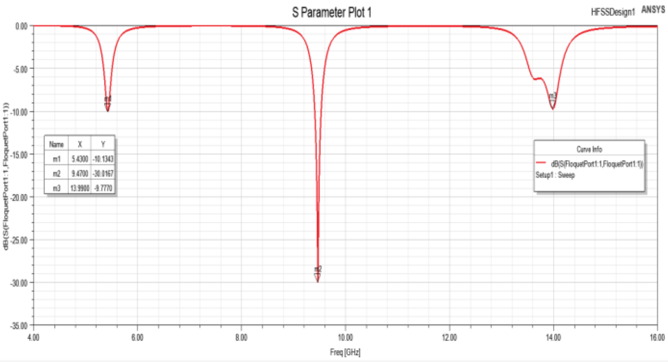


Fig. 8: S_{11} parameters of triple band absorber observed at 5.4GHz, 9.47GHz and 13.99GHz

A broadband polarization-insensitive single layer wideband metamaterial absorber using lumped resistors has been presented. The proposed structure has reflection coefficient less than (-10 dB) from 5.65 GHz to 12.55 GHz, having bandwidth of 69.31% at 6.96 GHz.

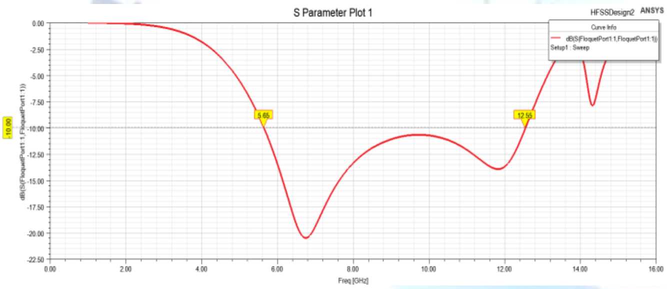


Fig. 9: S_{11} parameters of single layer wide band absorber observed between 5.65GHz to 12.55 GHz

The dual layer wideband absorber shows two distinct absorption peaks at the frequencies 7.59 GHz (C-band) and 13.56 GHz (X-band) with more than 99% absorption The structure can be used for battle field and airborne radar applications

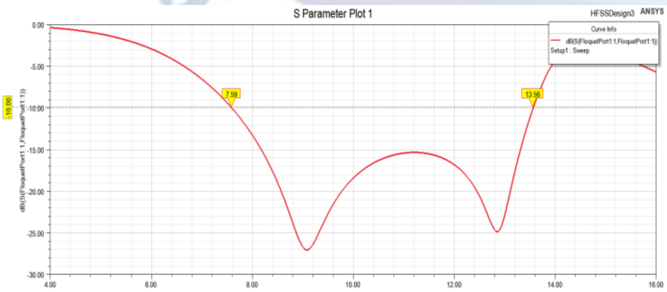


Fig. 10: S_{11} parameters of dual layer wide band absorber observed between 7.59GHz to 13.56 GHz

A Multi-layer broadband absorber based on lumped resistors has been presented, which is composed of two FSS printed dielectric layers separated by an air spacer. The proposed structure has reflection coefficient less than -10 dB from 7.2 GHz to 15.39 GHz, having bandwidth of 79.31% at 8.19 GHz.

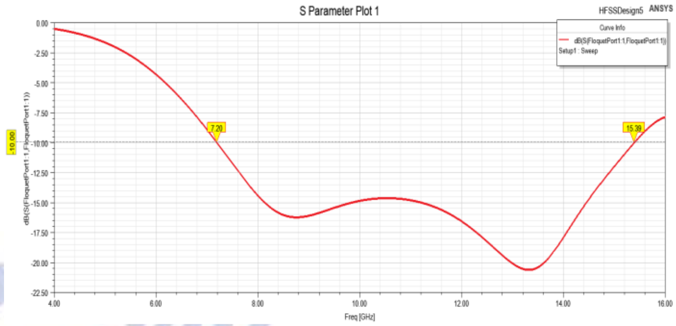


Fig. 11: S_{11} parameters of multilayer broadband absorber observed between 7.20GHz to 15.39GHz

7. CONCLUSIONS

A concentric circular CRR structure has been proposed exhibiting absorptions in three distinct frequencies in FCC defined radar frequency bands. The strong electromagnetic absorption occurs due to the overlap of magnetic excitation and electric excitation at the frequencies of absorption. The structure shows high absorption over a wide angle of incidence of 60º while the structural symmetry makes the structure polarization invariant.

A broadband polarization-insensitive metamaterial absorber using lumped resistors has been presented. The proposed structure has reflection coefficient less than -10 dB from 5.65 GHz to 12.55 GHz, having bandwidth of 69.31% at 6.06 GHz. The absorption mechanism of the designed absorber has been explained using some parametric studies.

A Multilayer broadband absorber based on lumped resistors has been presented, which is composed of two FSS printed dielectric layers separated by an air spacer. The top and bottom FSS has DSL and SSL arrays, respectively, and each of the circular loops contains four lumped resistors. The proposed structure has been analysed by the equivalent circuit model where the circuit simulation matches closely with the full-wave analysis. Several parametric studies have also been conducted to exhibit the effects of the geometrical dimensions on the absorption performance.

Conflict of interest statement

Authors declare that they do not have any conflict of interest.

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