

# An Ultra-thin Dual-Band Polarization-Independent Metamaterial Absorber for EMI/EMC Applications

Praneeth Munaga<sup>1</sup>, Saptarshi Ghosh<sup>2</sup>, Somak Bhattacharyya<sup>3</sup>, Devkinandan Chaurasiya<sup>4</sup>, Kumar Vaibhav Srivastava<sup>5</sup>

Department of Electrical Engineering, Indian Institute of Technology Kanpur, India

<sup>1</sup>[praneeth\\_munaga@gmail.com](mailto:praneeth_munaga@gmail.com), <sup>2</sup>[joysaptarshi@gmail.com](mailto:joysaptarshi@gmail.com), <sup>3</sup>[bhattacharyya.somak@gmail.com](mailto:bhattacharyya.somak@gmail.com), <sup>4</sup>[chaurasiya.dev1189@gmail.com](mailto:chaurasiya.dev1189@gmail.com), <sup>5</sup>[kvs@iitk.ac.in](mailto:kvs@iitk.ac.in)

**Abstract**—In this paper, an ultra-thin polarization-independent dual-band metamaterial absorber has been presented in microwave frequency regime. The unit cell structure is composed of tetra-arrow cave structure in the top layer imprinted on a grounded dielectric substrate. The geometrical parameters have been optimized in such a way that near-unity absorption takes place at two different frequency bands (C and X-bands). The proposed structure is polarization-insensitive as well as wide-angle absorptive (upto 60°) for both TE and TM polarizations. The structure is fabricated on FR4 substrate, and experimental results are in good agreement with simulated responses. The designed absorber is ultra-thin, compact and appears to be potentially instructive for various EMI/EMC applications.

**Index Terms**—metamaterial absorber, polarization insensitive, dual-band, EMI/EMC applications.

## I. INTRODUCTION

Of late there is more emphasis in research on metamaterials due to their unusual electromagnetic properties in sub-wavelength scale which makes them attractable to applications like lens imaging [1], cloaking [2], antenna structures [3] etc. One such application is metamaterial absorber, which offers benefits over conventional absorbers due to ultra-thin nature, near-unity absorptivity, and increased effectiveness. Initially, split ring resonator (SRR) based structures were proposed as absorbers [4], but they were replaced by electric field driven LC (ELC) resonators [5] due to their less travelling distance within the structure.

Till date many ELC based structures have been designed in single band and multi-band applications incorporating several characteristics like wide-angle, polarization-insensitivity, etc. However, multi-band absorber structures have been produced either by forming arrays of differently scaled unit cells [6] or stacking multiple resonators vertically one above another [7]. But in either case, the period or the thickness of the unit cell increases drastically, thus preventing them from practical applications. Some dual-band absorbers have been presented, where different resonators are embedded one inside another, thus being free from the above limitations, but the structures are asymmetrical [8-9].

In this paper, a dual-band polarization-insensitive metamaterial absorber comprising of tetra-arrow cave structure has been presented, which exhibits near-unity absorption peaks in C and X-bands. The simulated result shows that the absorption occurs at two distinct frequencies 4.27 GHz and 10.67 GHz with peak absorptivities of 98.1% and 98.9% respectively. The surface current densities at the absorption frequencies have been studied to analyze the absorption phenomenon. The responses of the structure for different

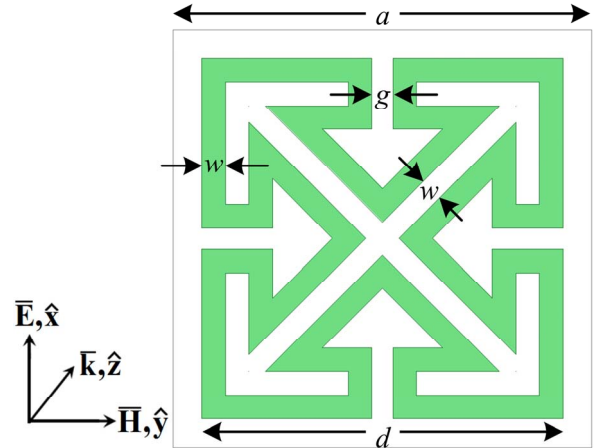


Fig. 1. Front view of the unit cell geometry of the proposed structure.

angles of incidence and for different angles of polarization are also examined for verifying its wide angle absorption and polarization-insensitive characteristics. Finally, the structure has been fabricated using standard printed circuit board (PCB) technology and its absorption characteristics are validated with numerical simulations.

## II. DESIGN AND SIMULATED RESULTS

The front view of the unit cell geometry of the structure is illustrated in Fig. 1. The proposed structure is designed on top of grounded FR4 substrate ( $\epsilon_r = 4.4$  and  $\tan\delta = 0.02$ ) of 1 mm thickness. The top surface consists of a tetra-arrow cave structure, where the cave part has been created within the tetra-arrow ELC structure. The bottom surface is completely metal laminated. Both the top and bottom surfaces are made of copper with conductivity of  $5.8 \times 10^7$  S/m and thickness of 0.035 mm. The geometric dimensions of the unit cell shown in Fig. 1 are optimized to  $a = 8$  mm,  $d = 6.9$  mm,  $w = 0.45$  mm and  $g = 0.4$  mm. The direction of propagating wave vector is perpendicular to the plane of top surface with electric and magnetic field vector directions are also shown in the figure.

When the plane wave is normally incident on the structure, the reflectance, transmittance and absorbance can be expressed as:

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

where  $A(\omega)$ ,  $|S_{11}(\omega)|^2$  and  $|S_{21}(\omega)|^2$  are the absorbance, reflectance and transmittance at an angular frequency  $\omega$ . Since the bottom surface is completely copper laminated, the transmittance is zero, thus modifying (1) as:

$$A(\omega) = 1 - |S_{11}(\omega)|^2 \quad (2)$$

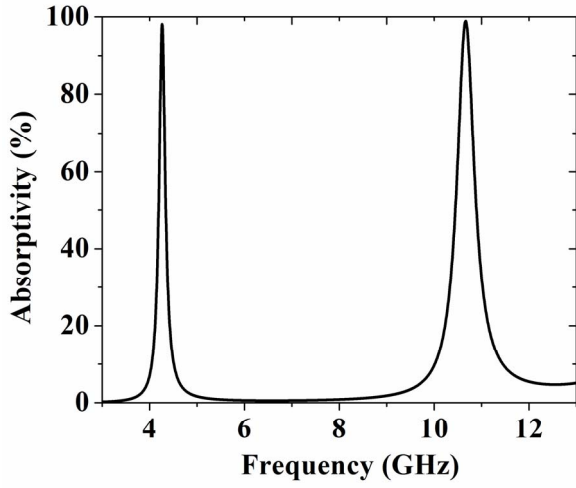


Fig. 2. Simulated absorptivity of the proposed structure.

When the input impedance of the structure  $Z(\omega)$  is perfectly matched with free space impedance  $\eta_0$ , then the reflectance becomes minimum as expressed in (3) and absorptivity will be maximum-

$$S_{11}(\omega) = \frac{Z(\omega) - \eta_0}{Z(\omega) + \eta_0}. \quad (3)$$

The proposed structure is simulated using FEM based Ansys HFSS software with periodic boundary conditions. It is observed from Fig. 2 that two distinct absorption peaks occur at 4.27 GHz (C-band) and 10.67 GHz (X-band) with absorptivities of 98.1% and 98.9% respectively. The normalized input impedance ( $Z$ ) of the absorber has been calculated and plotted in Fig. 3. It is evident that the real and imaginary parts of  $Z$  are nearly equal to unity and zero, respectively, at both the absorption frequencies.

The proposed structure provides inductance along the length of the metallic patch, whereas the capacitance part has been provided by the slot present in the tetra-arrow cave structure [10]. The dielectric substrate sandwiched between top metallic patch and bottom ground plane also provides some vertical capacitances. These lumped elements combinedly form electromagnetic resonance phenomena, which form narrow dips in reflectance spectrum and simultaneous maximization of absorptivity [11].

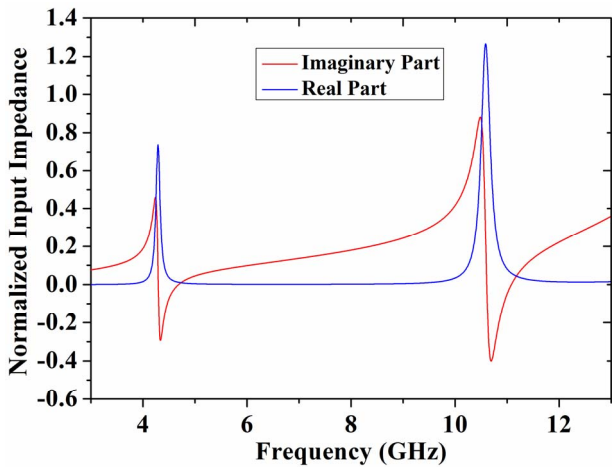


Fig. 3. Simulated normalized input impedance of the proposed absorber.

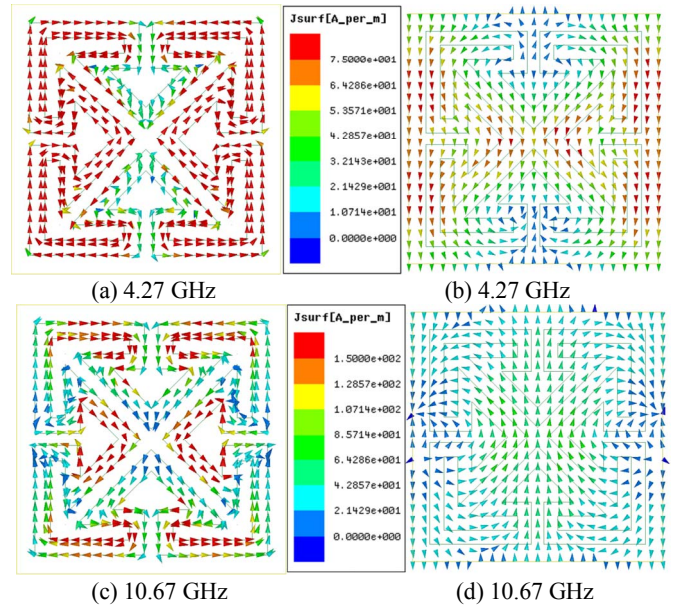


Fig. 4. The surface current distributions on the top surface (a, c) and bottom surface (b, d) at the absorption frequencies.

In order to further analyze the absorption mechanism of the structure, the surface current distributions at the peak absorption frequencies have been illustrated in Fig. 4. It is observed that at lower frequency 4.27 GHz, the top surface current is distributed in the entire tetra-arrow cave structure, whereas the current travels smaller distance at higher frequency 10.67 GHz. The top and bottom surface currents are anti-parallel to each other, thus forming circulating loop around incident magnetic field at both the absorption frequencies.

The proposed structure is investigated for different angles of polarization ( $\phi$ ) whose results are shown in Fig. 5. It is shown that the structure exhibits almost same absorptivity for different polarization angles (upto  $45^\circ$ ) under normal incidence at both the absorption frequencies.

The structure is further studied for oblique incidence under both TE and TM polarized waves as shown in Fig. 6(a) and Fig. 6(b), respectively. The direction of incident electric field is kept fixed, while the magnetic field and wave propagation directions are rotated with an angle  $\theta$  for TE polarization. In

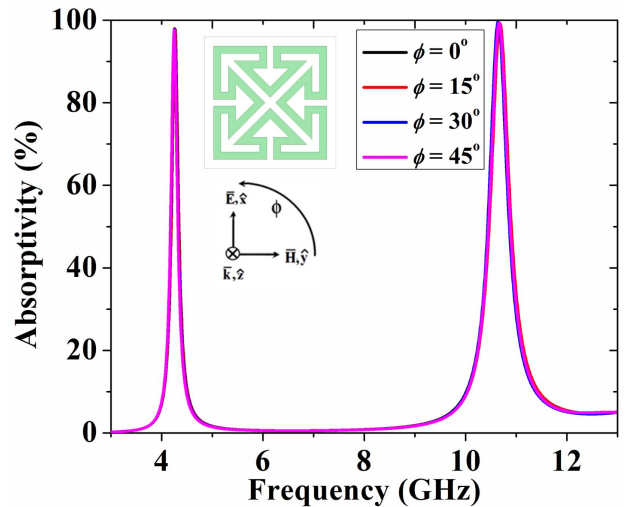


Fig. 5. Simulated absorptivity for different polarization angles under normal incidence.

### III. EXPERIMENTAL VERIFICATION

The proposed structure is implemented as a  $30 \times 30$  array which is fabricated on a  $240 \text{ mm} \times 240 \text{ mm}$  FR-4 substrate of 1 mm thickness using printed circuit board (PCB) technology. The fabricated structure is shown in Fig. 7(a) with its enlarged view in Fig. 7(b).

The absorptivity of the structure is determined experimentally in microwave anechoic chamber using an Agilent N5230A network analyzer and two identical broadband horn antennas with operating bandwidth of 1-18 GHz. A conductive copper sheet having identical dimension as that of the fabricated structure is used to calibrate the test environment, which is used as reference level. The measured result shows two discrete absorptions peaks at 4.35 GHz and 11.05 GHz with absorptivities of 98% and 99.07%, respectively, as shown in Fig. 8. The measured result is in good agreement with the simulated response except for a small shift in higher frequency absorptivity peak which may be due to variation in material parameters of FR4 substrate at higher frequencies.

The structure is examined for its polarization-insensitive behavior by rotating around its axis in  $xy$  plane without

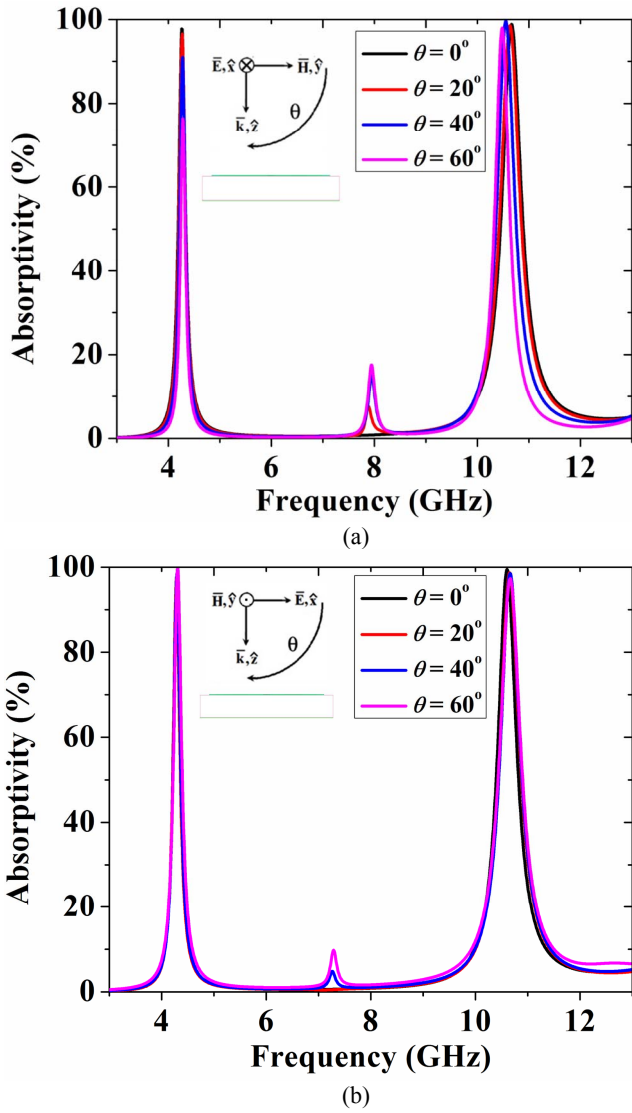


Fig. 6. Simulated absorptivity for different incident angles under (a) TE and (b) TM polarizations of the proposed structure. In the case of TM polarization, the direction of incident magnetic field is kept constant and the incident electric field and wave propagation vectors are rotated with an angle  $\theta$ . The simulated responses for both TE and TM polarizations show that the absorptivity remains high (above 80% for TE and above 95% for TM) for incident angles up to  $60^\circ$ . There is an extra absorption peak observed at around 8 GHz, where absorptivity level is negligibly small.

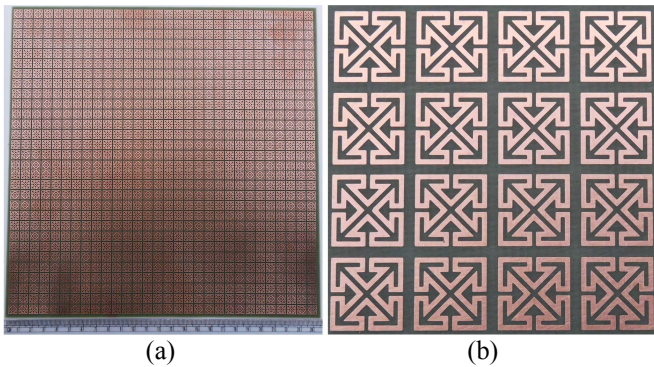


Fig. 7 (a) Fabricated structure of the proposed dual band absorber, and (b) its enlarged view.

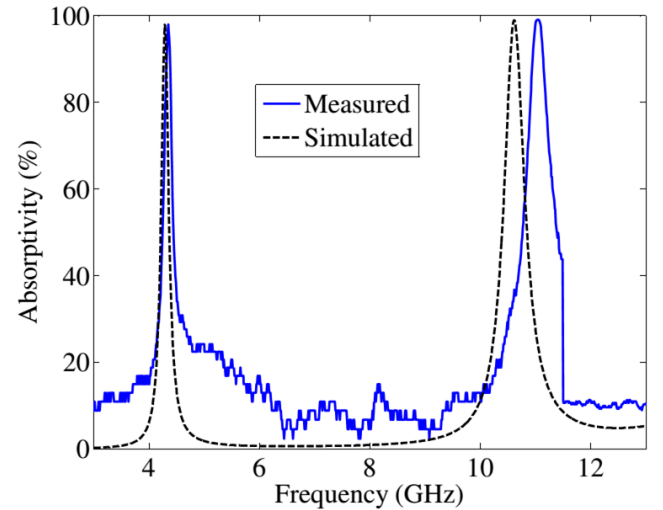


Fig. 8. Comparison of simulated and measured absorptivity of the proposed absorber under normal incidence.

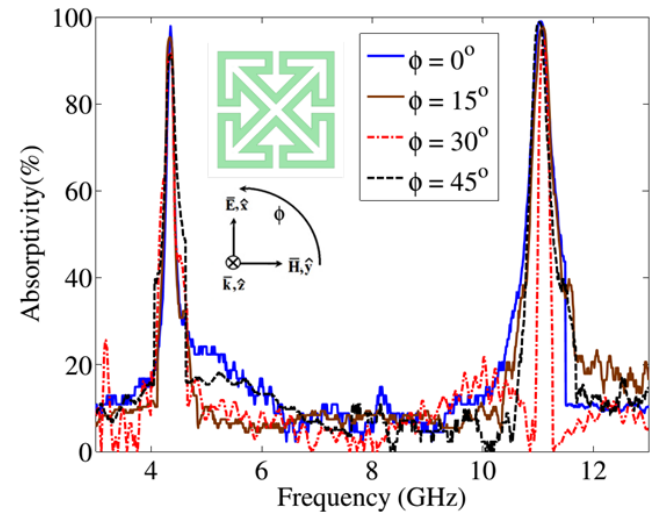


Fig. 9. Measured absorptivity for different polarization angles under normal incidence.

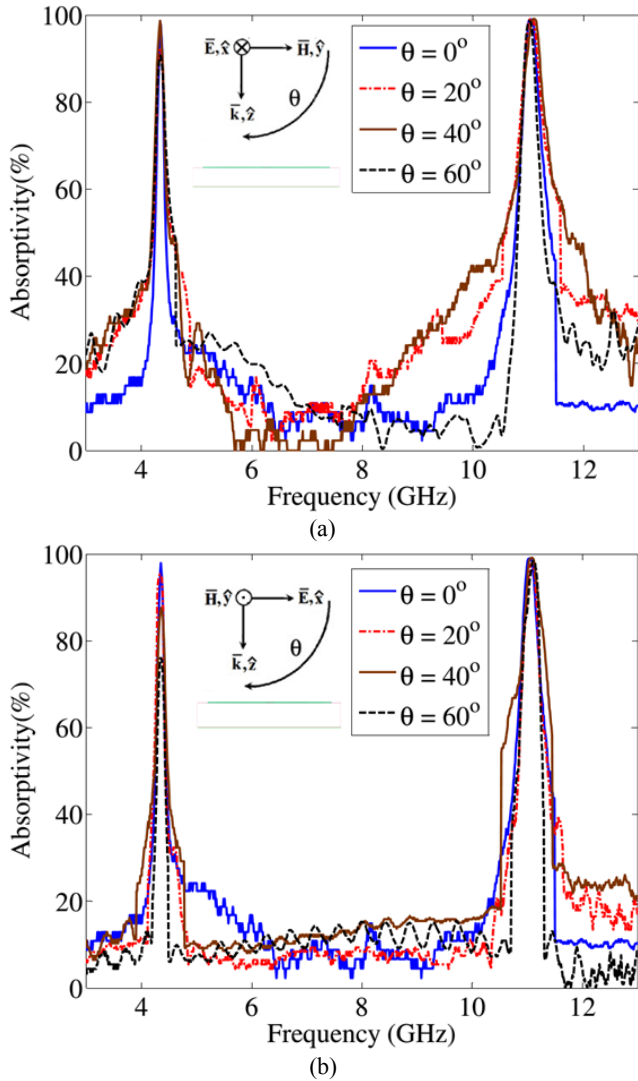


Fig. 10. Measured absorptivity for different incident angles under (a) TE and (b) TM polarizations of the proposed structure.

disturbing the transmitting and receiving antennas. The measured absorptivity of the fabricated structure is depicted in Fig. 9, which shows almost identical absorption peaks for different polarizing angles upto  $45^\circ$  under normal incidence, thus verifying the polarization-insensitive behavior of the structure.

The absorption characteristics for oblique incidence under TE and TM polarizations have also been measured as shown in Fig. 10. In case of TE polarization, the horn antennas are rotated in such a way that the electric field is kept fixed, whereas the magnetic field and the propagating wave vector are varied with angle  $\theta$ . On the contrary, the magnetic field direction is kept constant and remaining two wave vectors are rotated in case of TM polarization oblique incidence measurement. It is observed that the measured results are in good agreement with the simulated responses and show high absorptivity for incident angle upto  $60^\circ$  for both TE and TM polarizations.

#### IV. CONCLUSION

A dual-band metamaterial absorber comprising of tetra-arrow cave ELC structure has been presented in this paper. The proposed structure is parametrically optimized to obtain

near-unity absorption frequencies at two different frequency bands (C and X-bands). The surface current distributions have been illustrated to explain the absorption mechanism of the structure. The proposed absorber, being axial symmetric, is polarization-independent and wide-angle absorptive (upto  $60^\circ$ ) for both TE and TM polarizations, and all these cases have been verified by experimental measurement. The structure is only 1 mm thick ( $\sim \lambda/28$  with respect to the higher frequency), thus making it ultra-thin in nature. The designed absorber is compact, easily tunable to different frequency bands, and can be used in many potential areas like EMI/EMC applications, stealth technology, wireless communication, and mobile technology.

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