

Comment on “A Wideband Wide-angle Ultra-thin Metamaterial Microwave Absorber”

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Abstract—In the recently published article, Sood and Tripathi (*Progress In Electromagnetics Research M*, Vol. 44, 39–46, 2015) proposed a wide-angle ultra-thin metamaterial absorber structure for wideband applications. The reported unit cell was shown to have simulated wideband absorptivity FWHM bandwidth of 1.94 GHz, i.e., from 5.05 GHz to 6.99 GHz. In this article, we prove that the reported structure is not an electromagnetic wave absorber. For the reported structure, we find that absorption is less than 22.3% over a operating bandwidth of 4 GHz to 8 GHz. It is demonstrated that the strong absorption was caused due to ignorance of cross-polarization effect rather than true absorption as they claimed.

1. INTRODUCTION

In recent times, planar electromagnetic metamaterial absorbers have gained a lot of attention from researchers after Landy et al. published the first paper [1]. Near unity absorption was realized using electric LC resonators and cut-wires separated by dielectric spacer. Nowadays, several works related to a metamaterial absorber have been published at microwave and THz frequency regime. With further developments, research in this area includes achieving near unity absorption characteristics for multi-band, broadband frequencies maintaining polarization insensitive and ultra-thin profile. There are articles which report broadband absorption phenomenon [2–6]. However, on further investigations, it was found that the broadband absorption resulted from ignorance of cross-polarized reflections from the structures. This fact is addressed by the articles respectively [7–11]. In subsequent section, study and investigations are carried out on the structure proposed in [12], and it is shown that already reported structure is not a metamaterial absorber.

2. NUMERICAL SIMULATION, RESULTS AND DISCUSSIONS

Recently, Sood et al. published an article on a wide-angle ultra-thin, wideband metamaterial absorber structure [12]. The presented structure had four circular slots etched from 45° inclined hexagonal metal patch as shown in Fig. 1. The proposed design was printed on an FR-4 substrate ($\epsilon_r = 4.4$ and $\tan \delta = 0.02$). The other face of the substrate was made of complete copper for zero transmission. The authors reported that for the proposed structure absorptivity has FWHM bandwidth of 1.94 GHz, i.e., from 5.05 GHz to 6.99 GHz. The structure was simulated in full wave electromagnetic solver Ansys HFSS using periodic boundary conditions and Floquet port excitation. The absorption peaks for the structure were reported at 5.34 GHz, 6.33 GHz with absorption rates of 99.20% and 99.62%, respectively.

We again resimulated the structure using Ansys HFSS to understand wide-band absorption phenomenon. The details of geometrical and structural parameters are the same as mentioned by Sood et

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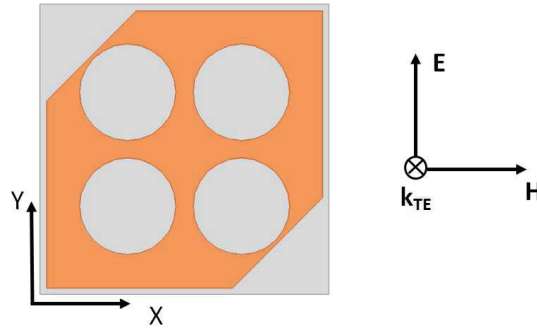


Figure 1. Top view of the reported unit cell [12].

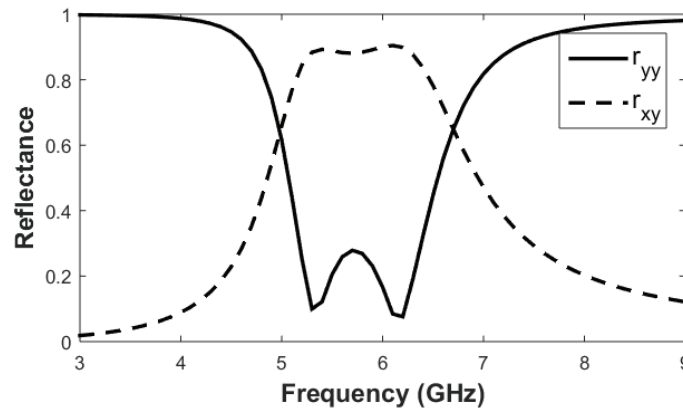


Figure 2. Numerically simulated co-polarized (r_{yy}) and cross-polarized (r_{xy}) reflections under normally incident y -polarized (TE) electromagnetic wave.

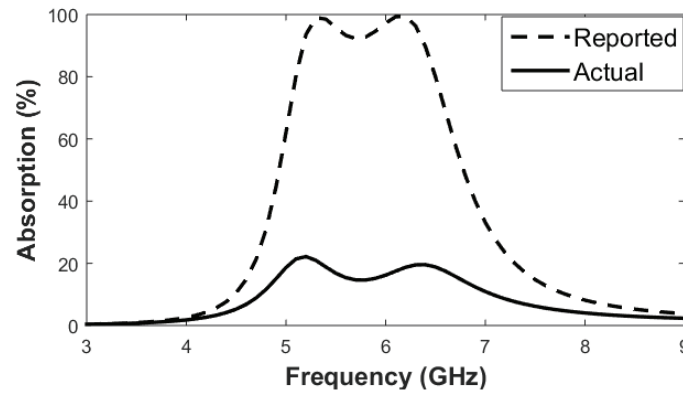


Figure 3. Numerically simulated absorption spectra under normally incident y -polarized (TE) electromagnetic wave.

al. [12]. It is found that the absorptivity for the proposed structure is less than 22.3% within operating frequency band of 4 GHz to 8 GHz. The absorption peaks are found at 5.2 GHz and 6.4 GHz having value of 22.3%, 20% as shown in Fig. 3. This low value of absorption is obtained due to consideration of cross-polarized reflections in the calculations of absorptivity. The original authors in [12] may have ignored this fact and found very high absorption over wide bandwidth. We have plotted co-polarized and cross-polarized reflectances as shown in Fig. 2.

For linearly polarized electromagnetic wave impinging on the object, the absorption is calculated as:

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

where $S_{11}(w)$ and $S_{21}(w)$ are reflection and transmission coefficients, respectively. The backside of the reported structure is grounded with metal layer, and therefore, transmission coefficient $|S_{21}(w)|^2$ is zero. The reflectance is expressed as $|S_{11}(w)|^2 = |r_{yy}(w)|^2 + |r_{xy}(w)|^2$. The terms $r_{yy}(w)$ and $r_{xy}(w)$ represent co- and cross-polarized reflections for y (or TE) polarized wave. The comparison is performed between the reported and actual absorptivity curves as shown in Fig. 3. It can be observed that the incident EM wave is not absorbed in the structure, but greater portion is reflected due to cross-polarized reflections. The magnitude of co-polarized reflectance has value less than 0.4 between 5.1 GHz and 6.5 GHz. This low value of co-polarized reflectance and high value (> 0.75) of cross-polarized reflectance support our claim. It implies that the major portion of the wave is reflected as cross-polarized reflectance. Original authors fabricated a prototype structure and presented measurement results showing close agreement with near unity absorption. However, measurements might have done only for co-polarized reflections. To measure cross-polarized reflections, receiving horn antenna has to be rotated by 90° with respect to transmitting horn.

The polarization conversion ratio (PCR) can be obtained from co-polarized and cross-polarized reflectances as given below. PCR computed using Eq. (2) as shown in Fig. 4 has conversion efficiency more than 90% from 5.2 GHz to 6.4 GHz. The structure can be served as a wideband high efficiency polarization converter [13].

$$\text{PCR} = \frac{r_{xy}^2}{r_{xy}^2 + r_{yy}^2} \quad (2)$$

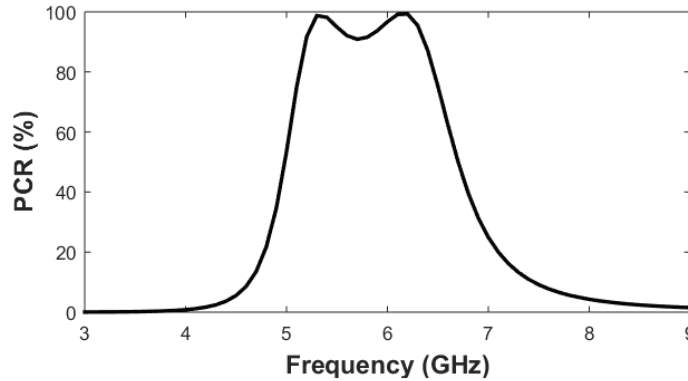


Figure 4. Numerically simulated results of polarization conversion ratio (PCR) for normally incident y -polarized electromagnetic wave.

To understand the cause of polarization conversion, a new coordinate system (u - v) is defined by 45° anticlockwise rotation to original coordinate system (X - Y) as shown in Fig. 5(a). The structure is simulated by decomposing y -polarized incident E -field along u -polarized and v -polarized normal incidences [13] as shown in Fig. 5(b). The magnitude of reflectances (r_{uu} , r_{vv}) and phase difference ($\Delta\phi = \phi_{vv} - \phi_{uu}$) along u and v -polarized incidences are plotted as shown in Figs. 6 and 7, respectively. The magnitude of reflectance (r_{uu} , r_{vv}) is close to unity, although dips are observed in r_{uu} and r_{vv} at 5.2 GHz and 6.4 GHz, which may be due to absorption related to dielectric and ohmic loss in the structure. The phase difference between reflection phases (ϕ_{uu} , ϕ_{vv}) is shown in Fig. 7, which has values just equal to 180° near frequencies 5.3 GHz and 6.2 GHz. Therefore, orthogonal polarization rotation at 5.3 GHz and 6.2 GHz is realized for y -polarized linearly incident wave, whereas phase difference at frequencies near 3.5 GHz is 0° indicating that there is no polarization conversion for reflected wave [13]. The structure is diagonally symmetric, and therefore, only TE mode of incident wave is investigated here. Similar observations can be found for the other mode (TM).

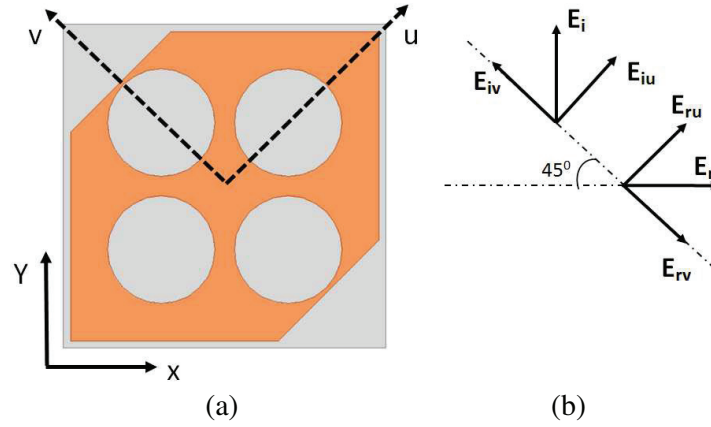


Figure 5. (a) Co-ordinate rotation and (b) polarization rotation.

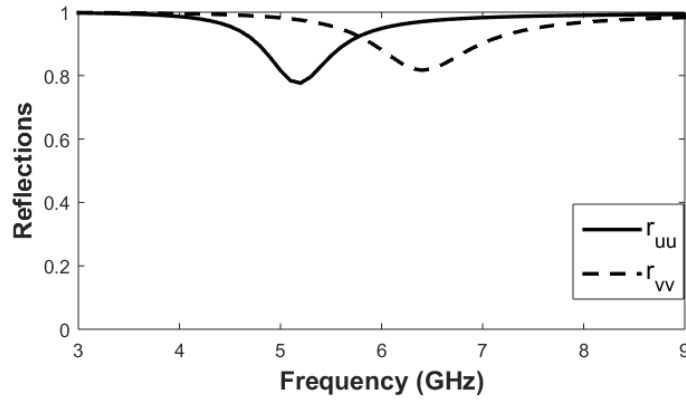


Figure 6. Numerically simulated reflection magnitude for decomposed u -polarized and v -polarized incident electromagnetic wave.

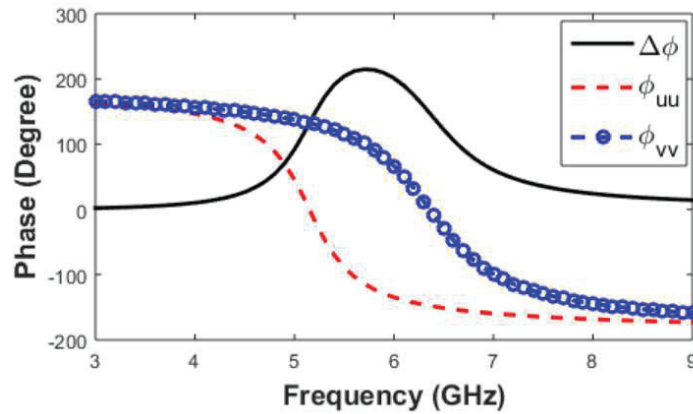


Figure 7. Numerically simulated reflection phases (ϕ_{uu} , ϕ_{vv}), phase difference ($\Delta\phi = \phi_{vv} - \phi_{uu}$) for u -polarized and v -polarized incident electromagnetic wave.

3. CONCLUSION

From the above study, it can be concluded that the reported asymmetric structure is not an efficient electromagnetic wave absorber. The asymmetry in the structure or disorientation of polarization of incident wave on top metal surface may create polarization conversion. This fact was not considered by Sood and Tripathi, and they claimed that the structure was a perfect metamaterial absorber. The cross-polarization effect should be considered while designing perfect wave absorber.

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