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Ultra-Wideband Hybrid Based Metamaterial Absorber

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Abstract

In this paper, we propose a multi-resonance MM design which will be used for the realization of an ultra-wideband hybrid microwave absorber. The metamaterial absorber consists of a symmetrical structure, called V-shape, with different scales of coupled resonators and the hybrid absorber is carried out by the association of this metamaterial to a lossy dielectric layer, made of epoxy foam composite loaded with low weight percentage (0.075 wt.%) of 12 mm length carbon fibers. The simulation and measurement results of the hybrid material of 16.2 mm thickness show an absorption bandwidth between 2.6 GHz and 18 GHz for both normal and oblique incidences.

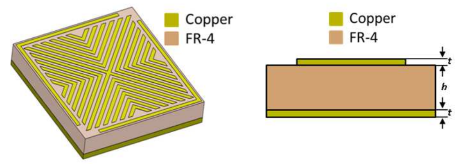
1 Introduction

Generally, metamaterials (MM) are considered as resonant absorbers, but many efforts have been made in the literature in order to achieve multiband, broadband, or ultra-wideband microwave metamaterial absorbers. Few methods were tested, such as combining various absorption peaks by combining multiple resonating structures [1], stacking different MM structures [2] or stacking multiple metallic/dielectric layers, forming a pyramidal [3] or a cylindrical [4], 3D structures and finally, incorporating lumped elements into the MM resonators [5]. Most of the cited methods have failed to cover several bands together; all designs have mostly focused on one or two frequency bands among the C-band (4-8 GHz), X-band (8–12 GHz), Ku-band (12–18 GHz) or K-band (18–27 GHz), whereas only few MM designs for absorption in the S-band (2–4 GHz) were reported so far. The aim of this work is to propose a simple method to broaden the MM absorber bandwidth, covering several bands, and to achieve a good absorption at the low frequencies (< 4 GHz) with a compact structure.

2 Design and materials used

2.1 Schematic of single unit cell

The new proposed design of the MM consists of 15 mm x 15 mm unit cell and of three layers. The first layer is composed of symmetrical copper resonators (L, X and V shapes), shown in Figure 1, while the second layer is the FR-4 dielectric substrate with dielectric constant $\varepsilon'_r = 4.3$, loss tanδ = 0.025 and h = 3.2 mm. The top and bottom layers are made of copper with an electric conductivity of 5.8×10^7 S/m and thickness of t = 17 μm. The overall dimensions of this proposed MM cell is 12,8 mm x 12,8 mm.



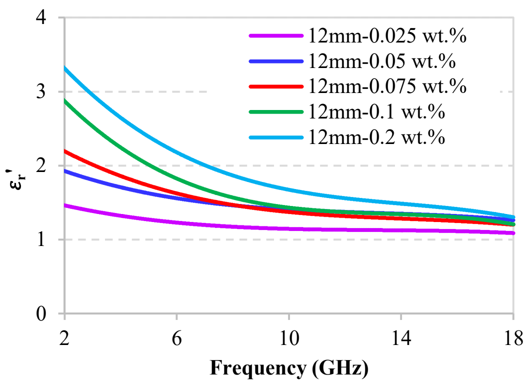
(a) *(b)*

Figure 1. (a) perspective and (b) side views of the proposed V-shape MM.

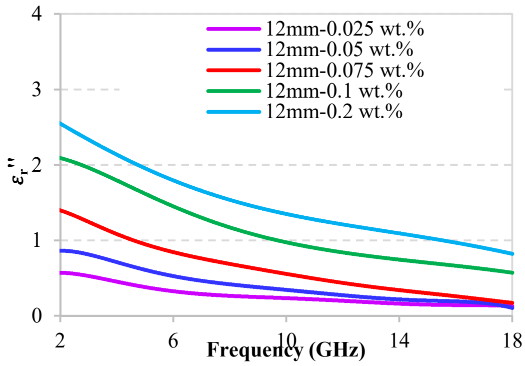
The simulation results of the proposed MM are obtained using (CST) Microwave Studio software.

2.2 Epoxy composite materials

The epoxy resin, hardener and carbon fibers are used for the elaboration of our composite. CFs have a diameter of 7 μm and length of 12 mm. The elaboration steps of the epoxy foam loaded with carbon fibers are detailed in [7]. The density of this composite is 0.12 g.cm^{-3}. The dielectric properties of the used composites are presented in Figure 2. As expected; this figure shows an increase of permittivity, as a function of the CF rate. Moreover, it will be noted here that a high ε_r'', associate with low ε_r', are obtained with these composite materials.



(a)



(b)

Figure 2. Real εr' (a) and imaginary εr'' (b) parts of dielectric permittivity of low-loaded epoxy foam composites with 12 mm CFs.

3 Results and discussion

3.1 V-shape MM absorber results

The proposed MM absorber is fabricated with 10 × 10 unit cells of the total dimension of 150 mm × 150 mm × 3.2 mm where the dimension of each unit cell is 15 mm x 15 mm; the laser etching technique, using an LPKF station available at the IETR laboratory, is used for the elaboration of the proposed MM that is shown in Figure 3

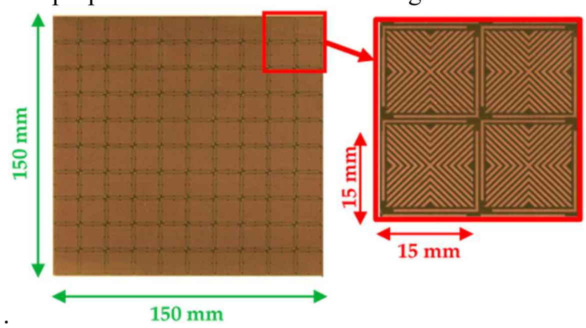
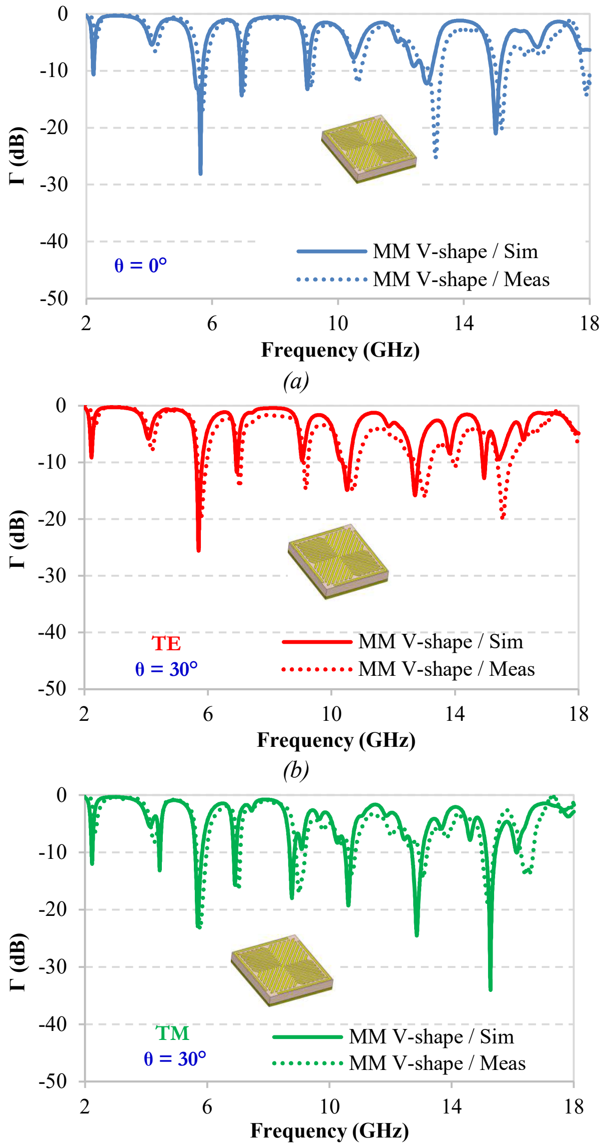


Figure 3. Photo of the realized V-shape MM.

Comparison between measured and simulated reflection coefficients, of the proposed MM, at normal incidence and at oblique incidence of 30° for TE and TM polarizations are shown in Figure 4 (a), (b) and (c). The proposed MM exhibits several distinct resonances (with a reflection coefficient < -10 dB) that occurs at 2.2 GHz, 5.63 GHz, 6.94 GHz, 8.99 GHz, 12.8 GHz, and 15.01 GHz. A good agreement between measurement and simulation is also observed for both incidences and for TE and TM modes, but with a slight difference at some frequencies. The weak observed difference is probably due to a geometric deviation between the perfect simulated structure of the MM and the produced one.



(c)

Figure 4. Comparison between simulated and measured reflection coefficients for (a) normal incidence and oblique incidence of 30° for (b) TE and (c) TM modes.

3.2 Hybrid microwave absorber results

A hybrid absorber that combines a layer of "natural" absorber, based on epoxy composite layer, with the artificial absorber, based on V-shape MM, is proposed; this hybrid absorber is shown in Figure 5.

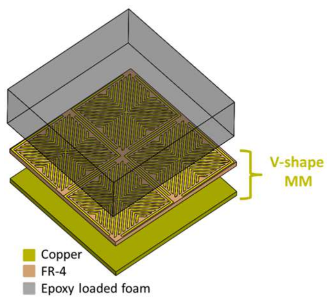


Figure 5. Proposed hybrid absorber.

Simulations of the reflection coefficient of the hybrid absorber were carried out using 13 mm thickness of different epoxy foam composites loaded with different wt.% of the 12 mm CFs. Results are compared to that of the MM absorber alone (black dash) in Figure 6. It is observed that when low weight percentages (0.025 or 0.05 wt.%) of CFs are used (dotted curves), the reflection coefficients of the MM is improved, but the losses are too low to broaden the bandwidth, and an uninterrupted large bandwidth ($\Gamma < -10$ dB) could not be obtained. On the other hand, when high CF loads (0.1 or 0.2 wt.%) are used (continuous line), higher reflections, compared to the one of the MM with 0.075 wt.% loaded foam, are obtained. Here, the composite loaded with 0.075 wt.% seems as the better compromise, it is adopted for the next step.

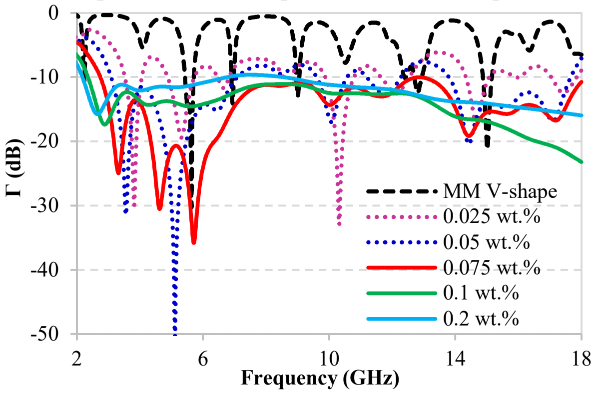


Figure 6. Simulated reflection coefficients of the MM alone and the hybrid absorber based on composites loaded with different CF rates.

Simulations of the reflection coefficients of the hybrid absorber (with the composite loaded with 0.075 wt.% of CFs), using different thicknesses d, were carried out (Figure 7). With d = 13 mm, the reflection coefficient becomes less than -10 dB between 2.6 GHz and 18 GHz. This thickness is used for the achievement of the hybrid absorber prototype.

Simulations of the reflection coefficients of the hybrid absorber with the chosen composite were performed for incidence angles between 0° and 60°; a 3D plots of these results are presented in Figure 8 (a) and Figure 8 (b) for TE and TM modes, respectively.

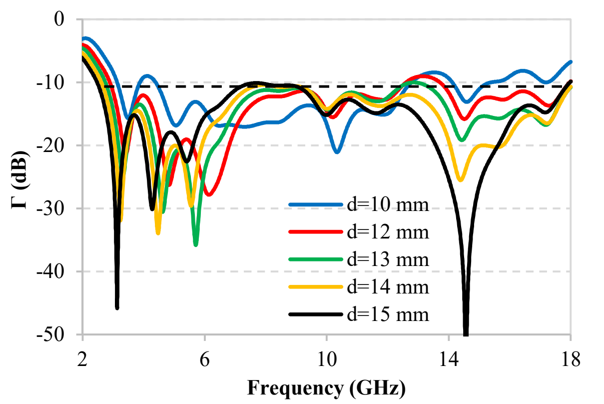


Figure 7. Simulated reflection coefficients of the hybrid absorber using different thicknesses of composite.

The simulations of Figure 8 predict a reflection coefficient less than -10 dB between 2.6 GHz and 18 GHz, for the different angles of incidence. However, for the TE mode and for the highest angles ($\theta \geq 45°$), the absorption performance is slightly affected at low (< 4.5 GHz) and high (>16 GHz) frequencies (Figure 8 (a)).

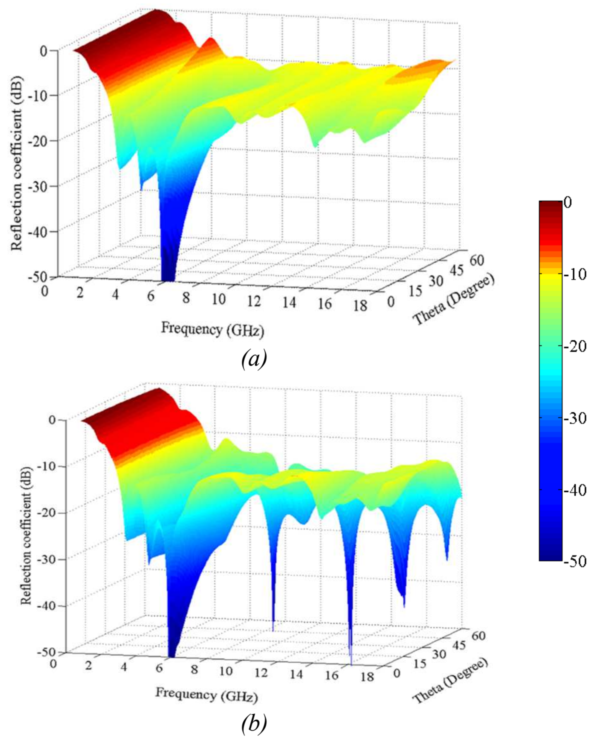


Figure 8. Simulated reflection coefficients of the hybrid absorber with different angles of incidence for (a) TE and (b) TM modes.

The realized hybrid MM absorber prototype is shown in Figure 9 (a). The simulation and measurement results, at normal incidence, are compared in Figure 9 (b). The predicted absorption performance in ultra-wideband is confirmed here by the measurement. Note that, a slight difference between measurements and simulations is obtained. A decrease in the performance occurs at 4.2 GHz with a reflection coefficient of -7.65 dB; this is due to a problem in the anechoic chamber where the measurements were done. Contrariwise, a better performance is obtained by measurement for the highest frequencies.

The measurement results are compared to that of simulations, for oblique incidence of 30°, in Figures 9 (c) and (d), for TE and TM modes, respectively. For both polarizations, a reflection coefficient less than -10 dB is obtained between 2.6 GHz and 18 GHz with the same observations of the normal incidence. Note that the measurement for the other angles of incidence (> 30°) were not carried out because of the space restrictions in the used anechoic chamber.

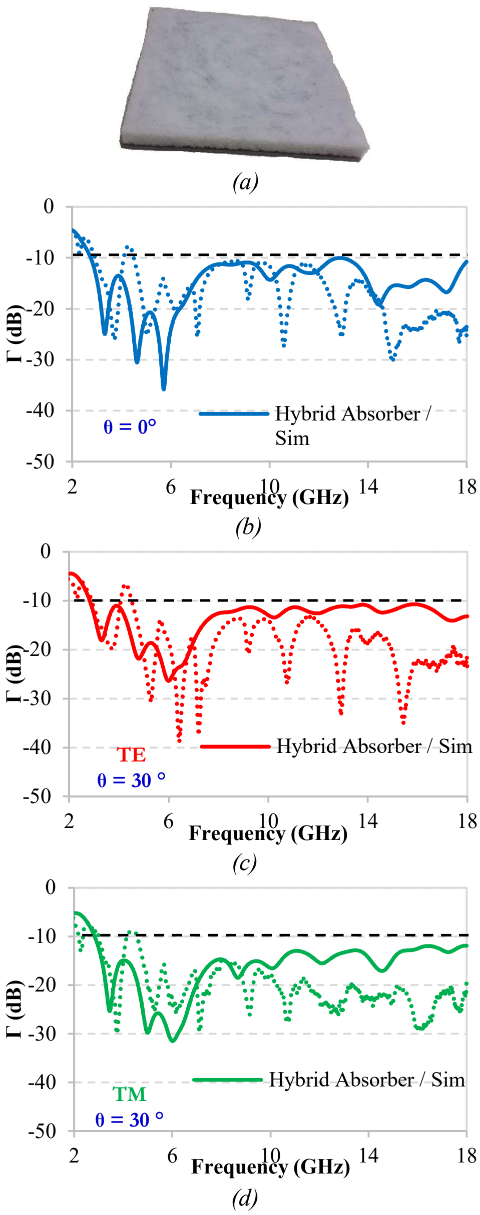


Figure 9. Photo of the achieved hybrid absorber (a) and comparison between simulated and measured reflection coefficients for normal (b) and oblique incidence of 30° for TE (c) and TM (d) polarizations.

4 Conclusion

A multi-resonance MM absorber, called V-shape MM, with unit cell dimensions of 15 mm x 15 mm was proposed. This geometry presents several resonances between 2 and 18 GHz. A thin (13 mm) dielectric layer, made of 0.075 wt.% CFs loaded epoxy foam, is associated to the front of the MM absorber in order to broaden its absorption performance. The proposed MM has a thickness of 3.2 mm, so the hybrid absorber presents a total thickness of 16.2 mm. Absorption higher than 90% is obtained from 2.6 GHz to 18 GHz, for TE and TM polarizations at normal and oblique ($\theta < 45°$) incidences. As a result, an ultra-wideband, light, and compact absorber that covers 70 % of the S-band (2.6–4 GHz) and the entire C-band (4–8 GHz), X-band (8–12 GHz), and Ku-band (12–18 GHz) is achieved.

5 Acknowledgements

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6 References

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