A novel ultra-thin flexible metamaterial absorber for human body protection from EMF hazards

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Abstract

In this paper, a new ultra-thin flexible absorber based on a novel tetra Y-inspired metamaterial unit cell is designed for human body protection from electromagnetic (EM) field Hazard and (EM) Thermal Impact. The polyimide Kapton film is used as the substrate for its mechanical and thermal advantages. The simulation results show that the proposed Flexible Metamaterial Absorber (FMA) features a high absorption peak at 5.2 GHz with the absorptivity of 98%. The simulation investigations confirm that the FMA sample is polarization insensitive for transverse electric and transverse magnetic incident waves. They also exhibit that high absorption for wide angle of incidence up to 75°. The same results feature a high and stable absorptivity for conformal configurations with an absorptivity value near 99% at 5.25 GHz. The experimental results of fabricated FMA samples using inkjet-printing technology show a resonant behavior around 5GHz with 70% measured absorptivity.

1. Introduction

With the explosive development of wireless energy transfer and communication systems, especially in wearable and IoT configurations, the ambient electromagnetic radiation sources are becoming increasingly disruptive to the human environment [1]. Some new WPT (Wireless Power Transfer) systems for civilian or military applications aim to transfer high-power energy via electromagnetic radiation [2]. The interaction of electromagnetic radiation with the human body through a high Specific Absorption Rate (SAR) creates a real danger to the human health [3]. Moreover, thermal effects, as tissues are exposed to unlimited electromagnetic energy over very wide frequency ranges, can be a solemn health hazard [4]. The impact of the Electromagnetic field (EMF) danger depends on the surface of the human body that is exposed to the RF energy and on the power and propagation mode of the incident wave [3],[4]. The use of an absorbent material for the protection of some parts of the human body seems to be a well-needed solutions against the danger of EMF [5],[6]; the design process of the absorbent material should take into consideration a set of parameters: (a) polarization insensitive absorptivity, (b) mechanical flexibility insensitive absorptivity, (c) low profile of material substrate, (d) thermal isolation. In this paper, we propose an ultra-thin and flexible absorber based on a novel metamaterial unit cell array, which can be used for the reduction of EMF impact and thermal isolation in human body. This paper is structured as follows. Section 2 describes the design and substrate material choice of the Flexible metamaterial Absorber (FMA) and Section 3 describes the numerical investigation of the FMA under several Electromagnetic excitation modes. The fabrication process and experimental results are explained in Section 4, while Section 5 concludes the paper.

2. Flexible metamaterial absorber design

The proposed Flexible Metamaterial Absorber (FMA) based on the novel resonant structure is presented in Figure. 1. The top layer consists of a set of four diagonal Y-inspired metallic sheets in a concentric periodic pattern and the bottom layer is a copper reflector. The polyimide-based Kapton film is used as the substrate separating the two metallic layers. The Kapton film was chosen due to its good thermal, electrical and mechanical properties.

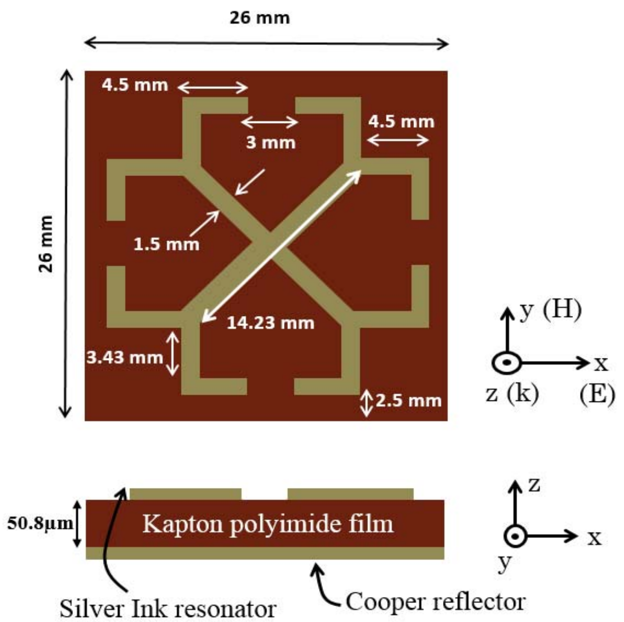


Figure 1. Schematic showing the proposed novel resonant structure of the metamaterial absorber unit cell.

The Kapton polyimide offers a very low profile (50.8 µm), with a stable dielectric permittivity over large temperature ranges between 65 °C to 350 °C. Yet, the Kapton film is highly suitable for conformal or flexible applications [7]. The full FMA is then realized by the periodic extension of the unit cell in both x and y directions. The FMA unit cell was designed and investigated with Ansys HFSS using periodic boundary conditions. An incident plane wave was used as the excitation source for the FMA unit cell; the E-field was polarized along x- direction and the magnetic field along y-axis. The geometrical parameters of the resonator were optimized to constrain the resonant frequency around 5 GHz as given in Figure.1.

3. Numerical results

The absorptivity can be calculated by (1), where $A(\omega)$, $|S_{21}(\omega)|^2$ and $|S_{11}(\omega)|^2$ are the absorptivity, transmitted power, and reflected power, respectively, at an angular frequency(ω). Due to the copper reflector backing, there is no transmitted power ($|S_{21}(\omega)|^2 = 0$).

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

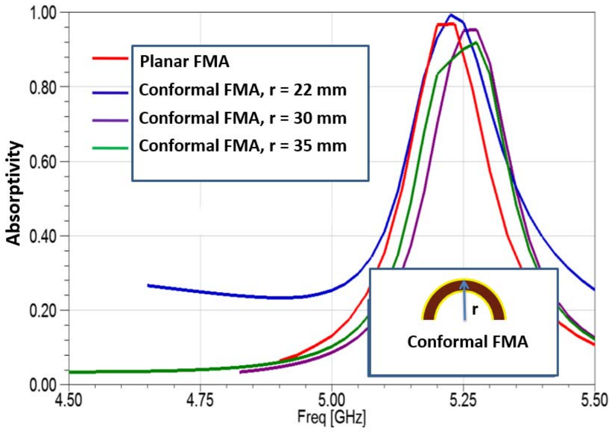
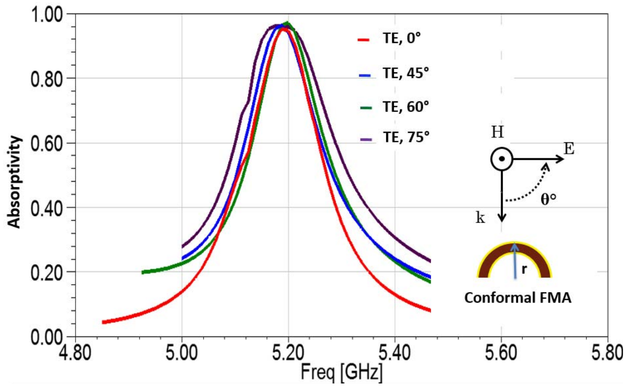
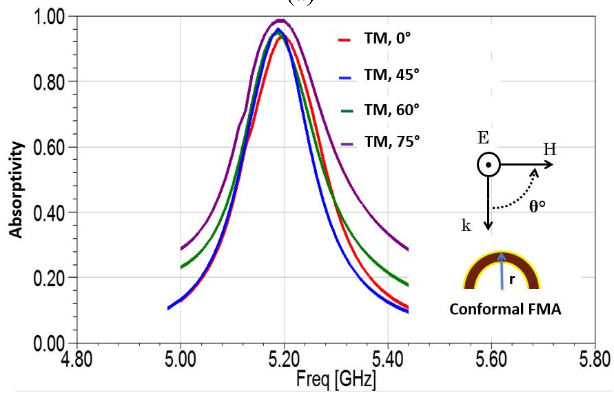


Figure 2. Comparison of the simulated absorptivity for both TE and TM polarizations for the topologies of the planar FMA.

Due to the symmetrical design of the tetra Y-inspired resonator, the planar FMA structure is polarization insensitive as illustrated in Figure 2. The peak absorptivity is almost the same for both TE and TM polarizations. Fig.2 shows a near-ideal peak absorptivity near 98% at 5.23GHz. Moreover, It is interesting to note that FMA features a high and stable absorptivity for conformal configurations for three different radii of curvature/flexing (r = 22 mm, r = 30 mm and r = 35 mm) with only a slight frequency shift of 70MHz being observed for conformal configurations in comparison to the planar one.



(a)



(b)

Figure 3. Conformal FMA (r = 23 mm) simulated absorptivity for (a) TE and (b) TM incident waves.

The frequency dependence of the absorption for different angles of incidence is depicted in Figure 3. The full wave simulations were performed to verify the angle dispersion for both TE polarization (Figure. 3(a)) and TM polarization (Figure. 3(b)). The incident angle was varied from 0° to 75°. For both TE and TM polarizations, the results show stable and high absorbance peaks near 98% at 5.2 GHz.

4. Fabrication and experimental results

For proof-of-concept demonstration purposes, two inkjet-printed prototypes, a 4x4 and an 8x8-unit cell array, were fabricated. As shown in Figure 4, the conductive traces of FMA were printed on a (50.8 µm and εr = 3.5) Kapton polyimide film from DuPont by utilizing a silver nanoparticle-based ink, EMD5730 from Sun Chemical, which contains 40% silver nanoparticles diffused in an ethanediol-based solvent. After the printing, the FMA was cured on a hotplate at 120 °C for 10 min after a gradual temperature ramp from 30 °C with the rate of 360 °C per hour to dry the solvent in order to realize uniform printed conductive traces [7].

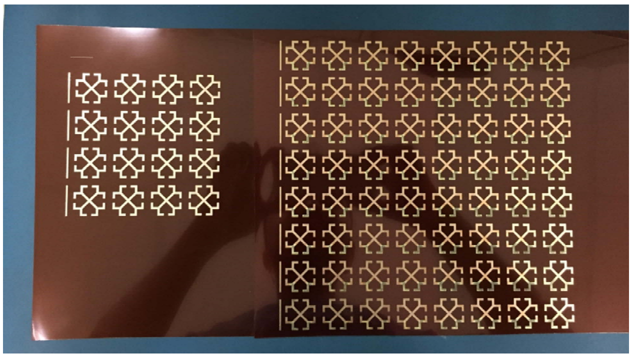


Figure 4. Inkjet-printed FMA samples on Kapton (4x4 unit cell array and 8x8 unit cell array).

The FMA absorptivity measurement setup, shown in Figure 5, consists of an Agilent N5245A vector network analyzer connected to two reference wideband horn antennas used as the electromagnetic sources. In this setup, we have realized only a TE polarization configuration with a wave initially incident on the planar FMA. The measurement must be performed under anechoic environment; the two horns antennas are tilted to different angles with respect to the normal direction of the FMA planar surface. The distance between the horn antennas must be chosen to eliminate any near field coupling. Before measuring the FMA response, a calibration step must be performed by measuring the S-parameters of a metallic reflector, which has the same dimensions with the FMA sample under test. The measured absorptivity can be considered as the difference between the metallic transmission response and the FMA transmission response.

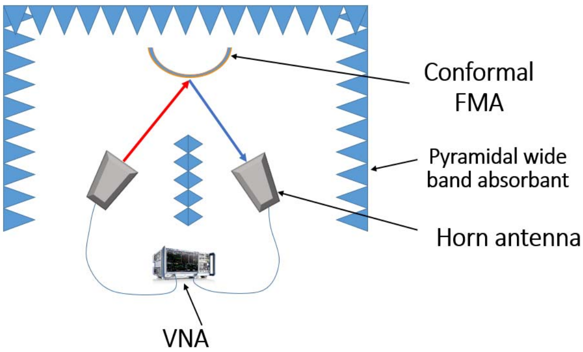


Figure 5. FMA samples absorptivity measurement setup

Figure. 6 shows the measured absorption curve for a TE-polarized incident wave to the planar FMA; the experimental results show a reasonable agreement with the simulations absorptivity responses with almost 70% measured absorptivity obtained around 5.2 GHz. The measured absorptivity peak level is relatively lower than the simulation results. We expect that this disagreement with the simulations is probably caused by the finite number of unit cells utilized in the prototypes as well as by printing fabrication tolerances of the FMA sample and other scattering problems.

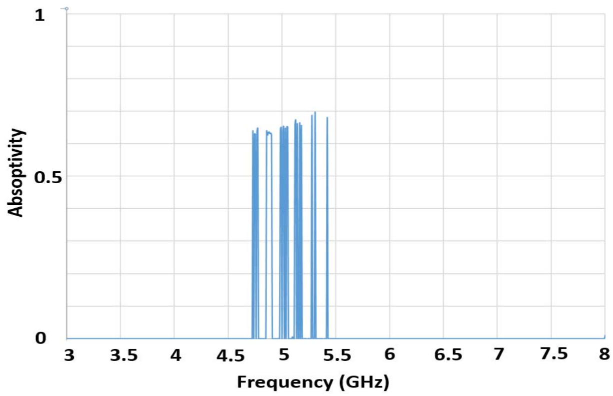


Figure 6. TE polarization measured absorptivity for the planar FMA prototype (8x8 unit cell array).

5. Conclusion

A new ultra-thin flexible absorber based on a novel tetra Y-inspired metamaterial unit cell is proposed. The proposed structure takes in to account numerous design constraints for the human body protection from EMF hazards. The proposed FMA structure it is especially tiny (50.8 µm) and exhibits a high (theoretically near-ideal) absorption peak for all studied conformal configurations. Numerical investigation under full wave simulations demonstrates a polarizations insensitive behavior for normal incidence. They also shows a very good absorption over a wide angle of incidence for both TE and TM polarizations. Prototypes fabricated using inkjet-printing technology show that additive manufacturing could be a very promising way to fabricate massively scalable ultra-thin and conformal absorbers for human body protection from EMF Hazards.

6. Acknowledgment

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7. References

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