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Design of a Metamaterial Absorber for ISM Applications

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Abstract

This paper proposes a metamaterial (MTM) absorber for 2.45 GHz band applications. The unit cell of the proposed absorber consists of an electric LC (ELC) resonator and a strip line, which are printed on opposite sides of the substrate. The ELC resonator comprises two split ring resonators (SRRs) and a connecting line with a resistor. The designed absorber exhibits an absorption of 94 % and a half-max bandwidth of 0.16 GHz at 2.45 GHz.

Key words: Metamaterial (MTM), Absorber, Electric LC Resonator.

Ⅰ. Introduction

Metamaterials (MTMs) are artificial electromagnetic structures composed of metals and dielectrics. The initial impetus driving MTM research was the realization of their effective negative permittivity, permeability, and refractive index [1]~[4].

Various MTM structures are naturally coupled to either the electric or magnetic components of light in frequency ranges from radio to near optical [5], [6]. The major advantage of MTMs over natural materials is that the macroscopic parameters can be designed to have desired values. Much of the recent MTM research has been focused on the real part of $\varepsilon(\omega)$ and $\mu(\omega)$ to enable the creation of a negative refractive index material. However, although the use of MTMs will potentially enhance the performance of absorbers, the wave absorption properties of MTMs have not been adequately studied.

Conventional absorbers cannot be made sufficiently thin because of diffraction limitations. The reduction in the electrical thickness of absorbers is one of the challenging aspects of their design. The need is urgent for designs of innovative absorbers that can overcome these two disadvantages of conventional absorbers. Tao et al. replaced the copper strip with a complete backplane and achieved 96 % absorption at 1.6 THz with a 16-μm-thick surface. Their device showed good broad angle performance in both TE and TM modes [7]. In their design, the metallic backing plate is necessary to prevent power transmission, which may represent a problem for stealth applications. Bilotti et al. proposed an SRR-based absorber by arranging SRR arrays behind a resistive sheet. This SRR-based absorber can be used in stealth technology, owing to the absence of metallic backing plates [8]~[10]. However, a resistive sheet, which is used to match the impedance of the free space, is necessary in this type of design.

This study uses an ELC resonator structure with a resistor to control the electric coupling of the MTM and absorption. The magnetic coupling was generated by combining the center strip of the ELC and a thin strip on the bottom side of the substrate. The proposed absorber can be used for 2.45 GHz band applications such as radio-Frequency Identification (RFID), wireless local area network (WLAN), and industrial, scientific and medical (ISM) systems.

Ⅱ. Design of an Absorber

As an effective medium, an MTM can be characterized by a complex electric permittivity $\varepsilon(\omega)=\varepsilon_1+j\varepsilon_2$ and magnetic permeability $\mu(\omega)=\mu_1+j\mu_2$ [5]. The real parts of ε and μ denote the relative constants, which are responsible for the negative refractive index of the material. The imaginparts of ε and μ account for losses and can be adjusted for high absorption. An MTM absorber introduced by Landy et al. [11], which utilizes the tuning of losses, has two requirements for the effective absorption of electromagnetic waves. One

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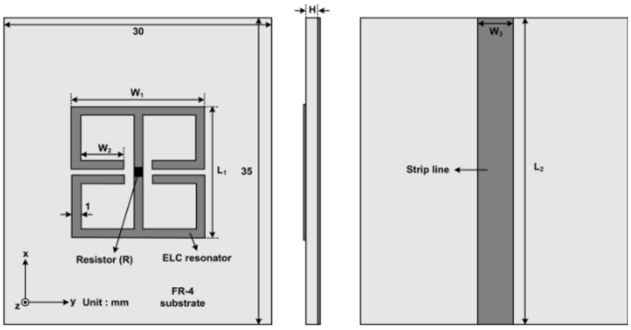
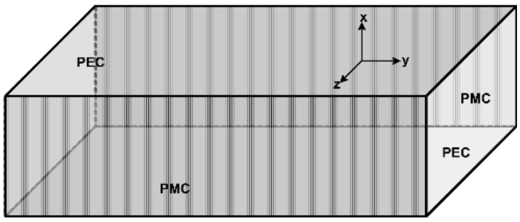
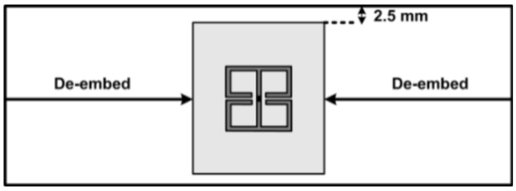


(a) Top view (b) Side view (c) Bottom view

Fig. 1. Geometry of the proposed absorber.



(a) PEC (y-z plane) and PMC (x-y plane)



(b) de-embedded structure

Fig. 2. Boundaries of the proposed absorber.

is that the impedance should be matched to the free space: $Z \approx Z_0$ to ensure minimum reflection. The other is that the imaginary part of the refractive index should be as large as possible to maximize the absorption of incident waves. In practice, the loss of material is measured by the amount of absorbed electromagnetic power. The absorption $A(\omega)$ of a material is related to its transmission $T(\omega)$ and reflectance $R(\omega)$, according to $A(\omega)=1-T(\omega)-R(\omega)$, where $T(\omega)=|t(\omega)|^2=|S_{21}|^2$ and $R(\omega)=|r(\omega)|^2=|S_{11}|^2$. The refractive index n and impedance Z are given by $n(\omega)=\sqrt{\varepsilon(\omega)\mu(\omega)}$ and $Z(\omega)=\sqrt{\mu(\omega)/\varepsilon(\omega)}$, respectively, [5], [12], [13], [14], [15].

Fig. 1 shows the unit cell geometry of the proposed absorber, which consists of an ELC resonator, a strip line, a lumped resistor, and an FR4 substrate (ε_r=4.4) with a thickness of 0.2 mm. The ELC resonator is printed on the top of the FR4 substrate and occupies an area of 15 mm×15 mm. It is constructed using two SRRs and a connecting line with a resistor and has both inductive and capacitive elements. The strip line is printed on the bottom of the FR4 substrate and occupies an area of 4.2 mm×35 mm.

The periodic metamaterial cell is analyzed by placing perfect electric conductors (PECs) on the top and bottom planes, and perfect magnetic conductors (PMCs) are placed on the front and back planes, as shown in Fig. 2(a). The magnetic field is perpendicular to the x-y plane and the electric field is parallel to the y-z plane. Therefore, the propagation direction is along the y-axis. The de-embed technique is used to obtain the *S*-parameter of the absorber, as shown in Fig. 2(b).

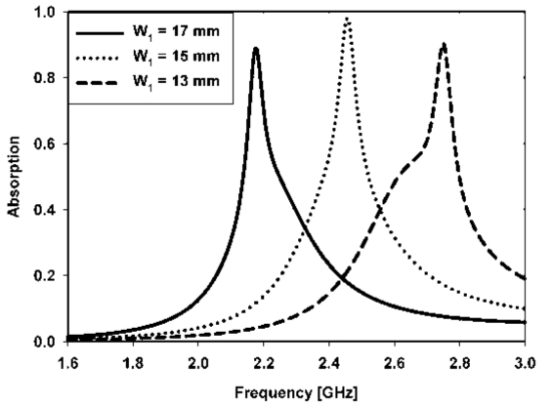
Figs. 3(a) and 3(b) show the simulated absorption characteristics of the proposed absorber for various ELC resonator widths (W_1) and lengths (L_1). Increases in W_1 and L_1 shift in the frequency band for the absorption toward a lower-frequency band. The required frequency band can be obtained by controlling the inductance of the ELC resonator. Fig. 3(c) shows the simulated absorption characteristics of the proposed absorber for various stub lengths (W_2) of the ELC resonator. Increases in W_2 shift the absorption frequency band toward a lower-frequency band because of enhancement of the inductive and capacitive coupling between the SRR structure and the center strip.

Fig. 4 shows the simulated absorption characteristics of the proposed absorber for various strip lengths (L_2) on the bottom side of the substrate. The peak absorption is obtained for a strip length (L_2) of approximately 35 mm because of the capacitive effect between the center strip of the ELC resonator and the strip on the bottom side of the substrate.

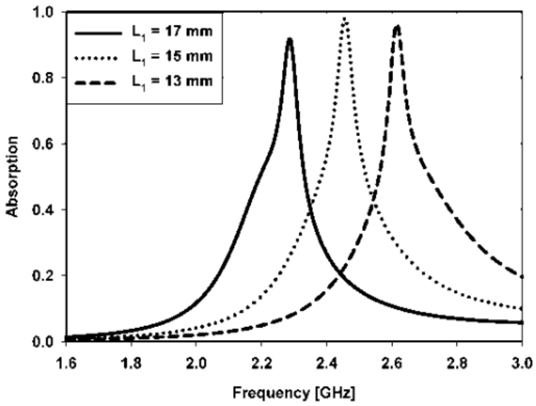
The absorption can be controlled by changing the resistance of the resistor. As shown in Fig. 5(a), the absorption increases with an increase in the resistance value (R). Peak absorption occurs when the resistance of the resistor is 200 Ω. Fig. 5(b) shows the absorption characteristics for various incident angles of EM waves. A peak absorption of approximately 97 % at 2.45 GHz is obtained for incident angles ranging from 0° to 60°. The absorption at other angles gradually decreases because the incident magnetic field can no longer efficiently induce circulating currents on the absorber.

Fig. 6 shows the simulated transmission, reflection, and absorption of the proposed absorber. An absorption of approximately 97 % is obtained at 2.45 GHz, and the half-max bandwidth is approximately 0.16 GHz. The transmission and reflectance are obtained as 0.05 and 0.01, respectively, at 2.45 GHz.

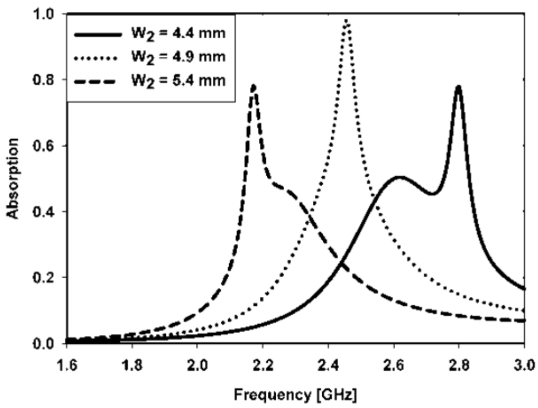
The operating mechanism of the proposed absorber structure at 2.45 GHz is verified by analyzing the electric field, magnetic field, and current distributions, which are shown in Fig. 7. The electric and magnetic resonances clearly are strongly generated by the two



(a) Variation in W_1



(b) Variation in L_1



(c) Variation in W_2

Fig. 3. Simulated absorption characteristics.

SRR elements and the two strips. Both the transmission and reflectivity are minimized because of the impedance matching and large loss in the absorber, and the incident energy will be converted to heat.

Figs. 8(a) and 8(b) show the retrieved effective permittivity and permeability of the proposed absorber. Fig. 8(c) shows the impedance $Z(w)$, and Fig. 8(d) shows the refractive index $n(w)$, indicating how closely the structure approximates an absorber. The real part of input impedance is near unity and the imaginary part is almost

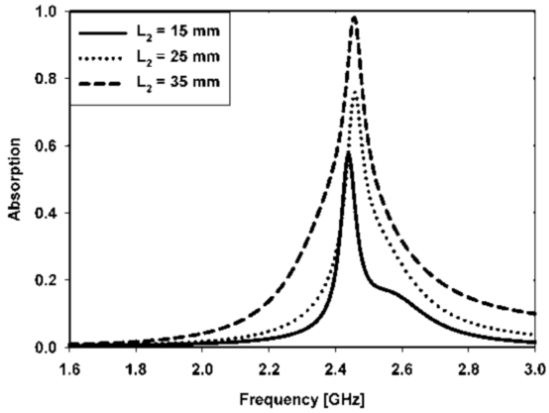
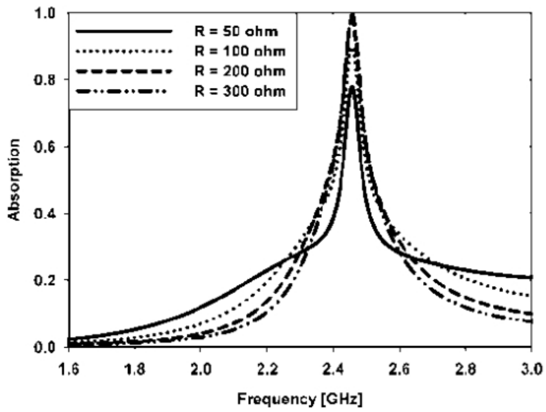
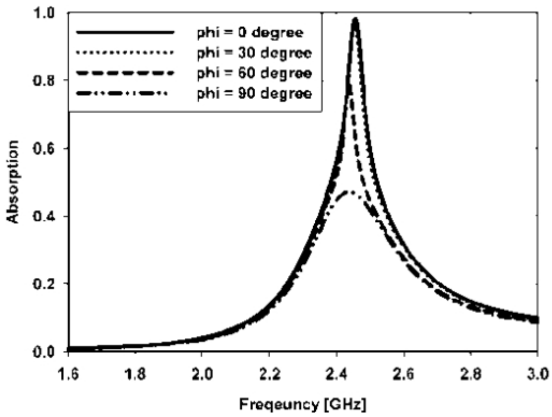


Fig. 4. Simulated absorption characteristics with variation in L_2.



(a) Various resistance (R) values



(b) Various incidence angles

Fig. 5. Simulated absorption characteristics.

zero, such that $R \approx 0$. As desired, the imaginary part of the refraction index is maximized at 2.45 GHz, which minimized T. This results in a peak absorptivity of 97 %, plotted as the dotted curve shown in Fig. 6. The proposed absorber structure was designed and analyzed using a high-frequency structure simulator (HFSS V14) [16].

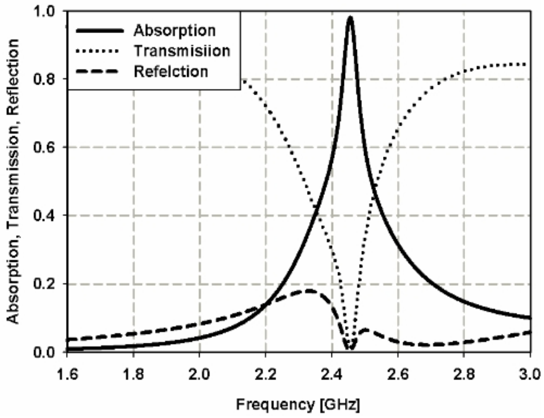
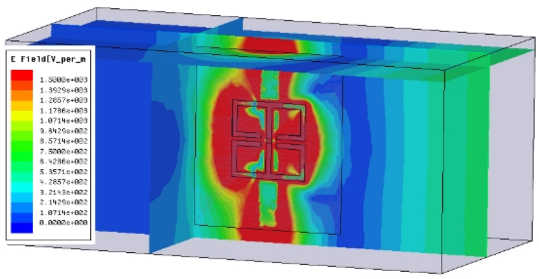
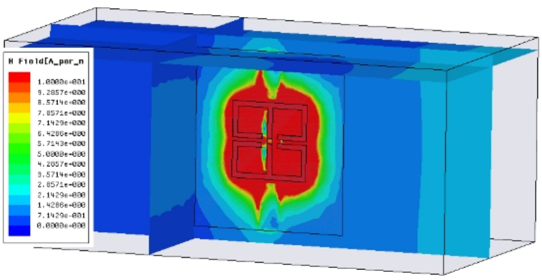


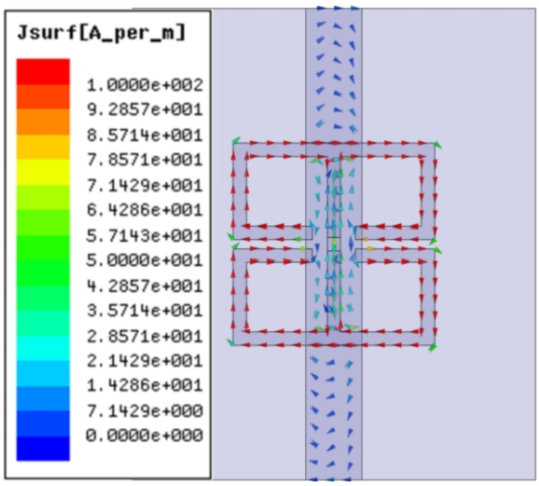
Fig. 6. Simulated absorption, transmission and reflection characteristics.



(a) Electric field

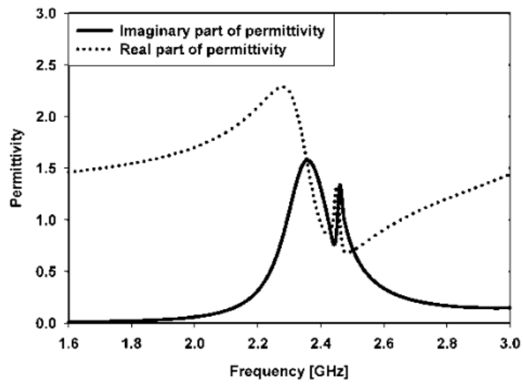


(b) Magnetic field

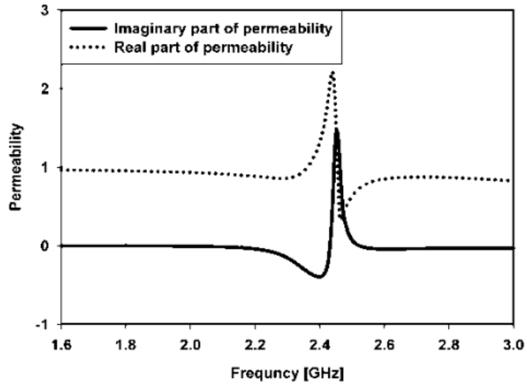


(c) Current

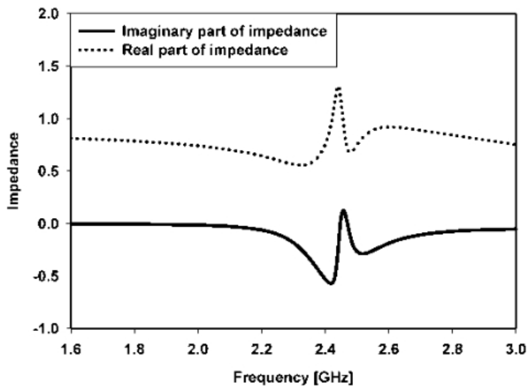
Fig. 7. Simulated distributions.



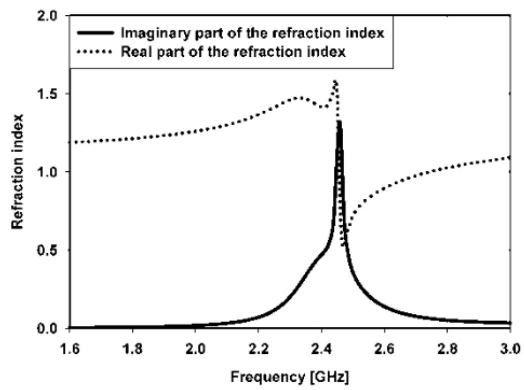
(a) Effective permeability



(b) Effective permittivity

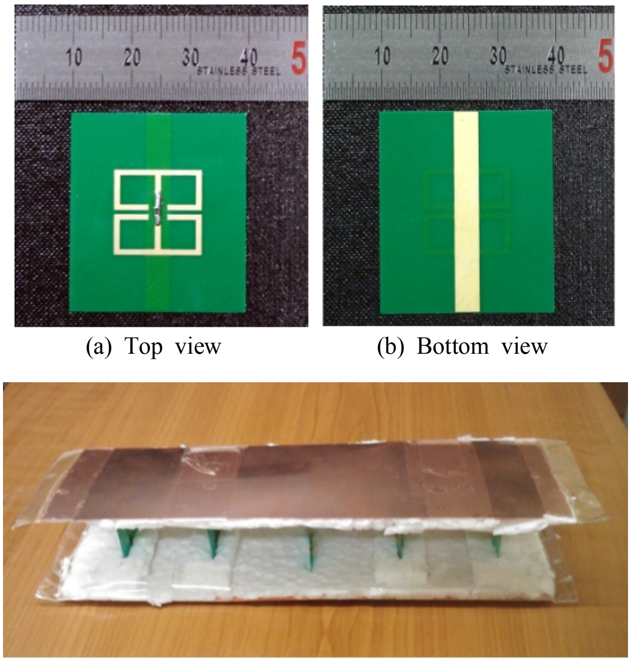


(c) Impedance



(d) Refractive index

Fig. 8. Retrieved constitutive parameters.



(a) Top view (b) Bottom view

(c) Five-unit array

Fig. 9. Fabricated absorber.

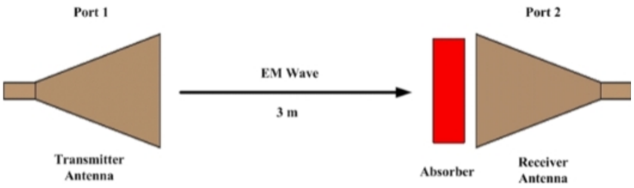


Fig. 10. Experimental setup.

Ⅲ. Results

Fig. 9 shows photographs of the fabricated unit cell and five-unit cell absorber. Styrofoam was used in the absorber to elevate the absorber into the air.

Two horn antennas, placed 3 m apart, were used to measure the characteristics of the designed absorber, as shown in Fig. 10. Measurements were performed with an Agilent 8719ES Network Analyzer.

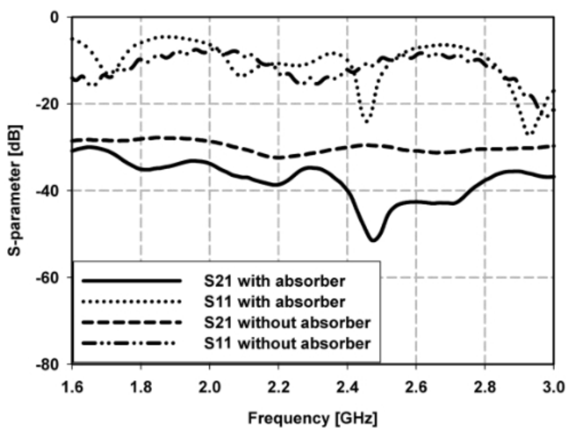


Fig. 11. Measured *S*-parameter characteristics.

Fig. 11 shows the S-parameters of the two antennas with and without the absorber. Without the absorber, S_{21} and S_{22} at 2.45 GHz are approximately −30 dB and −11 dB, respectively. With the absorber, S_{21} and S_{22} at 2.45 GHz become approximately −50 dB and −22 dB, respectively. The differences in the *S*-parameters across the frequency band, except at the frequency of interest, are attributed to the parallel conducting plate of the absorber.

Ⅳ. Conclusion

This paper proposes an absorber using an MTM structure operating at 2.45 GHz, and a prototype was successfully implemented. The proposed absorber exhibited an absorption of approximately 97 % and a half-max bandwidth of approximately 0.16 GHz. The absorption performance can be controlled by adjusting the resistance of the resistor (R). The proposed absorber had a negative permeability and a negative permittivity at the operating frequency. The proposed metamaterial can be utilized to reduce the effect of body on a WBAN antenna.

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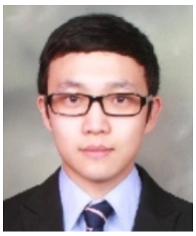

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