Broadband Metamaterial Absorber for both Normal and Oblique Incidence

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Abstract—**This paper presents a design of a broadband absorbers for X-band applications based on circular sectors in a single layer. Chip resistors are inserted into the gap between each circular sector on the top of a single-layer substrate. A full-wave analysis investigates the placement and value of a resistor. Simple methodologies for design and analysis of the absorber are presented. Experimental results show 5.7 GHz wide absorption from 7 to 12.7 GHz with absorptivity larger than 96.5% for all polarization angles under normal incidence. As the oblique incidence angle varies from 0^0 to 45^0, the measured absorptivity from 7 to 12.1 GHz remains above 91% in transverse electric (TE) modes.**

Keywords—Broadband absorber, single-layer absorber, RCS reduction, thickness-to-bandwidth ratio, polarization independent

I. INTRODUCTION

Almost all the applications of electromagnetic absorbers, such as electromagnetic interference (EMI) reduction, radar absorbing materials (RAM) in stealth technology, etc., require minimum thickness and maximum bandwidth with certain level of reflection reduction [1]. Thin thickness and wide absorption bandwidth are two of the most important properties of an ideal radar absorber [2]. As ferrite absorbers can be produced as tiles and provide a compact solution for attenuating reflections [3]. However, structure-based absorbers that are cheap, thin, and light have been recently attracting more attention because conventional material-based absorbers remain expensive, bulky, and heavy.

Several methods have been shown to achieve the wideband absorber. As the fractal metal structures [4], and loading with lumped element was utilized to achieve broadband absorption [5]. Recently, the single layer and multilayer periodic resistive surfaces have been applied to design wideband absorber for reducing the radar cross section in wideband frequency. But the realized thickness of these absorbers is far greater than the theoretical limit of minimum thickness [6].

In this paper, a relatively thin single layer and low-cost metamaterial absorber is designed by inserting chip resistors into the gap between each circular sector on the top of a single-layer FR4 substrate is proposed. Its bandwidth is considerably increased by using an additional resistor (R). A full-wave analysis investigates the placement and value of a resistor. The simulation results agree with the experimental results. Compared to the previous metamaterial absorbers, the proposed absorber has the advantages of a relatively thin thickness of 3.4 mm, minimum number of lumped resistances in a unit cell with only four resistors, and it uses low-cost FR4 substrate. Moreover, an angle and polarization-insensitivity as well as broad bandwidth are achieved for both normal and oblique incidence.

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II. METMATERIAL ABSORBER DESIGN

The unit cell of the proposed broadband absorber is illustrated in Fig. 1(a). The unit cell is composed of a symmetric and simple design. In order to increase the bandwidth, four 150 Ω chip resistors are added. A full-wave analysis investigates the placement and value of a resistor. Fig. 1(b) shows a three-dimensional view of the proposed absorber. The proposed absorber has a single layer. The top layer has the circular sector pattern and chip resistors on an FR4 substrate thickness 3.4 mm, and the bottom layer fully covered by copper sheet to prevent transmission. Chip resistors are inserted into the gap between each circular sector to broaden a bandwidth. In order to verify the performance of the proposed broadband absorber was fabricated on a size of 210 mm × 210 mm substrate as shown in Fig. 2. The thickness, relative permittivity, and dielectric loss of FR4 were 3.4 mm, 3.9, and 0.02, respectively. In Fig. 2, a final prototype sample, including circular sector design on the top of an FR4 substrates and chip resistors are inserted into the gap between each circular sector are proposed to broaden bandwidth.

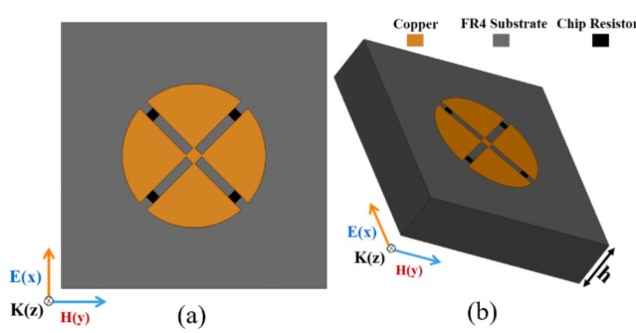


Fig. 1. Illustration of (a) the unit cell of the proposed broadband absorber and (b) three-dimensional view of the unit cell.

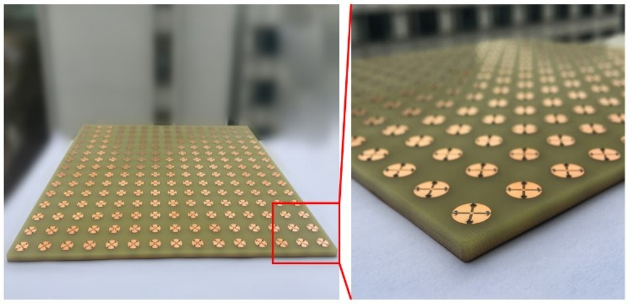
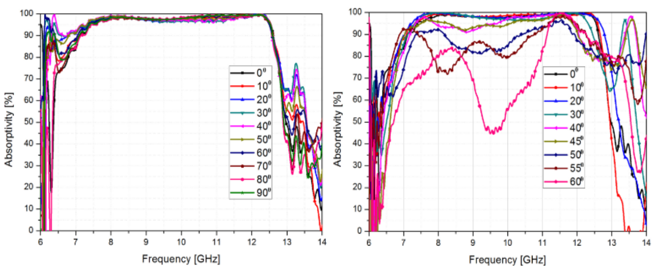


Fig. 2. Pictures of the fabricated broadband metamaterial absorber



(a) (b)

Fig. 3. Measured absorptivity of the proposed absorber (a) for different polarization angles ϕ under normal incidence ranging from 0° to 90°, (b) for oblique incidence angles θ ranging from 0° to 60° in (a) TE polarization.

The circular sector array on the top plane is realized by using a conventional printed-circuit-board (PCB) manufacturing process on a 3.4 mm thick flexible PCB (FPCB) substrate. The 150 Ω chip resistors were soldered by surface mount technology (SMT). Simple methodologies for design and analysis of the absorber are presented

III. Measurement Results

To demonstrate the performance of the proposed absorber, a bistatic radar cross section (RCS) measurement setup was used to measure the scattering parameter. The absorption ratio, $A(\omega)$, can be calculated by the reflectance, $R(\omega)$, and the transmittance, $T(\omega)$, as given by

$$A(\omega) = 1 - \Gamma(\omega) - T(\omega) \quad (1)$$

However, the bottom side of the proposed broadband absorber was fully covered with the copper sheet, so the EM wave could not pass through the proposed absorber. Therefore, we did not need to consider the transmission coefficient. The absorption ratio could obtain by measuring only reflection coefficients. Before measuring reflection coefficients of the absorber prototype, for calibration purposes, we first measured the reflection coefficient of a copper plate with the same size as that of the fabricated absorber prototype.

Fig. 3 shows measured absorption ratios for both Fig. 3(a) normally incident and Fig. 3(b) oblique incidence angle. Experimental results show 5.7 GHz wide absorption from 7 to 12.7 GHz with absorptivity larger than 96.5% for all polarization angles under normal incidence. As the oblique incidence angle varies from 0^0 to 45^0, the measured absorptivity from 7 to 12.1 GHz remains above 91% in transverse electric (TE) polarization. The simulation results agree with the experimental results.

IV. Conclusion

In conclusion, a ultrathin and low-cost absorber is designed by inserting chip resistors into the gap between each circular sector on the top of a single-layer FR4 substrate is proposed. In order to demonstrate its performance, 225 unit cells were fabricated. A conventional PCB manufacturing process was adopted to realize the resonator patterns, and SMT was used to solder the chip resistors. Simple methodologies for design and analysis of the broadband absorber are presented. The measured results show wide absorption from 7 to 12.7 GHz with absorptivity larger than 96.5% for all polarization angles under normal incidence. As the oblique incidence angle varies from 0^0 to 45^0, the measured absorptivity from 7 to 12.1 GHz remains above 91% in transverse electric (TE) modes. Compared to the previous metamaterial absorbers, the proposed broadband absorber has the advantages of an optimum thickness of 3.4 mm, minimum number of lumped resistances in a unit cell with only four resistors, and it uses low-cost FR4 substrate.

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