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Author(s): Brian B. Glover, Matthew J. Radway and Keith W. Whites

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Realizing Thin Electromagnetic Absorbers for Wide Incidence Angles from Commercially Available Planar Circuit Materials

Brian B. Glover, Matthew J. Radway‡ and Keith W. Whites†

Los Alamos National Laboratory
P. O. Box 1663, Los Alamos, NM 87545, USA
(gloverb@lanl.gov)

‡Department of Electrical and Computer Engineering
University of Colorado at Boulder
425 UCB, Boulder, CO 80309-0425, USA
(radway@colorado.edu)

†Laboratory for Applied Electromagnetics and Communications
South Dakota School of Mines and Technology (SDSMT)
501 East Saint Joseph Street, Rapid City, SD 57701, USA
(whites@sdsmt.edu)

Abstract

A thin electromagnetic absorber for incidence angles greater than 30° but less than 60° and both polarizations is computationally demonstrated. This absorber utilizes high-permittivity, low-loss microwave substrate in conjunction with an engineered lossy sheet impedance. The lossy sheet impedance is easily engineered with simple analytical approximations and can be manufactured from commercially available laminate materials on microwave substrate.

1. Introduction

In this study, recent work on engineering R-card surface resistivity with printed metallic patterns [1, 2] is extended to the design of thin electromagnetic absorbers. Thin electromagnetic absorbers for wide incidence angles and both polarizations have recently been computationally verified by Luukkonen *et al.* [3]. These absorbers are analytically modeled high-impedance surfaces with capacitive arrays of square patches [4] implemented with relatively high dielectric constant and high loss substrate. However, the advantages provided by the accurate analytical model are largely negated by the need to obtain high dielectric constant material with accurately engineered loss. Fig. 1(c) illustrates full-wave computational results [5] for an absorber without vias engineered as proposed in [3]. Unique values for the dielectric loss are required for different center frequencies. Parameters for the capacitive grid are D=5.0 mm and w=0.1 mm for a center frequency of 3.36 GHz. The relative permittivity and thickness is 9.20(1−j0.234) and t=3.048 mm. Consider a center frequency of 5.81 GHz and again t=3.048 mm, the required parameters for the capacitive grid are D=2.0 mm and w=0.2 mm where the required relative permittivity is now 9.20(1−j0.371) Admittedly, engineered dielectrics are themselves a historically interesting and fruitful research area [6] which benefits today from advances in monolithic fabrication using direct-write of dielectrics with nanometer scale inclusions (see for example [7]). However, our objective in the present study is to realize the advantages of the absorber proposed in [3] without resort to engineered lossy dielectrics. Specifically we are restricted to commercially available planer circuit materials without use of in-house direct-write technology or materials engineering capability [8]. The materials considered here are TMM 10 laminate with (35 μm copper cladding with a complex permittivity 9.20−j0.0022) and Ohmegaply resistor conductor material (maximum 250 Ω/sq.) [9], [10].

2. Alternative Absorber

The alternative absorber in this study differs from the vialess absorber of [3] in only one significant manner: an engineered lossy layer of patterned Ohmegaply resistor conductor material provides loss rather than the distributed loss of the dielectric substrate. Fig. 2(b) illustrates the transmission line analog of the alternative absorber of this study and the absorber type of Ref. [3] Fig. 1. Previously we have experimentally demonstrated a high-impedance surface absorber utilizing a layer of 370 Ω/sq. Kapton® XC placed very near the reactive grid [11]. However, Non-perforated Ohmegaply resistor conductor material provides a maximum sheet impedance of 250 Ω/sq. necessitating the lossy sheet be imbedded between the ground plane and the reactive grid of the alternative absorber. It is convenient, though not necessary, to restrict the position of the lossy engineered sheet to halfway between the reactive grid and the ground plane. For normal incidence, an expression can be written for the vector difference between the surface impedance for the absorber of Fig. 1(a) and for the absorber of Fig. 1(b) respectively:

$$\frac{Z_{SCL}}{1+Z_{SCL}/Z_G}-\eta^2\frac{2R_s+Z'_{SCL}}{\eta^2(1+R_s/Z'_{SCL})+R_sZ'_{SCL}}=\vec{\Delta} \qquad (1),$$

where it is understood that $\text{Im}\{\varepsilon_r\}$ and the parameters w and D can be different between the two absorbers. $Z_{SCL} = \eta\text{Tan}[t\omega[\varepsilon_r\varepsilon_0\mu_0]^{½}]$, $Z'_{SCL} = \eta\text{Tan}[0.5t\omega[\varepsilon_r\varepsilon_0\mu_0]^{½}]$, $\eta = [\mu_0(\varepsilon_r\varepsilon_0)^{-1}]^{½}$, and $Z_G = -j\pi[\omega\varepsilon_0(\varepsilon_r+1)D\ln([\sin(w\pi/2D)]^{-1})]^{-1}$. Numerically minimizing Eq. (1) gives the parameters for the capacitive grid as D=5.2 mm and w=0.1 mm for a center frequency of 3.36 GHz. The relative permittivity of the dielectric layer is 9.20(1–j0.0022), t=3.048 mm and the required sheet impedance R_s = 100.9 Ω/sq. Fig. 2(b) illustrates the performance of this absorber where the sheet impedance is computationally modeled as a d =17 μm thick sheet with an effective conductivity of $(dR_s)^{-1}$ S/m.

2. Engineered Sheet Impedance (Ohmega-Ply® with an Array of Copper Patches)

We are restricted in this study to Ohmega-Ply® resistor–conductor–material, where a nickel–phosphorous alloy, conductivity 10^5 S/m, is electro-deposited, on 35 μm copper, in thicknesses ranging from 40 nm to 400 nm to achieve a resistor–material sheet resistance ranging between 250 Ω/sq to 25 Ω/sq. The utility of Ohmega-Ply® originates from the ability to laminate the resistor–conductor–material onto a wide variety of microwave laminates and subsequently, use printed circuit board techniques to remove the conductor material (copper) with fine feature definition [10]. Previous work with printed, simple cubic centered, metallic squares or square rings on Kapton XC® has shown that the 2D Maxwell Garnet formula [6] gives an accurate estimate for the effective bulk conductivity of such an engineered resistive film [1, 2]. Fig. 2(a) shows the range of engineered surface resistivity obtainable using this technique with Ohmega-Ply® resister-conductor-materials. Tolerances for these materials are 250±25, 100±5, 50±2.5, and 25±1.25 Ω/sq, so that there is some significant uncertainty at lower area fractions in the case of 250 Ω/sq Ohmega-Ply®. A sheet impedance of 100.9 Ω/sq. requires simple cubic centered, metallic squares with an area fraction of 0.43 per unit cell of 250 Ω/sq Ohmega-Ply® resistor–conductor–material.

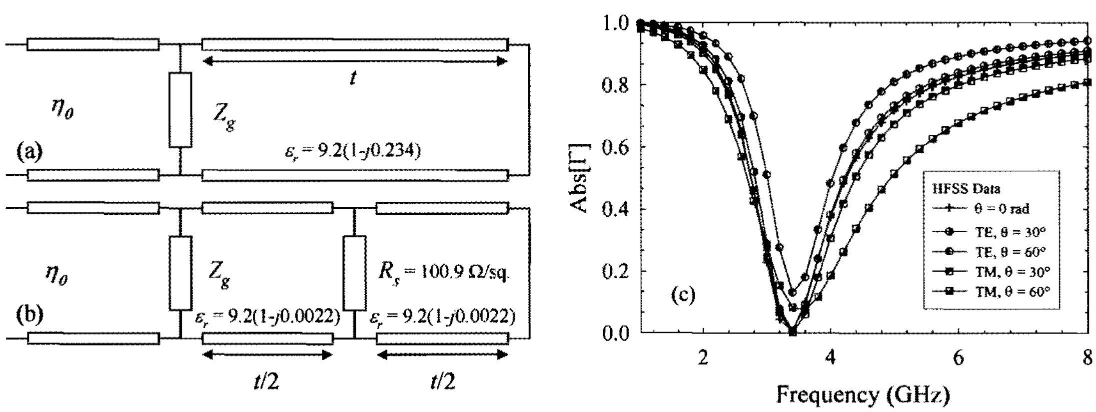

Fig 1: (a) and (b) Normal incidence circuit analogs and relevant parameters for the thin absorbers considered in this study. (c) The numerically computed performance of a thin absorber engineered according to Ref. [1] with D=5.0 mm, w=0.1 mm, ε_r = 9.20(1–j0.234) and t=3.048 mm.

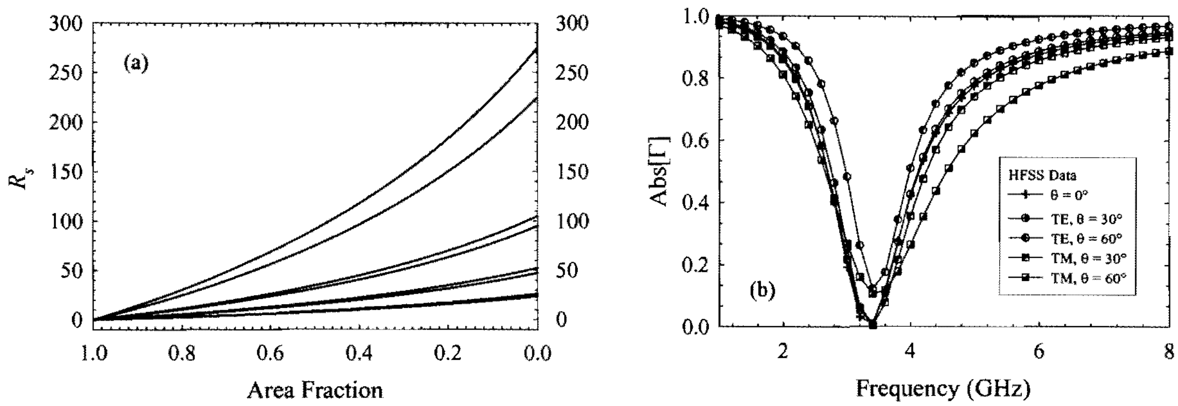

Fig 2: (a) The range of sheet impedances that can be obtained from an array of simple cubic centered, copper squares on Ohmega-Ply® resistor–material. (b) The performance of the commercially obtainable absorber proposed in this study with with D=5.2 mm, w=0.1 mm, ε_r=9.20(1−j0.0022), t=3.048 mm and R_s=100.9 Ω/sq. Note that performance is quite similar to that shown in Fig. 1(c).

3. Conclusion

We have computationally demonstrated how the simple idea of a two-dimensional Maxwell Garnett engineered sheet impedance implemented with commercially available planer circuit materials allows realization of thin electromagnetic absorbers for wide incidence angles and both polarizations. The proposed absorber avoids the need for accurately engineered lossy dielectric materials and can be modeled with simple analytically approximations. This is true for modeling the grid impedance and lossy sheet impedance both of which are planer structures that can be commercially obtained.

Acknowledgments

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