Design of a Millimeter-Wave Absorber Composed of Resistive Films Printed on a Flexible PET Substrate

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***Abstract*—A low-cost design of millimeter-wave absorbing sheets is investigated. The absorber is composed of a perforated resistive film on a flexible polyethylene terephthalate (PET) substrate which is backed by a resistive ground plane. Broadband (60 GHz to 120 GHz) and wide-angle (up to 80°) absorption (> 50%) is achieved for a design with a square lattice of circular holes (diameter d = 5.5 mm and lattice period a = 7.5 mm) in the perforated resistive film of thickness t_R = 100 µm and conductivity σ = 80 S/m.**

I. INTRODUCTION

WITH the soaring number of wireless mobile devices such as smartphones and tablet PCs, the rapidly growing demand for more data bandwidth has been driving mobile communication to the millimeter-wave regime [1]. The pervasive use of millimeter wave technologies in such as the 60 GHz unlicensed band will unavoidably cause electromagnetic interference (EMI) problems. Millimeter-wave absorbers are then much needed to shield or suppress the stray EMI signals. Traditionally, ferromagnetic materials are used for millimeter wave absorption [2]-[3]. While such millimeter-wave absorbers give superior absorption because of ferromagnetic resonance, they are generally of narrowband and the material and fabrication costs are not reasonably low. In this work, a design of millimeter-wave absorbing sheets is proposed for low-cost implementation using printed electronics techniques.

II. MILLIMETER-WAVE ABSORBER DESIGN

As shown in Fig. 1, the proposed millimeter-wave absorber consists of a perforated resistive film on one side of a flexible PET substrate. On the other side of the PET substrate, there is also a resistive film but it is of a uniform layer without any perforation and it serves as a ground plane. The resistive films on the two sides of the PET sheet have the same thickness (t_R = 100 µm) and conductivity (σ = 80 S/m). Both the t_R and σ values are within the range that can be engineered in conductive ink (either polymeric or metal-containing inks) printed on the substrate [4]. This engineering advantage allows low-cost fabrication of such absorbing sheets by printed electronics techniques. A common thickness of t_{PET} = 250 µm for PET sheets has been adopted in the design.

Regarding the perforation of the resistive film, it consists of a two-dimensional (2-D) array of circular holes with the diameter d = 5.5 mm and the lattice period a = 7.5 mm for absorption at 60 GHz and higher frequencies. A square lattice of circular holes is adopted because of the four-fold rotational symmetry. This can result in electromagnetic (EM) absorption that is less sensitive to the polarization of the incidence EM waves. In this design of EM wave absorbing sheets, the geometrical sizes (namely d and a) of the structure are comparable to the free-space wavelength (λ_0 = 5 mm for 60 GHz). The resistive film thickness should not be too small compared to the skin depth of the EM wave absorption.

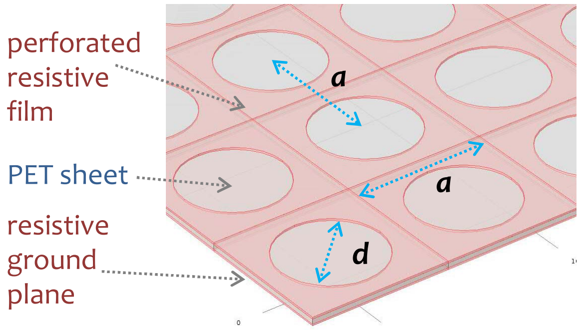

Fig. 1. Schematic illustration of the proposed absorber design with a square lattice of circular holes for the resistive film printed on one side of a PET substrate backed with a resistive ground plane.

III. ELECTROMAGNETIC SIMULATION RESULTS

The proposed millimeter-wave absorber design is computationally investigated using full-wave EM simulation (finite-element method with COMSOL Multiphysics). The PET sheet is modelled as an insulator layer with the relative permittivity ε_r = 3.0 and the loss tangent $\tan\delta$ = 0.002 while the resistive films are modelled as conductor layers with a uniform conductivity σ_R. In this work, σ_R = 80 S/m. 2-D and 3-D EM simulations were performed to obtain the frequency-dependent EM wave absorption at various incidence angles. Fig. 2 and Fig. 3 show the computed EM fields for a plane wave of 60 GHz incident on the absorbing sheets.

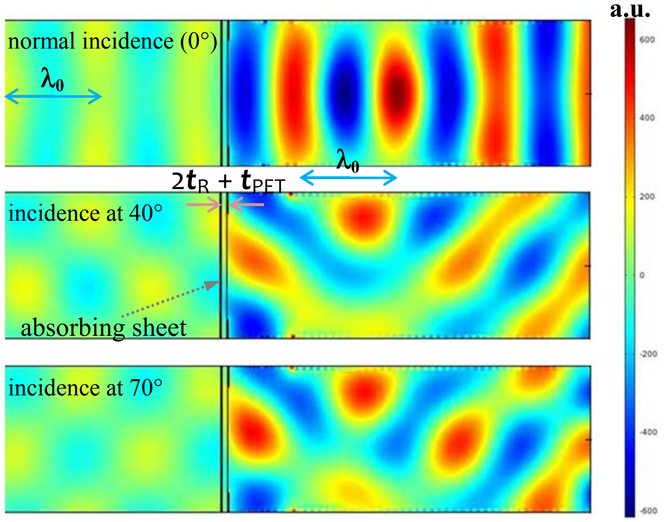

Fig. 2. Electric fields computed for the absorber design with d_{hole} = 5.5 mm, a = 7.5 mm, t_{PET} = 250 µm, t_R = 100 µm at normal incidence (0°) and oblique incidence (40° & 70°) for a plane wave of 60 GHz (λ_0 = 5 mm).

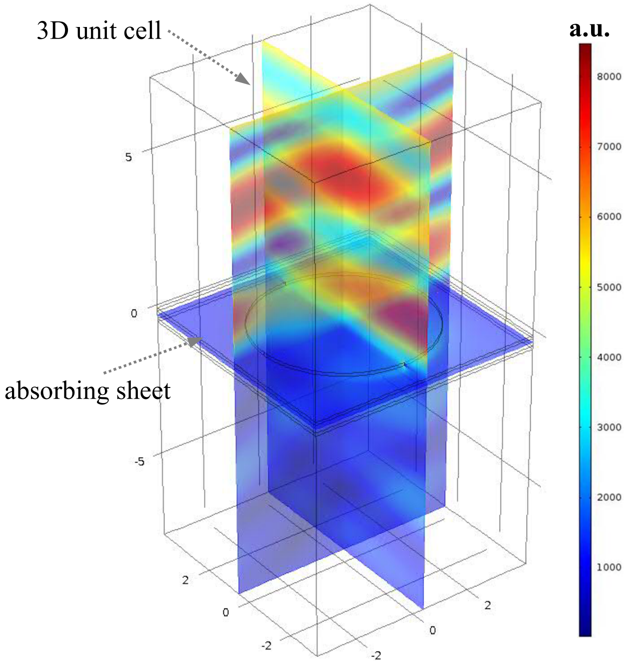

Fig. 3. 3D computation of electric fields of the proposed millimeter wave absorber design with $\boldsymbol{d_{hole}}$ = 5.5 mm, $\boldsymbol{a}$ = 7.5 mm, $\boldsymbol{t_{PET}}$ = 250 µm, $\boldsymbol{t_R}$ = 100 µm with a plane wave of 60 GHz at normal incidence from the top.

In both Fig. 2 and Fig. 3, only a unit cell of the full-wave EM simulation is shown. Floquet periodic boundaries were applied in the actual simulation settings with a plane wave impinged on the periodic structure. Fig. 2 shows a 2-D unit cell with a 60-GHz plane wave incident on the absorber at normal incidence, at 40° and 70°. Fig. 3 shows a 3-D unit cell with a plane wave of the same 60-GHz incident on the absorber at normal incidence. In both Fig. 2 and Fig. 3, it can be seen that the EM waves are significantly attenuated after propagating through the millimeter-wave absorber to the other side. It is also obvious that the proposed absorber design has a very thin profile which is overall much smaller than the free-space wavelength of the EM wave. Fig. 4 and Fig. 5 show the quantitative results of the EM wave absorption properties of the millimeter-wave absorber design.

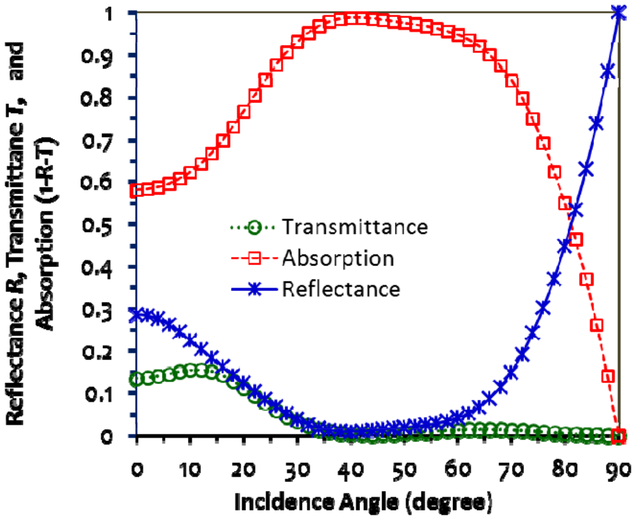

Fig. 4. Millimeter wave absorption of the proposed absorber design at 60 GHz with incidence angles from 0 to 90° showing wide-angle absorption.

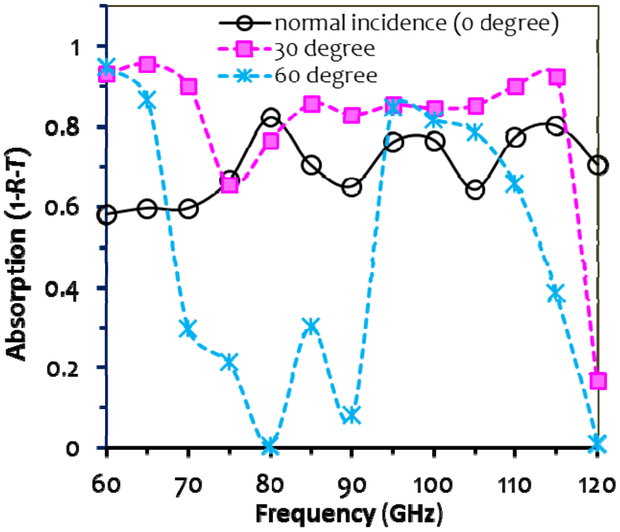

Fig. 5. Frequency dependence of the millimeter wave absorption of the proposed absorber design at normal and oblique incidence from 60 GHz to 120 GHz.

The EM wave absorption properties of the proposed absorber design are determined by regarding the unit cell as a waveguide. The reflectance $\boldsymbol{R}$ and transmittance $\boldsymbol{T}$ of the absorbing sheet are then obtained from the two-port S-parameters of the waveguide with $\boldsymbol{R} = |S_{11}|^2$ and $\boldsymbol{T} = |S_{21}|^2$. The EM wave absorption is simply obtained from the expression 1-$\boldsymbol{R}$-$\boldsymbol{T}$. As shown in both Fig. 4 and Fig. 5, the absorption at 60 GHz is almost 60% at normal incidence. At oblique incidence from 30° to 65° (Fig. 4), the absorption is above 90%. The millimeter wave absorption remains high (> 50%) from 60 GHz to 120 GHz at normal incidence (Fig. 5).

IV. SUMMARY

A design of flexible millimeter wave absorbing sheets feasible in printed electronics technology has been presented. As verified by full-wave EM simulations, broadband and wide-angle absorption is achieved with engineered parameters of the perforated resistive film. The design is of both low-cost and light-weight. It also has an ultra-thin profile relative to the free-space wavelength.

ACKNOWLEDGMENT

The author S.L. gratefully acknowledges help from Dr. Jensen Li of the School of Physics and Astronomy at the University of Birmingham. This work is supported by research development fund (RDF-14-02-36) from XJTLU.

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