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DEVELOPMENT OF A THIN, WAVE-ABSORBING GLASS USING DIVIDED CONDUCTIVE FILMS

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Abstract: We have developed a thin, transparent, wave-absorbing glass using divided conductive films (DCF). The glass absorbs 5.8GHz waves and is designed for use in ETC/ DSRC tollgates. This paper introduces a design process that comprises FEM simulation and measurement of absorption performance. The distinctive stability of the absorption peak frequency at various incident angles is also shown. In addition, the scattering patterns of the DCF absorber under conditions of oblique incidence are simulated.

Key words: transparent wave absorber, divided conductive film, ETC/ DSRC, low-E glass, oblique incidence.

1. Introduction

Wireless communications technologies are found in a wide range of applications, including cellular phones, wireless LANs, RF-IDs, and ETC (Electronic Toll Collection)/DSRC (Dedicated Short Range Communication) systems. There is increasing demand for electromagnetic absorbing materials that can prevent communication errors caused by multiple reflections due to reflective walls, glass windows, floors, ceilings, pillars and other reflective materials in the environment. One such material is a transparent wave absorber that can be used as window glass or as curtain walls of buildings. Transparent wave absorbers based on the λ/4-type wave absorber [1, 2] have already been developed using two transparent resistive sheets [3, 4]. These λ/4-type wave absorbers consist of matched resistive and reflective layers separated by a distance equal to one-quarter of the design wavelength.

We have developed another type of transparent wave absorber [5]. This new wave absorber, called the DCF absorber, has a configuration almost identical to that of the λ/4-type, but uses divided conductive film (DCF) instead of a matched resistive layer, as proposed by Tsuno [6, 7]. The DCF consists of many small resistive sheet patches that are arranged linearly and placed very close together. One difference between the matched layer and the DCF is in their sheet impedance. The DCF has very large capacitive reactance at a resonant frequency, while the matched layer has only real resistance. The large capacitive reactance means that the resistive sheets can be placed closer together than is possible with a λ/4-type wave absorber [8, 9], which allowed us to reduce the thickness of the absorbing layer to about 12% of the thickness of the λ/4-type.

This paper describes the performance of the DCF absorber, which is designed for use in ETC/DSRC systems and absorbs waves of 5.8 GHz.

2. Design of the DCF Absorber

The DCF absorber was developed from commercially available materials and technologies, such as low-E (low emissivity) glass and laminated glass. Low-E glass is a glass sheet with a conductive coating on one side that allows light to enter and also provides thermal insulation. Laminated glass consists of two (or more) sheets of glass sandwiching one (or more) plastic interlayer, which provides greater safety in the event of breakage.

Figure 1 is a schematic diagram of the DCF absorber. The absorber is comprised of two sheets of low-E glass with a PVB (polyvinyl butyral) interlayer. The conductive layers of the low-E glass consist of doped tin oxide (SnO_2) deposited by means of CVD (Chemical Vapor Deposition). One of the conductive layers is patterned by means of sandblasting to form the DCF, while the other conductive layer acts as a wave reflector. The two conductive layers are arranged face to face.

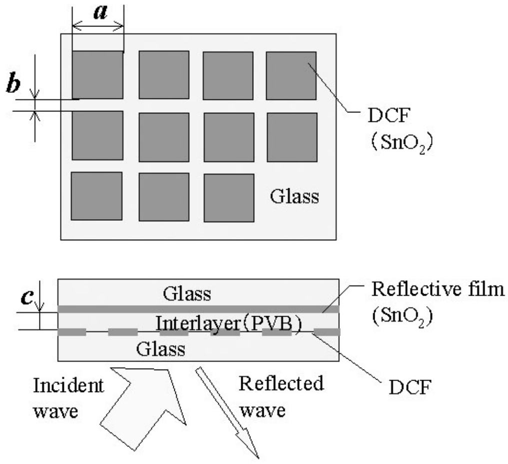


Figure 1. Schematic diagrams of the DCF absorber. Lower diagram: cross sectional view of the absorber; upper diagram: front view of the DCF layer.

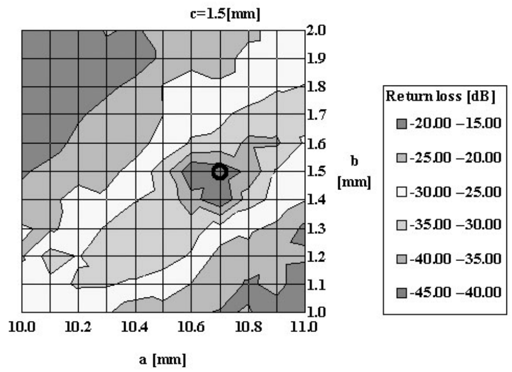


Figure 2. Contour diagram of the computed return loss for the case ***c*** = 1.5 mm. The open circle in the diagram indicates the design position of the test sample.

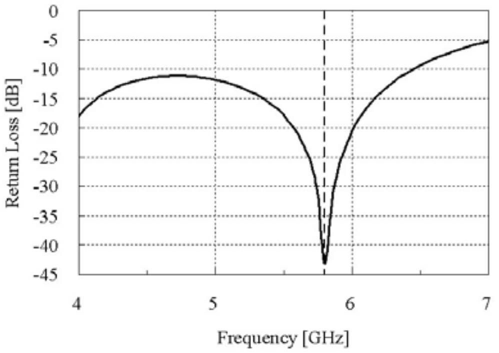


Figure 3. Simulated frequency characteristics of the return loss of an absorber having the dimensions of the design position indicated in Figure 2.

Figure 4. An oblique view of the DCF absorber

To determine the dimensions of the absorber, we computed the return loss of the normal incident wave at 5.8 GHz for various designs using an FEM (finite element method) simulator [10]. Constant values in the computation were the thickness of the sheets of glass t = 5.8 mm, the sheet resistance of the conductive layers R_s = 13 Ω/square, the dielectric constant of the glass $\varepsilon_g = 6.7\text{-}0.01j$, and the dielectric constant of PVB $\varepsilon_{PVB} = 2.97\text{-}0.1j$. The design parameters for the simulations were (a) the edge length of the squared patches comprising the DCF, (b) the distance between the patches, and (c) the thickness of the interlayer; these are indicated in Figure 1 as ***a***, ***b*** and ***c***, respectively. The sheets of glass are assumed to be planes of infinite size.

Figure 2 shows a contour diagram of the computed return loss for the case ***c*** = 1.5 mm. The open circle in the diagram indicates the dimensions of an actual absorber that was fabricated for use as test sample: ***a*** = 10.7 mm and ***b*** = 1.5 mm. The frequency characteristics of the return loss of the absorber were also simulated and are shown in Figure 3. The degree of absorbance peaks at around 5.8 GHz.

An oblique look of the fabricated absorber can be seen in Figure 4. The background and the woman's shoulder are clearly visible through the absorber. The PVB interlayer and the two glass layers are clearly visible at the edge. The total thickness is 13.1mm. Although we did not succeed in completely eliminating the lattice pattern, it is minimal when viewing the glass at a right angle.

3. Results

We measured the performance of the absorber by means of the free-space method using a vector

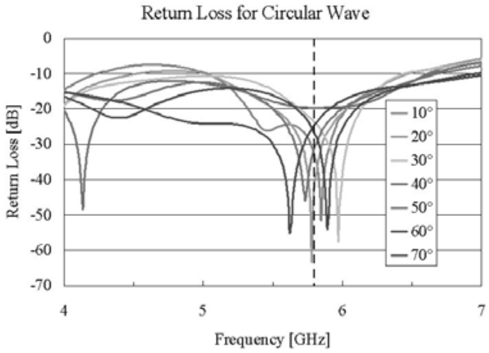


Figure 5. Measured frequency characteristics of the return loss for a circular polarized wave. The vertical dashed line indicates the design frequency of 5.8 GHz.

network analyzer with a time-domain function at oblique incidence. The incident wave, which is right circularly polarized (RCP) as it is in ETC/ DSRC systems, radiates from a helical antenna for RCP microwaves (ETS-EMCO, Model 3102). A similar helical antenna, one that is designed to receive left circularly polarized (LCP) incident waves, detects the reflected wave. Data were obtained for every 10° of incident angle between 10° and 70°.

Figure 5 shows the measured frequency characteristics of the return loss. A broken vertical line indicates the design frequency of 5.8 GHz. Note that the position of the peak remains stable at around 5.8 GHz even at different angles of incidence. In general, λ/4-type wave absorbers do not produce a fixed peak position under varying incident angles. This is because the peak frequency depends strictly on the wave path length between the matched layer and the reflector, which varies with the incident angle. The stability of the peak frequency against varying incident angles is a unique characteristic of DCF absorbers. Tsuno described similar characteristics for a DCF absorber by calculating the absorbable frequency of an absorber comprised of three resistive layers: an impedance matched layer, a DCF layer and a reflective layer [6, 7]. The stability makes the DCF absorber very useful for such applications as ETC tollgates, where the angle of reflection on the sidewalls of the gate varies as car moves forward.

Figure 6 plots data for the return loss at 5.8 GHz for each incident angle. Dashed lines in the figure also indicate the required specification that has been established by Japan Highway Public Corporation (JH) for wave absorbers in ETC tollgates. The oblique incident performance of the DCF absorber meets the JH specification at all angles of incidence. The degree of the return loss remains high (< -20 dB) even at high incident angles.

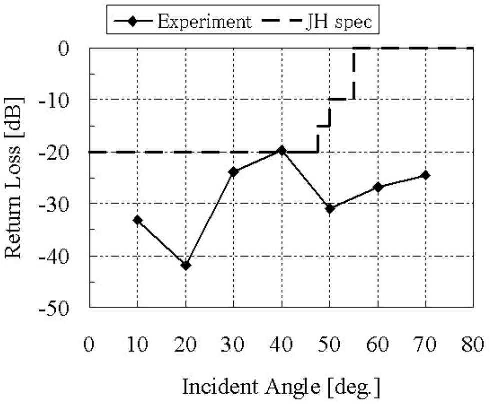
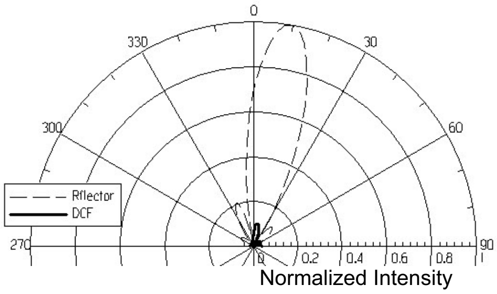


Figure 6. Measured return loss at 5.8 GHz plotted for each incident angle. Dashed lines indicate the JH specification required for wave absorbers used in ETC tollgates.

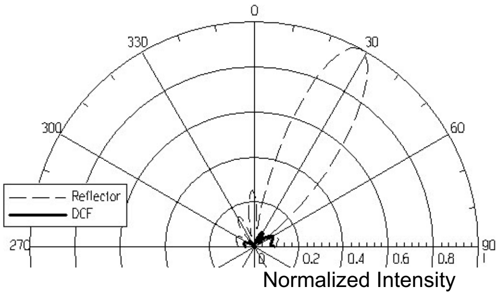
4. Simulation of Scattering Pattern Under Conditions of Oblique Incidence

We simulated scattering patterns for the DCF absorber under conditions of oblique incidence in order to ensure that there were no reflections in unexpected directions due to the periodic surface of the DCF. Reflections in unexpected directions may produce undesired waves in wireless communications. The modeling parameters for the simulation were the same as in the case of normal incidence except that, due to the limited memory capacity of the simulation computer, the sheet in the simulation model was no longer a plane of infinite size. The model contained 2 x 12 DCF patches, and the modeled sheet of glass was 147.6x147.6 mm in size. We also simulated the scattering patterns of a perfectly reflective surface and compared the results to those of the DCF absorber in order to evaluate absorption capacity of the DCF absorber.

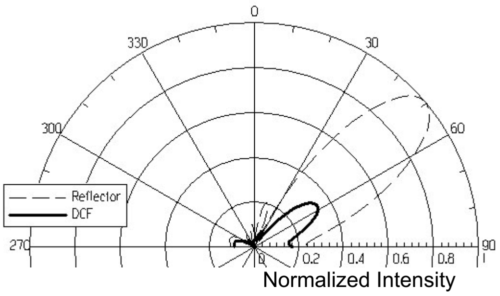
The calculated results of the scattering patterns are plotted in Figure 7 (a), (b), and (c) for incident angles of 10°, 30° and 50°, respectively. Solid lines describe the scattering pattern for the DCF absorber, while dashed lines describe the scattering pattern for the perfectly reflective surface. The radial axes in the plots indicate the linear intensity for the scattered far-field radiation normalized by the maximal intensity of the main lobe due to the perfectly reflective surface. These plots show that there is no distinctive scattering in any direction outside the main lobe of specular reflection. Furthermore, the intensity of the main lobe for the DCF absorber is much lower than it is for the perfectly reflective surface. This proves that the DCF absorber is practical and does not produce any unnecessary scattering or reflection.



(a) 10° incident angle



(b) 30° incident angle



(c) 50° incident angle

Figure 7. Simulated scattering patterns for the DCF absorber (solid lines) and for a perfectly reflective surface (dashed lines) at 5.8 GHz.

5. Conclusion

We have developed a DCF absorber consisting of a sheet of thin and transparent wave-absorbing glass. The design process uses an FEM simulator and measures the absorbing characteristics of an absorber designed to absorb 5.8 GHz waves. The developed absorber features distinctive stability at the absorption peak frequency for various incident angles, and produces no reflections in unexpected directions, as shown by simulation analysis of the scattering patterns under conditions of oblique incidence. The DCF absorber is a promising technology that can be applied to the sidewalls of ETC tollgates and other similar applications.

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