

Development of Broad-Band Electromagnetic Wave Absorber for X-band Sensors in Double-layered Type Using Carbon

*Chang-Mook Choi¹, Dong-Il Kim², Dong-Han Choi³, and Rui Li⁴

¹Radio Sciences & Engineering, Korea Maritime Univ.(E-mail: nav-sun@hanmail.net)

²Radio Sciences & Engineering, Korea Maritime Univ.(E-mail: dikim@mail.hhu.ac.kr)

³Research Institute of Industrial Technology, Korea Maritime Univ.(E-mail: livedong@hanmail.net)

⁴Radio Sciences & Engineering, Korea Maritime Univ.(E-mail: zcrlr@hotmail.com)

Abstract

In this paper, the EM wave absorbers were designed and fabricated for X-band sensors using Carbon of dielectric material with CPE. The complex relative permittivity of samples is calculated by the measured S-parameter data. We simulated the double-layered type EM wave absorber with broad bandwidth using the measured complex relative permittivity by changing the thickness and layer, which was fabricated based on the simulated design. The fabricated EM wave absorber consist of 1mm first layer sheet facing metal with Carbon composition ratio 70 vol% and 1.5 mm second layer sheet with Carbon composition ratio 60 vol%. The comparisons of simulated and measured results are good agreement. As a result, the optimized absorption ability of double-layered type EM wave absorber with thickness of 2.5 mm is higher than 10 dB from 7.8 GHz to 13.3 GHz.

Keywords: Absorption ability, Complex relative permittivity, CPE, EM wave absorber, X-band.

1. Introduction

With the rapid advancements in electronics industry and radio communication technology, mankind might enjoy its abundant life. On the other hand, serious social problems such as electromagnetic interference (EMI) and electromagnetic susceptibility (EMS) have arisen due to the increased applications of electromagnetic waves [1]. Therefore, a countermeasure against electromagnetic wave obstacle was embossed to an important subject [2].

Unnecessary electromagnetic waves leak from the circuits of communication and electronic equipments or such electromagnetic waves cause the equipment to malfunction. Problems regarding electromagnetic compatibility (EMC) are more likely to occur, as smaller, lighter, and more sophisticated electronic equipments are made and the packaging density of electronic components increases drastically.

In addition, radar systems create two major problems: false images and system-to-system interference [3]. False echoes cause driving hazards. These problems can be eliminated through the use of electromagnetic wave absorber.

As is well known, the EM wave absorbers can be broadly divided into two types from the viewpoint of material. One is a wave absorber using a dielectric material and the other is a magnetic wave absorber using a ferrite material [4].

In this paper, we fabricated EM wave absorbers for X-band sensors using Carbon of dielectric material with chlorinated polyethylene (CPE), and their impedances were measured. The complex relative permittivity ($\hat{\epsilon}_r = \epsilon_r' - j\epsilon_r''$) is calculated by the measured data. Double-layered type EM wave absorbers with broad bandwidth are simulated and fabricated based on the simulated design. The comparisons of simulated and measured results are good agreement.

2. Design of the EM wave absorber

For a multi-layered EM wave absorber made of a conductor-backed single layer as shown in Figure 1, the Return Loss (RL) can be obtained from the equivalent circuit as follows [5]:

$$RL = -20 \log_{10} \left| \frac{\hat{z}_{in} - 1}{\hat{z}_{in} + 1} \right| \quad [dB] \quad (1)$$

here, \hat{z}_{in} is the normalized input impedance.

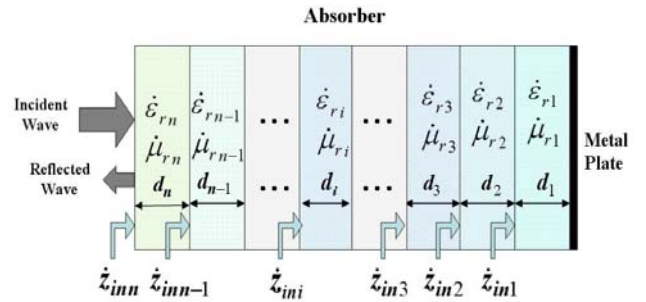


Figure 1. A multi-layered EM wave absorber

The normalized input impedance of the first layer, \hat{z}_{in1} , is calculated in terms of the following expression:

$$\hat{z}_{in1} = \sqrt{\frac{\hat{\mu}_{r1}}{\hat{\epsilon}_{r1}}} \tanh\left(j \frac{2\pi}{\lambda} \sqrt{\hat{\epsilon}_{r1} \hat{\mu}_{r1}} d_1\right) \quad (2)$$

Where $\hat{\epsilon}_r$, $\hat{\mu}_r$, d_1 and λ are the complex relative permittivity of the first layer, the complex relative permeability, the thickness, and the wavelength, respectively [2].

After calculated the input impedance repeatedly, the normalized input impedance from the i -th layer, \dot{z}_{ini} , is calculated by equation (3).

$$\dot{z}_{ini} = \sqrt{\frac{\dot{\mu}_{ri}}{\dot{\epsilon}_{ri}}} \cdot \frac{\dot{z}_{ini-1} + \sqrt{\frac{\dot{\mu}_{ri}}{\dot{\epsilon}_{ri}}} \tanh\left(j \frac{2\pi}{\lambda} \sqrt{\dot{\epsilon}_{ri} \dot{\mu}_{ri} d}\right)}{\sqrt{\frac{\dot{\mu}_{ri}}{\dot{\epsilon}_{ri}}} + \dot{z}_{ini-1} \tanh\left(j \frac{2\pi}{\lambda} \sqrt{\dot{\epsilon}_{ri} \dot{\mu}_{ri} d}\right)} \quad (3)$$

In the same method, the normalized input impedance from the last layer is calculated by equation(4).

$$\dot{z}_{inn} = \sqrt{\frac{\dot{\mu}_{rn}}{\dot{\epsilon}_{rn}}} \cdot \frac{\dot{z}_{inn-1} + \sqrt{\frac{\dot{\mu}_{rn}}{\dot{\epsilon}_{rn}}} \tanh\left(j \frac{2\pi}{\lambda} \sqrt{\dot{\epsilon}_{rn} \dot{\mu}_{rn} d}\right)}{\sqrt{\frac{\dot{\mu}_{rn}}{\dot{\epsilon}_{rn}}} + \dot{z}_{inn-1} \tanh\left(j \frac{2\pi}{\lambda} \sqrt{\dot{\epsilon}_{rn} \dot{\mu}_{rn} d}\right)} \quad (4)$$

Hence, if equation (4) is solved, the relationship between the material property and the sample thickness can be simulated. Further, it is possible to use equation (1) for confirmation of the absorption abilities.

3. Material Properties

3.1 Sample for measurement

We fabricated some samples in different composition ratio of Carbon and CPE. Carbon was mixed with the binder of CPE, and the sheet-type absorber was fabricated by using an open roller. The open roller's surface temperature was uniform as 70°C during sample preparation because the surface temperature affects the EM wave properties of sheet type absorbers [6]. The manufacturing process of absorber is shown in Figure 2.

For the investigation of material properties, the prepared composite EM wave absorbers were punched into toroidal shapes with inner diameters of 3.05 mm and outer diameters of 6.95 mm.

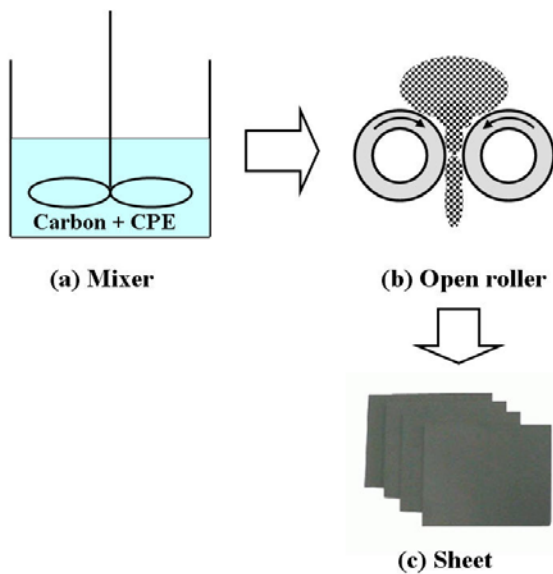


Figure 2. The manufacturing process of EM wave absorber

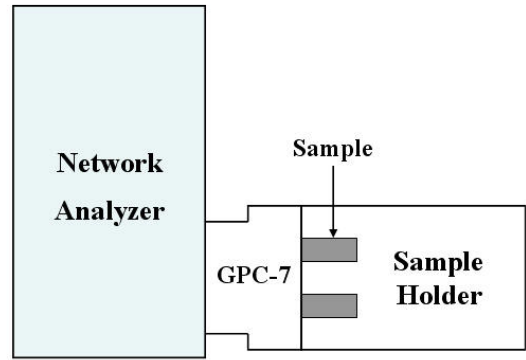


Figure 3. Measurement system

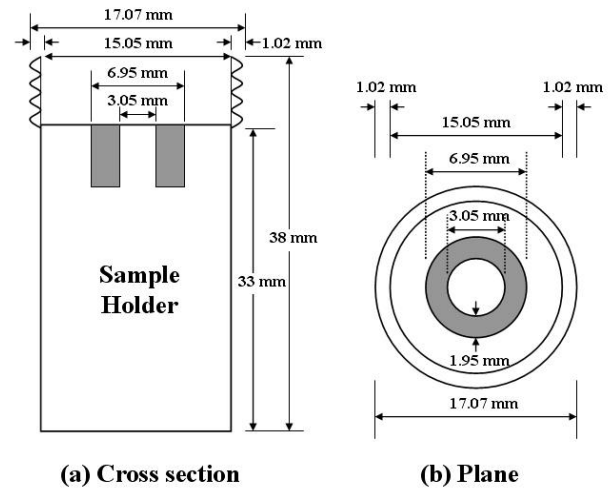


Figure 4. Sample holder

3.2 Measurement method

In this research, a WILTRON-MODEL 360B network analyzer was used for the reflection coefficient measurement. The reflection coefficient of the sample can be obtained from S-parameter after proper calibration.

Figures 3 and 4 represent diagrams of the measurement system and sample holder, respectively.

3.3 Measured results

The measurement equipments in this research are used for the reflection coefficient measurement. We carry out the EM wave absorber design with the samples containing 60 vol% and 70 vol% of Carbon. The material properties of these samples are calculated from S-parameter of samples using $\ell - 2\ell$ method [7].

Figures 5 and 6 show plots of the measured complex relative permittivity at different frequencies with the samples containing 50 vol%, 60 vol%, and 70 vol% of Carbon, respectively.

The EM wave absorption ability of dielectric materials is related with the dielectric loss $\tan \delta$, and the dielectric loss is strong for $\tan \delta > 1$. Figure 5 shows $\tan \delta \leq 1$ in frequency range of 1 GHz ~ 18 GHz. In Figure 6, the frequency ranges that satisfy the condition $\tan \delta > 1$ are 2 GHz ~ 4 GHz and 6.5 GHz ~ 10.5 GHz. In Figure 7, the frequency ranges that satisfy the condition $\tan \delta > 1$ are 2.5 GHz ~ 3.7 GHz and 9.2 GHz ~ 14 GHz.

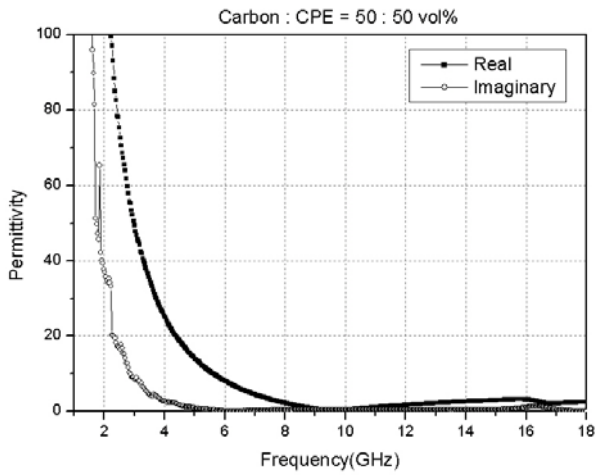


Figure 5. The measured complex relative permittivity (Carbon : CPE = 50:50 vol%)

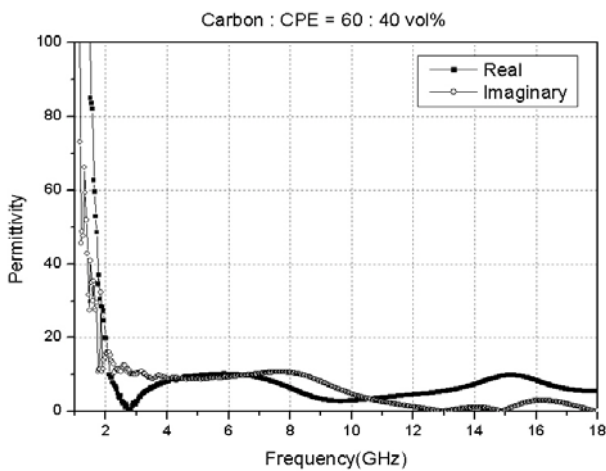


Figure 6. The measured complex relative permittivity (Carbon : CPE = 60:40 vol%)

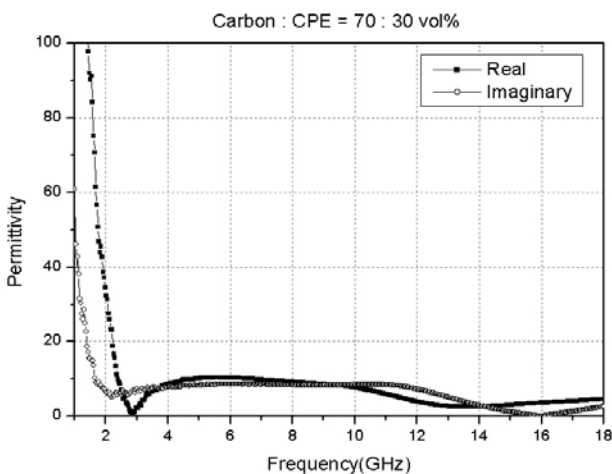


Figure 7. The measured complex relative permittivity (Carbon : CPE = 70:30 vol%)

3.4 The sheet resistivity

The characteristics of sheets are usually described in terms of their resistance or impedance in “ohms per square” [8]. The sheet resistivity of samples with dimensions of $50 \times 50 \times 1$ mm was

measured by four-probe method.

Corresponding to the volume fraction of conductive fillers from 50 % to 70 %, the resistivity of samples falls from $5.2 \text{ k}\Omega/\square$ to $167 \Omega/\square$.

In order to obtain a high reflection loss, the absorber layer must match the free space impedance (377Ω) and metal impedance (0Ω) for a broad frequency band.

When the sheet of Carbon composition ratio 60 vol% is in the front layer facing air, we can obtain highest reflection loss.

Table 1 shows the sheet resistivity of samples with difference composition ratio decreases with the increase of Carbon concentration.

Table 1. The sheet resistivity of samples by four-probe.

Composition Ratio[vol%]	Sheet Resistivity[Ω/\square]
Carbon:CPE = 50:50	5,220
Carbon:CPE = 60:40	279
Carbon:CPE = 70:30	167

4. Absorption Ability

4.1 Simulated results

The absorption abilities of EM wave absorbers are simulated by changing the thickness of sheet with layer sequence using the measured complex relative permittivity. The optimized result of double-layered EM wave absorber with thickness of 2.5 mm has absorption ability higher than 10 dB from 7.5 GHz to 14 GHz as shown in Figure 8.

The double-layered EM wave absorber consist of 1mm first layer sheet facing metal with Carbon composition ratio 70 vol% and 1.5 mm second layer sheet with Carbon composition ratio 60 vol%.

4.2 Measured results

The fabricated double-layer EM wave absorber with the thickness of 2.5 mm has absorption ability higher than 10 dB from 7.8 GHz to 13.3 GHz. Comparisons of simulated and measured results are good agreement as shown in Figure 8.

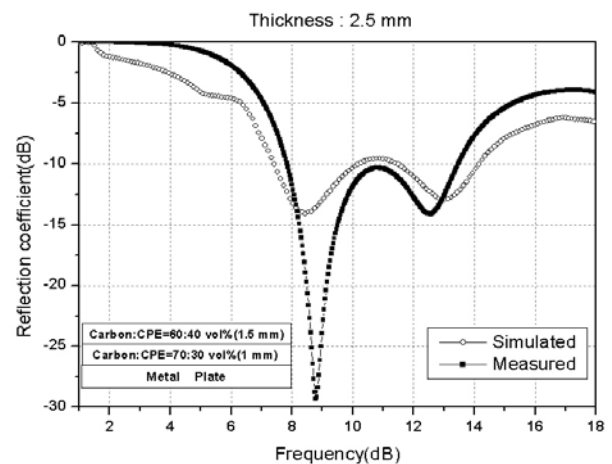


Figure 8. Comparisons of simulated and measured results.

5. Conclusion

The problems with false images and system-to-system interference can be eliminated through the use of EM wave absorber. Therefore, we fabricated EM wave absorbers for X-band sensors using Carbon. Especially, the double-layered EM wave absorber that consists of Carbon composition ratio materials (carbon : CPE = 60 : 40 vol.% and carbon : CPE = 70 : 30 vol.%) showed an improvement of the broadband EM wave absorber, and the absorption ability of EM wave absorber showed over 10 dB in the frequency range from 7.8 GHz to 13.3 GHz with thickness of 2.5 mm.

Acknowledgement

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