Development of the Electromagnetic Wave Absorber for 94 GHz Radar Sensors Using Permalloy

Chang-Mook Choi, Dong Il Kim, Rui Li, and Kwang-Soob Ko, *Member, KIMICS*

Abstract**—**In this paper, we fabricated the EM wave absorber for 94 GHz radar sensors using Permalloy of magnetic material with chlorinated polyethylene (CPE), and S-parameter was measured. The complex relative permittivity and permeability are calculated by the measured data. Absorption abilities are simulated according to different thickness of the EM wave absorbers, and the EM wave absorber was manufactured based on the simulated design. Simulated and measured results agree very well. As a result, we developed the EM wave absorber with the thickness of 1.15 mm which has an absorption ability of 18 dB at 94 GHz.

Index Terms**—**Absorption ability, EM wave absorber, Permeability, Permittivity, Radar.

I. INTRODUCTION

Radar sensors find widespread use at microwave and millimeter-wave frequencies. They are popular and low-cost systems, providing range and velocity information of a moving object. Millimeter-wave sensors in the 75~110 GHz range are well suited under environmental conditions where infrared systems fail, such as dust, fumes, and heat radiation [1]. The millimeter-wave frequency range offers in addition the advantages of small antenna size and high spatial resolution. However, radar systems create two major problems including false image and system-to-system interference [2]. False echoes cause navigational hazards. These problems can be eliminated through the use of EM wave absorbers.

As is well known, 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 [3].

In this paper, we fabricated the EM wave absorber for 94 GHz radar sensors using Permalloy of magnetic material with chlorinated polyethylene (CPE), and S-parameter was measured. The complex relative permittivity and permeability are calculated by the measured data.

The EM wave absorption abilities are simulated according to different thickness of the EM wave absorbers and the EM wave absorber was manufactured based on the simulated design. Simulated and measured results agree very well.

II. DESIGN OF THE EM WAVE ABSORBER

For the EM wave absorber made of a conductor-backed single layer as shown in Fig. 1, the Return Loss (RL) can be obtained from the equivalent circuit as follows[4][5] :

$$RL = -20\log_{10}\left|\frac{\dot{z}-1}{\dot{z}+1}\right| \quad [dB] \tag{1}$$

here, $\dot{z}$ is the normalized input impedance.

If the EM wave absorber is designed in a rectangular waveguide as shown in Fig. 2, TE10 mode is the only propagating mode in waveguide region [6], and the normalized impedance is expressed as equation (2) [7].

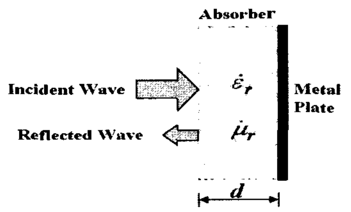
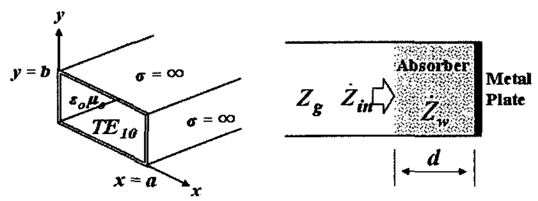


Fig. 1 The EM wave absorber.



(a) Rectangular waveguide (b) Absorber in rectangular waveguide

Fig. 2 The EM wave absorber in rectangular waveguide.

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Chang-Mook Choi is a Ph.D course student in the Dept. of Radio Sciences and Engineering, Korea Maritime University, Busan, 606-791, Korea (Email: nav-sun@hanmail.net)

Dong Il Kim is a professor in the Dept. of Radio Sciences and Engineering, Korea Maritime University, Busan, 606-791, Korea (Email: dikim@mail.hhu.ac.kr)

Rui Li is a Ph.D course student in the Dept. of Radio Sciences and Engineering, Korea Maritime University, Busan, 606-791, Korea (Email: zcrlr@hotmail.com)

Kwang-Soob Ko is a professor in the Dept. of Navigation, Naval Academy, Jinhae, 645-797, Korea (Email: kwangsoob @hanmail.net)

$$\dot{z} = \dot{\mu}_r \sqrt{\frac{1-(\lambda/2a)^2}{\dot{\varepsilon}_r\dot{\mu}_r - (\lambda/2a)^2}} \tanh\left(j\frac{2\pi}{\lambda}\sqrt{\dot{\varepsilon}_r\dot{\mu}_r - (\lambda/2a)^2}\, d\right) \quad (2)$$

where λ is the wavelength, d is the thickness of the sample, a is the x-direction length in the rectangular waveguide, $\dot{\mu}_r$ is the complex relative permeability, and $\dot{\varepsilon}_r$ is the complex relative permittivity. O. Hashmoto [7] has presented a design theory of EM wave absorber in a rectangular waveguide. The reflectionless condition for normal incidence of an electromagnetic wave is given by

$$\dot{\mu}_r \sqrt{\frac{1-(\lambda/2a)^2}{\dot{\varepsilon}_r\dot{\mu}_r - (\lambda/2a)^2}} \tanh\left(j\frac{2\pi}{\lambda}\sqrt{\dot{\varepsilon}_r\dot{\mu}_r - (\lambda/2a)^2}\, d\right) = 1 \quad (3)$$

From the result of equation (3), four parameters such as $\dot{\varepsilon}_r$, $\dot{\mu}_r$, λ, and d can determine absorption abilities.

Hence, if equation (3) 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.

III. MATERIAL PROPERTIES

A. Sample for Measurement

We fabricated some samples in different composition ratio of Permalloy and CPE. Permalloy 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℃ during sample preparation because the surface temperature affects the EM wave properties of sheet type absorbers [8]. The manufacturing process of absorber is shown in Fig. 3.

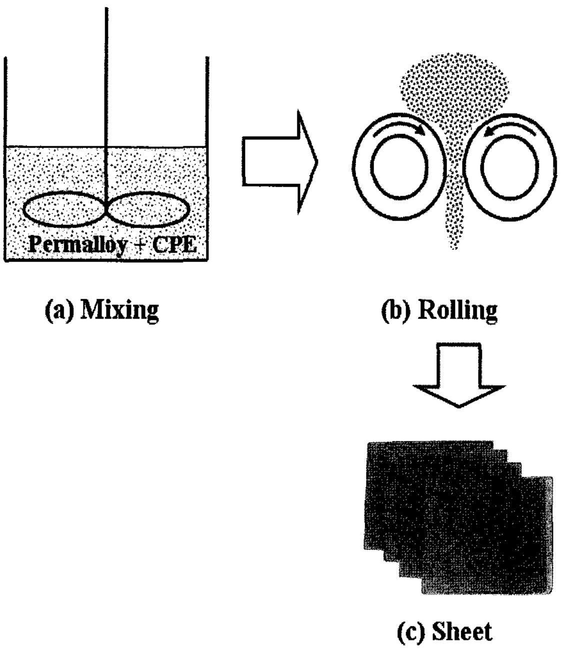

Fig. 3 Manufacturing process of EM wave absorber.

The dimensions of the samples for measurement of the complex relative permittivity and permeability were 2.54×1.27×1.5 mm and 2.54×1.27×3 mm.

B. Measurement Method

The measurement equipments in this research are used for the reflection measurement. It includes an ANRITSU ME 78080A broadband vector network analyzer, rectangular waveguide, sample jig, and short circuit. The network analyzer has become a basic tool in the measurement of the reflection coefficient of EM wave absorbers. The reflection coefficient of the sample can be obtained from S11 after proper calibration. The measurement system is shown in Fig. 4. Fig. 5 presents a photo of absorber, jig, and sample.

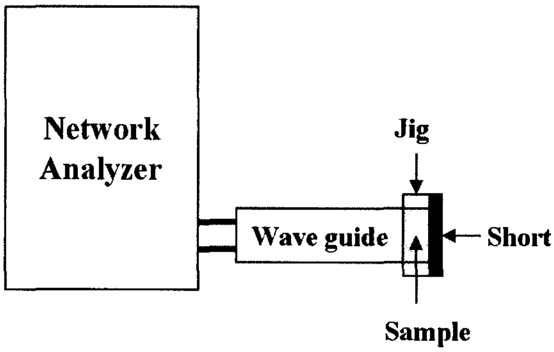

Fig. 4 Measurement system.

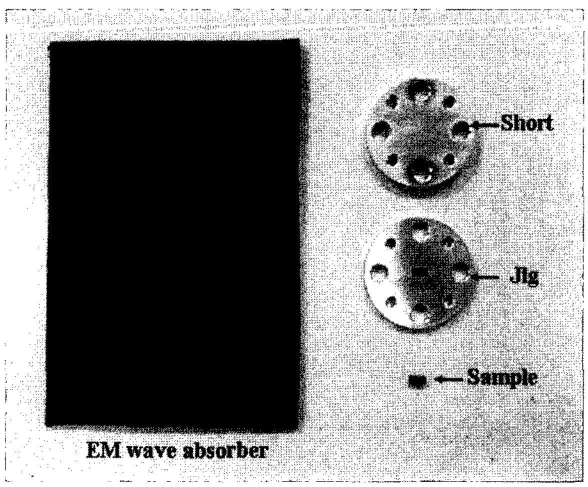

Fig. 5 A photo of absorber, test jig, and sample.

C. Measured Results

The measurement equipments in this research are used for the reflection measurement. Fig. 6 shows the composition ratio dependence on the measured reflection coefficient as a function of frequency. It is shown that the optimum composition ratio of Permalloy is about 70 wt%.

Therefore, we carried out the EM wave absorber design with a sample containing 70 wt% of Permalloy. The material properties of this sample are calculated from S-parameter of sample using $\ell - 2\ell$ method [9].

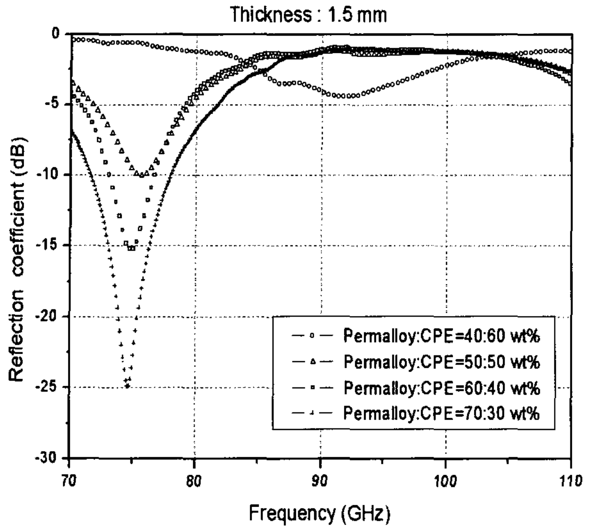

Fig. 6 Reflection coefficients of samples with different composition ratio (Thickness : 1.5 mm).

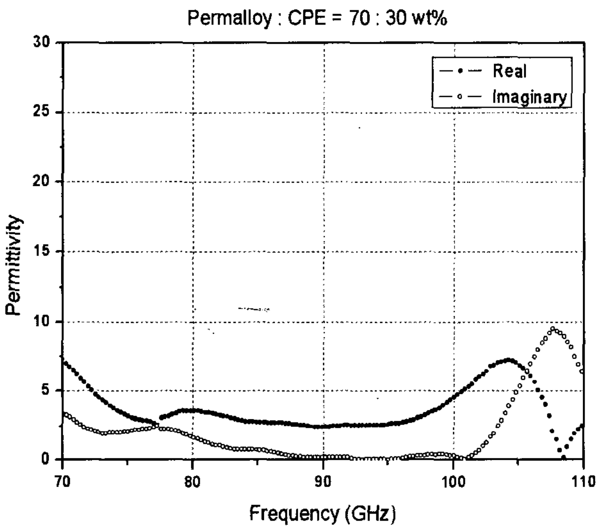

Fig. 7 The measured complex relative permittivity (Permalloy : CPE=70 : 30 wt%).

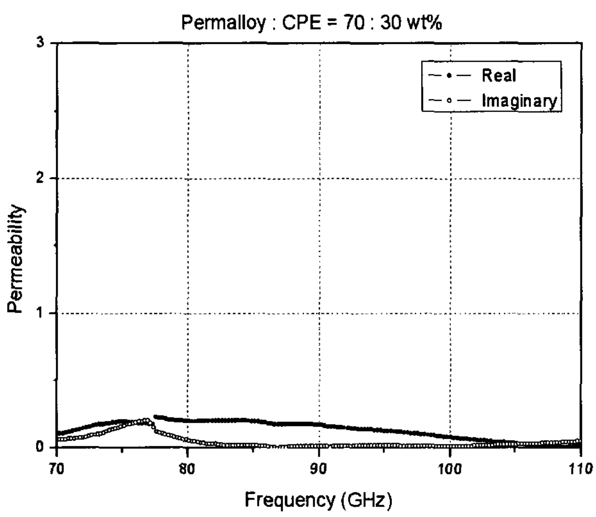

Fig. 8 The measured complex relative permeability (Permalloy : CPE = 70 wt%).

Fig. 7 and 8 show plots of the measured complex relative permittivity and permeability at different frequencies, respectively.

The loss tangent of the dielectric is shown $\tan\delta_e = 1$ at 77 GHz and 106 GHz, and the loss tangent of the magnetic is shown $\tan\delta_m = 1$ at 76 GHz and 104 GHz.

IV. ABSORPTION ABILITY OF THE EM WAVE ABSORBER

A. Simulated Results

Absorption abilities of the EM wave absorbers are simulated using the measured complex relative permittivity and permeability by changing the thickness without changing the composition.

The optimized EM wave absorber with the thickness of 1.15 mm has absorption ability over 20 dB at 94 GHz as shown in Fig. 9.

B. Measured Results

The fabricated EM wave absorber with the thickness of 1.15 mm has absorption ability of 18 dB at 94 GHz. The comparisons of simulated and measured results agree very well as shown in Fig. 9.

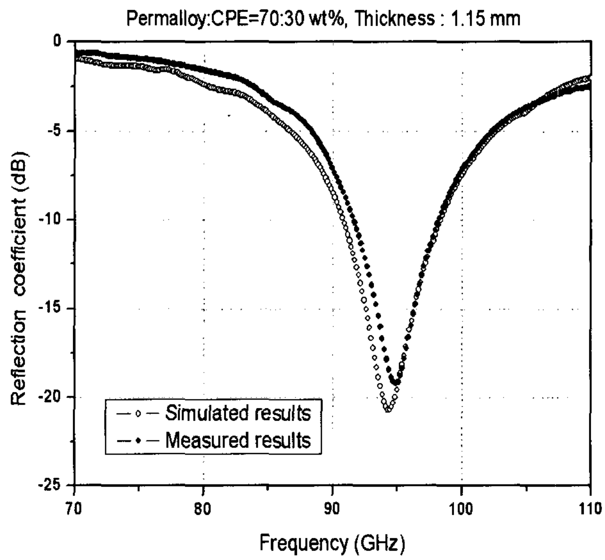

Fig. 9 The comparisons of simulated and measured reflection coefficients.

V. CONCLUSIONS

The problems of radar sensors with false images and system-to-system interferences can be eliminated by an application of EM wave absorber. Therefore, we designed and fabricated the EM wave absorber for 94 GHz radar sensors using Permalloy and CPE (Permalloy: CPE=70:30 wt%). Simulated and measured reflection coefficients agree very well. As a result, we developed the EM wave absorber with the thickness of 1.15 mm which has an absorption ability of 18 dB at 94 GHz.

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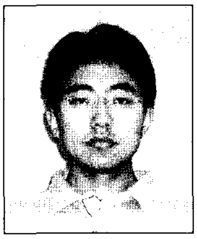
Chang-Mook Choi
He received the B.E degree from Korea Naval Academy in 1996 and M.E degree from AIMST in 2001. He is currently working toward the Ph.D. degree in department of radio science & engineering at Korea Maritime University. His research interests include the development of EM wave absorber, EMI/EMC, and navigation systems.

Dong Il Kim
He received his B.E. and M.E. degrees in nautical science and electronic communications from Korea Maritime University in 1975 and 1977, respectively, and his Ph.D. degree in electronics from the Tokyo Institute of Technology in 1984. He is past-president of the Korea Electromagnetic Engineering Society. Currently, he is a professor of the Dept. of Radio Sciences & Engineering at Korea Maritime University. His research interests include the design of microwave circuits and CATV transmission circuits, the development of EM absorbers, and EMC/EMI countermeasures. Prof. Kim is a member of the Institute of Electronics, Information and Communications of Japan, the IEEC of Korea, the KICS, and the KEES. He received the Academy Industry Cooperation (A-I-C) Award from the Korea A-I-C. Foundation in 1990, Treatise Awards from the Korea Electromagnetic Engineering Society and the Korea Institute of Navigation in 1993 and 1998, and the Korea President's Award from the Promotion of Science and Technology in 1995.



Rui Li
He received his B.S. degree in electrical engineering from Hebei University of Science & Technology, Shijiazhuang, China, in 2001, and his M.S. degree in radio sciences & engineering from Korea Maritime University, Busan, Korea, in 2005, and is currently working toward the Ph.D. degree in radio sciences & engineering at Korea Maritime University, Busan, Korea. His research interests include microwave integrated circuit and RF devices, and EMC/EMI countermeasures.

Kwang-Soob Ko
He received the B.E degree from Korea Naval Academy in 1979 and M.E degree in electronic communications from Korea Maritime University in 1983, and Ph.D. degree in electronics from the Clarkson University at Potsdam, USA in 1990. Currently, he is a professor of the Dept. of Navigation at Korea Naval Academy. His research interests include the navigation system, maritime communication system, and satellite navigation.