International Journal of Navigation and Port Research
Vol.30, No.9 pp. 767~772, 2006 (ISSN-1598-5725)

A Study on Multi-Layered EM Wave Absorber Using Natural Lacquer as a Binder

†*Dong-Han Choi* · Dong-Il Kim** · Chang-Mook Choi** · Rui Li***

**Research Institute of Industrial Technology, Korea Maritime University, Pusan 606-791, Korea*
***Radio Sciences & Engineering, Korea Maritime University, Pusan 606-791, Korea*

Abstract : *Generally, a silicone rubber and a chlorinated polyethylene(CPE) have been used as a binder for the development of high-performance composite EM(Electro Magnetic) wave absorbers. In this paper, the EM wave absorption performance of natural lacquer, which is newly proposed as a binder was investigated. The prepared MnZn ferrite EM wave absorbers are mixed with natural lacquer showed excellent EM wave absorption characteristics compared with MnZn ferrite EM wave absorbers which are mixed with the conventional binders. MnZn ferrite EM wave absorbers mixed with natural lacquer were prepared and their absorption ability was also investigated. The EM wave absorbers are fabricated in different proportions of MnZn, or NiZn ferrite and natural lacquer, and their reflection coefficients are measured. The permittivity and permeability are calculated by using the measured reflection coefficients. The EM wave absorption abilities are calculated according to different thicknesses of the EM wave absorbers.*

Key words : *CPE, Silicone rubber, Natural lacquer, EM wave absorbers, Permittivity, Permeability*

1. Introduction

It is really true that the development of various electronic equipments can provide convenience and entertainment for people's life. However, some new unexpected problems have arisen due to the rapid development in electronics, such as mis-operations presented in computer systems resulted from EMI (Electro-Magnetic Interference), ship accidents caused by ghost signals and a subject of disputation whether using mobile phones is harmful to people's health or not (Hashimoto et al., 1988).

Electromagnetic absorbers can absorb unwanted signals without reflecting EM waves, because they are made of some materials that have great ability to transform electromagnetic energy into heat energy. EM wave absorbing materials can be broadly classified into conductive, dielectric and magnetic ones, in which magnetic materials are mainly made up of oxides of Ferrite (Kotsuka, 2007 ; Kim et al., 2001).

To obtain shapes what we want, Ferrite-EM wave absorbers are usually manufactured with specific binders together, such as rubbers, CPE (Chloride Poly-Ethylene), silicone rubbers, and so on. From our recent research results, however, natural lacquer used as conventional enamel has EM wave absorbing abilities. Therefore, in this paper, natural lacquer is utilized as the binder for fabricating the EM wave absorber. It is a totally new proposal. Compared with the conventional binders, the fabricated EM wave absorbers using natural lacquer as the binder have more effective absorption ability. In this paper, we fabricated the multi-layed EM wave absorbers using MnZn or NiZn Ferrite mixed with natural lacquer, and measured the material properties (relative permittivity : ε_r, relative permeability : μ_r) of this type of EM wave absorbers by using Vector Network Analyzer. To extend the absorption bandwidth, the absorption characteristics of multi-layered EM wave absorbers have been investigated by comparing the simulated and measured results in accordance with different layer sequences and thickness.

2. Natural Lacquer Features

Natural lacquer, which is known as a kind of paint passed down from the oriental region for thousands of years, is broadly used for not only artistic handicrafts and lacquer wares, also a lot of furniture, tablewares, windows, and so on. Compared with conventional paints, natural lacquer has different hardening mechanism because of its hardening feature of an enzyme response. Due to this type

† Corresponding Author, Dong-Han Choi, livedong@hanmail.net, 051)410-4932
** dikim@hhu.ac.kr, 051)410-4314
** navs-sun@hanmail.net, 051)410-4932
** zcrlr@hotmail.com, 051)410-4932

of enzyme response, the temperature and humidity is very important when drying natural lacquer. The enzyme response of natural lacquer becomes slow under 0 ℃, and the activity will be lost beyond 50. Therefore, the most important thing is to maintain appropriate temperature and humidity during the whole drying process Hong et al.(2002).

Generally, the existing natural lacquer has some features. As is mentioned before, natural lacquer's composition is shown in Table 1, including Urushiol: 60~65%, Gummy substance, Nitrogen compounds, Laccase, and water, and so on Hong et al.(2000). Moreover, it is reported that the far ultraviolet can be radiated from natural lacquer due to its benzene structure.

Table 1 The Composition of Oriental Natural Lacquer

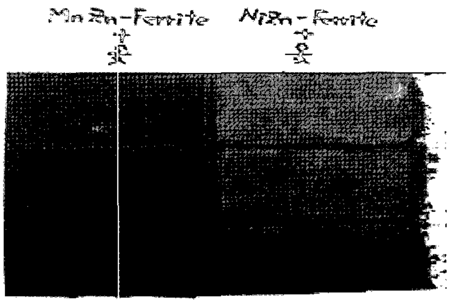
Composition	Concentration(%)	MW(g/mole)
Urushiol	60~65	320
Gummy substance	5~7	22000
Nitrogen compounds	2~3	8000
Laccase	0.2~0.9	120000
Water	25~30	18

3. Fabrication and Measurement of EM Wave Absorbers

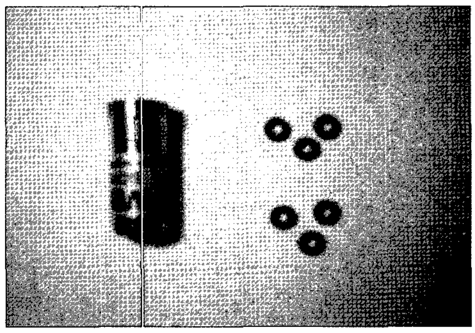
3.1 Fabrication of Samples

To fabricate the EM wave absorbers using natural lacquer as the binder, the temperature and humidity are the most important factors among the fabrication conditions. During the whole drying process, the temperature and the humidity should be over 27 ℃ and 75 % for achieving good hardening effect, and natural lacquer was fabricated from the beginning of summer to early autumn. MnZn Ferrite and NiZn Ferrite, which are usually used as magnetic materials, were mixed up with natural lacquer without refining respectively for about ten minutes. After that the mixtures are spreaded out evenly with thin thickness of 0.2 mm and then are placed into drying-room to be fully dried for about one week. With the same method, the EM wave absorbers with different thickness can be fabricated.

The fabricated EM wave absorber's samples are shown in Fig. 1(a), and a sample holder and some manufactured samples for measurements are shown in Fig. 1(b).



(a) Fabricated EM wave absorbers.



(b) Sample and sample holder.

Fig. 1 Fabricated EM wave absorbers and Processed sample.

3.2 EM Wave Absorption Ability Measurement

To measure the absorption ability for the fabricated EM wave absorbers, the samples are processed into ring-like shape with its internal diameter of 3.05 mm and external diameter of 6.95 mm. The diagrams of the measurement system including the Vector Network Analyzer and Sample Holder are shown in Fig. 2 and Fig. 3.

To measure the absorption abilities for the fabricated EM wave absorber samples, the samples are firstly embedded into the sample holder as shown in Fig. 3 and then the absorber-filled sample holder should be connected closely with the Vector Network Analyzer as shown in Fig. 2. After that the absorption abilities can be measured by using One-Port method.

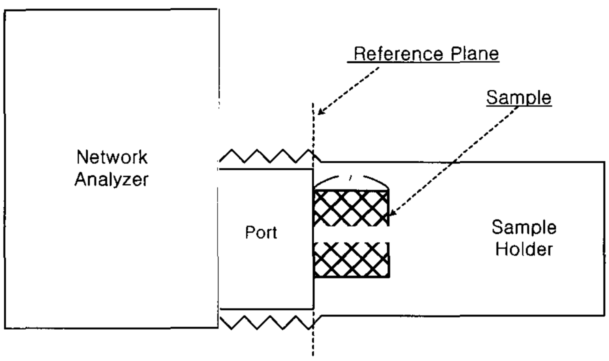


Fig. 2 Reflection coefficient measurement system of sample.

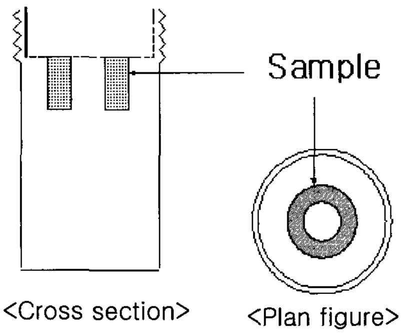


Fig. 3 Sample holder's structure in which a sample is inserted.

There are two kinds of samples to be embedded into different sample holders, in which one is of 2 mm (l) thickness and the other is of 4 mm (2l) thickness. Scattering parameters of these two kind of samples are measured, respectively. The material properties(ε_r and μ_r) can be calculated using Matlab programs by substituting the measured scattering parameters into Eqn. (1) and (2) (Kim et al.(1999), Park and Kim(1999)).

Substituting the calculated results into Eqn. (3), the absorption abilities of the EM wave absorbers can be simulated. The measured absorption abilities can be compared with the simulated results.

$$\varepsilon_r = -j\frac{C}{2\pi f}\frac{\frac{1}{l}\tanh^{-1}\sqrt{\frac{2Z_1-Z_2}{Z_2}}}{Z_1\sqrt{\frac{Z_2}{2Z_1-Z_2}}} \qquad (1)$$

$$\mu_r = -j\frac{C}{2\pi f}\frac{1}{l}Z_1\sqrt{\frac{Z_2}{2Z_1-Z_2}}\tanh^{-1}\sqrt{\frac{2Z_1-Z_2}{Z_2}} \qquad (2)$$

where

$$Z_1 = Z(l) = \frac{1+S_{2mm}}{1-S_{2mm}}, \quad Z_1 = Z(2l) = \frac{1+S_{4mm}}{1-S_{4mm}}$$

4. Simulation and Measurement Results

To investigate the absorption abilities of the binder by itself, each of CPE, silicone rubber and natural lacquer without mixed with Ferrite is manufactured with 5 mm thickness respectively and the EM wave absorption abilities by themselves are measured. The measured results are shown in Fig. 4.

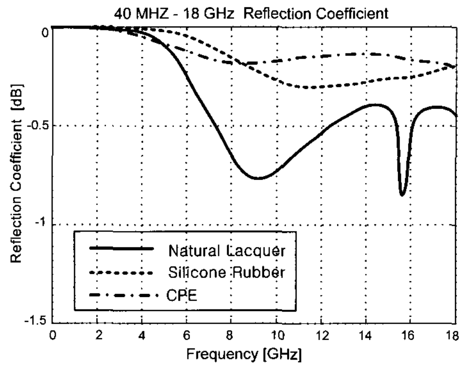
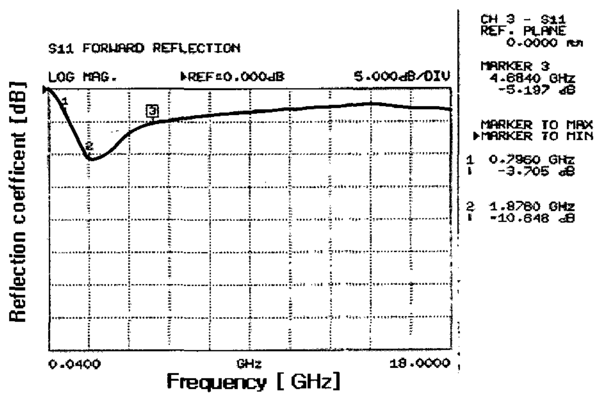
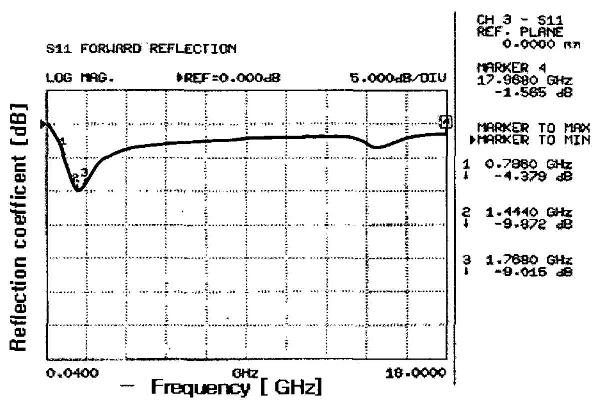


Fig. 4 Reflection coefficient of CPE, silicone rubber, and Natural Lacquer with a thickness of 5 mm.

As shown in Fig. 4, the absorption abilities of CPE and silicone rubber have about 0.3 dB at 9 GHz and 0.3 dB at 10 GHz, respectively. However, the absorption ability of natural lacquer has 0.8 dB near to 15 GHz. Three kinds of binders are mixed with MnZn Ferrite respectively. By using these mixtures, the EM wave absorbers with 3 mm thickness are fabricated. The measured absorption abilities are shown in Fig. 5. In general, the bandwidth is one of the significant measure of the EM wave absorber.

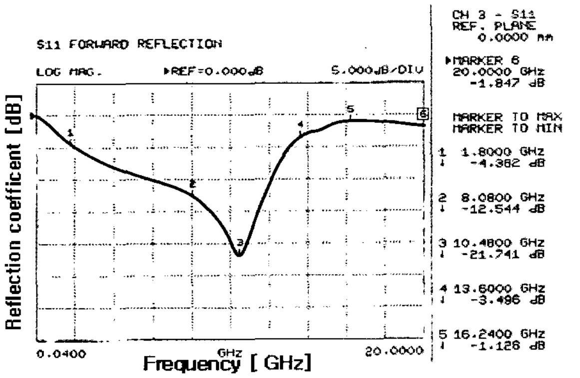


(a) Reflection coefficient of mixed MnZn ferrite absorber with CPE.



(b) Reflection coefficient of mixed MnZn ferrite absorber with silicone rubber.

International Journal of Navigation and Port Research
Vol.30, No.9 pp. 767~772, 2006 (ISSN-1598-5725)



(c) Reflection coefficient of mixed MnZn ferrite absorber with natural lacquer.

Fig. 5 Reflection coefficient of a MnZn ferrite electromagnetic wave absorber with a thickness of 3mm mixed with (a) CPE, (b) silicone rubber, and (c) natural lacquer.

As shown in Fig. 5, the frequency bands in which the absorption abilities are over 5 dB include: (a) 1 GHz ~ 4.7 GHz, (b) 1 GHz ~ 3 GHz, (c) 2 GHz ~ 12 GHz. By comparing the absorption abilities of the three kinds of absorbers fabricated with different binders, the absorbers manufactured by using natural lacquer as binders have more broad bandwidth than those prepared by using CPE and silicone rubber as binders. In addition, the absorbers made of MnZn Ferrite and natural lacquer showed high performances, such as -10.6 dB at 1.8 GHz, -9.8 dB at 1.4 GHz, and -21.7 dB at 10.5 GHz. The complex relative permittivity and permeability of the MnZn Ferrite absorbers fabricated by using natural lacquer as binders are shown in Fig. 6 and Fig. 7.

There is a very close relationship between the absorption abilities of the EM wave absorbers fabricated using Ferrite magnetic materials and their loss tangent function ($\tan\delta = \mu'' / \mu'$). It has been reported that superior absorption abilities appear when the imaginary part of the complex relative permeability is greater than the real part, namely, $\tan\delta > 1$ (Hashimoto, 1983). As shown in Fig. 6, the location of $\tan\delta = 1$ is at about 1 GHz. All these samples fabricated in this work fit completely this viewpoint.

A method generally used to extend the bandwidth of the Sheet-type and Tile-type EM wave absorbers is to make multi-layered absorbers. In this case, an analysis for the multi-layered EM wave absorbers has been performed using Matlab program. From the analysis results, we can find how the absorption abilities change when varying the lay-sequences and the thickness of each layer.

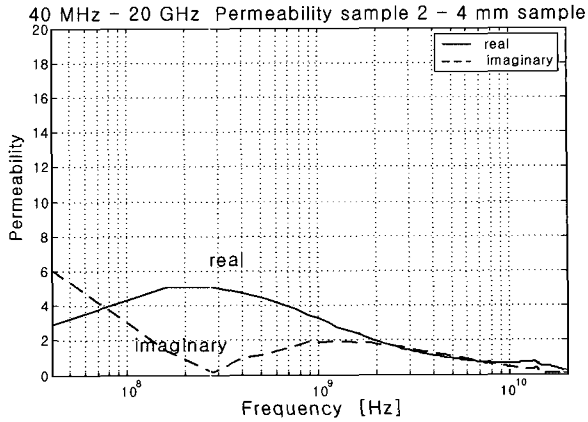


Fig. 6 Complex permeability
(MnZn : Natural Lacquer = 70 : 30 wt%)

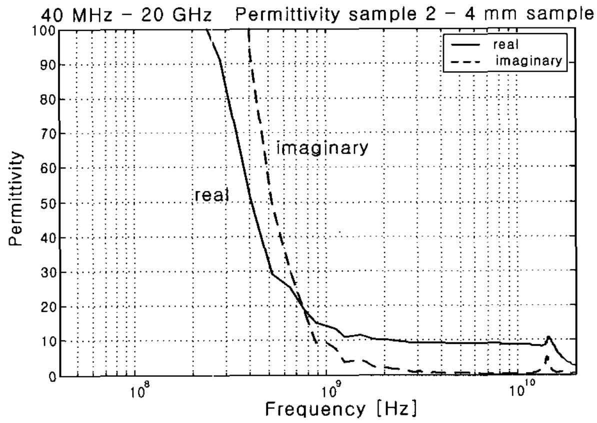


Fig. 7 Complex permittivity
(MnZn : Natural Lacquer = 70 : 30 wt%)

The normalized characteristic impedance Z_n can be obtained by substituting the relative permittivity (ε_r) and permeability (μ_r) calculated above into Eqn. (3), and then by using Eqn. (4), the reflection coefficients can be calculated.

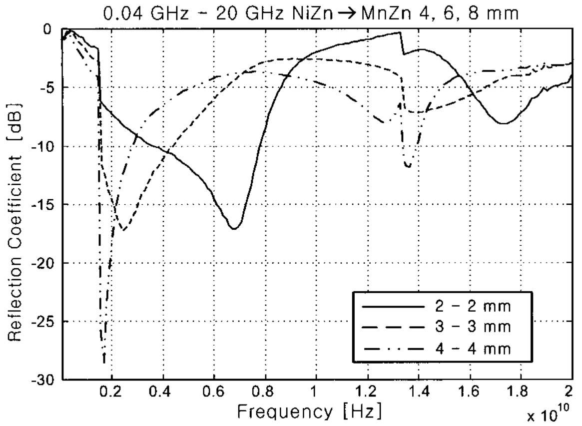
$$Z_n = \sqrt{\frac{\mu_{rn}}{\varepsilon_{rn}}} \frac{Z_{n-1} + \sqrt{\frac{\mu_{rn}}{\varepsilon_{rn}}} \tanh\left(j\frac{2\pi}{\lambda}\sqrt{\mu_{rn}\varepsilon_{rn}}d_n \right)}{\sqrt{\frac{\mu_{rn}}{\varepsilon_{rn}}} + Z_{n-1}\tanh\left(j\frac{2\pi}{\lambda}\sqrt{\mu_{rn}\varepsilon_{rn}}d_n \right)} \quad (3)$$

$$\Gamma(x) = \frac{Z_n - 1}{Z_n + 1} \quad (4)$$

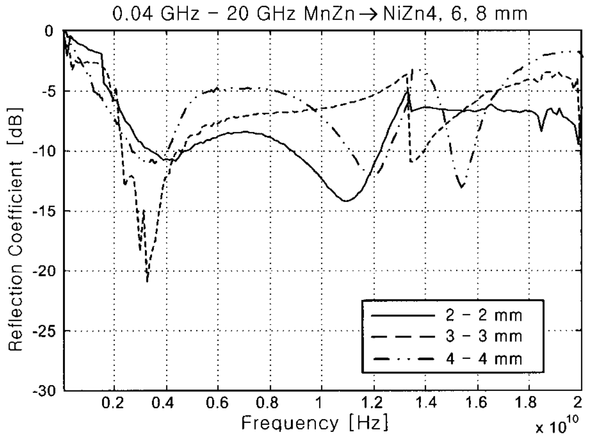
Fig. 8(a) and 8(b) show the simulation results of the multi-layered absorbers constructed on the base of NiZn Ferrite and MnZn Ferrite absorber layers, respectively.

As shown in Fig. 8, the multi-layered absorber based on

MnZn Ferrite layer has more broad bandwidth than one based on NiZn Ferrite layer with same thickness. Therefore, in order to obtain the absorbers with more broad bandwidth, a scheme of fabricating absorbers by using the mixtures of MnZn Ferrite and natural lacquer is proposed firstly.



(a) Conductor plate → NiZn → MnZn



(b) Conductor plate → MnZn → NiZn

Fig. 8 Simulation values for determination of two-layer order.

Comparisons between the calculated and measured results of the two type of fabricated multi-layered absorbers(NiZn Ferrite + natural lacquer, MnZn Ferrite + natural lacquer) are shown in Fig. 9 and Fig. 10. Fig. 9 shows the absorption abilities of absorbers (MnZn Ferrite absorber with 2 mm thickness + NiZn Ferrite absorber with 4 mm thickness), and Fig. 10 shows the absorption abilities of absorbers (MnZn Ferrite absorber with 2 mm thickness + NiZn Ferrite absorber with 6 mm thickness). The measured results almost agree with the simulated those. The absorption ability of the multi-layered absorber with 8 mm thickness is over 10 dB from 1 GHz ~15 GHz.

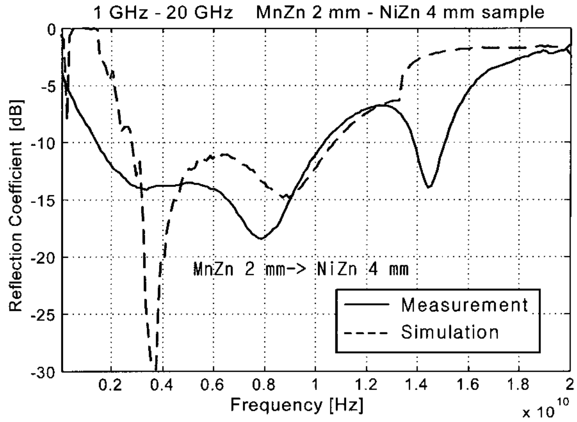


Fig. 9 Comparison of reflection coefficient by Calculated and measured values(6 mm).

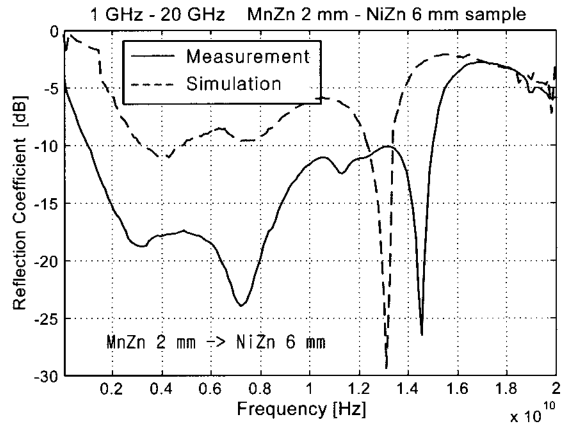


Fig. 10 Comparison of reflection coefficient by Calculated and measured values(8 mm).

5. Conclusion

In this paper, natural lacquer, which has been painted on the traditional artificial handicrafts, is used to fabricate the EM wave absorbers as a new type of binder. By comparing the absorption abilities by the binders themselves, natural lacquer has more effective absorption abilities than the conventional binders, such as CPE and silicone rubber. Moreover, the absorption abilities of the MnZn and NiZn Ferrite absorbers fabricated by using the proposed natural lacquer as the binder are better than those of the absorbers fabricated by using the conventional binders CPE and silicone rubber as the binder. The material properties of the MnZn and NiZn absorbers can be calculated based on the measured results of the manufactured samples. To extend the absorption bandwidth, two-layered absorbers have been prepared, and the layer-sequence can be determined by the simulation analysis using the material properties (permittivity : ε_r and permeability : μ_r) calculated above.

According to this layer-sequence, the thickness of each layer is optimized by simulation results with the same method. Finally, we fabricated and measured the EM wave absorbers with the MnZn Ferrite absorber of 2 mm thickness as the first layer and the NiZn Ferrite absorber of 6 mm thickness as the second layer. From the measured results, the absorption ability of the multi-layered absorber with 8 mm thickness is over 10 dB from 1 GHz ~ 15 GHz.

Acknowledgement

This work was supported by the Korea Research Foundation Grant funded by the Korean Government (MOEHRD)(KRF-2005-005-J00502).

Reference

[1] Hashimoto, Y.(1983), "The application of ferrite as an absorber", Jap. J. Appl. Phys., Vol.6, No. 3, pp. 175-177.

[2] Hashimoto, Y., Kurihara, H., Ishino, K.(1988), "Electro-magnetic Absorbing Wall for TV Ghost Suppression", EMCJ88-6, pp. 37-44.

[3] Hong, J. W., Park, M. Y., Kim, H. K., Park, K. J.(2000), "The Study on Properties of Modified Oriental Lacquer Coating Through UV-Curable Acryl Monomer" J. Korean Ind. Eng. Chem., Vol. 11, No 6, 693-696.

[4] Kim, D. I., Park, Y. J. Kim, H. G., Guen, S. G.(1999), "A Study on Electromagnetic Wave Absorbing Properties of Complex Isotropic Ferrite-Rubber Composite", Journal of The Korea Institute of Maritime Information & Communication Sciences, Vol. 3, No. 1 pp. 35-42.

[5] Kim, D. I., Bae, J. Y., Son, J. Y., Won, Y. S., Song, J. M. (2001), "A Study on Fabrication and Evaluation of Ferrite Electromagnetic Wave Absorber", Journal of The Korea Electromagnetic Engineering Society, Vol. 1, No. 1, pp. 95-99.

[6] Kotsuka, Y.(1997), "Ferrite Electromagnetic Wave Absorber", Journal of The Japan Institute of Application Magnetics, Vol. 21, No. 10, pp. 1159-1166.

[7] Park, Y. J., Kim, D. I. (1999), "A Study on Electromagnetic Wave Absorbing Properties of Ni-Mn-Zn Spinel Ferrite-Rubber Composite", Journal of The Korean Institute of Navigation, pp. 15-22.

Received 4 December 2006
Accepted 8 January 2007