

DEVELOPMENT OF THE ESTIMATION SYSTEM OF ELECTRIC PARAMETERS FOR MANY TYPES OF MATERIALS AND ITS EVALUATION

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ABSTRACT

We developed the estimation system of electric parameters. For the non-magnetic materials, the estimated relative permeability was the same as the nominal values. For the ferromagnetic materials, the estimated relative permeability varied 0% to 30% from the nominal values. For both types of materials, the estimated conductivities were 0% to 9.8% different from nominal values. Next, we apply our estimation method to shielding sheets, and we can estimate the electric parameters for items such as thin cloths. Then, we estimate the dielectric constant for liquid materials. The accuracy is such that the estimated value is different from the nominal value by less than 2%. These results show that we have successfully developed an estimation system of electric parameters for these cases. Using our estimation system, we can estimate considering the frequency characteristics for electric parameters in about 2 minutes.

INTRODUCTION

With the continuing development of information and electrical technology, the number and kinds of electric devices in our society have increased rapidly. It has been shown that electromagnetic waves leaking from electronic devices may cause incorrect operation of other electronic devices. One method to eliminate the electromagnetic noise which is emitted from electric devices is the use of an electromagnetic shielding sheet. In order to eliminate the electromagnetic noise, the design of the electromagnetic shielding sheet must take into account the electromagnetic field from various noise source points. To do this properly, we must investigate the propagation mechanism of the electromagnetic wave by using numerical analysis [1]. Then it is important to know the electric parameters (ε_r , μ_r , σ), because they are used for calculation of the electromagnetic field. In this research, we used a shield box in order to easily measure the Shielding Effectiveness (SE). We estimated the electric parameters by considering the propagation of waves through metallic materials [2], thin shielding sheets [3], and liquid materials [4]. For the numerical calculations, we had to consider the location of the source, and we used the Sommerfeld integral that expresses spherical waves by compositions of cylindrical waves. We fitted the calculated values to measurement values, and we were able to estimate the electric parameters. We then evaluated our method by comparing the values obtained by our method with the nominal values [5]. Finally, we concluded that we had developed a successful estimation system.

AN ESTIMATION METHOD OF RELATIVE PERMEABILITY AND CONDUCTIVITY

In this section, we suggest the estimation method of relative permeability and conductivity for metallic materials and thin shielding sheets. For estimation, we measured the SE using a shield box, and calculated the SE fitted to the measured SE . The best fitted values are the estimated values. For measurement of SE for magnetic fields, we used the shield box which we have developed. A transmitter and a receiver are located in the shield box. The planes of the transmitting and receiving loop antennas and the testing materials are parallel in the shield box. The SE of the magnetic field is expressed by eq. (1). The SE is defined as the ratio of the magnetic field strength at the receiver without the testing material (H_0) to that with the testing material (H_1).

$$SE = 20 \log_{10} \frac{|H_0|}{|H_1|} \quad [\text{dB}] \quad (1)$$

Our calculation model is the Multi-layered model shown in fig. 1. In this research in consideration of the near source, we used the Sommerfeld integral that expresses spherical waves by a composition of cylindrical waves. The source is assumed to be at $z=h$ with homogeneous layers above and below the dipole extending to infinity in the horizontal directions. The axial direction of the dipole source is located vertically perpendicular to each layer. H_i expresses the Hertz vector in the i th layer. The superscript u identifies the up-going wave; d is the down-going wave, and p is the direct wave.

SE has different characteristics as a function of frequency for different types of materials. In the case of non-magnetic materials (Al, Pb, Cu), we do not need to consider the frequency characteristics of electric parameters. But the cases of ferromagnetic materials (Fe, Ni), we have to calculate SE by taking the frequency characteristics into account [6]. Fig. 2 shows SE when the frequency characteristics of the relative permeability were considered. By changing the relative permeability parameter, we can estimate the frequency characteristics of the relative permeability as shown in Fig. 3. Since most of the data of relative permeability available in reference books are for DC, we have to determine for ourselves the nominal values for the AC case. In order to determine the nominal values for the AC case, we determined the relative permeability as a function of frequency by using $B-H$ curve generators. When this was completed, we evaluated our estimation method.

Table 1 shows the relative permeability and conductivity of metallic materials. The calculated conductivity was the same as the nominal value for Pb, 1.9% greater for Cu, and 3.3% greater for Al. For the ferromagnetic materials, the calculated value was 4.1% higher for Ni and 9.8% higher for Fe. For comparison, measurement of conductivity using the four point probe method had a typical error rate of about 20%. Thus, we find that our method is better than the existing method. The nominal values for the relative permeability of the ferromagnetic materials are close to the values derived with our $B-H$ curve testing as shown in Fig. 3. For Fe, the nominal and calculated values ranged from the same to 3% difference. For Ni, they ranged from the same to 33% difference from the nominal values. Then, next we apply it to the shielding sheets and estimate the electric parameters. Table 2 shows the results of estimation of electric parameters for thin shielding sheets.

AN ESTIMATION METHOD OF RELATIVE DIELECTRIC CONSTANT

In this section, we suggest the estimation method of relative dielectric constant for liquid materials. For estimation, we use a procedure similar to that used in above section. The SE of the electric field is expressed by eq. (2). The SE is similarly defined as the ratio of the electric field strength at the receiver without the testing material (E_0) to that with the testing material (E_1). For the measurement SE of liquid materials, we used a container made of acrylic that has no influence on SE .

$$SE = 20 \log_{10} \frac{|E_0|}{|E_1|} \quad [\text{dB}] \quad (2)$$

Our calculation model is the multi-layered model using an electric dipole source. The SE has different characteristics as a function of frequency for different types of materials. Fig. 4 shows the SE of liquid materials. The measurement value and the calculation value are very close.

Table 3 shows the dielectric constant of liquid materials. The estimated dielectric constant was the same as the nominal value for Glycerin, 1.2% smaller for pure water, and 2.0% greater for physiological saline (1.2wt% NaCl). The values of the conductivity of the liquid materials are very small. Most of the conductivities of liquid materials are less than 2 [S/m].

ESTIMATION SYSTEM

Our estimation system consists of two parts as shown in figs. 5 and 6. One is the measurement system of SE ; and the other is the calculation of the electric parameters. The SE is measured by using the shield box. The PC both gathers the data for the measured SE and estimates the electric parameters. For the case of non-magnetic materials, it takes one and a half minutes using our system to estimate the relative permeability and the conductivity for materials. For the case of magnetic materials, it takes two minutes using our system to estimate the relative permeability with frequency characteristics and the conductivity. For the case of the liquid materials, it takes about two minutes using our system to estimate the relative dielectric constant. The results are not different from the results using the spectrum analyzer system. As PC technology has advanced, we can now do the calculations on a PC and we do not need to use an expensive machine such as a workstation.

And we can easily do a complex calculation such as a multi-layered problem using a Sommerfeld integral.

CONCLUSION

We measured SE using a shield box. Since near-field and far-field calculation methods are different, we had to consider the distance from the source to the observation point. For our measurements, the distances from the dipole source to the observation point are smaller than a wave length. We calculated the electromagnetic field at the observation point by using the Sommerfeld integral that expresses spherical waves as compositions of cylindrical waves.

Measurement values of the non-magnetic materials and the liquid materials of SE are very close to the calculated SE values using nominal electric parameters, and we were able to estimate the electric parameters easily. But in the case of ferromagnetic materials, the measurement values and the calculated values differ as the frequency increases. When we considered the frequency characteristics of the electric parameters, changing the parameters allowed us to determine the relative permeability and conductivity as a function of frequency. Finally, we developed the estimation system for both two types.

Using our method, we can estimate the electric parameters not only for non-magnetic materials and liquid materials but also for ferromagnetic materials. This will be very useful for the simulation of electromagnetic fields. And we hope that the present experimental studies help simulate an electromagnetic field's effect on a human's body and improve measures for EMC.

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TABLES AND FIGURES

Table 1: Nominal electric parameter values compared to estimated values

Materials (thickness)	μ_r [nom. / est.]	σ [S / m] [nom. / est.]
Al (0.1 mm)	1.0 / 1.0	3.63×10^7 / 3.51×10^7
Cu (0.11 mm)	1.0 / 1.0	5.80×10^7 / 5.69×10^7
Pb (0.11 mm)	1.0 / 1.0	0.50×10^7 / 0.50×10^7
Fe (0.25 mm)	111.0 / 108.0	1.02×10^7 / 0.92×10^7
Ni (0.1 mm)	13.0 / 10.0	1.45×10^7 / 1.39×10^7

Table 2: Results of estimation for thin shielding sheets

Material (thickness)	μ_r	σ [S / m]
Su-80-301 (0.085mm)	1.0	4.38×10^5
Su-4x-8055 (0.08mm)	1.0	2.17×10^5
Si-80-301 (0.085mm)	1.0	3.10×10^5
Sui-10-56 (0.125mm)	1.0	8.80×10^4
Sui13-30FR (0.135mm)	2.0	2.55×10^5

Table 3: Nominal relative dielectric constant compared with estimated values

material (thickness)	ϵ_r [nom. / est.]
Pure water (1.3 mm)	81.0 / 80.0
Glycerin (1.5 mm)	50.0 / 50.0
Physiological saline (1.3 mm)	49.0 / 50.0

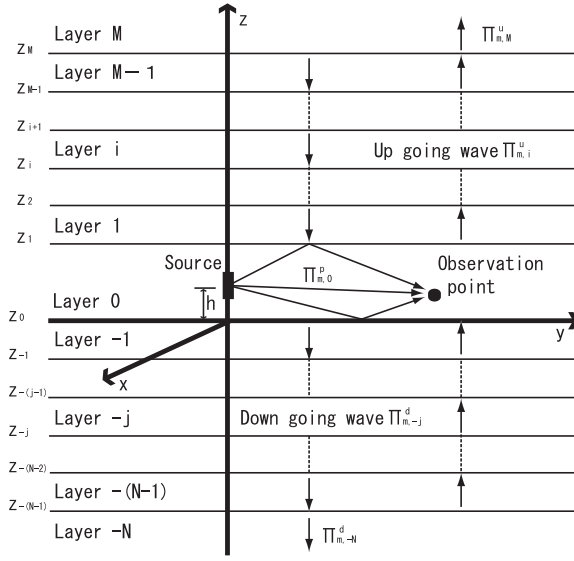


Figure 1: Multi-layered model

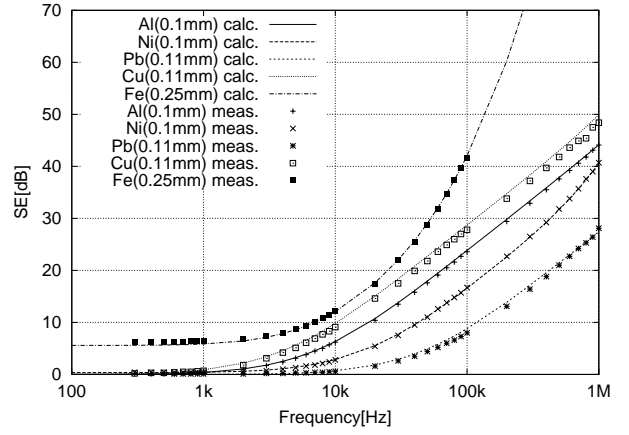


Figure 2: *SE* of metallic materials after consideration of frequency characteristics

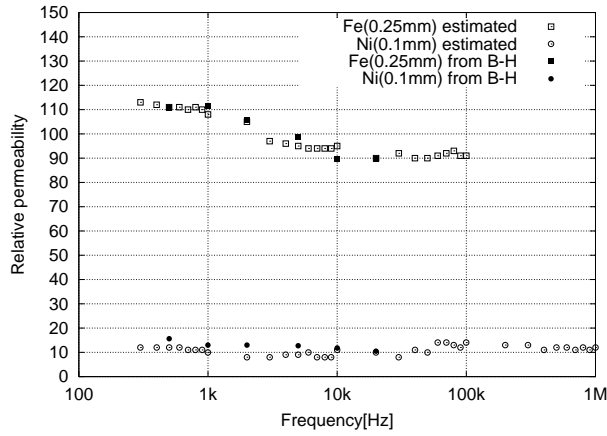


Figure 3: The frequency characteristics of the relative permeability

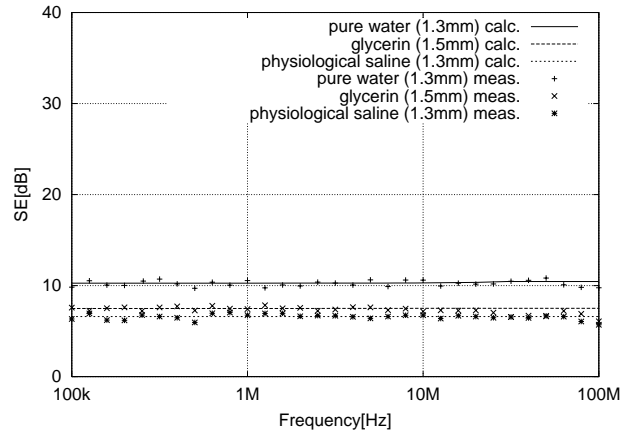


Figure 4: *SE* of liquid materials

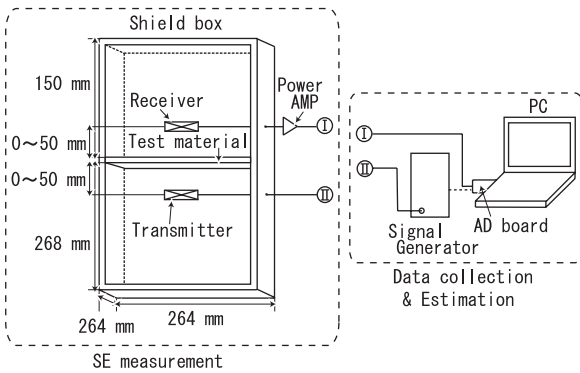


Figure 5: Estimation system of relative permeability

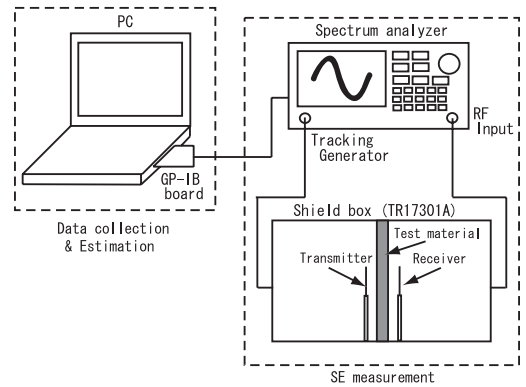


Figure 6: Estimation system of relative dielectric constant and conductivity