Development of a presumption System of Electric Parameters

T. Tosaka, I. Ngano, S. Yakitani

tosaka@reg.is.t.kanazawa-u.ac.jp, nagano@is.t.kanazawa-u.ac.jp, yagitani@is.t.kanazawa-u.ac.jp

Faculty of Engineering, Kanazawa Univ., 2-4-20, Kodatsuno Kanazawa, Ishikawa, JAPAN 920-8667

Y. Yoshinura

yyoshi@irii.go.jp

Product and Technology Dep., Indust. Res. Inst. of Ishikawa,
2-1, Kuratsuki, Kanazawa, Ishikawa, JAPAN 920-8203

Abstract: One of the effective measures for shielding an electromagnetic wave is using shielding materials. For the design of shielding materials, it is important to know about the propagation of electromagnetic waves. For numerical analysis, it is necessary to know about the electric parameters. If we know about the material, we use nominal values. But many of the electric parameters of materials are not known. We developed a shielding box for measuring the shielding efficiency (SE). We propose a method to estimate unknown electric parameters of shielding materials by using the SE measurement system and numerical calculations.

Introduction

Recently, the use of electromagnetic waves is increasing in the technology of electronics, information, and communication. It is believed that electromagnetic wave leaks from electronic devices may cause incorrect operation of other electronic devices and may be a bad influence on the human body. Therefore it is necessary to consider an electromagnetic shield seat that can intercept an electromagnetic wave that leaks from some electronic devices. An electromagnetic shield seat is a thin cloth that is covered by metal plating. Since the surface is uneven and no presumption system exists for this case, we could not determine the electrical parameters (ε, μ, ρ, σ). But it is important to know about these parameters, because they decide the rate of interception of an electromagnetic wave.

In this study, we developed a presumption system for the electric parameters of thin cloth that was not previously available. We presumed the electric parameters of the thin material and evaluated this system using known parameters.

Electromagnetic field analysis using a dipole source inside a multi-layered medium

If the distance z from the observation point to a source with wave length λ is \( z \gg \frac{\lambda}{2\pi} \), the radiated field is the dominant wave emitted from the source and can be regarded as a plane wave. In this case, the shielding efficiency (SE) of the shielding material is not related to the position of the source. But the distance of the source from the observation point is \( z \ll \frac{\lambda}{2\pi} \), and it cannot be considered that the radiated field is the wave emitted from source. Thus it is necessary to calculate the electromagnetic field of a near source when calculating SE.

In this study in consideration of the source, we used the Sommerfeld integral that expresses spherical waves by composition of cylindrical waves.

Analytical model and coordinates system. The coordinate system of a multi-layered model assuming an infinite plate is shown in Fig.1. A magnetic dipole source is assumed at \( z=h \), with homogeneous layers above and below the dipole. In the diagram, \( \Pi_m \) denotes the Hertz vector. Superscripts identify the up-going wave (u), the down-going wave (d), and the direct wave (p), while subscripts indicate the layers.

Boundary conditions. The electromagnetic field can be found from Eqs. (1) and (2) by using the Hertz vectors related to the magnetic dipole. In addition, ignoring time dependence, \( \Pi_m \) can be expressed as in Eq. (3).

\[
E = -j\omega \mu V \times \Pi_m \\
H = \nabla \times \Pi_m + k^2 \Pi_m \\
\Pi_m = \frac{nS}{4\pi} \frac{e^{-jR}}{R} I_z
\]

(1) 

(2) 

(3)

Here \( E \) is the electric field, \( H \) is the magnetic field, \( \omega \) is the angular frequency, \( \mu \) is the magnetic permeability, \( k \) is \( \omega \sqrt{\mu} \), \( \epsilon \) is the complex electric constant, \( n \) is the number of turns, \( S \) is the loop area, I
is current, and $R$ is the distance from the wave source. In Eq. (3), $j$ is complex and $i_z$ is the element of the vector that is in the $z$ direction.

The boundary conditions between layers $i$ and $i+1$ on the XY-plane may be expressed as in Eqs. (4) and (5) by applying the continuity of the electric field's tangential component to Eqs. (1) and (2).

$$\mu_r I_m, i = \mu_{r+1} I_{m, i+1}$$  
(4)

$$\frac{\partial I_m, i}{\partial z} = \frac{\partial I_{m, i+1}}{\partial z}$$  
(5)

These are expressed by Hertz vectors $I_m, i$ for layer $i$ and $I_{m, i+1}$ for layer $i+1$.

**Numerical calculation algorithm.** There are various methods for numerical calculation of the semi-infinite Sommerfeld integral. In this calculation, however, the trapezoidal rule is employed for simplicity. Since the integral converges as the numerical calculation proceeds, the processing is terminated as soon as the increment falls below $10^{-9}$. In addition, the electromagnetic field in Eqs. (1) and (2) is found by numerical differentiation of $I_m$ by the central finite difference method.

In the analysis used in this study, the electro-magnetic field can be calculated both in the vicinity of a magnetic dipole wave source and far away from it because the Hertz vectors are taken into account.

**Measurement using a Shield Box**

In this study, we used a measurement system of shield efficiency. A shield box was made from 3mm thick copper (Cu) plate. The transmitter and receiver installed in the box.

Shielding material was placed in the middle part of the box and the $SE$ was estimated as the ratio of the magnetic field strength at the observation point without the shielding material ($H_0$) to that with the shielding material ($H_S$):

$$SE = 20 \log_{10} \left| \frac{H_0}{H_S} \right| [\text{dB}]$$  
(6)

If the transmitted magnetic field from the source was observed through a side plane, an upper plane, or a lower plane of the shield box, we could not accurately find the shielding efficiency of that material. Therefore, the influence of the circumference of the shield box is taken into consideration.

To do this, we carried out a computer simulation to calculate the attenuation of the transmitted magnetic field outside the shield box. The set up and results are shown in Fig. 2. All transmitted signals outside the box were attenuated 30dB or more. Thus any transmitted signal that returns through the side or upper or lower plane would be attenuated even more. Thus, theoretically, we can ignore the influence of the circumference of the shield box.

**Presumption method of Electric parameters**

The $SE$ calculations are most influenced by the electric parameters. $SE$ has different characteristics with electric parameters of different types of materials and characteristic curves can be drawn for each type. For example, we see that only the $SE$ of ferromagnetic shielding can be observed at low frequency.

When the presumption of electric parameters technique is used, electric parameters are calculated by bringing $SE$ close to the experimental values. The electric parameters are changed in order, and the difference between the analytic values and the experimental values is made as small as possible. The $SE$ is at its presumption value when it is closest to the experimental values. In this study, the least square method was used as the method to get close to the experimental values.

Until now, this system was not available to estimate the electric parameters for ferromagnetic material, because the calculated $SE$ was not in agreement with the measured value in the frequency range of interest. We considered the possibility that the transmitter current changed as one of the causes. How the transmitter current changed for different materials was investigated. Regardless of the material, it did not change. We then found out that by taking into account the frequency characteristic of the permeability of the materials, the presumption of electric parameters, for not only diamagnetic material but also for ferromagnetic material, could be attained.

**Presumed result**

In this study, we tested the presumption of electric parameters technique by using materials that had known
electric parameters beforehand. We were able to evaluate the accuracy of the presumed result by comparing the SE of the analytic value and the experimental value as is shown in Fig.3. We used the nominal electric parameter values for the numerical analysis. From this figure, we see that the experimental values and the analytic values are nearly the same.

Then, we can presume the electric parameters from this approximation. Table 1 compares the nominal values and the electric parameters that are presumed from this method.

**Conclusion**

This research studied a method to estimate unknown electric parameters of shielding materials by using the SE measurement system and numerical calculations. We did an electromagnetic field analysis of a magnetic dipole placed inside a multi-layered medium. Our numerical analysis used the Sommerfeld representation of spherical waves by integration of cylindrical waves. We investigated the effects of the return of the transmitter signals through a side plane, an upper plane, and a lower plane of the shield box. We found no influence on the measuring of SE from external sources because no waves left the shield box and no waves returned to the shield box.

We determined presumed electric parameters with a shield box which we made. We were able to presume electric parameters for diamagnetic materials with high accuracy. But our presumed electric parameters for ferromagnetic materials were less accurate. Since the nominal values of electric parameters are determined for the direct current case, it is not clear how significant is our comparison of the nominal values and our presumed values.

In the future, we want to theoretically presume the characteristics of a shielding material actually used in our society and to experimentally evaluate it.

**Reference**


**Table 1.** Nominal electric parameter values compared to presumed values

<table>
<thead>
<tr>
<th>Material</th>
<th>thickness</th>
<th>( \varepsilon_r ) [nom/cal.]</th>
<th>( \mu_r ) [nom/cal.]</th>
<th>( \sigma ) [nom/cal.]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al (0.1mm)</td>
<td>1.0/1.0</td>
<td>1.0/1.0</td>
<td>3.63 X 10^{-7} / 3.51 X 10^{-7}</td>
<td></td>
</tr>
<tr>
<td>Cu (0.1mm)</td>
<td>1.0/1.0</td>
<td>1.0/1.0</td>
<td>5.83 X 10^{-7} / 5.19 X 10^{-7}</td>
<td></td>
</tr>
<tr>
<td>Pb (0.11mm)</td>
<td>1.0/1.0</td>
<td>1.0/1.0</td>
<td>5.00 X 10^{-6} / 5.00 X 10^{-6}</td>
<td></td>
</tr>
<tr>
<td>Fe (0.25mm)</td>
<td>1.0/1.0</td>
<td>140.80/115.0</td>
<td>1.02 X 10^{-7} / 0.92 X 10^{-7}</td>
<td></td>
</tr>
<tr>
<td>Ni (0.1mm)</td>
<td>1.0/1.0</td>
<td>50.50/12.0</td>
<td>1.45 X 10^{-7} / 2.00 X 10^{-7}</td>
<td></td>
</tr>
</tbody>
</table>