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Shielding Effectiveness Measurement for Anisotropic Materials using DFFC

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1. Introduction

With the continuing development of information and communication technology, the number and kinds of such devices in our society have increased rapidly. It has been shown that electromagnetic waves leak from these devices, and it may cause interference with other communication systems. One method to reduce the electromagnetic noise which is emitted from ICT equipments is the use of the electromagnetic shielding sheets. Effectiveness of the sheets can be evaluate by *SE* (Shielding Effectiveness) that is an index of attenuation of electromagnetic wave. Many methods exist to measure *SE* [1] [2]. But the most of measurement method is usable under 1 GHz. From the reason, we proposed a method for measuring *SE* using DFFC (Dual Focus Flat Cavity) [3]. The method has a large dynamic range of about 100 dB. There are many types of material in our daily life, and the materials are not limited to just isotropic materials. Therefore, we must measure the *SE* considering the anisotropy of the material. In this paper, we calculated *SE* of isotropic materials using DFFC and compared with the measured value to check the validity of the DFFC. Then, we measured *SE* of anisotropic materials considering the axis of material.

2. Measurement setup

For measurement of *SE*, we used a DFFC as shown in Fig. 1. The shape of the DFFC is an oval in the x-y plane and the internal sizes of the long axis (along the x axis), short axis (along the y axis), and width (along the z axis) are 280 mm, 243 mm, and 10 mm, respectively. The usable frequency range of the DFFC is from 1 GHz to around 15 GHz. The feed pins for the transmitting point and receiving point are located at the foci of the DFFC. The length of each feed pin is 10 mm. The transmitting and receiving halves of the DFFC can be separated by the flanges at the center of the DFFC. The material to be tested is placed between the flanges of the transmission part and the receiving part of the DFFC. TE waves are emitted from the transmitting point T, and the waves are focused at the receiving point R through the testing material.

SE is an index of attenuation of electromagnetic waves at the receiving focal point for the cases with and without testing material, and it is defined in eq. (1). V_{with} shows the received voltage with testing material, and $V_{without}$ shows that without testing material.

$$SE_{meas.} = -20\log_{10}\left|\frac{V_{with}}{V_{without}}\right| \quad (1)$$

Fig. 2 shows the measurement setup of *SE* using the DFFC and a network analyzer. Port one of the network analyzer is connected to the transmitting point of the DFFC and port two is connected to the receiving point of the DFFC. We determined *SE* from the difference of S_{21} (measured in dB) of the S-parameters instead of voltage.

In the design of the DFFC, we selected the distance from the transmitting point to the receiving point such that the one-time reflected wave from the oval boundary of the DFFC is observed at the receiving point by 1 ns delay from the signal input to the transmitting point. Thus, we can eliminate the

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direct wave and the multi-time reflected waves by using time gating so that the mathematical treatment becomes easier.

3. Calculation

For calculating *SE*, we have to know the scattering coefficient of the TE waves at the receiving point when the testing material is in place and when is not in place. When a testing material is not in place, we determine the scattering coefficient from the boundary conditions of the DFFC. When the testing material is in place, we first calculate the incident TE wave with multimodes (TE_{p0}) that are incident onto the testing material. Next, we represent the transmitted wave through the testing material using transmission coefficients. Then we replace the transmitted wave with multimode waves and the scattering coefficient. Using the derived scattering coefficient, we can calculate the convergent wave and determine *SE*. The calculation model is shown in Fig. 1. In our calculation, we used cylindrical coordinates in the x-y plane. Electric field in the DFFC has only the z axis component. T is the transmitting point, R is the receiving point, C is the boundary of the DFFC, and P is one of the points on C that can be expressed by the parameter θ.

3.1 Received value at receiving point R without testing material

The transmitted wave that goes from T to P is expressed by a Hankel function of the second kind of order zero. The convergent wave that goes from P to R is represented by a Hankel function of the first kind. The transmitted wave and the convergent wave vanish at P. By applying the continuity on C, we can determine the scattering coefficient a_{m0}. Using the derived scattering coefficient, we can calculate the received value when the testing material is not placed between the flanges of the DFFC, and it can be expressed as shown in eq. (2).

$$E_{without} = \sum_{m=0}^{\infty} a_{m0} H_m^{(1)}(k_0\rho') \cos m\varphi' \tag{2}$$

3.2 Received value at receiving point R with testing material

To determine the transmitted wave that goes through the testing material, we have to calculate the incident TE wave onto the surface of the testing material. We already know the scattering coefficient a_{m0} from the previous section, and by using the derived value, we can calculate the incident TE wave onto the surface of the side of the transmitting point of the testing material.

We calculated the multimodes of the TE wave that converges to R. First, we calculated the scattering coefficient a_{ml} using a boundary condition when the cylindrical wave is radiated with lth mode from T. The lth mode wave vanish on the boundary C. From the boundary conditions for the lth mode of the DFFC, the scattering coefficient a_{ml} is determined.

The transmitted wave that through the testing material is composed by multimode waves. By replacing the transmitted wave with the multimodes of the TE wave, we can determine the scattering coefficient b_l on the surface of the testing material, and the value b_l consists of the transmitting coefficient that derived from measurement using APC-7 and the scattering coefficient a_{ml} that derived from the calculation of multimodes of the TE wave. Using the derived scattering coefficients a_{ml} and b_l, we can calculate the level of the convergent wave at R after passing through the testing material, and it can be expressed as shown in eq. (3).

$$E_{with} = \sum_{l=0}^{L} b_l \sum_{m=0}^{\infty} a_{ml} H_m^{(1)}(k_0\rho') \cos m\varphi' \tag{3}$$

3.3 Calculation of *SE*

We already know the level of the convergent waves as shown in eqs. (2) and (3), therefore, *SE* can be expressed as shown in eq. (4).

$$SE_{calc.} = -20\log_{10}\left|\frac{E_{with}}{E_{without}}\right| = -20\log_{10}\left|\frac{\sum_{l=0}^{L} b_l a_{0l}}{a_{00}}\right| \tag{4}$$

4. Measurement of *SE*

We measured *SE* for the isotropic materials and the anisotropic materials shown in Fig. 3, where (a), (b) and (c) are isotropic materials, and (d) and (e) are anisotropic materials. Fig. 4 shows the calculated value and measured value of *SE* for the case of the isotropic materials. The lines show the measured value, and the symbols show the calculated value. The measured values were obtained by the average of the 10 times measurements. We measured the transmission coefficients for the isotropic materials by placing the testing material between two APC-7 connectors using a network analyzer. The APC-7 connectors are coaxial lines, and the incident wave to the material was a TEM wave. In the case of isotropic material, we can assume that the transmitting coefficients for the TE wave and for the TEM wave in the APC-7 are the same. Then, using the measured value of the transmission coefficient, we could determine the transmitted wave from the multimodes of the TE wave. For the case of *SE* for isotropic material, the calculated value and the measured values are very close at each frequency. The difference between the measured and calculated values are less than 3 dB. The difference might be mainly due to the instability of the contact between the connectors and the material when measuring the transmitting coefficient using APC-7.

Next, we applied the method for fabric shielding material that is expected to have an anisotropic characters. Fig. 5 shows the measured value for *SE* considering the axis of material, where the axis of material is defined by the direction of the longer side of the rectangular gap. The anisotropic materials were tested in vertical axis (meaning the electric field and the axis of the material are parallel), and in horizontal axis (meaning the electric field and the axis of the material are perpendicular). The *SE* in vertical axis is larger than in horizontal axis. The maximum difference is 10 dB, thus we can conclude that these materials have the anisotropy.

5. Conclusion

In this paper, we evaluated the measurement method of the *SE* using the DFFC from the calculated and measured values. From our results, we can measure with acceptable accuracy (less than 3 dB) in the microwave frequency range. Then we measured the anisotropic materials. We could measure the difference of *SE* depending on the axis. The difference was 10 dB maximum in our experiment. It is conclude that the DFFC method is also effective for the measurement of the anisotropic material.

6. Figures and Tables

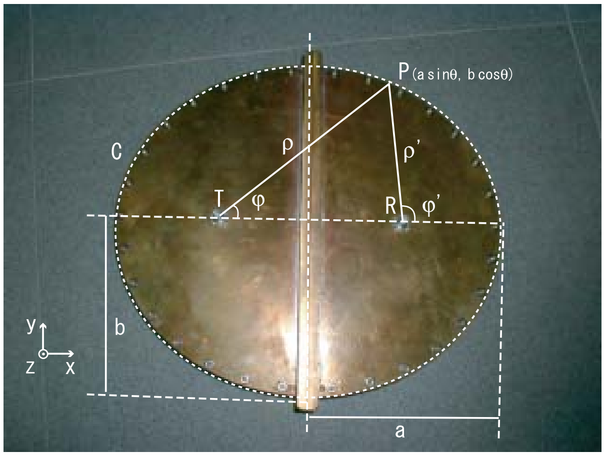

Figure 1: Calculation model

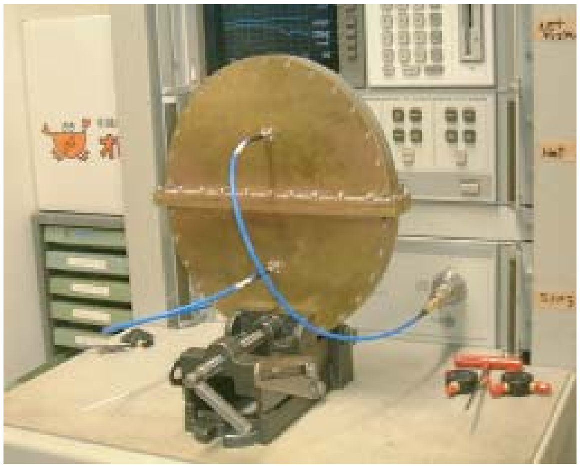

Figure 2: Measurement setup

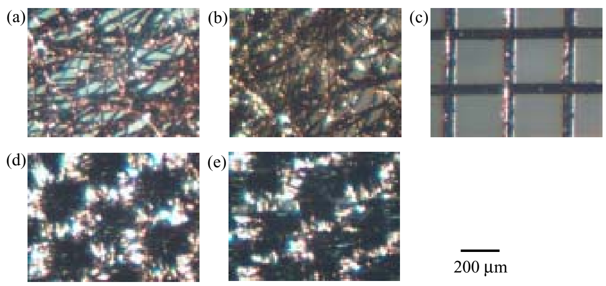

Figure 3: Surface of the materials

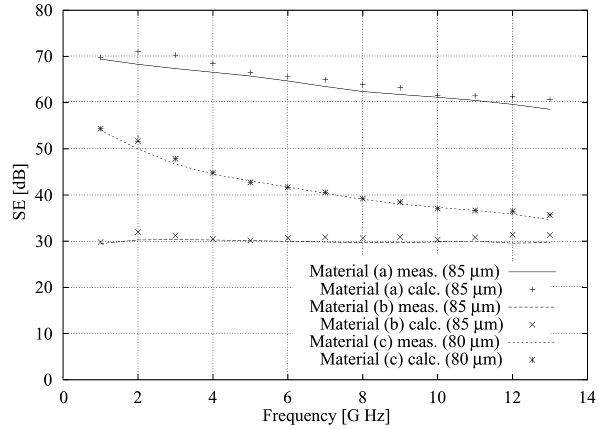

Figure 4: *SE* of calc. and meas. value

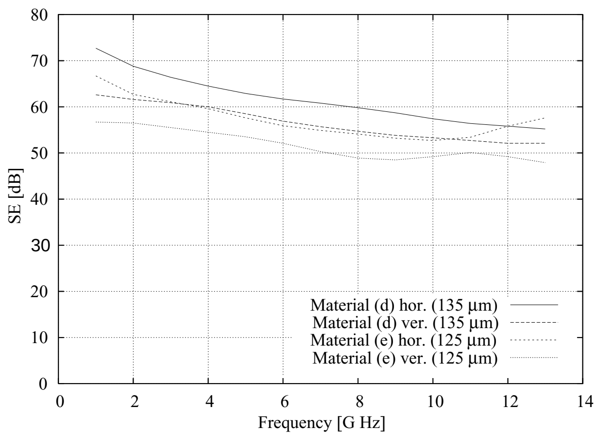

Figure 5: *SE* of anisotropic materials

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[3] A. Nishikata, T. Tosaka, K. Taira, and Y. Yamanaka, "Shielding Material Measurement Device in Microwave Frequencies Utilizing Dual-Focus Flat Cavity", *Proc. on 2005 Pan-Pacific EMC Joint Meeting*, May 2005..