RF Magnetic Shielding Effects of a Bincho-Charcoal Plate

Keisuke Itoh*   Member

Mineo Itoh*   Member

Recently, there has been increased interest for electromagnetic shielding in the radio frequency (RF) region. The use of effective electromagnetic shields has, moreover, been required to improve the electromagnetic environment. The present paper has applied bincho-charcoal, a high quality charcoal found in Japan, to improve RF electromagnetic shields. Bincho-charcoal makes an excellent shield, due to a very large value of relative permittivity in the RF region. In the present research, the evaluation of the RF magnetic shielding degree SD_H of the bincho-charcoal was limited to a plate being exposed to an electromagnetic wave. The SD_H of the single plate was found to increase with an increase in RF frequency over the range from 1 MHz to 1 GHz. The value of SD_H at 100 MHz was found to be about 15 dB. The present authors have, furthermore, improved the value of SD_H by the use of a triple plate, constructed from three bincho-charcoal plates. The SD_H of the triple plate at 100 MHz was found to be improved by about 15 dB over that of the single plate. In addition, the SD_H was shown to be improved by the superposition of a copper plate over the triple plate.

Keywords : bincho-charcoal plate, relative permittivity, RF magnetic shielding effect, RF electric shielding effect.

1. Introduction

Recently, electromagnetic environmental problems have become more serious[1]. In general, therefore, there has been a rising need for electromagnetic shields in the radio frequency (RF) region. As one of the basic areas of research for the improvement of the electromagnetic environment, the present paper has applied bincho-charcoal, a high quality charcoal found in Japan, as RF magnetic shields[2]. This is advantageous since the relative permittivity of bincho-charcoals has a very large value (10^7 - 10^2) in the RF region (1 MHz - 1 GHz).

In the present research, the evaluation of the RF magnetic shielding degree SD_H for the bincho-charcoal is limited to a plate (100 mm square, 5 mm thick) being exposed to an electromagnetic wave. It was found that the value of SD_H for a single plate in the frequency region of 1 MHz to 1 GHz increased with frequency, and had a value of 15 dB at 100 MHz. The present authors have, furthermore, improved the value of SD_H by the use of double and triple plates, constructed from two or three bincho-charcoal plates. The SD_H of triple plate at 100 MHz was found to be improved by about 15 dB over that of the single plate.

Experimental results revealed several characteristics of the bincho-charcoal plate that include the dependence of the relative permittivity of the bincho-charcoal on radio frequency (1 MHz - 1 GHz), the dependence of SD_H on radio frequency, the nondependence of SD_H on the value of RF output power, the nondependence of SD_H on the value of thickness, and the dependence of SD_H on the value of surface area. Also included are the characteristics of the RF electric shielding effect SD_E for the bincho-charcoal plates as a function of radio frequency. In addition, the RF magnetic shielding effect revealed to be improved by the superposition of a copper plate over the triple bincho-charcoal plate.

* Interdisci. Grad. School of Science and Engineering,
  Kinki University
  3-4-1 Kowakae, Higashi-Osaka, Osaka 577-8502

2. Experimental Procedure

2.1 Fabrication of the Bincho-charcoal Plate   The bincho-charcoal, as the absorbing material for the electromagnetic wave, is obtained from very hard oak, sintered under high temperature conditions (1000 °C for example) and then rapidly cooled. This charcoal has the properties hardness, fewer fissures, and less warping compared with other charcoals, and is well-known in Japan as a high quality charcoal.

The bincho-charcoal tiles (10 mm square, 5 mm thick) were fabricated by use of a diamond saw at low cutting rates to inhibit the effect of heat. The paste for gluing the tiles was prepared by homogeneous mixing bincho-charcoal powder (about 2 μm or smaller) with polyvinyl-alcohol. And the weight ratio of the powder to polyvinyl-alcohol was 1:1. The tiles were glued using the paste and then dried naturally in the room temperature (300 K) for about 8 hours. Figure 1 shows a part of the geometry of a typical bincho-charcoal plate (100 mm square, 5 mm thick).

Typical surface scanning electron microscope (SEM) photograph of the bincho-charcoal tile is shown in Fig. 2. The bincho-charcoal tile exhibits the scanty porous structure without cracks.
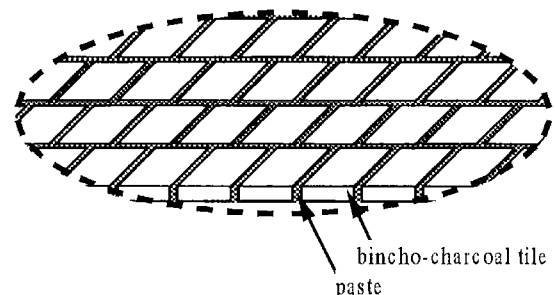

Fig. 1.   Sketch of part of the geometry of a typical bincho-charcoal plate.

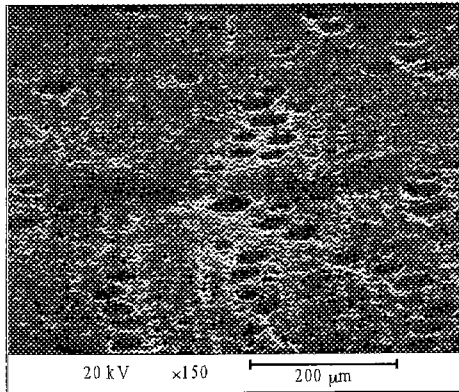Fig. 2. Typical surface SEM microphotograph of a bincho-charcoal tile.

2.2 Measuring system for the RF Electromagnetic Shielding Effect

Figure 3 is a schematic diagram illustrating the experimental arrangement used to measure the RF electromagnetic shielding effects, SD_H and SD_E, at the center of a bincho-charcoal plate under temperature condition of 300 $K^{(2)\sim(5)}$. In the present research, it is measured the SD_H and SD_E under the constant air space (3.4 m^3). The RF output, in the frequency region from 1 MHz to 1 GHz, of the tracking generator (HP 8594) having a spectrum analyzer, is amplified by 40 dB by use of a broad band power amplifier (EIN 411LA). The amplified output is then guided to a transmitting antenna. The signal from the receiving antenna is amplified by 71 dB by use of two preamplifiers (HP 847D and NF SA-230F5), and guided to the input terminal of the spectrum analyzer. The results from the spectrum analyzer are then transferred through GPIB to a lap-top computer.

In the RF shielding system, propagation of the electromagnetic wave from the transmitting antenna to receiving antenna was always arrayed to be perpendicular to the surface of the shielding plate. In this measuring system, the coaxial cable employed as the receiving line was threaded through ferrite rings, in order to reduce any mutual relationship between the transmitting and receiving lines, such as reported in Ref. (2).

The electromagnetic shielding degree SD can be specified in terms of the reduction in magnetic and/or electric field strength due to the shielding material[6]. In general, SD_H is defined as $SD_H=10\log(P_{H0}/P_{H1})$. Here, P_{H0} and P_{H1} are the strengths of the incident magnetic field power and the magnetic field of the transmitted wave as it emerges from the bincho-charcoal plate, respectively. Also, the electric shielding degree SD_E is defined as $SD_E=10\log(P_{E0}/P_{E1})$, where P_{E0} and P_{E1} are the output power of the electric field power of the receiving antenna without and with the bincho-charcoal plate, respectively. The input power of the transmitting antenna and the distance (30.0 mm) between the transmitting and receiving antennas are held constant. Loop and probe antennas are used for the measurements of the magnetic shielding degree SD_H and electric shielding degree SD_E, respectively.

3. Results and Discussion

3.1 Relative Permittivity

In general, the relative permittivity ε_r for a dielectric, in the radio frequency RF region, can be expressed as $\varepsilon_r = \varepsilon_r' - j\varepsilon_r''$, where ε_r' and ε_r'' are the real and imaginary relative permittivities, respectively and j is the
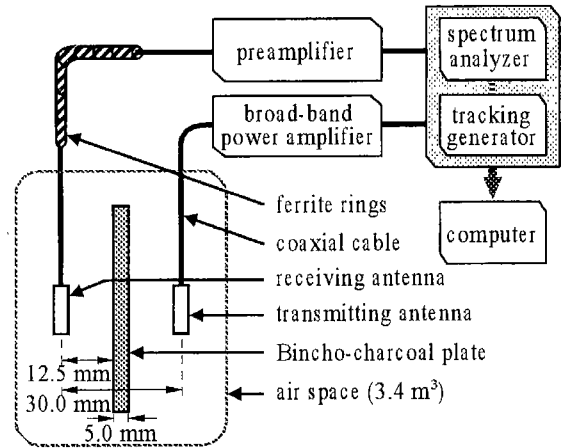

Fig. 3. Schematic diagram of the experimental arrangement used to measure the electromagnetic shielding characteristics.
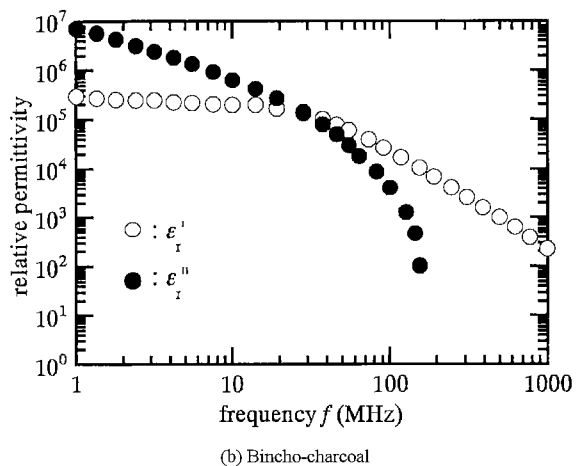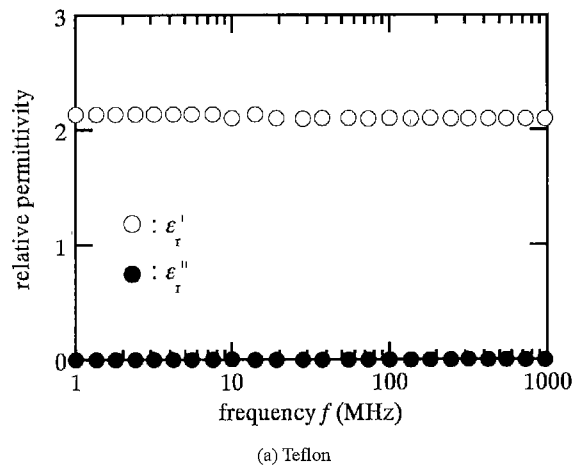

(a) Teflon

(b) Bincho-charcoal

Fig. 4. Typical characteristics of the relative permittivity of (a) teflon and (b) bincho-charcoal as functions of frequency f. The open and solid circles represent the real ε_r' and imaginary ε_r'' relative permittivities, respectively.

imaginary unit. In addition, the values of ε_r form the determinant for the electromagnetic shielding effects.

Figure 4 (a) shows the dependence of the values of ε_r' (open circles) and ε_r'' (solid circles) for a teflon shield (as the standard material for measuring the relative permittivity in the RF region),

on the frequency f in the frequency region from 1 MHz to 1 GHz. The values of ε_r' and ε_r" remain constant versus the values of f, and reflect very low values compared with those of bincho-charcoal.

Figure 4 (b) shows the typical values of ε_r' (open circles) and ε_r" (solid circles) for the bincho-charcoal shield, as functions of frequency f, over the radio frequency range from 1 MHz to 1 GHz. It can be seen that the characteristics of ε_r (ε_r', ε_r") decrease as the frequency increases. The values of ε_r (ε_r', ε_r") for the bincho-charcoal are very large (10^7 - 10^2) in the RF region. Therefore, bincho-charcoal can be considered as the material for use as electromagnetic shields. These values were measured by use of a RF impedance material analyzer (HP 4291A).

3.2 RF Magnetic Shielding Effect of Bincho-charcoal Plate
Figure 5 shows the RF magnetic shielding degree SD_H of the bincho-charcoal plates as a function of frequency f, over the frequency range from 1 MHz to 1 GHz, under a constant RF output power P_H (33 dBm) of the transmitting antenna. The value of the power flux density at the center of bincho-charcoal plate is about 10 W/m² at 100 MHz. In this figure, the curves formed by the open squares, solid circles, and open triangles represent the shielding characteristics for the single, double, and triple plates of bincho-charcoal, respectively. As can be seen in Fig. 5, the values of SD_H for the plates increase as the values of the frequency f increase, in the frequency region from 1 MHz to 1 GHz. It can also be seen that the value of SD_H for the triple plate at 100 MHz was improved by about 15 dB over that of the single plate. That is, the value of SD_H was remarkably improved as a function of the superposition-layer number of the bincho-charcoal plate.

In addition, the values of SD_H were systematically measured by changing the air gap distance δ between the two bincho-charcoal plates in the double plate shield. The dependence of SD_H for δ of 10 mm on the f exhibited similar characteristics such as those shown for the triple plate (open triangles) in Fig. 5. Namely, the value of SD_H for δ of 10 mm for the double plate at 100 MHz was improved by about 13 dB over that of the single plate.

The characteristics of SD_H for values of RF output power P_H of the transmitting antenna for the bincho-charcoal plates at 1 GHz are displayed in Fig. 6. The open squares, solid circles, and open

triangles represent the single, double, and triple plates of the charcoal, respectively. It can be seen that the characteristics of SD_H for the bincho-charcoal plates display no evidence of dependence on the values of P_H in the region between 3 dBm and 33 dBm. Namely, the values of SD_H remain constant and are not dependent on the value of P_H in this power region.

The nondependence of SD_H on the value of thickness t for the single bincho-charcoal plate is displayed in Fig. 7. In this figure, open squares, solid circles, open triangles, and solid diamonds represent the values of SD_H at RF frequencies of 1 MHz, 10 MHz, 100 MHz, and 1 GHz, respectively, under a constant RF output power P_H of 33 dBm. It can be seen that the characteristics of SD_H for the single plate display no evidence of dependence on the values of t in the region between 3 mm and 20 mm. Namely, the SD_H is constant and not related to value of t for the single plate in this thickness region. In addition, it was found that the SD_H as a function of t for single plate displayed no dependence on the values of P_H in the region between 3 dBm and 33 dBm. That is, the SD_H vs t characteristics in this power region exhibited similar results for the frequency region from 1 MHz to 1 GHz, such as
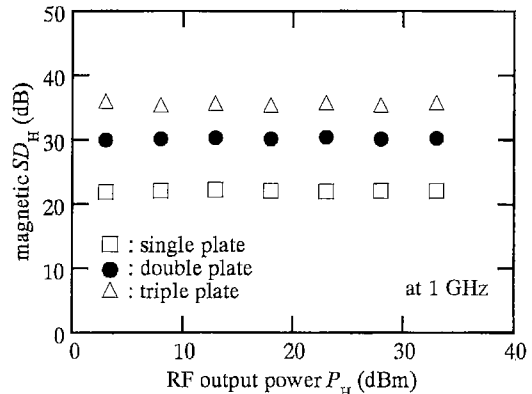

Fig. 6. Typical characteristics of SD_H for the bincho-charcoal plates at the frequency of 1 GHz as functions of the RF output power P_H. The open triangles, solid circles, and open squares represent the values of SD_H for the triple plate, double plate, and single plate, respectively.
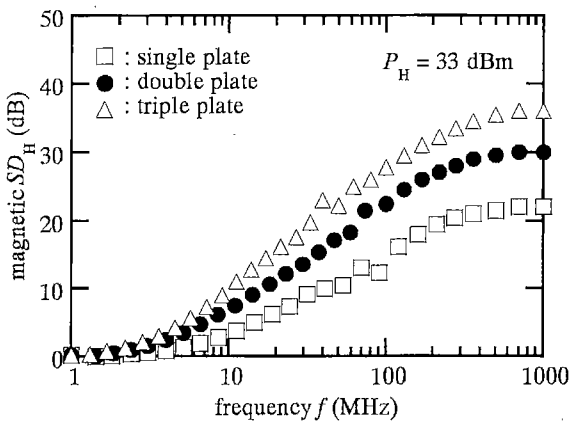

Fig. 5. RF magnetic shielding degree SD_H for the bincho-charcoal plates as functions of radio frequency f. The open triangles, solid circles, and open squares represent the values of SD_H for the triple plate, double plate, and single plate of bincho-charcoal, respectively, under a constant RF output power P_H (33 dBm) of the transmitting antenna.
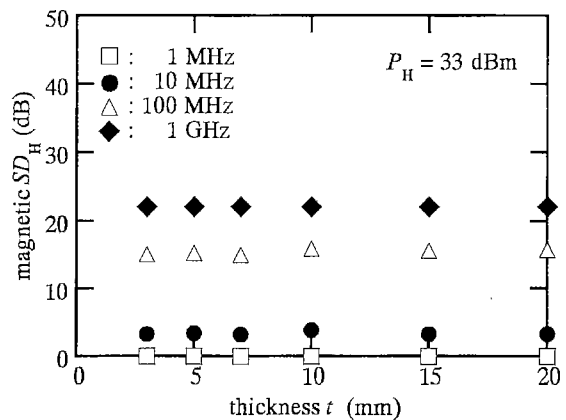

Fig. 7. RF magnetic shielding effect SD_H as a function of the thickness t of the single bincho-charcoal plate. The open squares, solid circles, open triangles, and solid diamonds represent the values of SD_H at RF frequencies of 1 MHz, 10 MHz, 100 MHz, and 1 GHz, respectively, under a constant RF output power P_H (33 dBm) of the transmitting antenna.
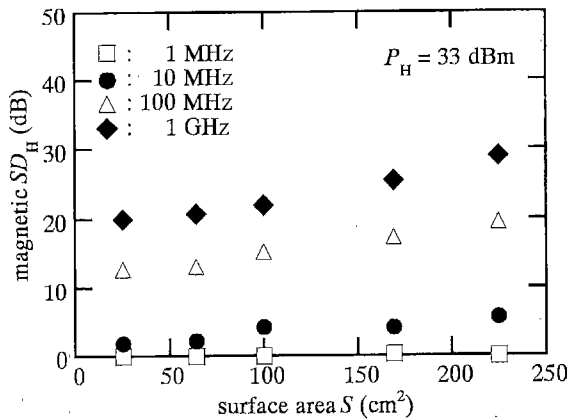
Fig. 8. Typical RF magnetic shielding degree SD_H as a function of the surface area S of the single bincho-charcoal plate. The open squares, solid circles, open triangles, and solid diamonds represent the values of SD_H at RF frequencies of 1 MHz, 10 MHz, 100 MHz, and 1 GHz, respectively.

Fig. 9. Distributions of the RF electric shielding degree SD_E for the bincho-charcoal plates as functions of frequency f, under a constant RF output power P_E (33 dBm) of the transmitting antenna. The open triangles, solid circles, and open squares represent the values of SD_E for the triple plate, double plate, and single plate of bincho-charcoal, respectively.

shown in Fig. 7.

The plotted points in Fig. 8 denote the values of SD_H as a function of the surface area S (25 ~ 225 cm square, 5 mm thick) of the single plate. In this figure, open squares, solid circles, open triangles, and solid diamonds represent the values of SD_H at RF frequencies of 1 MHz, 10 MHz, 100 MHz, and 1 GHz, respectively, under condition RF output power P_H of 33 dBm. It can be seen that the values of SD_H increase as the values of S of the single plate increase in the frequency region from 10 MHz to 1 GHz. The values of SD_H at frequency 1 MHz, however, displayed little or no evidence of dependence on the surface area of the single plate in this surface region. Furthermore, the characteristics of SD_H such as shown in Fig. 8 displayed no dependence on the values of P_H in the region between 3 dBm and 33 dBm.

3.3   RF Electric Shielding Effect of Bincho-charcoal Plate

The plotted points in Fig. 9 denote the RF electric shielding effect SD_E for the bincho-charcoal plates as functions of the RF frequency f, over the radio frequency range from 1 MHz to 1 GHz, under a constant RF output power P_E (33 dBm) of the transmitting antenna. In this figure, the open squares, solid circles, and open triangles represent the values of SD_E for the single, double, and triple plates of charcoal, respectively. The RF electric shielding characteristics such as shown in this figure exhibit no remarkable effects. In addition, the characteristics of SD_E for the bincho-charcoal plates displayed no evidence of dependence on the RF output power P_E in the range between 3 dBm and 33 dBm (not shown). The authors are presently investigating these characteristics in a theoretical analysis along with the experimental results.

3.4   Improvement of RF Magnetic Shielding Effect   In order to further improve the RF magnetic shielding effect, a commercial copper plate (100 mm square, 1 mm thick) was superimposed over the triple charcoal plates, hereafter termed the superimposed plate. Figure 10 displays the typical RF magnetic shielding characteristics of three different plates as a function of frequency f, over the frequency range from 1 MHz to 1 GHz, under a constant RF output power P_H (33 dBm). In this figure, the curves formed by the open triangles, open diamonds, and solid squares represent the shielding characteristics for the triple
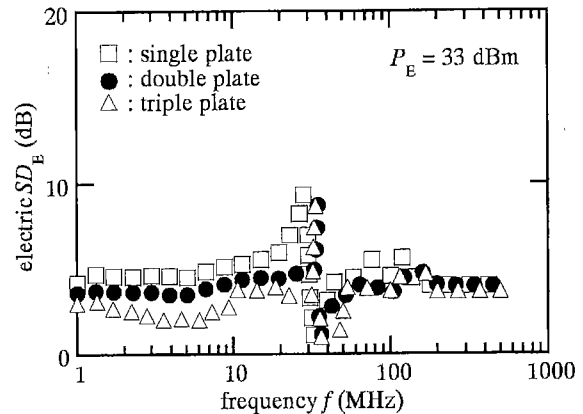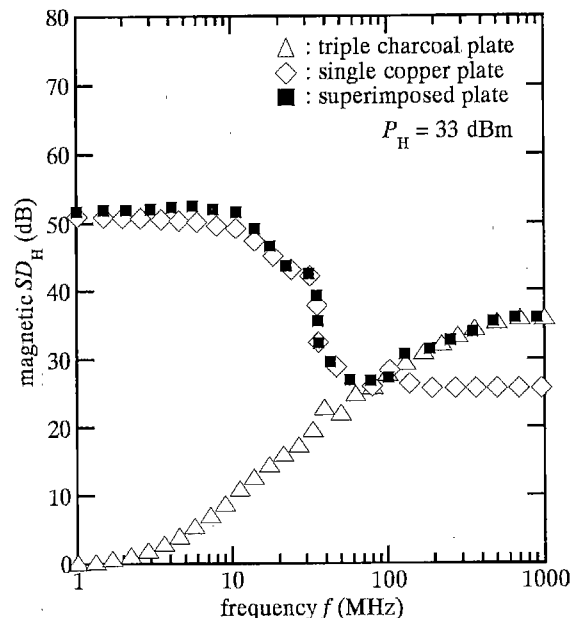

Fig. 10. Typical RF magnetic shielding characteristics of the various plates as functions of frequency f, under a constant RF output power P_H (33 dBm) of the transmitting antenna. The open triangles, open diamonds, and solid squares represent the values of SD_H for the triple bincho-charcoal plate, single copper plate, and superimposed plate, respectively.

bincho-charcoal, single copper, and superimposed plates, respectively. The values of SD_H are improved over that of the triple charcoal plate by superimposed the copper plate over the triple charcoal plate in the frequency region from 1 MHz to 50 MHz. That is, the copper and triple charcoal plates are complementary to each other in the frequency region from 1 MHz to 1 GHz, such as shown in Fig. 10. The present authors are now investigating the physical meaning of these characteristics. These results show an important criterion for improvement in the application of practical electromagnetic shielding.

4. Conclusions and Summary

Previously, the electromagnetic characteristics of bincho-charcoal as radio frequency (RF) shielding material had been unknown. Therefore, the present paper has examined and clarified the electromagnetic characteristics of bincho-charcoal, including the RF magnetic shielding degree SD_H, the RF electric shielding degree SD_E, and the relative permittivity ε_r (ε_r', ε_r''), in the RF region (1 MHz - 1 GHz). Furthermore, it was shown how to improve the value of SD_H for the bincho-charcoal plates. The results of this paper can be summarized as follows:

(1) The characteristics of ε_r for the bincho-charcoal decreased as the frequency increased. The values of ε_r for bincho-charcoal are very large (10^7 - 10^2) in the frequency region from 1 MHz to 1 GHz, such as was shown in Fig. 4 (b).

(2) The value of SD_H for the triple plate at 100 MHz was improved by about 15 dB over that of the single plate. In addition, the value of magnetic shielding degree SD_H was remarkably improved as a function of the superposition-layer number of the bincho-charcoal plates, such as was shown in Fig. 5.

(3) The values of SD_H are improved over that of the triple charcoal plate by superimposed the copper plate over the triple charcoal plate in the frequency region from 1 MHz to 50 MHz. That is, the copper and triple charcoal plates are complementary to each other in the frequency region from 1 MHz to 1 GHz, such as shown in Fig. 10.

These results represent important criteria fundamental in the design of practical RF shielding systems having greater reliability. The present authors are now investigating the physical meaning why values of SD_H are influenced by the air gap distance between the two bincho-charcoal plates in the double plate shield.

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Keisuke Itoh   (Member) graduated from the Department of Electronic Engineering of Kinki University, receiving a M. E. degree from Kinki University in 2001. He is presently a student in the doctoral course of the Interdisciplinary Graduate School of Science and Engineering, Graduate School of Kinki University, studying the RF magnetic shielding characteristics of an HTS plate. Mr. Itoh is a member of the Japan Society of Applied Physics and the Magnetic Society of Japan.

Mineo Itoh   (Member) graduated from the Graduate School of Engineering of Kobe University, and received M. E. and Ph. D degrees in Engineering from Kobe University. Since 1966 he has been a member of the School of Science and Engineering, Kinki University, and currency holds the title of Professor. His research includes electronic measurements, the sensors made from HTS, the magnetic shielding using a superconductor, and the development of biosensors. Dr. Itoh is a member of the Japan Society of Applied Physics, the Society of Instrumentation and Control Engineering, and the Magnetic Society of Japan.