Improvement in the Frequency Characteristics of RF Magnetic Shielding: Effects of the Superposition of Two Ferrite Plates over a BPSCCO Plate

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Abstract. A high-critical temperature superconductor (HTS) is ideal for use as an RF electromagnetic shield. As one of the basic areas of research for the improvement of the electromagnetic environment by the use of a bulk HTS as an electromagnetic shield, the present paper has applied a Bi-Pb-Sr-Ca-Cu-O (BPSCCO) plate to the far field region. In the frequency region from 1 to 30 MHz, however, the RF magnetic shielding degree $SD_H$, with an average value of approximately 30 dB for the single BPSCCO plate, is not sufficient enough to shield electromagnetic waves. Accordingly, the present research has improved the frequency characteristics of $SD_H$ for the single BPSCCO plate to realize shielding over a broadband frequency region of 1 MHz to 3 GHz by the superposition of two ferrite plates; termed the sandwiched plate. The frequency characteristics of $SD_H$ for the sandwiched plate was improved by an average value of approximately 30 dB over the frequency region of 1 to 30 MHz. Experimental results revealed several characteristics of the sandwiched plate, which include the value of $SD_H$ as a function of radio frequency, and the non-dependence of $SD_H$ on the value of RF output power.

1. Introduction

Recently, with the rapid development in the field of information technology, there has been an increased need for electromagnetic shielding in the radio frequency (RF) region. Electromagnetic shielding plates are used to reduce the influence of environmental electromagnetic waves, and to protect the environment from the leakage of generated electromagnetic waves [1-5]. The present research has examined a bulk Bi-Pb-Sr-Ca-Cu-O (BPSCCO) plate, which employs perfect diamagnetism, as an ideal material for use as an RF shield [6-8]. Results indicate that the values of magnetic shielding degree $SD_H$ for the BPSCCO plate increased as the applied frequency of the electromagnetic wave increased, over the RF range from 1 to 30 MHz, and then remained approximately constant in the region from 30 MHz to 3 GHz. The present authors have improved the frequency characteristics of the RF magnetic shielding of the BPSCCO plate, in the frequency region from 1 to 30 MHz, to realize shielding over a broadband frequency region of 1 MHz to 3 GHz. This was accomplished by the superposition of two ferrite plates [9] over a BPSCCO plate; termed the sandwiched plate. The present study examines three different sandwiched plates.

Experimental results revealed several characteristics of the three different sandwiched plates, including the RF magnetic shielding degree $SD_H$, as a function of radio frequency $f$, and the non-dependence of $SD_H$ on the value of RF output power.
2. Experimental procedure
In present experiment, three different sandwiched plates were constructed, as illustrated in Fig. 1. In this figure, the constructed plates in (a), (b), and (c) are termed sample A the ferrite-BPSCCO-ferrite plates (FBF), sample B the BPSCCO-ferrite-ferrite plates (BFF), and sample C the ferrite-ferrite-BPSCCO plates (FFB), respectively. Here, the B and F represent the BPSCCO (Toshima, Lot. 7805-01, 50 mm square, 4 mm thickness) and ferrite (TDK, IB-015, 50 mm square, 6 mm thickness) plates, respectively. As depicted in this figure, the arrows represent the incident direction of the electromagnetic wave.

![Sketch of the geometry of the sandwiched plates. Here, (a), (b), and (c) illustrate sample A the ferrite-BPSCCO-ferrite plates (FBF); sample B the BPSCCO-ferrite-ferrite plates (BFF); and sample C the ferrite-ferrite-BPSCCO plates (FFB), respectively.](image)

The arrangement of the experimental system for measuring RF magnetic shielding effects in the far field region in the present study was previously described in Ref. [5]. The RF output in the frequency region from 1 MHz to 3 GHz of the tracking generator (HP, 8594E), which incorporates a spectrum analyzer, is amplified by 50 dB by the use of a broadband amplifier (Kalmus, 210LC-CE). The amplified output is then guided to a transmitting antenna in a metal cell. The signal is further transmitted to the receiving antenna in another metal cell, amplified by 38 dB by a preamplifier (Sonoma, 317), and then guided to the input terminal of the spectrum analyzer. The results from the spectrum analyzer are then transferred through a GPIB cable to a laptop computer. Figure 2 schematically illustrates the arrangement of the antennas and the two metal cells [10-12]. In the present research, the input power of the transmitting antenna and the distance between the two cells (17 mm) are held constant. In addition, loop antennas were used to measure the RF magnetic shielding effects.

The magnetic shielding degree $SD_{m}$ can be specified in terms of the reduction in the magnetic field

![Schematic diagram of the two metal cells used to measure the RF magnetic shielding effects for the sandwiched plate.](image)
strength due to the shielding material [13]. In general, the value of \(SD_h\) is defined as

\[
SD_h = 10 \log \left( \frac{P_{H0}}{P_{H1}} \right)
\]  

(1)

In this equation, \(P_{H0}\) and \(P_{H1}\) are the respective strength of the incident magnetic field and that of the magnetic field power of the transmitted wave, as it emerges from the sandwiched plate, i.e., the RF shield.

3. Results and discussion

Figure 3 shows the RF magnetic shielding degree \(SD_h\) for the BPSCCO, single-ferrite, and double-ferrite plates as functions of frequency \(f\), under a constant RF output power \(P_H\) of 10 dBm of the transmitting antenna. In this figure, the open circles, open squares, and open triangles demonstrate the shielding effects for the BPSCCO, single-ferrite, and double-ferrite plates, respectively, under temperature conditions of the boiling point of liquid nitrogen (77.4 K). For the BPSCCO plate, notable

![Figure 3](image)

**Figure 3.** Dependence of \(SD_h\) for the BPSCCO (open circles), single-ferrite (open squares), and double-ferrite (open triangles) plates on frequency \(f\), under temperature conditions of 77.4 K and a constant RF output power of 10 dBm.

![Figure 4](image)

**Figure 4.** Typical dependences of \(SD_h\) for the BPSCCO (solid circles), single-ferrite (solid squares), and double-ferrite (solid triangles) plates on frequency \(f\), under temperature conditions of 300 K and a constant RF output power of 10 dBm.
results of the characteristics of $SD_H$ are displayed in the frequency region from 30 MHz to 3 GHz. On the other hand, the values of $SD_H$ for the single- and double-ferrite plates remain constant in the frequency region from 1 to 40 MHz, and then decrease as the frequency $f$ increases in the region from 40 MHz to 3 GHz. Furthermore, it is noted that the magnetic shielding characteristics of the single-ferrite plate exhibit characteristics similar to those of the double-ferrite plate.

The solid circles, solid squares, and solid triangles in Fig. 4 denote the values of $SD_H$ for the BPSCCO, single-ferrite, and double-ferrite plates, respectively, under a constant $P_H$ of 10 dBm and temperature conditions of 300 K (room temperature). As can be seen in this figure, the values of $SD_H$ for the single- and double-ferrite plates decrease as the values of the frequency $f$ increase, and have similar characteristics, in the frequency region from 1 MHz to 3 GHz. The characteristics of $SD_H$ for the BPSCCO plate at room temperature were previously unknown, but are now revealed to increase from 18 to 38 dB in the frequency region from 1 MHz to 3 GHz. Namely, the BPSCCO plate can be

![Graph](image1)

**Figure 5.** Characteristics of $SD_H$ for the BPSCCO plate (open circles), samples A (FBF, open diamonds), B (BFF, open triangles), and C (FFB, open squares) as functions of frequency $f$, under temperature conditions of 77.4 K and a constant RF output power of 10 dBm.

![Graph](image2)

**Figure 6.** Typical dependences of $SD_H$ for the BPSCCO plate (solid circles), samples A (FBF, solid diamonds), B (BFF, solid triangles), and C (FFB, solid squares) on frequency $f$, under temperature conditions of 300 K and a constant RF output power of 10 dBm.
effective by employed as a magnetic shield over a wide frequency region.

To improve the frequency characteristics of the RF magnetic shielding effects for the BPSCCO plate, in order to realize broadband frequency characteristics, three different sandwiched plates were constructed, such as illustrated in Fig. 1. Figure 5 displays the RF magnetic shielding degree $SD_h$ for the sandwiched plates as functions of frequency $f$, under a constant RF output power $P_h$ of 10 dBm and temperature conditions of 77.4 K. In this figure, the open circles, open diamonds, open triangles, and open squares represent the shielding characteristics for the BPSCCO, samples A (FBF), B (BFF), and C (FFB), respectively. It can be seen that the values of $SD_h$ for sample A (FBF) were improved over those of the BPSCCO plate in the frequency region from 1 to 30 MHz. Namely, the characteristics of $SD_h$ for sample A have been improved by an average value of approximately 30 dB in this frequency region. Furthermore, it is found that the magnetic shielding characteristics of sample B (BFF) exhibit characteristics similar to those of sample C (FFB). However, the average values of $SD_h$ for the samples B (BFF) and C (FFB) have been improved by only about 15 dB over that of the BPSCCO plate in frequency region from 1 to 30 MHz.

The sandwiched plates were then subjected to varying frequencies at room temperature (300 K). Figure 6 shows the dependence of $SD_h$ for the three different sandwiched plates on frequency $f$, under a constant $P_h$ of 10 dBm and temperature of 300 K. At this temperature, the values of $SD_h$ demonstrate that the sandwiched plates were particularly effective as RF magnetic shields in the low frequency region, i.e., below 40 MHz. In particular, the values of $SD_h$ for sample A remain fairly constant at approximately 65 dB over this frequency region.

On the different characteristics for three sandwiched plates such as shown in Figs. 5 and 6, it is assumed to be due to the boundary condition between plates. However, it is necessary to consider the order of the combination of the individual plates when constructing the sandwiched plate. The present authors are now investigating the physical meaning behind these results. Needless to say, however, these results demonstrate an important criterion for the fabrication of practical electromagnetic shielding.

Figure 7 displays the characteristics of $SD_h$ for sample A (FBF) as functions of RF magnetic output power $P_h$ of the transmitting antenna, under the temperature condition of 77.4 K. The open circles, solid circles, open diamonds, and solid diamonds represent the results for values of RF of 1 MHz, 10 MHz, 100 MHz, and 1 GHz, respectively. It can be seen that the values of $SD_h$ for sample A (FBF) display no evidence of dependence on the values of output power $P_h$ over the region between 5 to 30 dBm. Similar results were found for samples B (BFF) and C (FFB) (not shown).

Figure 7. Characteristics of $SD_h$ for sample A (FBF) as functions of RF output power $P_h$, under temperature conditions of 77.4 K. The open circles, solid circles, open diamonds, and solid diamonds represent the results for values of RF of 1 MHz, 10 MHz, 100 MHz, and 1 GHz, respectively.
4. Conclusions
As part of development of RF magnetic shielding for a high-critical temperature superconductor (HTS) plate, the present paper has applied a superconducting BPSCCO plate in the far field. The characteristics of $SD_H$ of a single-BPSCCO plate display notable results in the frequency region from 30 MHz to 3 GHz. The present study has, however, improved the frequency characteristics of the BPSCCO plate for realizing the RF magnetic shielding characteristics over a broadband frequency region of 1 MHz to 3 GHz. This was accomplished by constructing the sandwiched plate with the superposition of two ferrite plates over a BPSCCO plate. The values of $SD_H$ for sample A (FFB), such as was shown in Fig. 5, have been improved by an average value of approximately 30 dB in this frequency region. In addition, the values of $SD_H$ for samples B (BFF) and C (FFB) have been improved by an average value of approximately 15 dB, greater than those of the BPSCCO plate, in the frequency region from 1 to 30 MHz, with both samples exhibiting similar characteristics.

The dependence of $SD_H$ for the three different sandwiched plates on frequency $f$, under temperature conditions of 300 K was also demonstrated, such as was shown in Fig. 6. It was found that, at room temperature, the characteristics of $SD_H$ as a function of $f$ revealed that the sandwiched plates were particularly effective as RF magnetic shields in the low frequency region, that is, less than 40 MHz.

From the results shown in Figs. 5 and 6, it was concluded that it is necessary to consider the order of the combination of the plates when constructing the sandwiched plate.

The authors are now investigating the physical meaning behind these results. It is noted that these results demonstrate an important criterion for the fabrication of practical electromagnetic shielding.

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