Improved Frequency Properties of the Orientation Characteristics of a Slit Carbon Plate in an RF Magnetic Field: The Sandwich Structure of Two Slit Ferrite Plates on a Slit Carbon Plate

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As one of the basic areas of research for improving the electromagnetic environment, the present authors have developed a slit carbon plate, as a natural resource, that displays orientation characteristics in a radio frequency (RF) magnetic field. When the slit was held perpendicularly to the ground, the value of RF magnetic shielding degree SD_{HP} increased with frequency in the region of 1 MHz (7 dB) to 3 GHz (70 dB). When the slit was held horizontally to it, the values of RF magnetic shielding degree SD_{HH} indicated an average value of approximately 10 dB over this frequency region. The difference in the values, $SD_{HP}-SD_{HH}$, indicated the orientation characteristics. The slit carbon plate was particularly effective with respect to the orientation characteristics at frequencies above 70 MHz. However, the values of $SD_{HP}-SD_{HH}$ below 70 MHz, having an average value of approximately 15 dB, were not significant enough to display orientation characteristics. Accordingly, the present research improved the orientation characteristics by construction of a slit carbon plate sandwiched between two slit ferrite plates; termed the slit sandwich plate. The value of $SD_{HP}-SD_{HH}$ for the slit sandwich plate improved by an average value of 40 dB in the frequency region from 1 MHz to 70 MHz. The above results confirmed that an important criterion was developed for the fabrication of a slit sandwich plate having highly reliable orientation characteristics.

Key words: RF magnetic shielding, orientation characteristics, natural resource, carbon, ferrite

1. INTRODUCTION

The contamination of environment by electromagnetic pollution has increased with the employment of more electronic equipment constructed with digital technology [1, 2]. Electromagnetic compatibility (EMC) for improvement of the electromagnetic environment is defined as the ability of an electronic system to work correctly in its electromagnetic environment while the surrounding environment is protected from electromagnetic pollution [1]. Therefore, the use of shielding techniques as one of the EMC technologies has increased in order to improve environmental conditions. Conventional electromagnetic shielding techniques, however, are all but impossible in the fundamental solution of the problems in the information and communication fields, such as “ghosts” of terrestrial digital media broadcast, communication failures of wireless local area networks (LANs), virtual images in radar, malfunction of electronic toll collection systems (ETCs), among others. These problems can be solved by the use of a shielding material that displays orientation characteristics. That is, the shield is required to receive an electromagnetic wave as the information signal, and to shield it from an unnecessary noise in the form of electromagnetic waves. Therefore, the present research has developed the slit carbon plate which has the excellent orientation characteristics over the frequency region between 70 MHz and 3 GHz. Orientation characteristics, however, are not found in the frequency region between 1 MHz and 70 MHz, as reported in Ref. [3].

Accordingly, the present authors improved the orientation characteristics by construction of a slit

carbon plate sandwiched between two slit ferrite plates; termed the slit sandwich plate, for the frequency region of 1 MHz – 3 GHz, which is typical of civilian communication equipment. As a consequence, the orientation characteristics improved by an average value of approximately 35 dB for $SD_{HP}-SD_{HH}$, in the frequency region from 1 MHz to 3 GHz. Here, SD_{HP} and SD_{HH} are the radio frequency (RF) magnetic shielding degrees when the slits are held perpendicularly and horizontally to the ground, respectively.

Experimental results demonstrated the improvement in the orientation characteristics, and developed important criteria fundamental in the design of a slit sandwich plate having highly reliable orientation characteristics.

2. EXPERIMENTAL PROCEDURE

2.1 Fabrication of the slit plates

In the present research, use was made of commercial carbon (Toyo-Tanso, IG-110, 50 mm square, thickness of 1 mm) and ferrite (TDK, IB-015, 50 mm square, thickness of 2 mm) plates. Slits were cut in the surface of the carbon and ferrite plates by the use of a diamond saw, operated at a low cutting rate to prevent any influence of heat and cracking [4]. All slits were made through the entire thickness of the plates. In Table 1, the length L , width w , and slit number N are listed for the optimum size of the slit plates for displaying the maximum orientation characteristics in RF magnetic shielding effects, as reported in Refs. [3, 4]. It has been reported that the orientation characteristics for the slit ferrite plate are opposite to those for the slit carbon plate, in association with the value of characteristic impedance Z_s ($>Z_0$ ($=120\pi \Omega$), characteristic impedance of free

Table 1. Optimum sizes of the slit plates for maximum orientation characteristics in RF magnetic shielding effects [3, 4]. Here, L , w , and N represent the length, width, and number of slits, respectively.

slit plate	optimum size of slit		
	L (mm)	w (mm)	N
carbon	42 mm	3 mm	1
ferrite		1 mm	11

Fig. 1. Schematic illustration of the construction of the three different slit sandwich plates. (a), (b), and (c) represent sample 1 (FCF), sample 2 (CFF), and sample 3 (FFC), respectively. Here, the arrows represent the direction of the incident electromagnetic wave.

space) for ferrite [3, 4]. Therefore, when the slit sandwich plates are constructed, the slit directions of the slit ferrite plates are arranged to perpendicularly intersect those of the slit carbon plate.

In order to improve the orientation characteristics for the slit carbon plate in the frequency region from 1 MHz to 70 MHz, the present research constructed three different slit sandwich plates by the superposition of two slit ferrite plates ($N = 11$) on the slit carbon plate, as illustrated in Fig. 1. In this figure, (a), (b), and (c) respectively represent sample 1 (FCF), sample 2 (CFF), and sample 3 (FFC). Here, C and F are the slit carbon and ferrite plates, respectively. The arrows in this figure represent the incident direction of the electromagnetic wave. When the slit sandwich plates are constructed, the slit direction of the slit ferrite plates ($N = 11$) is arranged to perpendicularly intersect that of the slit carbon plate. In addition, the orientation of the slit sandwich plates, when the slit of the carbon plate is oriented horizontally, is termed the horizontal-slit sandwich plate (as shown in Fig. 1). On the other hand, when the slit of the carbon plate is oriented perpendicularly, the plate is termed the perpendicular-slit sandwich plate (not shown).

2.2 Experimental system for measuring the orientation characteristics in RF magnetic shielding

The experimental system for measuring the orientation characteristics in the RF magnetic shielding was arranged as reported in Refs. [3–5]. The RF output of the tracking generator (HP, 8594E), which includes a spectrum analyzer in the frequency region from 1 MHz to 3 GHz, is amplified by 50 dB by the use of a broadband amplifier (Kalmus, 210LC-CE), and then guided to the transmitting loop antenna located in two metal cells. The two metal cells for forming plane wave

have the same shape and size as those reported in Refs. [4, 6]. The output of the receiving antenna is amplified by 38 dB using a preamplifier (Sonoma, 317), and 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. In this arrangement, the coaxial cable employed as the receiving line was threaded through ferrite rings, in order to reduce any interference between the transmitting and receiving lines [7–11]. Moreover, the RF magnetic output power P_H of the transmitting antenna and the distance between both metal cells were held constant at 10 dBm and 17 mm, respectively.

The RF magnetic shielding degree SD_H can be defined as follows, in terms of the reduction in the magnetic field that occurs due to the shielding material, by reference to Ref. [12]. In the present research, the value of SD_H is defined as $SD_H = 10 \log_{10} (P_{H0}/P_{H1})$. Here, P_{H0} and P_{H1} are the strength of the incident magnetic field power and that of the transmitted magnetic field as it emerges from the shielding plate, respectively. When the slits are held horizontally and perpendicularly, the values of SD_H are termed SD_{HH} and SD_{HP} , respectively.

3. RESULTS AND DISCUSSION

3.1 Orientation characteristics of the slit carbon and ferrite plates in RF magnetic shielding

Figure 2 shows the RF magnetic shielding degree SD_H for the non-slit and slit (slit length L of 42 mm, slit width w of 3 mm, slit number N of 1) carbon plates as functions of frequency f , under the constant conditions of RF magnetic output power P_H (10 dBm) of the transmitting antenna and room temperature T (300 K). In this figure, the values of RF magnetic shielding degree SD_{HN} (open squares), SD_{HH} (open circles), and SD_{HP} (solid circles) represent the results for the non-, horizontal-oriented, and perpendicular-oriented (to the ground) slit carbon plates, respectively. It can be seen that the values of SD_{HN} , SD_{HH} , and SD_{HP} all increase as the frequency f increases in the frequency region from 1 MHz to 3 GHz. It can also be seen that the values of SD_{HH} are much less than those of SD_{HP} in the region from 1 MHz (SD_{HH} : 2 dB, SD_{HP} : 7 dB) to 3 GHz (SD_{HH} :

Fig. 2. The RF magnetic shielding degree SD_H of the carbon plates as functions of frequency f , under a constant RF magnetic output power P_H of 10 dBm. Here, the open squares (SD_{HN}), open circles (SD_{HH}), and solid circles (SD_{HP}) represent the shielding characteristics for the non-, horizontal-oriented, and perpendicular-oriented slit plates, respectively.

Fig. 3. The orientation characteristics, $SD_{HP} - SD_{HH}$, for the slit carbon plates as a function of frequency f , under a constant P_H of 10 dBm.

20 dB, SD_{HP} : 70 dB). The values of difference in the RF magnetic shielding degrees, $SD_{HP} - SD_{HH}$, of the carbon plate indicate the orientation characteristics. These characteristics are more remarkable for higher values of frequency f , as shown in Fig. 3. For example, the difference of $SD_{HP} - SD_{HH}$ is approximately 50 dB at 3 GHz. Furthermore, the results of the difference between the values of SD_{HH} and SD_{HP} are considered to indicate that the components of the electric (perpendicular direction) and magnetic (horizontal direction) fields for electromagnetic waves propagate in phase at right angles to each other, as reported in Ref. [5].

The plotted points in Fig. 4 show the RF magnetic shielding degree SD_H for the non-slit and slit (slit length L of 42 mm, slit width w of 1 mm, slit number N of 11) ferrite plates as functions of frequency f , under the constant conditions of P_H of 10 dBm and T of 300 K. The values of RF magnetic shielding degree SD_{HN} (open squares), SD_{HH} (open triangles), and SD_{HP} (solid triangles) represent the results for the non-, horizontal-oriented, and perpendicular-oriented (to the ground) slits of the ferrite plates, respectively. The values of SD_{HN} , SD_{HH} , and SD_{HP} increase as the frequency f decreases in the frequency region from 1 MHz to 3 GHz. It is found that the values of SD_{HP} are low compared with those of SD_{HH} in the frequency region from 1 MHz to 200 MHz.

Fig. 4. The characteristics of the RF magnetic shielding degree SD_H for the ferrite plates as functions of frequency f . The open squares (SD_{HN}), open triangles (SD_{HH}), and solid triangles (SD_{HP}) represent the values of SD_H for the non-slit, horizontal-oriented slits, and perpendicular-oriented slits of the plates, respectively.

Fig. 5. The orientation characteristics, $SD_{HH} - SD_{HP}$, for the slit ferrite plate as a function of frequency f , under a constant P_H of 10 dBm.

That is, the slit ferrite plates display evident orientation characteristics. In addition, these characteristics are more remarkable for lower values of f , as shown in Fig. 5. For example, the difference of $SD_{HH} - SD_{HP}$ is approximately 33 dB at 1 MHz. The orientation characteristics for the slit ferrite plates are, however, opposite to those for the slit carbon plates. From the results in Figs. 3 and 5, it is found that the slit carbon and ferrite plates display more remarkable orientation characteristics at frequencies above and below 70 MHz, respectively.

3.2 Orientation characteristics for the three different slit sandwich plates

In order to improve the orientation characteristics of the slit carbon plate to realize broadband frequency characteristics over the range from 1 MHz to 3 GHz, three slit sandwich plates are formed by the stacking two slit ferrite plates and a slit carbon plate, as shown in Fig. 1 (a, b, c). Figure 6 displays typical characteristics of RF magnetic shielding degrees SD_{HH} and SD_{HP} for the three slit sandwich plates as functions of frequency f , under the constant conditions of P_H of 10 dBm and T of 300 K. In this figure, the curves formed by the open and solid diamonds represent the shielding characteristics of SD_{HH}

Fig. 6. The characteristics of SD_H for the slit sandwich plates as functions of frequency f . The open (SD_{HH}) and solid (SD_{HP}) diamonds are the results for the horizontal- and perpendicular-sample 1 (FCF), respectively. In addition, the open and solid inverted triangles show the results for the horizontal- and perpendicular-samples 2 (CFF) and 3 (FFC), respectively.

Fig. 7. The orientation characteristics, $SD_{HP} - SD_{HH}$, for the three slit sandwich plates as functions of frequency f , under a constant P_H of 10 dBm. Here, the solid diamonds represent the result for the sample 1 (FCF). In addition, the open inverted triangles are the results for samples 2 (CFF) and 3 (FFC).

and SD_{HP} for sample 1 (FCF), respectively. The open and solid inverted triangles are the results of SD_{HH} and SD_{HP} for samples 2 (CFF) and 3 (FFC), respectively.

The orientation characteristics, the differences in the values of $SD_{HP} - SD_{HH}$, for the slit sandwich plates are shown in Fig. 7. In this figure, the solid diamonds represent the results for sample 1. It is found that the orientation characteristics, the values of $SD_{HP} - SD_{HH}$, for the slit carbon plate have been improved by an average value of approximately 35 dB over the frequency region from 1 MHz to 3 GHz. These most remarkable orientation characteristics were never found in previous research results.

In addition, the open inverted triangles represent the results for samples 2 and 3, respectively. Furthermore, it was found that the values of the orientation characteristics ($SD_{HP} - SD_{HH}$) for samples 2 and 3 decreased by an average value of approximately 6 dB, in the frequency region of 1 MHz to 10 MHz, compared with those found for sample 1. The different characteristics found for the three slit sandwich plates are assumed to result from the boundary conditions between the plates. That is, it is necessary to consider the order of the combination of the individual plates, when the slit sandwich plate is constructed. The present authors will investigate the physical meaning behind these results. Needless to say, however, the present results demonstrate an important criterion for the fabrication of a practical RF magnetic shielding plate that demonstrates orientation characteristics.

These results are highly suggestive for use in the design of new applications, such as a highly sensitive and accurate radiometer, a new type of antenna with greater directivity and low noise, among others.

4. CONCLUSIONS

In order to improve the orientation characteristics of a slit carbon plate, the present research has developed three slit sandwich plates, formed by the combination of two slit ferrite plates and the slit carbon plate. The results of present research can be summarized as follows:

(1) The slit carbon plate was particularly effective in displaying orientation characteristics in the frequency range above 70 MHz. However, the difference in the values of RF magnetic shielding degree, $SD_{HP} - SD_{HH}$, below 70 MHz, was not significant enough to yield orientation characteristics.

(2) The slit ferrite plate displayed evident orientation characteristics in the low frequency region from 1 MHz to 200 MHz, with the results opposite of those of the slit carbon plate (for example, compare Figs. 2 and 4).

(3) The orientation characteristics, i. e., the values of $SD_{HP} - SD_{HH}$, for the slit carbon plate have been improved by an average value of approximately 35 dB over the frequency region from 1 MHz to 3 GHz. This was accomplished by constructing a “sandwich” plate of ferrite-carbon-ferrite as shown as sample 1 in Fig. 1.

(4) The characteristics of $SD_{HP} - SD_{HH}$ for samples 2 and 3 (see Fig. 1) were, on average, approximately 6 dB less, in the frequency region of 1 MHz to 10 MHz, compared with those for sample 1 (see Fig. 1). It was thought that the different characteristics for the three slit sandwich plates were due to the boundary conditions between the plates.

These results indicated most remarkable orientation characteristics that had not previously been found in the research. Important criteria fundamental to the design of the slit sandwich plate were developed. The present results can be utilized to better receive a required electromagnetic wave as the information signal, and to shield it from an unnecessary electromagnetic waves as noise.

REFERENCES

- [1] H. W. Ott, “Noise Reduction Techniques in Electronics Systems”, John Wiley & Sons, Inc., Canada (1988) pp. 1-27.
- [2] U. S. Inan and A. S. Inan, “Electromagnetic Waves”, Ed. by M. Horton, Prentice Hall Inc., New Jersey (2000) pp. 35-7.
- [3] T. Nishikubo, H. Endo, and M. Itoh, *IEEE Trans. on Instrumentation and Measurement Technology*, **58**, 3788-95 (2009).
- [4] T. Nishikubo, H. Endo, and M. Itoh, *IEEE Trans. on Applied Superconductivity*, **20**, in printing.
- [5] T. Nishikubo, “Development of a Slit Plate Having the Orientation Characteristics in RF Magnetic Shielding”, *Ph. D. Thesis*, Kinki Univ. (2010).
- [6] H. Norikane, T. Nishikubo, S. Gokyu, K. Itoh, and M. Itoh, *IEEE Trans. on Applied Superconductivity*, **16**, 1765-8 (2006).
- [7] T. Nishikubo, H. Endo, K. Itoh, and M. Itoh, *IEEE Trans. on Applied Superconductivity*, **18**, 1382-6 (2007).
- [8] T. Nishikubo, H. Endo, and M. Itoh, *Trans. of the Materials Research Society of Japan*, **34**, 647-50 (2009).
- [9] T. Nishikubo, H. Norikane, H. Endo, K. Itoh, F. Tojo, and M. Itoh, *Trans. of the Materials Research Society of Japan*, **32**, 1063-6 (2007).
- [10] T. Nishikubo, H. Endo, H. Norikane, K. Itoh, F. Tojo, and M. Itoh, *Trans. of the Materials Research Society of Japan*, **32**, 1067-70 (2007).
- [11] K. Itoh and M. Itoh, *IEEE Trans. on Electronics, Information and Systems*, **124**, 399-403 (2004).
- [12] S. A. Schelkunoff, “Electromagnetic Waves”, Van Nostrand, Princeton (1943) pp. 303-11.