New Electromagnetic Shielding Sheets Using Carbon-nanotube-composite Paper

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ABSTRACT

We propose new electromagnetic shielding (EMS) sheets using carbon-nanotube (CNT)-composite paper. The paper has good electrical conductivity despite being paper and does not deteriorate unlike metal materials, because of both the CNT and the pulp properties. Therefore, these EMS sheets are potentially useful. In this study, we aim to use the paper to make new sheets that have a good shielding effectiveness (SE) over 30 dB in the whole frequency from 0.1 MHz to 10 GHz. Here, we make test samples and observed their SE by the KEC method. In our results, our previously produced paper represented a good SE from 0.1 MHz to 100 MHz frequency. However, the SE in GHz band was 16 dB. To increase the SE in GHz band, we designed and simulated many new-shaped shielding sheets as the second step of this study. From this, we could obtain positive results indicating that the new-shaped shielding has a better SE in GHz band.

***Keywords*:** carbon nanotube composite papers, electromagnetic shielding sheets, Dome shaped shield

1 INTRODUCTION

Recently, with the rapid development of information technology, the electromagnetic environment surrounding equipment and devices such as mobile phones and personal computers has become increasing complexity because of the complicated electromagnetic noise of electronics. The electromagnetic noise can cause other electronic devices to make incorrect actions, which we call electromagnetic penetration. The electromagnetic wave made by electronics can also take the electronics' important information to the environment, which is called electromagnetic information leakage. To solve the problems of electromagnetic penetration and information leakage, needless waves must be decreased. Nowadays, metallic shielding materials are mainly used to solve these problems [3,4].

However, these materials are typically heave, have high cost, and suffer metal deterioration (rust). Therefore, we need a new material to solve these problems. CNT-composite paper [5] combining pulp (paper fibers) and the CNTs has many advantages over metal. For example, this paper has good electrical conductivity despite being paper, is light, is easy to handle, and does not deteriorate because it has unique properties caused by both the CNT and the pulp. The CNT-composite paper can be manufactured easily by a simple method based on a traditional method for making Japanese washi paper [5]. For example, in the first step for manufacturing, we prepare a pulp suspension by soaking and dispersing 300 mg of pulp in 60 ml of water. Second, we also prepare a CNT suspension by dispersing 30 mg of CNTs with 30 mg of sodium dodecyl sulfate (SDS) in 20 ml of water. Third, we mix the pulp and the CNT suspensions to make a mixed suspension. Finally, we scoop the paper containing the CNTs by a tray-screen and dry it. The fabricated sample is about 5×3 cm^2 and 0.15 mm thick. Figure 1 shows a sample of CNT-composite paper.

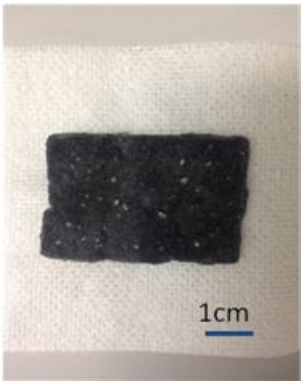

Figure 1 Sample of CNT-composite paper.

There are three mechanisms for electromagnetic shielding (EMS): reflection, absorption, and multiple-reflection [6,7,8-10]. The CNT-composite paper can reflect the electromagnetic wave on the surface of the papers and convert the electromagnetic energy into heat energy in the CNT-composite paper to absorb the electromagnetic wave efficiently, and our paper can also by applied with the multiple-reflection process to decrease the electromagnetic wave. We have already made test samples and obtained a good shielding effectiveness (SE) over 30 dB in the whole frequency from 0.1 MHz to 100 MHz using them in previous study [2]. However, the SE in GHz band was 16 dB. To increase the SE in GHz band, we designe and simulate many new shapes of shielding sheets as the second step of this study.

2 SIMULATION METHOD

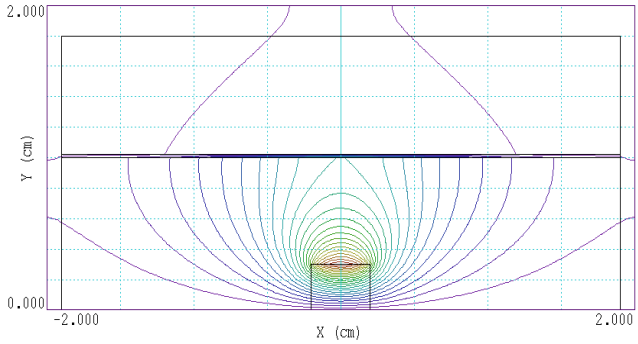

Figure 2 Simulated result of CNT-composite paper in electric field with frequency of 500 MHz.

In this study, our final goal is to create an EMS sheet that has a good SE over 30 dB in the whole frequency from 0.1 MHz to 10 GHz by using CNT-composite paper up to 0.5 mm thick. For efficiency, the EMS sheet is first simulated before being fabricated. Consequently, we use a Finite Difference Time Domain (FDTD) Method, which is often used for electromagnetic modeling. The simulating software MESH6.5 (Field Precision) can help us to simulate the electromagnetic environment and create a new EMS sheet. Figure 2 shows a simple simulated result of CNT-composite paper in 500 MHz frequency by illustration. The square in the bottom of the picture represents the electromagnetic source. The bar in the middle of the illustration shows our CNT-composite paper, which was 0.2 mm thick. Most electromagnetic waves are clearly cut down by our CNT-composite paper. Our sample shows good performance.

In contrast, to test the made sample, we use the KEC method [1], which can check SE for both the electric field and magnetic field. The SE can be calculated by the formula below.

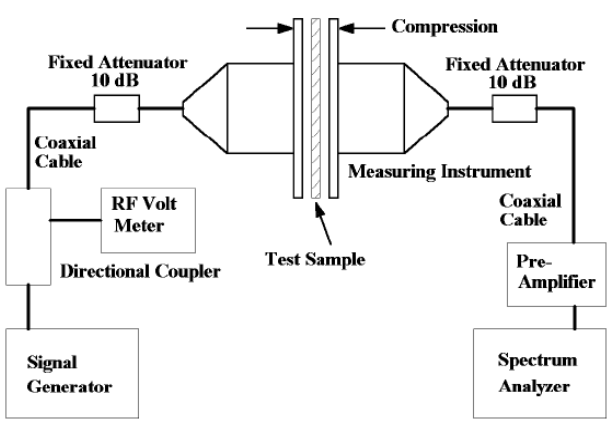

Figure 3 Schematic electromagnetic shielding effectiveness test.

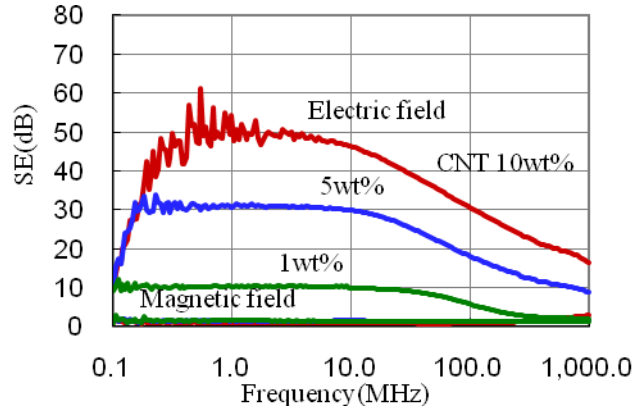

Figure 4 Electromagnetic SE of CNT-composite papers using KEC method [2].

$$SE(dB) = 20 \log E_1 - 20 \log E_2 \quad (1)$$

Where,

E_1 : the receivable level when the test sample is absent.

E_2 : the receivable level when the test sample is present.

Figure 3 shows a simple measurement instrument (based on the transmission level when the test sample is absent, we can measure SE as the insertion loss). Figure 4 shows results of SE for our samples using the KEC method [1]. The results revealed that the CNTs weight percent is an important factor for SE. To obtain a better SE, we should use more CNTs. In the whole frequency from 0.1 MHz to 100 MHz, our sample shows a good SE over 30 dB. However, the SE in GHz band was 16 dB [2], which is not satisfactory.

Ideally, it needs to be over 30 dB. To increase the SE in GHz band, we simulate the electromagnetic environment and the CNT-composite papers by computer simulation to search for and design a suitable and advanced structure as one approach. It is widely accepted that the thickness and the shape of the shield greatly influence SE [11]. Therefore, we design and simulate many new-shaped shieldings.

Finally, we design an originally shaped shielding sheet that we call Dome-shaped shield (Fig. 5) and simulate it by using CNTs. There is a two-layer sheet shield with four Dome-shaped shields below it. In the center of the shield, we added another smaller Dome-shaped shield to reflect the electromagnetic wave efficiently because the center of shield accepts the most powerful electromagnetic wave.

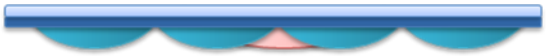

Figure 5 Dome-shaped shield.

3 SIMULATION RESULT

In this section, we describe the design of our original Dome-shaped shield and check the SE .

3.1 Dome-shaped and former samples

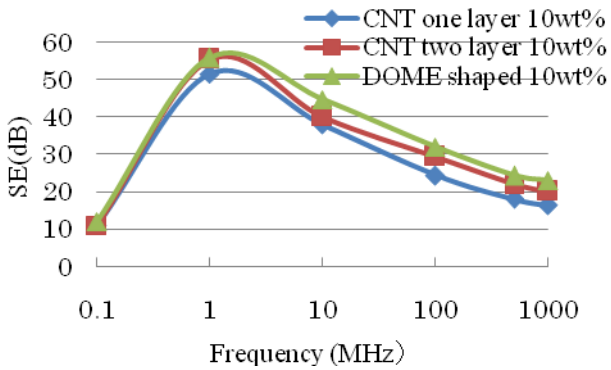

Figure 6 Simulated result of SE in electric field for previously and newly designed samples.

Figure 6 shows the simulated results of SE in electric field for previously [1] and newly designed samples. Both are simulated by using CNTs. Obviously, the Dome-shaped shield has a better SE than CNT one-layer and CNT two-layer sheets in the whole frequency from 0.1 MHz to 1 GHz. Moreover, it also obtains a 23 dB of SE in GHz band, which is better than the previously designed samples. The simulated results of SE in electric field suggest that the thicker shield has a better SE.

Figure 7 shows other previously designed samples that are created by both sheet and zigzag-shaped shields [1]. We also compared our Dome-shaped shield with the other previously designed samples, and Figure 8 shows the results. We can find that even if the Previous-A, Previous-B, and Previous-C have a better SE than a sheet-shaped shield over 16 dB, the Dome-shaped shield has a better SE than all of them.

It is important to recognize that the original four Dome-shaped shields and smaller Dome-shaped shield in the center of the shield reflect the electromagnetic wave efficiently through the simulated results of SE in electric fields in both Figs. 6 and 8. It seems that good reflectance is the key to obtaining a better SE.

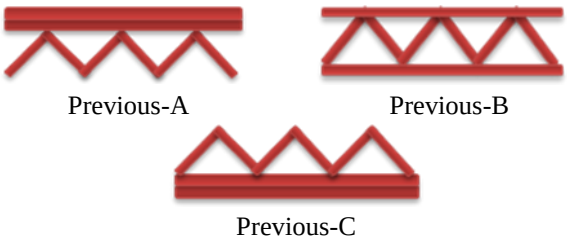

Figure 7 Previously designed samples.

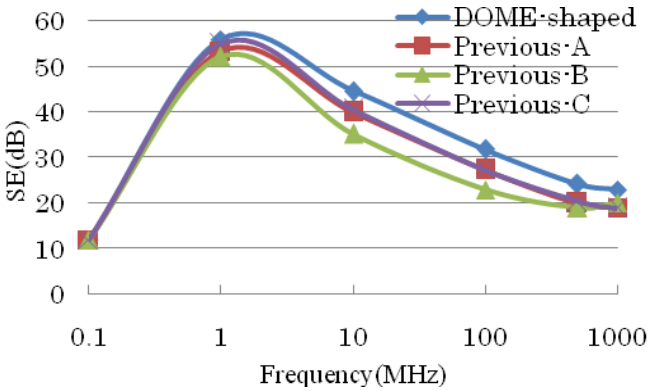

Figure 8 Simulated result of SE in eletric field for former and designed samples.

3.2 Dome-shaped and original samples

It has been convincingly argued that the thickness and the shape of the shield greatly influence SE [11]. The simulated results of SE in electric fields for previously and newly designed samples, show us that both thickness and original shape are important factors. We also know that good reflectance is a significant factor in our study. On the basis of this result, we created some new structures based on our previously and newly designed samples.

Figure 9 shows our original samples (newly designed samples). A two-layer sheet shield is used as a base sheet in all of our samples. We made a zigzag-shaped shield in the center of the shield in Original-A. On other samples, we made Dome-shaped shields to reflect the electromagnetic wave in the center of the shield. We also use zigzag-shaped and Dome-shaped shields on the right and left sides of the shield. It is not difficult to see that Original-C has only one zigzag-shaped shield on either side and Original-B has more zigzag-shaped shields on both sides. The different structures of simulated results of SE could show us which more efficiently reflects the electromagnetic wave.

Figure 10 shows the simulated result of SE in electric fields for dome-shaped and original samples.

Even though original samples shows a little lower SE than the Dome-shaped shield, the original samples perform

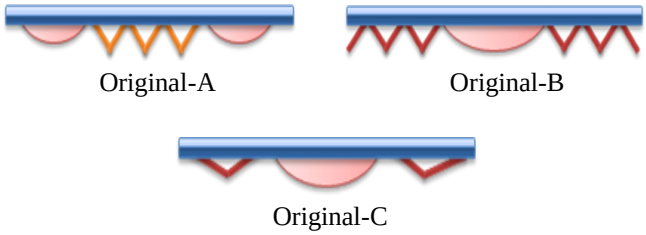

Figure 9 Original samples

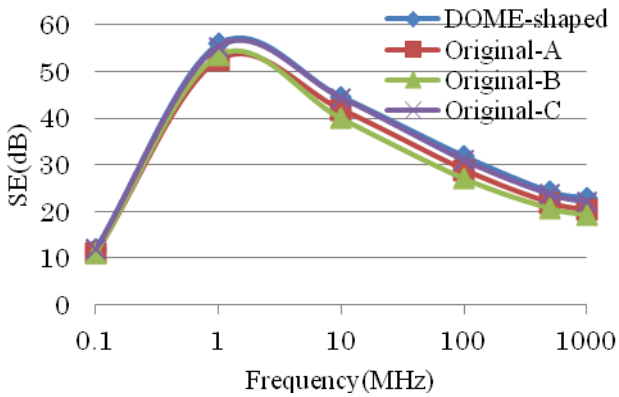

Figure 10 Simulated result of SE in electric fields for Dome-shaped and original samples.

a better SE than previously designed samples (Previous-A, Previous-B, and Previous-C sheet-shaped shields). The original-B shows a good 22 dB of SE in GHz band.

The simulated results of SE in electric fields for Dome-shaped and original samples confirmed that the shape of the shield greatly influences SE. Because of its dome-shape, the shield has a good SE due to reflection. The large surface area of the Dome-shaped shield gives us a new hint as to how make new EMS.

4 CONCLUSIONS

In this study, we aimed to make an EMS sheet that has a good SE over 30 dB in the whole frequency from 0.1 MHz to 10 GHz by using the CNT-composite paper up to 0.5 mm thick. First, we used the simulation software to create an originally shaped shield that we named Dome-shaped shield. Second, we compared our Dome-shaped shield with other previously and newly designed samples. Surprisingly, this Dome-shaped shield obtained a 23 dB of SE, which is better than 16 dB shown by our previously designed one. Moreover, it was also better than other previously designed samples that used both sheet and zigzag-shaped shields.

In conclusion, our CNT-composite papers showed a good SE from 0.1 MHz to 1 GHz bands. Moreover, simulated results revealed that surface area was also an important factor for SE. The large surface area of the Dome-shaped shield could reflect the electromagnetic wave efficiently and obtain a better SE. The large surface factor gives us a hint as to how to create new EMS.

In the future, we are going to fabricate the new shield based on the Dome-shaped CNT-composite paper, and confirm and improve the SE.

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ACKNOWLEDGMENTS

The authors are grateful to Mr. Yoshiyuki Terashima, Mr. Yuki Tamagawa, Mr. Masahiko Shibuya, and Mr. Tomoyuki Unno of KJ Special Paper Corporation, Japan for their supports.