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PROPERTIES OF ELECTROMAGNETIC SHIELDING CASE MADE OF PLYWOOD LAMINATED WITH CONDUCTIVE SHEETS

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ABSTRACT

Electromagnetic shielding cases have been regarded as an adequate solution for electromagnetic interference problems. Most electromagnetic shielding cases are made of metal, conductive plastics and carbon materials. Wood-based electromagnetic shielding cases have gained high levels of public interests due to their availability, cost, and renewability. In this study, the case was constructed of electromagnetic shielding plywood connected by copper foil. Shielding properties of the case were evaluated using shielded room testing. It was found that shielding effectiveness of the case ranged from 30.01 to 43.89 dB (30 MHz to 1 GHz), which indicated it met the secondary shielding effectiveness requirements of general cases for electronic equipment and could be used under the high requirements of electromagnetic compatibility. The results also showed seam leakage between the sides of cases resulted in a decrease of electromagnetic shielding effectiveness. The longer the seam length, the lower the shielding performance was. In addition, it was observed that rectangular waveguide resonance had an obvious influence on the case, which led to a sharp decrease of shielding effectiveness at the frequency of 720 MHz.

KEYWORDS: Electromagnetic shielding case, electromagnetic shielding plywood, copper foil connection, electromagnetic compatibility, rectangular waveguide resonance, spherical dipole antenna.

INTRODUCTION

Recently, with the rapid development of power electronics and electrical automation technology, the electromagnetic (EM) environment has become more complex and the interference between electronic equipment has been increasingly serious. Electromagnetic interference (EMI) has become an important issue that cannot be ignored (Tsai 2007; John Noto et al. 2010; Liu et al. 2013). To ensure equipment is working properly, electromagnetic shielding cases have been used to isolate internal EM field from outside, which is regarded as an adequate solution for EMI problems (Wu and Zou 2004; Liu and Hao 2009; Guo 2011; Chen et al. 2013).

In general, the EM shielding case is made of shielding materials bonded by methods of welding, riveting, screwing, and conductive adhesives fixed according to the properties of materials. A desirable case is required to have good electrical continuity. Many EM shielding materials have been developed to prepare EM Shielding cases (Dong and Li 2012) and the SE of cases was investigated by a series of approaches (Herlemann and Koch 2008; Fang et al. 2008; Filip et al. 2009). Most of the EM shielding cases were made of electric-conductive or magnetic materials such as metal, conductive plastics and carbon materials, however, these cases were high cost, and unaesthetic with few environmental benefits. Wood-based EM shielding cases gained much public interest due to their availability, cost, and renewability.

Among the wood-based EM shielding materials, EM shielding plywood has shown many advantages and has now become the dominant material in developing wood-based EM shielding case. In addition, among the study of wood-based EM materials, most research focused on developing the materials (Pruksanuba 2011; Wang and Liu 2011; Yuan et al. 2013). Little study has been done on the engineering application of EM shielding materials (Lu 2007). Furthermore, no research effort has been found studying the development of materials into final products. From the previous study, it was concluded that the copper foil connection was the best bonding method to suppress the EM leakage (Lu et al. 2013). The objective of this study is to develop a shielding case using EM shielding plywood by copper foil connection method. Shielding properties of the case will be examined in this study.

MATERIAL AND METHODS

Material

The EM shielding case (460×460×230 mm) was made with the EM shielding plywood using the copper foil connection. The bonding method was selected following an analysis of the EMC structure design and considering the characteristics of EM shielding plywood (where conductive shielding is layered inside the plywood) (Lu et al. 2013). The bonding interface was fixed by glue as shown in Fig.1 a and a photo of the case is shown in Fig.1 b.

The plywood was prepared by laminating wood veneers with two layers of conductive sheets (200 $g.m^{-2)}$ under hot-pressing for 6 minutes. The pressing temperature was 120°C and the press pressure was 1 MPa. The usage of UF resin was 150 $g.m^{-2}$ for each bonding line.

Urea formaldehyde resin (30-910) was provided by Taier, Beijing, China. The PH value of the UF resin was between 8.5 and 9.5, its solid content was 52 %, and the viscosity ranged from 110 to 170 cps (30°C). Chinese fir (*Larix*) veneers with the dimension of 700×700×2 mm were provided by Genghe Company (Neimengu, China) and were used to make the plywood samples. Copper foil was provided by Baote Company, Beijing, China. Its thickness was 0.03 mm.

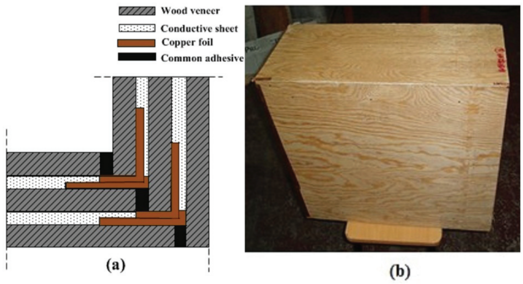

Fig. 1: Connection of step joint and picture of the case.

Test methods

The electromagnetic shielding effectiveness (SE) is defined as the attenuation of an EM wave produced by its passage through a shield. It is expressed in decibels (dB) and calculated according to formula:

$$SE = 10 \log (P_t/P_i) \quad (1)$$

where: P_t - the power of the transmitted wave,
P_i - the power of the incident wave.

The samples were put on a test table located in the shielding room according to GJB 52540 2004 (Fig. 2a) (Razavi and Khalaj-Amirhossenji 2010; Zhong and Fang 2010). The setup consists of transmitting (spherical dipole) and receiving antenna with their input and output connected to power amplifier (737LC-CE, KALMUS Company, USA) and spectrum analyzer (ROHDE & SCHWARA Company, USA). The frequency of the transmitted signal ranged from 30 MHz to 1 GHz. As shown in Fig. 2 b), the case was tested in two types of sides (*I* and *II*, I_1 and I_2 were the front and rear door; II_1 and II_2 were the side doors). Each side was tested from vertical and horizontal polarization orientation respectively. The final test value was chosen as the minimum value in every measured frequency point.

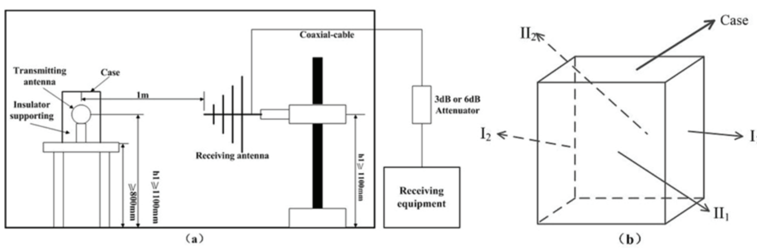

Fig. 2: SE test of the case.

RESULTS AND DISCUSSION

Effect of rectangular waveguide resonance on the SE of case

Fig. 3 shows the SE of different sides under the vertical and horizontal polarization orientation test. The SE curve appeared to reach a catastrophic point at a frequency of 720 MHz, which was obviously less than the test value of adjacent regions. This was due to the phenomenon of rectangular waveguide resonance which happened during the test (LV and Jiang 1991).

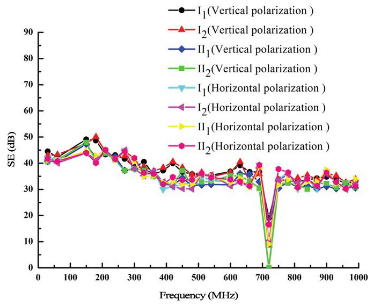

Fig. 3: SE of the different sides of case.

The case was designed to be cuboid. Once the inner radiation field was motivated and multiple reflected by the case surface, it formed a series of standing wave distributions in the case which resulted in a great decrease of the SE near the resonance frequency. The phenomenon of rectangular waveguide resonance was also found in the metal shielding cabinet (300×300×300 mm) investigated by Herlemann and Koch (2008) and the corresponding resonance frequency was 700 MHz at which the SE broke down to negative values. According to the size of the case, the frequency of rectangular waveguide resonance could be calculated by the following formula (Bhag and Huseyin 2000; David 2007, Chen 2013):

$$f_{omnp} = \frac{1}{2\sqrt{\mu\varepsilon}} \sqrt{\left(\frac{A}{W}\right)^2 + \left(\frac{B}{T}\right)^2 + \left(\frac{C}{L}\right)^2} \qquad (2)$$

where: W, T and L - the dimension parameters of the case in m,
μ - the permeability of the medium in the case in H/m,
ε - the dielectric constant of medium in the case in F/m,
A - the number of semi standing wave along the width of the case,
B - the number of semi standing wave along the height of the case,
C - the number of semi standing wave along the length of the case.

Their value ranged from 0 to 2; When *A*, *B* and *C* was 0, 1 and 1 respectively, the calculated resonance frequency of the case was 729.2 MHz. Thus, it was concluded that there was a sharp SE decrease of the case at a resonance frequency of 720 MHz and the result of this frequency point should be removed.

Effect of the bonding seam length on SE of the case

Fig. 4 and Tab. 1 show the SE comparison and difference between side *I* and side *II* under the vertical and horizontal polarization orientation test. The SE

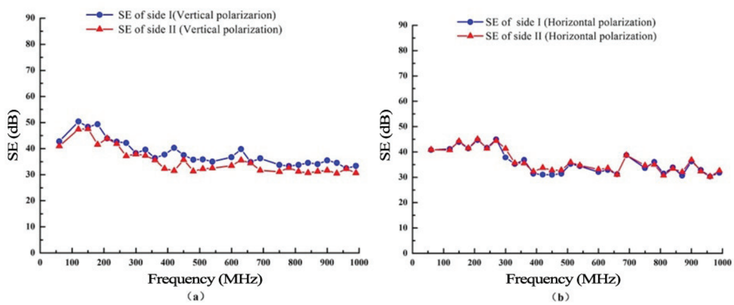

Fig. 4: SE comparison of side I and side II.

Tab. 1: SE difference between side I and side II

Polarization orientation	Vertical polarization	Horizontal polarization
Maximal difference of SE(dB)	8.78	3.48
Minimum difference of SE(dB)	0.05	0
Average difference of SE(dB)	2.92	0.79

difference ranged from 0.05 to 7.79 dB and the average SE difference was 2.92 dB. It was observed that the SE of side *I* was larger than that of side *II* under the vertical polarization orientation test. This was due to the length of bonding seam (perpendicular to the direction of test) for side *II* being longer than that of side *I* under the vertical polarization orientation test. Analysis by quoting SE formula of the seam Cai (1997):

$$SE = 27.3\frac{t}{p} + 20log\frac{(1+N)^2}{4N} \tag{3}$$

where: N - the ratio between wave impedance of seam and free space,
p - the length of seam in cm,
t - the depth of seam in cm.

During the test, t and N was constant. As *p* increased, the rise of wave impedance led to a decreasing of reflection loss. The increasing of EM leakage from seams resulted in the decrease of all SE of the case. The longer the bonding seam length was, the lower the shielding performance would be (Xu 2008). Thus, there was an obvious difference on SE of the case between side *I* and side *II* under the vertical polarization orientation test.

However, it was also found that the SE of side *I* and side *II* were almost the same under the horizontal polarization orientation test. The difference ranged from 0 to 3.47 dB and the average SE difference was 0.79 dB. This was due to length of the bonding seam (perpendicular to the direction of test) for side *II* being the same as that of side *I* under the horizontal polarization orientation test. Thus, the SE difference was very small.

Effect of polarization orientation testing on SE of the case

Fig. 5 and Tab. 2 show SE comparison between different sides of the case. It was noticed that the average SE difference of side I_1 and I_2 was 1.07 dB and that of side II_1 and II_2 was 1.02 dB under the vertical polarization test. In addition, the average difference of SE between side I_1 and I_2 was 0.78 dB, and that of side II_1 and II_2 was 1.20 dB under the horizontal polarization test. It was concluded that the SE difference of different sides of the case was very small. This was due to the bonding seam length of corresponding sides (I_1 VS I_2, II_1 VS II_2) was equal under the same polarization orientation test and had no effect on the SE difference of case. In addition, the shielding room was placed with wave-absorbing materials in the corresponding direction during testing. The electromagnetic wave transmitted from non-testing surface was absorbed by wave-absorbing materials and could not be received by the testing antenna again, which had no effect on the results. This indicated the polarization orientation test had little influence on SE of the case.

Tab. 2: SE difference between the different sides.

Polarization orientation	**Vertical polarization**		**Horizontal polarization**	
	I_1 VS I_2	II_1 VS II_2	I_1 VS I_2	II_1 VS II_2
Maximal difference of SE(dB)	1.78	2.81	2.80	6.19
Minimum difference of SE(dB)	0.06	0.01	0.00	0
Average difference of SE(dB)	1.07	1.02	0.78	1.20

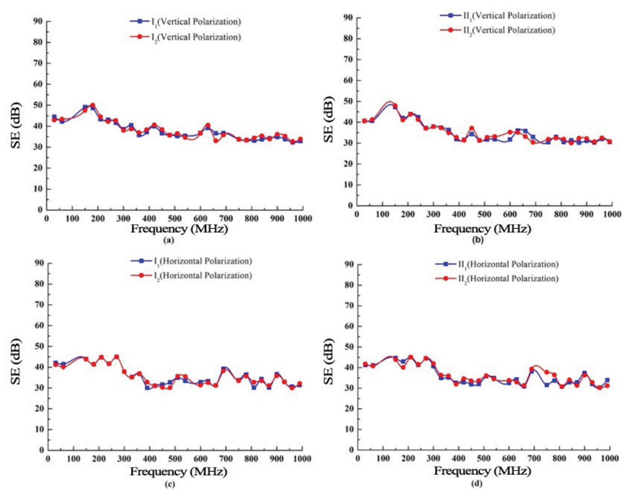

Fig. 5: SE comparison between the different sides.

SE comparison between the case and materials

Fig. 6 shows SE of the case (shielding room test) and EM shielding plywood (window test) with SE of the case ranged from 30.01 to 43.89 dB (30 MHz to 1 GHz). In addition, from the range of 30 to 240 MHz, minimum SE of the case was more than 40 dB, and from the range of 270 MHz to 1 GHz, the minimum SE of the case was greater than 30 dB. It was indicated that SE of the case constructed from electromagnetic shielding plywood met the secondary SE requirements of general cases for electronic equipment and the case could be used under the requirements of electromagnetic compatibility. It was also noted that SE of plywood declined sharply after bonding due to electromagnetic leakage from the bonding seams. SE of the aluminum alloy sheet with 1mm thick determined Lu (unpublished paper) was ranged from 69 to 104 dB (30 MHZ to 1 GHz). Moreover, results reported by Fang (2008) revealed that SE of the enclosure (350 ×350 ×150 mm) constructed of aluminum alloy sheet ranged from 0 to 30 dB

(100 MHz to 1 GHz) under the reverberation chamber (RC) methodology. The wood-based electromagnetic shielding case exhibited greater SE than the former. As described in effect of the bonding length on SE of the case, the longer bonding seam length resulted in lower SE of the case. So, it was critical to study seam leakage problems in EMC design in developing the wood-based electromagnetic shielding materials into final products.

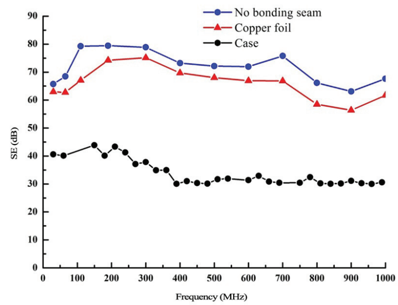

Fig. 6: SE of the case and materials.

CONCLUSIONS

The wood-based electromagnetic shielding case was constructed from electromagnetic shielding plywood and copper foil. Shielding properties of the case were evaluated using shielding room tests. Shielding Efficiency of the case ranged from 30.01 to 43.89 dB (30 MHz to 1 GHz) which indicated it met the secondary SE requirements of general electronic equipment cases and could be used under high requirements of electromagnetic compatibility. It was determined the rectangular waveguide resonance had an obvious influence on SE of the case and the frequency of 720 MHz was considered as the rectangular waveguide resonance frequency point which should be removed. Under the vertical polarization orientation test, the SE difference between different sides of the case was obvious due to the bonding seam length (perpendicular to the direction of test). It was also observed that the SE of wood-based EM shielding plywood decreased sharply after bonding and the bonding seams between the different sides resulted in the decline of EM performance of the case. Thus, it was critical to study seam leakage problems in EMC design in developing the wood-based electromagnetic shielding materials into final products.

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