L'ÉNERGIE AU CŒUR DES ONDES
RESSOURCES ET ENVIRONNEMENT :
GESTION "INTELLIGENTE"

Évaluation de l'Efficacité de Blindage Large-Bande d'un Panneau Composite pour les Boîtiers de Protection

Assessment of Broadband Shielding Effectiveness of Composite Panels for Protective Enclosures

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Composite, Boîtier, Champ lointain et proche, Efficacité de blindage
Composite, Enclosure, Far- and Near-field, Shielding effectiveness

Résumé/Abstract

Le papier étudie l'efficacité de blindage d'un boîtier métallique avec un capot composite multicouche sur une large bande de fréquences, allant du blindage magnétique en champ proche (1 Hz – 1 MHz) au blindage électromagnétique en champ lointain (4 GHz – 14 GHz). Deux boîtiers ont été considérés : un boîtier conducteur en aluminium (Al) et un boîtier magnétique en acier. Le composite multicouche est un tricouche combinant une fine couche conductrice de graphène et une fine couche magnétique d'un alliage Fe-Ni placées de part et d'autre d'une plaque en fibre de verre. Afin de déterminer l'efficacité de blindage de ces boîtiers à la fois à basses fréquences et à hautes fréquences, deux dispositifs expérimentaux et deux modèles numériques ont été développés. L'utilisation du capot composite, à la place du capot métallique, donne un niveau d'efficacité de blindage similaire en champ lointain et une efficacité de blindage spécifique (i.e. efficacité de blindage divisée par la densité du matériau) plus élevée en champ proche de 1 Hz à 2 kHz. Cette analyse quantitative est un premier pas pour concevoir des boîtiers entièrement fait avec des plaques composites afin de faire face aux contraintes CEM dans les systèmes embarqués.

The paper investigates the shielding effectiveness (SE) of a metallic enclosure with a multilayer composite cover over a wide frequency range, from near-field magnetic shielding (1 Hz – 1 MHz) to far-field electromagnetic shielding (4 GHz – 14 GHz). Two enclosures are considered: a conductive enclosure made of aluminum (Al) and a magnetic enclosure made of steel. The multilayer composite is a trilayer combining a thin conductive layer of graphene and a thin magnetic layer of a Fe-Ni alloy on either side of a fiberglass plate. To determine the SE of these enclosures in both low-frequency and high-frequency approaches, two experimental setups and two numerical models are developed. The use of the composite cover, instead of the metallic one, gives a similar level of SE in the far-field and a higher specific SE (i.e. SE divided by the material density) in the near-field from 1 Hz to 2 kHz. Such quantitative analysis is the first step to design practical enclosures entirely covered with composite panels to face EMC constraints in embedded systems.

1 Introduction

The recent growing use of electronic devices, especially in the automotive and aeronautic industries, led to an increase in different sources of disturbance. These disturbances can lead to serious problems in the performance and reliability of electronic systems due to electromagnetic interference (EMI). Thus, manufacturers design their products to reduce or eliminate the effects of these interferences. One solution is the use of electromagnetic shielding as an enclosure.

Metallic enclosures are commonly used thanks to their natural efficiency to face EMI [1]. However, to facilitate the integration of embedded devices and reduce the mass of equipment in the automotive and aircraft industries, lightweight composites present a strong interest. From the literature, shielding enclosures are either designed for low-frequency applications from DC (Direct Current) to tens of kHz [2], or for high-frequency applications from a few MHz to several GHz [3]. Furthermore, most studies focused only on a restricted frequency range. However, in transportation means, embedded personal communication devices increase the range of frequencies, and at the same time, vehicle electrification enhances the radiated perturbations of power systems which mainly operate at low frequencies.

In this context, this paper investigates numerically and experimentally the shielding effectiveness (SE) of a lightweight multilayered composite used as an enclosure cover over a wide frequency range. The proposed multilayer is a three-layer composite [4] combining a thin conductive layer of graphene and a thin magnetic layer of a Fe-Ni alloy, called Mu-ferro. Between these two layers, a glass-fiber composite (GFC) sheet is used as a mechanical support.

2 Materials, experimental setups, and numerical models

2.1 Enclosure and materials

In this study, two enclosures are considered: a conductive enclosure made of aluminum (Al) and a magnetic enclosure made of steel. The use of the composite cover is compared to the metallic ones. Figure 1 shows a picture of the Al enclosure alongside a schematic transversal cut with the composite cover. The external sizes of both enclosures are 120 mm x 120 mm x 92 mm. The walls and the GFC thicknesses are 2 mm. Graphene and Mu-ferro thicknesses are respectively 50 µm and 23 µm. A small square hole (7 mm x 7 mm) is made on one side of the enclosure for experimental measurements.

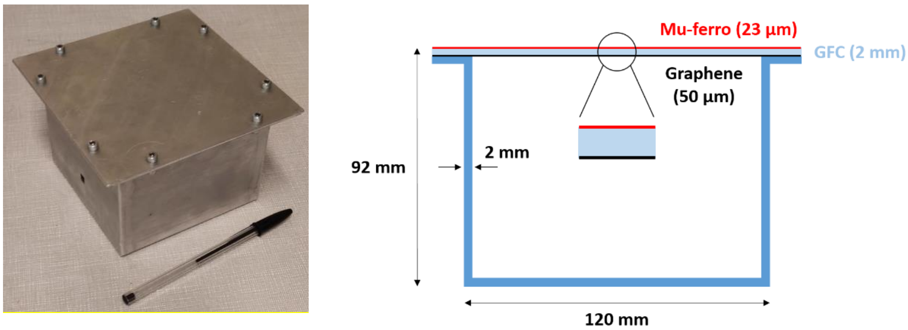


Figure 1: Al enclosure and schematic diagram with the trilayer composite cover

The properties of each material are listed in Table 1. The conductivity is deduced from resistivity measurements performed by a four-probe method. Relative permeabilities of steel and Mu-Ferro are obtained from experimental measurements of the SE of plane samples in the near-field (1 Hz - 1 MHz) [4]. The steel permeability is considered constant in this frequency range. However, the change in permeability of the Mu-Ferro layer is taken into account. In the case of far-field simulations (> GHz), all relative permeabilities are considered equal to 1.

Material	Thickness	Conductivity (S/m)	Relative Permeability
Al	2 mm	35.8e6	1
Steel	2 mm	7.7e6	140 (1 Hz – 1 MHz) 1 (4 GHz – 14 GHz)
Mu-ferro	23 µm	4.8e5	11 380 (1 Hz) 560 (1 MHz) 1 (4 GHz – 14 GHz)
Graphene	50 µm	8.5e5	1
GFC	2 mm	1e-12	1

Table 1: Thickness, conductivity, and relative permeability of each material

2.2 Experimental setups and 3D numerical models

Figure 2 and Figure 3 present experimental setups respectively for the low-frequency and high-frequency shielding measurements. For the low-frequency range, from 100 Hz to 1 MHz, the SE is determined from the measurements of the magnetic field generated by a coil placed inside the enclosure. An impedance/gain-phase (HP4104A) analyzer is used to obtain the gain (dB) between two circular coils of 50 turns with a diameter of 3 cm and a height of 1 cm. The distance between the emitting coil (Fig. 2 (a)), centered inside the enclosure, and the receiving coil (Fig. 2 (b)), placed above, is 60 mm. For the high-frequency range, from 4 GHz to 14 GHz, the SE is determined from the measurement of the electrical field inside the enclosure via an optical probe. A vector network analyzer (R&S®ZVA67) is used to obtain the transmission coefficient $S21_{dB}$ between an exciting horn antenna and the optical probe (Fig. 3 (a)). To avoid disturbances, measurements are performed in an anechoic chamber. The distance between the horn antenna and the enclosure is 700 mm.

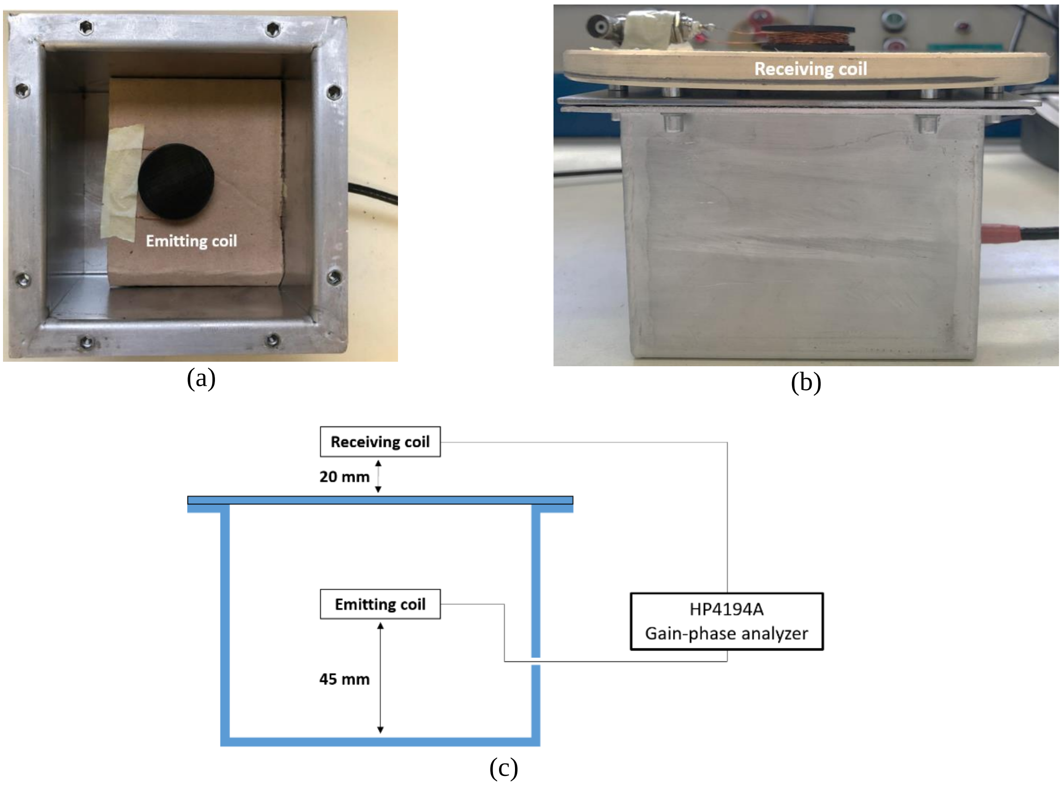


Figure 2: Experimental setup for the low-frequency shielding measurements, view of the centered emitting coil (a), view of the receiving coil (b), and schematic diagram of the setup (c)

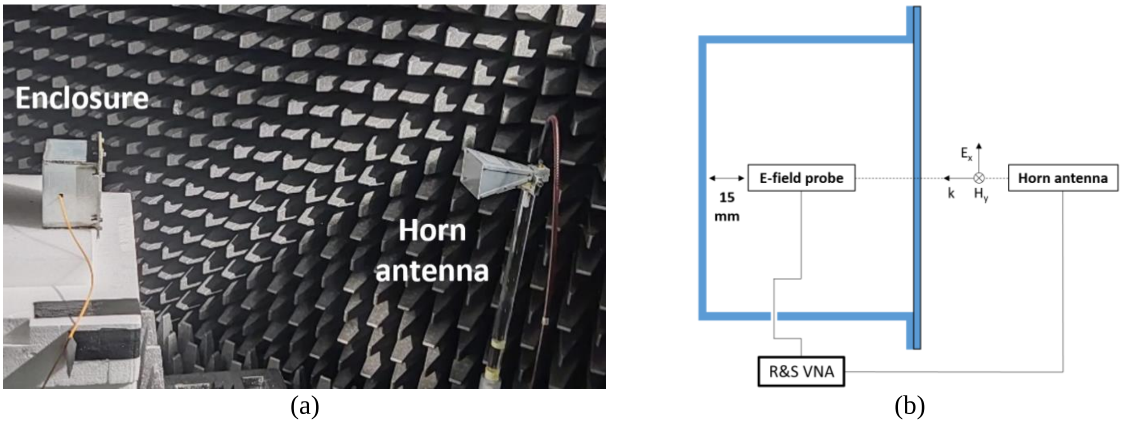


Figure 3: Experimental setup for the high-frequency shielding measurements, view of the anechoic chamber (a), and schematic diagram of the setup (b)

Two numerical models corresponding to the experimental setups are developed with COMSOL Multiphysics, a FEM commercial software covering both low-frequency and wave propagation issues. Both configurations are presented in Figure 4. Only one-quarter of the enclosure is considered to reduce computation time. For the low-frequency configuration, the numerical model is developed with the AC/DC module. The emitting and receiving coils are respectively simplified by a circular filamentary loop and a measuring point. The modeling of thin-layer is quite challenging, especially in 3D applications. Thus, to simplify numerical calculations, Artificial Material-Single Layer (AMSL) method [5] is used to mesh enclosure walls by only 4-parallelepiped entities in the thickness. For the composite cover, a homogenization method [6] is applied before using the AMSL method. For the high-frequency configuration, the numerical model is developed with the RF module. The optical E-field probe is reduced to a measuring point. The enclosure is illuminated by a plane wave polarized along the x-axis.

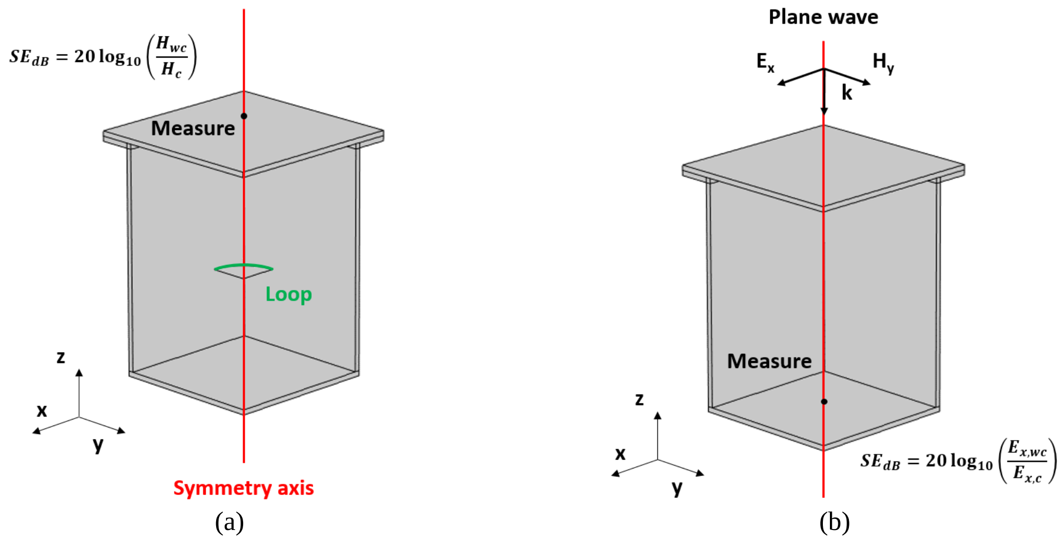


Figure 4: Geometries of the 3D numerical models for the low-frequency (a) and the high-frequency (b) configurations

3 Results

Experimental and numerical SE for both Al and steel enclosures with the composite cover are presented in Figure 5 for low-frequency configuration. In both graphs, the numerical results are quite close to the experimental ones, from 1 kHz when the latter becomes more valid and less noisy. However, experimentally, two positions of the cover can be achieved: either the Mu-ferro layer or the graphene layer is in contact with the enclosure (cf. Fig.1). Numerically, the composite cover is homogenized, thus, this point cannot be addressed. In the case of the Al enclosure, the position of the cover has a slight impact on the SE, it is slightly higher when the Mu-ferro layer is in contact with the enclosure. However, in the case of the steel enclosure, the cover position shows a significant effect on SE. The shielding is far more effective when the graphene layer is in contact with the enclosure. A higher conductivity and a better electrical contact could explain this difference.

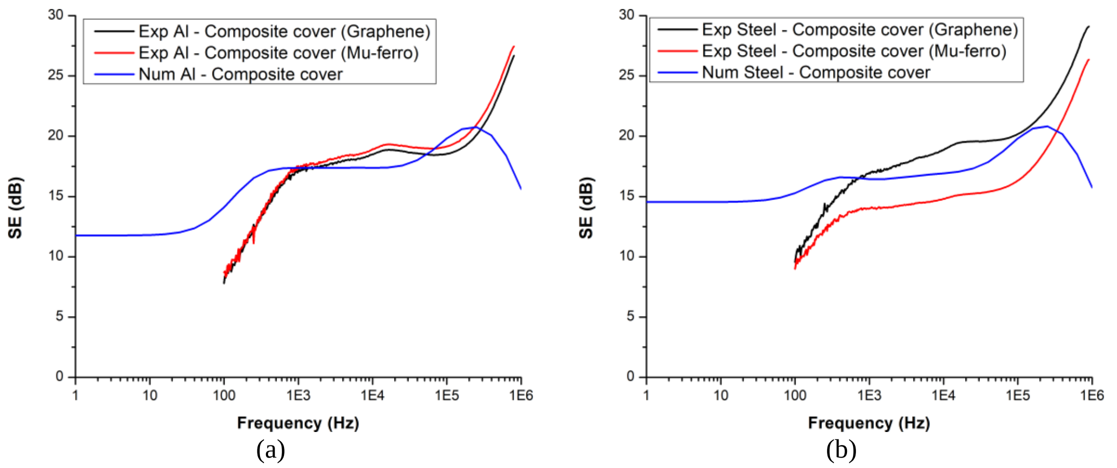
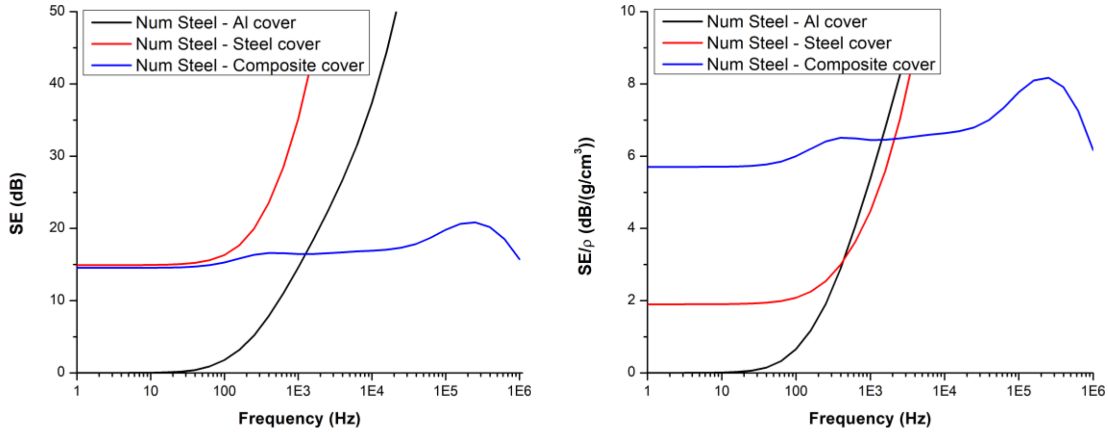


Figure 5: Experimental and numerical SE of the Al (a) and steel (b) enclosures with the composite cover

In Figure 6 (a), the SE of the steel enclosure obtained numerically with the different covers is plotted. The high conductivity of the Al and steel panels combined with their thickness explains the strong growth of SE with frequency. Nevertheless, the composite cover offers a better SE from 1 Hz to 1 kHz compared to the Al cover. Furthermore, its SE at low frequencies (< 100 Hz) is similar to the steel cover (~ 15 dB). One of the strengths of the composite is its lightness, indeed its density is 2.55 g/cm^3, lower than the ones of Al and steel which are respectively 2.71 and 7.85 g/cm^3. The specific SE (i.e. SE divided by the material density) is then plotted in Figure 6 (b). The specific SE of the composite cover is greater than the ones of Al and steel from 1 Hz to around 2 kHz.



(a) (b)

Figure 6: Numerical SE (a) and specific SE (b) of the steel enclosure with Al, steel, and composite covers

It can be noticed that the composite thickness is chosen to have the same thickness as the Al and steel covers. However, the GFC thickness can be reduced without impairing the composite SE as seen in Figure 7. Moreover, to improve the SE of the composite in the low-frequency range, one possibility is to double the Mu-ferro thickness with a second layer (46 µm instead of 23 µm) without increasing its density too much (2.64 g/cm^3 instead of 2.55 g/cm^3) as presented in Figure 7. By doubling the thickness of the Mu-ferro, the composite SE increases of 4 dB for frequencies under 10 kHz.

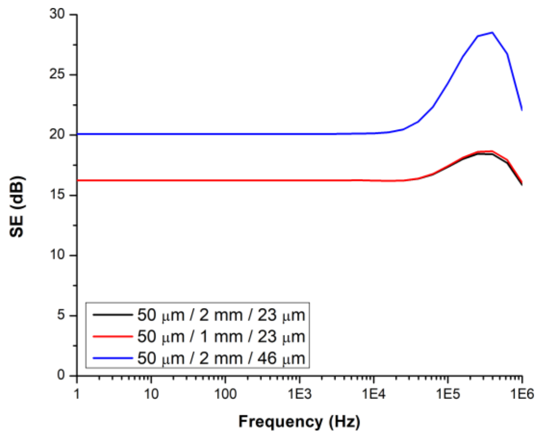


Figure 7: SE of the trilayer composite (Graphene/GFC/Mu-ferro) obtained with a 2D-axi numerical model presented in [4] for a plane sheet with different thicknesses of the GFC and Mu-ferro layers

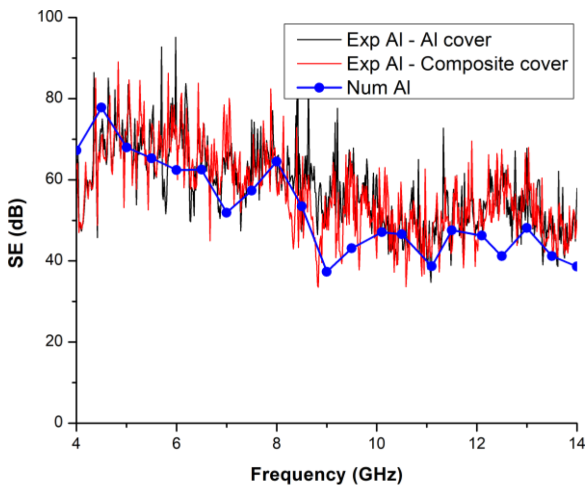


Figure 8: Experimental and numerical SE of the Al enclosure with the Al and composite covers

In Figure 8, the SE of the Al enclosure with the metallic cover or with the composite cover is plotted from 4 GHz to 14 GHz. It is observed that the SE with the composite cover is nearly the same as the one with the Al cover. This is easily understood since for such a frequency range, the conductivity of the composite is sufficiently high enough to behave as a perfect conductor. Experimental curves present peaks that could be considered as noise at first glance but correspond, in fact, to several cavity resonances. The numerical result is quite close to the experimental one and presents the same behavior with a decrease of the SE with frequency, from around 70 dB to 50 dB.

4 Conclusion

In this work, the SE of a three-layer composite as a panel of a 3D enclosure has been determined both numerically and experimentally. As the major conclusion, the proposed composite combines lightness (density of 2.55 g/cm^3) and a high level SE over a large frequency range, from 1 Hz to 14 GHz. Indeed, its conductivity is high enough to reach similar SE to Al or steel in the far-field for frequencies from 4 GHz to 14 GHz. Moreover, thanks to the high relative permeability of the Mu-ferro layer, a greater specific SE is observed with the composite from 1 Hz to 2 kHz. Numerical results are quite close to experimental measurements for both low-frequency and high-frequency approaches and confirm the efficiency of the layered composite. However, the mid-range frequency extending from 1 MHz to 4 GHz has not been addressed due to limitations of the experimental setups. It remains to be investigated.

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