Application of Composite Materials to Electronic Enclosures

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Composite enclosures meet EMI and environmental requirements while weighing substantially less than aluminum equivalents.

OVERVIEW

The substitution of lightweight, composite materials for metal in electronic enclosures, which range from "black boxes" to full size cabinets, is a growing trend for military and commercial applications. The approach is based on the need for equivalent performance with reduced weight, as compared to metal electronic enclosures. These composite enclosures must meet all functional and environmental requirements, including electromagnetic interference (EMI) shielding. The primary focus of this article is the EMI shielding in the composite enclosure. The functional requirements, design and fabrication, and EMI shielding testing of a Navy 3/4 Air Transportable Rack (3/4 ATR) are used as an example.

Electronic devices emit electronic energy which can travel as radiated energy. Electronic noise of this type is often emitted from devices and associated cabling. This is EMI. Electronic devices are not able to distinguish between authentic signals that they receive and bogus signals that they pick up from other sources. Therefore, they must be provided with a sufficient resistance, or shielding from EMI.

Several resin matrix composite (RMC) enclosures have been designed, fabricated and tested that fulfill all functional requirements and weigh 40 to 50 percent less than an equivalent aluminum enclosure. Two typical composite avionics enclosures that have gone through this process are shown in Figures 1 and 2. Figure 1 shows the graphite composite 3/4 ATR fabricated for the Navy on the left and the equivalent aluminum 3/4 ATR on the right. Figure 2 shows a set of three graphite RMC enclosures fabricated for an avionics display system.

The key steps in the development process include: definition and prioritization of the functional and environmental requirements; composite constituent materials selection; design of the enclosure; selection of the manufacturing process; fabrication of the enclosures; and testing to verify performance. The 3/4 ATR enclosure was developed using this process and will be used as an example. The end result was an electronics enclosure that was 40 percent lighter than the equivalent aluminum design and which demonstrated performance that fulfilled all design requirements.

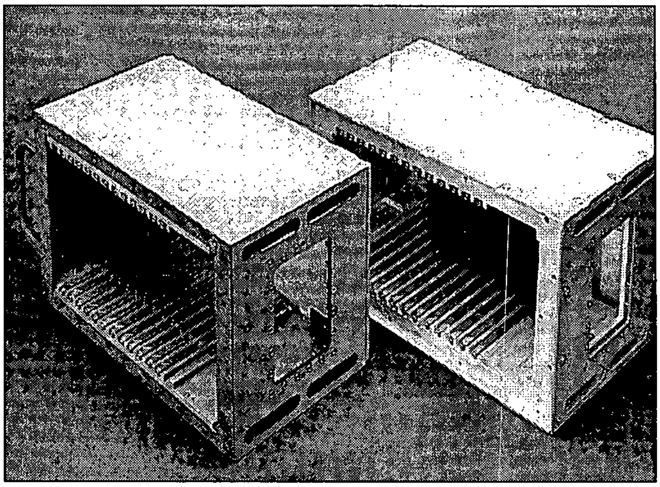

Figure 1. *3/4 Air Transportable Racks. Graphite composite on left and equivalent aluminum on right.*

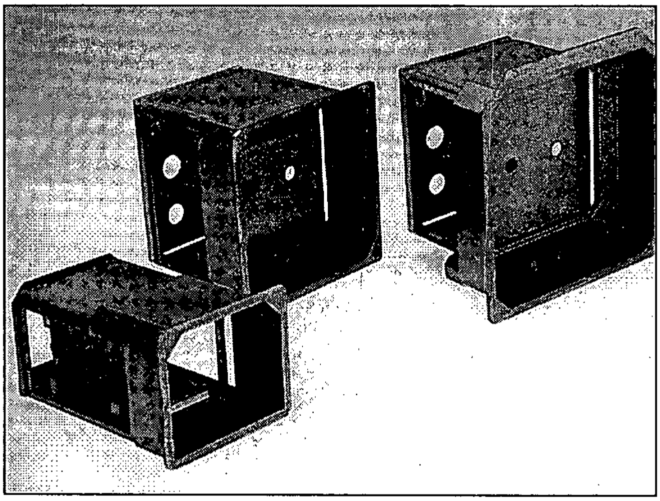

Figure 2. *Graphite Composite Enclosures for an Avionics Display System.*

REQUIREMENTS

Complete information on configuration and functional requirements are critical before any design or fabrication can begin. A key prerequisite to obtaining optimally designed enclosures is the development of a prioritized list of the functional and environmental requirements. With this information, the composite material or enclosure designer can tailor the properties of the composite to fulfill the highest priority requirements.

The primary requirement for use of composites is typically weight minimization. Other high priority design requirements include: EMI shielding levels; thermal management; chemical compatibility; producibility and maintainability constraints; and life-cycle cost limits. The optimum constituents of the composite material must be chosen to fulfill multiple design and manufacturing requirements. The prioritized list is used to help make the selection between different candidate reinforcements fibers, resins and coating systems.

In military applications, uniformity of the basic configuration is usually an important requirement, but often there are internal and external changes that vary with system and installation requirements. Sources for design requirements for military electronic enclosures include: MIL-STD-85726 and MIL-STD-2036, for electromagnetic shielding requirements; MIL-STD 1788 and MIL-E-85726, for external configuration envelope and loading environment/requirements; MIL-STD-810C, for vibration, shock testing, and crash testing; MIL-STD- 810D for acceleration; and MIL-STD- 810E for high temperature, low temperature and humidity testing. In commercial applications there is less uniformity because of greater variations in requirements and cost limitations. Commercial design requirements also vary with application and country.

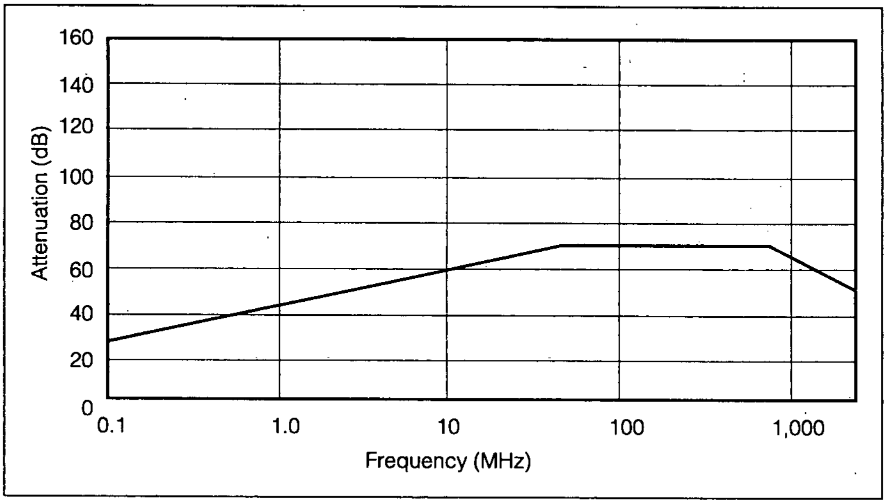

Figure 3. *EMI Shielding Requirements for 3/4 ATR Enclosure.*

Providing a sufficient amount of EMI shielding is a problem since RMCs are not good shields. The amount of shielding and range of frequencies over which it is required is dependent upon the specific application and nature of the electronics within the enclosure. A typical example of shielding requirements for a 3/4 ATR military electronics enclosure is shown in Figure 3.

CONSTITUENT MATERIALS

Selection of the constituent materials used in the enclosure was based on meeting or exceeding functional, manufacturing or cost requirements. The constituents chosen, the selection rationale and their use in the 3/4 ATR are summarized in Table 1.

There are three primary phenomena associated with EMI shielding: absorption, which is a function of conductivity, permeability, thickness and frequency; reflection, which is a function of conductivity, permeability, and frequency; and leakage, which is a function of gap size and frequency. The actual amount of shielding in any enclosure depends upon the type of material, its thickness, its electrical conductivity, and any apertures (holes, cracks, joints, slots, etc.) in the enclosure.

The fact that EMI shielding is partially a function of the electrical con-

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CONSTITUENT	SELECTION RATIONALE	LOCATION
Woven Cloth	High strength, moderate elastic modulus, wide availability, and low cost	Primary reinforcement fiber in composite
934 Epoxy	Compatibility with other constituents, toughness, availability, low cost	Resin matrix in composite material
Nickel-coated Chopped Graphite Mat	Minimum weight impact, T-300 Plain conformable to enclosure configuration	EMI shielding material in composite material
Syncore HG9872/Hysol Syntactic Foam	Specific strength, ease of workability	Low-density material in frames around enclosure openings

Table 1. *Composite Enclosure Constituent Materials.*

Of the three primary phenomena associated with EMI shielding, leakage is usually the source of the greatest problem.

ductivity of the enclosure materials affects the selection of constituents. Small amounts of metals are integrated with the RMC materials where higher shielding levels are required. The resulting "hybrid composites" offer a slightly heavier solution (< 0.5 percent of overall weight) to the shielding problem. These hybrid composite materials, which provide both EMI shielding and a ground plane function, include a basic RMC plus:

- Application of thin metal coatings, hundreds of angstroms thick, to the RMC surface.
- Layers of expanded metal screening or metal-coated continuous fibers that are located near the surface of the composite and serve a structural purpose.
- Metal-coated discontinuous fiber in a mat form located at both surfaces of the composite.
- Combinations of any two or three layers.

Candidate external surface coating materials include nickel, stainless steel or copper. The primary material for the expanded metal screening is copper. Nickel is typically used for coating on both the woven and nonwoven graphite fiber.

The raw material cost of the graphite RMC constituents is typically higher than the raw material cost for metals but the overall life cycle costs (LCC) are lower. LCC savings associated with composites are usually based on efficient manufacturing processes for high volume production, integration of multiple subcomponents into one composite assembly, weight savings of the final part, or systems cost savings based on weight saved.

Six hybrid composite panels were fabricated and subjected to testing. The composite panels included integral nickel graphite cloth; integral nickel-coated graphite mat material; integral expanded copper mesh; externally applied vacuum deposited layers of stainless steel/copper/stainless steel (SS/Cu/SS); an externally applied vacuum deposited layer of aluminum; and a bare graphite epoxy composite (Gr/Ep) panel for reference. Data comparing the cost penalty, unit weight penalty, and electrical resistance performance of the five different hybrid composite panels to the Gr/Ep RMC reference panel is given in Table 2.

DESIGN

Of the three primary phenomena associated with EMI shielding, leakage is usually the source of the greatest problem. Minimizing the number of penetrations and apertures in the enclosure reduces the number of escape paths for the signal and is a key aspect of maximizing EMI shielding levels in the design of any enclosure.

This concept, plus incorporation of the nickel-coated chopped fiber in the RMC was used in the redesign of the aluminum 3/4 ATR enclosure. The original aluminum enclosure had six sides which were removable. The aluminum box had 16 major pieces including card guides, 106 screws and bolts, and weighed 11.25 pounds. The redesigned composite enclosure had two removable sides as shown (Figure 1). The equivalent composite 3/4 ATR had three major pieces, two metal card guides, 54 screws and weighed 6.4 pounds.

To meet EMI shielding requirements, all of the walls and covers of the RMC enclosure were made of hybrid material which had layers of nickel-coated chopped graphite mat adjacent to both inner and outer surfaces. The shielding provided by the hybrid composite material was less than that of aluminum of equivalent thickness, but the reduction in the number of joints in the box resulted in equal overall box shielding performance.

The three composite electronic enclosures shown in Figure 2 are being fabricated for use in an avionics display system and incorporate a coating shield. The enclosures are made from a graphite epoxy cloth composite. The EMI shielding consists of a surface coating of layers of stainless steel, copper, and stainless steel applied over all surfaces. The inner layer of stainless steel bonds well with the composite material, providing good peel resistance. The external stainless steel surface provides excellent surface abrasion resistance, and the copper provides high electrical conductivity. The coating is also an excellent electrical ground plane interface with the aircraft. This shielding concept was tested and met the system shielding requirements.

MANUFACTURING PROCESS

The selection of a manufacturing process depends upon the strength and stiffness requirements, the constituents selected, the form and number of parts to be fabricated, and cost limitations. The general process used to fabricate prototype composite enclosures with continuous cloth or tape reinforcement involved either a vacuum bag or autoclave cure procedure. These two processes typically result in one

TYPE	COST PENALTY	WEIGHT PENALTY	RESISTANCE
Nickel Coated Fiber Cloth	$15	0.005 lb/ft^2	0.3 ohms
Nickel Mat in Gr/Ep	$15	0.003 lb/ft^2	1.1 ohms
Copper Mesh in Gr/Ep	$11	0.006 lb/ft^2	0.6 ohms
SS/Cu/SS Coated Gr/Ep	$60	0.009 lb/ft^2	0.5 ohms
Al coated Gr/Ep	$15	0.006 lb/ft^2	0.3 ohms
Gr/Ep Uncoated	Baseline	Baseline	10.0 ohms

Table 2. *Cost, Weight, and Electrical Resistance of Composite Panels.*

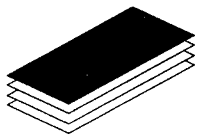
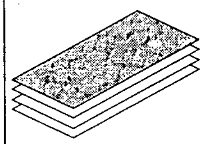
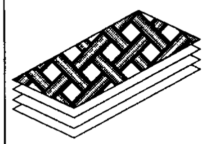
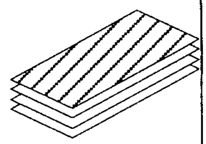
Application				
	Metal Sheet Sputter Coating Plating Surface Mesh (Apply Secondarily)	Random Nickel-coated Graphite Fiber Mat (Non-Woven) (Molded-In)	Nickel-coated Graphite Fiber Cloth (Woven) (Molded-in)	Co-woven Metal Filament (Molded-in)
EMI Shielding	Good	Good	Excellent for flat shapes	Minimal
Ground Plane	Excellent	Minimal	Good	Good

***Figure 4.** Summary Evaluations Resulting from Flat Panel Testing.*

finished surface and one rough surface. The 3/4 ATR and the display panel enclosures were fabricated using a matched metal net molding process. This process results in net shaped parts with all finished quality surfaces and attachment fittings molded into the part. Other processes available for high volume production of the larger parts include compression molding, automated tape layup, and resin transfer molding. These processes require a higher initial tooling investment and are not used for prototype or low production fabrication.

EMI SHIELDING TESTING

Flat panel and full enclosure EMI shielding testing has been conducted on various samples of materials. The six flat panels mentioned above were tested to compare the EMI shielding performance of different candidate material concepts. The panels were 12″ x 12″ x 0.056″ thick and the reinforcement orientation layup was 0°,+45°, -45°, +45°, 0°, -45°, and 0°. They were tested in accordance with MIL-STD-285, "EMI Shielding Effectiveness." The testing was done over the range of 100 kHz to 1 GHz and the results varied with frequency, geometric effects and leakage effects. The SS/Cu/SS shielded panel exhibited the highest EMI shielding level and the integrated nickel-coated graphite mat was second highest.

Surface resistance values were measured on the panels using a four-probe multimeter and are summarized along with relative cost and weight data (Table 2). The specific conclusions that can be drawn from the table are: the presence of the shielding material results in a reduction in surface resistance of a factor of 10 or more; the costs of the shielding material is relatively inexpensive; and the weight penalty associated with the shielding materials is very low. The key results of the shielding testing are summarized in Figure 4.

EMI shielding testing of full enclosures was conducted on the 3/4 ATR enclosure and the avionics display panel enclosures. Both met their design shielding requirements. The shielding testing of the 3/4 ATR was done by the Naval Air Warfare Center, Aircraft Division, Indianapolis (NAWC-AD-I). This typical testing[1] was done using the mode-stir technique in which the boundary conditions in the chamber are changed continuously by a rotating aluminum paddle wheel. This prevented nulls in the chamber from persisting at any chamber location. A smaller mode stirring paddle wheel was also placed inside the enclosure for a similar purpose. The test setup is shown in Figure 5.

The 3/4 ATR test results show a decrease in shielding from approximately 0.86 GHz out to about 10 GHz (Figure 6). There is an indication of increasing shielding below 0.86 GHz. A standard aluminum 3/4 ATR was also subjected to the same testing after completion of the composite enclosure test and the shielding test levels measured in that test were equivalent to the composite 3/4 ATR. The ratio-

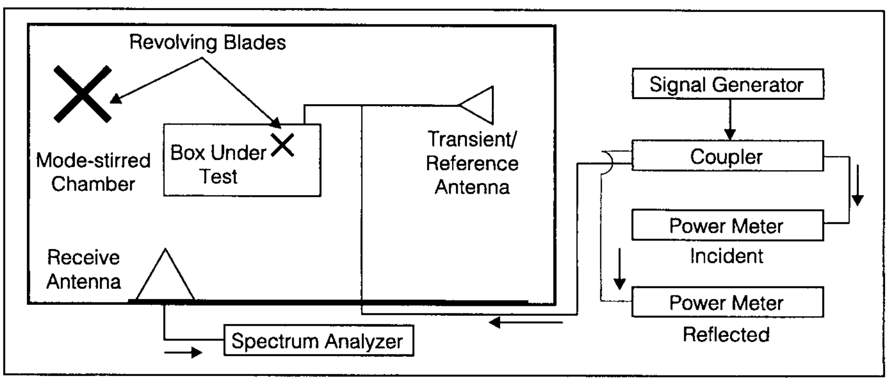


***Figure 5.** Shielding Effectiveness Test Setup.*

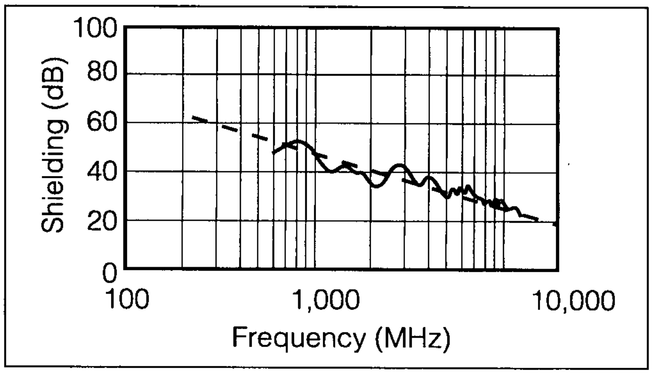


Figure 6. *Composite 3/4 ATR Shielding Effectiveness Test Results.*

nale for this equivalence is that although the RMC material has a lower shielding capability, there are fewer gaps for the radiation to pass through in the composite box. The result is that the material and design effects cancel each other, resulting in parity in shielding performance between the two boxes.

The composite enclosure was also subjected by NAWC-AD-I to tests associated with the other functional and environmental requirements and successfully passed all of them.

CONCLUSIONS

Graphite resin matrix composite enclosures have been fabricated for multiple avionics applications. They can be designed and fabricated to provide performance, including EMI shielding, equivalent to aluminum enclosures while weighing 40 percent less. Graphite resin matrix composite enclosures can also be fabricated on a life-cycle, cost competitive basis.

REFERENCE

1. J. Glatz, R. Morgan, and D. Neiswinger, "EMI Shielding of Advanced Composite Enclosures," 6th International SAMPE Electronics Conference, June 1992.

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