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Design Considerations for a Composite Chassis of Shielding and Structural Integration

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Abstract. This study describes the designing and shaping technology of a composite chassis. Materials with a capable shielding capacity were chosen to perform shielding designing according to the electromagnetic shielding criteria. To fulfil the high mobility with the shielding material manufacturing requirement, we developed a suitable design to reduce the weight of all structure components to comb the shielding ability with its own structure. The integral shaping technique was used for chassis manufacture. We also further tested the weight, electromagnetic shielding, and environmental adaptation conditions of the chassis. The verification results indicate that our manufacturing protocol met the design requirements of the chassis.

1. Introduction

With the increasingly demanding requirements for the miniaturization and light weight of modern military equipment, the use of composite materials has become much more extensive. To complete assignments, a radar chassis needs to frequently change its orientation, such that superior mobility is required[1]. To fulfil this requirement, one must focusona weight reduction design. However, there is limited room for weight reduction in a chassis made of metal. Composite materialsarecharacterized by light weight, highstrength, and remarkable designability. Thus, we decided to design a composite chassis using carbon-fiber materials with electromagnetic shielding (hereinafter referred to as ES) capability after comparing several proposals to realize weight reduction and superior mobility. A large number of programmable logic controllercomponents that are highly sensitive to external electromagnetic interference are mounted in the chassis; hence, the function of protecting internal components from the influence of external electromagnetic fields is a necessity for the chassis to operate normally[2–3]. In addition, the leakage of the electromagnetic field generated inside the chassis must be prevented. Therefore, the mechanism for achieving the ES effect that meets the design requirements is the key to the chassis design.

This work presents the design criteria, structural characteristics, design, and molding process of the chassis and verifies the molded chassis according to the design criteria.

2. Chassis overview

2.1. Chassis construction

The overall dimension, including the height of the upper round flange, of the chassis body is 680mm × 540mm × 461mm. The external surface area is approximately 1.2 m². Each of the two narrow surfaces has an end cover to open or close the chassis, which is connected to the body through a hinge.

Avertical and a horizontal plate inside the body divide the internal space into separateblocks for installation of each system module. One of the body surfaces is configured with an air vent for ventilation and heat dissipation. Figure 1 shows the modelofthe chassis body structure.
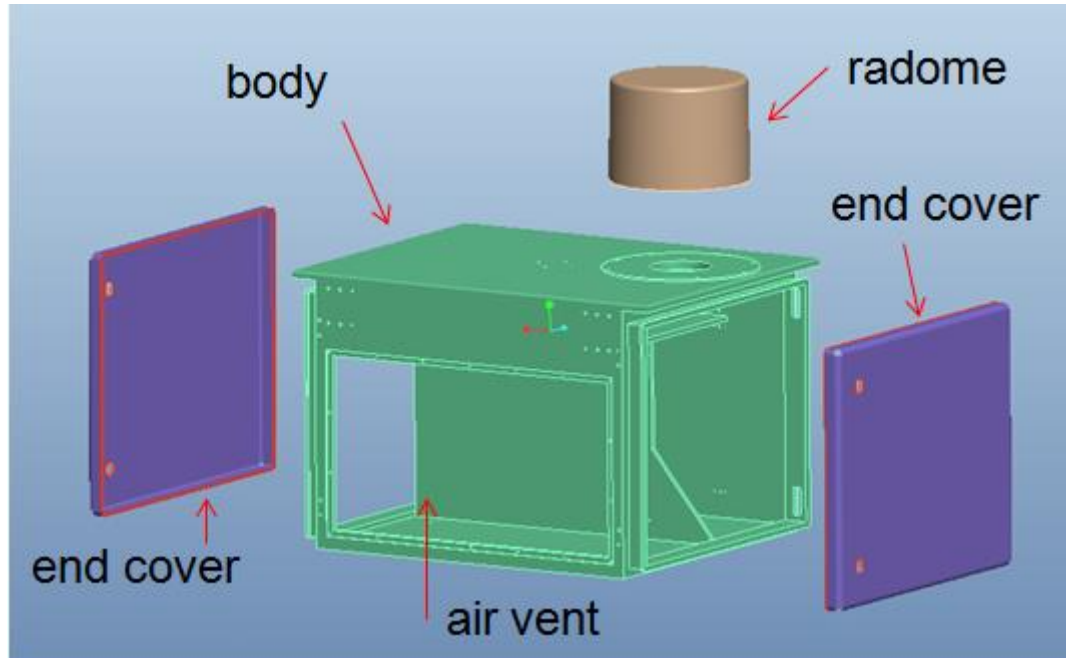

Figure 1. Diagram of the body structure model.

2.2 Chassis technical requirements
Primary technical criteria:
Chassis weight: ≤10.5 kg (body≤ 8.5 kg, each of end cover ≤ 1 kg)
Service temperature: −40 °C ~ +50 °C
Storage temperature: −45 °C ~ +70 °C

Rainproof requirements: The chassis should be free from water leakage under the conditions of 1 mm/min rainfall intensity, 16 m/s wind speed, and 2 h rain exposure time.

In obtaining the design weight, the chassis should be designed not only to minimize weight, but also to meet the requirements of body strength and internal loading strength of the chassis.Insatisfying thechassisES criteria, ES must be considered when designing the material composition, construction, and edges of adjoining faces. Only by doing so can the product requirementsbe met.

3. Overall chassis design
According to the product design criteria, the design purpose of the chassis is conformity to the desired weight, ES, and environmental adaptability,whichis greatly dependent on the material category selected. This section focuses on the design for ES and weight reduction.

3.1. Electromagnetic shielding design
Based on the functions of the electronic equipment inside a chassis, slotted gaps or holes are usually used for ventilation and heat dissipation or serve as the port for removal, installation, and connection with peripheral devices. Therefore, the decisive factors for the chassis ES effectiveness include not only chassis wallthickness and material, but also the holes and gaps.

ES is a practice of blocking both electric and magnetic fields. It generally refers to the shielding of alternating electromagnetic fields above 10 kHz. One of the most common theories explaining the ES mechanism is the transmission line theory. According to this theory,a shield is considered as a

transmission line, and the ES mechanism includes three parts, where the first part is the reflection loss of the shield surface; the second part is the absorption loss of the shield material; and the third part is the loss caused by multiple reflections inside the shield (Figure 2).
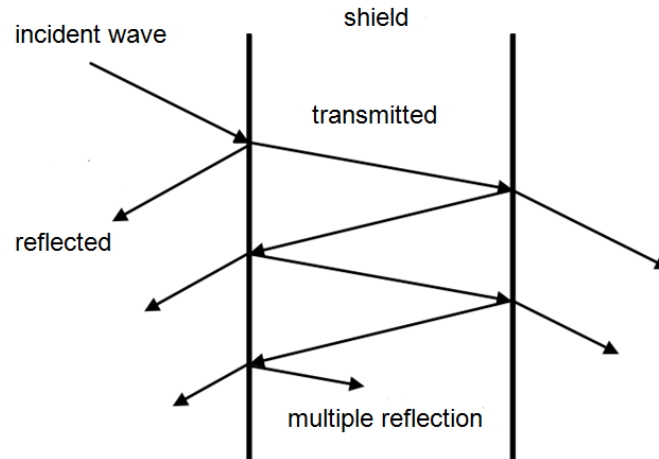

Figure 2. Diagram of the ES mechanism.

In transmission line theory, a uniform shielding material is deemed as a transmission line model, and the Schelkunoff formula used for the model solution is the most suitable calculation formula,which is only applicable to uniform and flat shielding materials. This calculation methodapplies in our study because the four walls of the chassis product are made of uniform and even materials. The total shielding effectiveness is calculated by:

$$SE=SE_A+SE_R+SE_M,$$

where SE_A (unit: dB) is the absorption loss of the shielding material; SE_R (in dB) is the single reflection loss of the shield surface; and the SE_M (unit: dB) is the multiple reflection loss inside the shield.

SE_A, SE_R, and SE_M in the above formula are calculated as follows:

$$SE_A= 131.43t\sqrt{f\mu_r\sigma_r} \tag{1}$$

$$168.2 + 10\lg(\frac{\sigma_r}{f\mu_r})\text{(plane wave)} \tag{2}$$

$$SE_R= 20\lg\left(5.35r\sqrt{\frac{f\sigma_r}{\mu_r}} + 0.354 + \frac{1.17\times10^{-2}}{r}\sqrt{\frac{\mu_r}{f\sigma_r}}\right)\text{(magnetic field)} \tag{3}$$

$$3.217+10\lg\left(\frac{\sigma_r}{f^3r^3\mu_r}\right)\text{(electric field)} \tag{4}$$

$$SE_M=10\lg[1 - 2 \times 10^{-0.1SE_A}\cos 0.23SE_A + 10^{-0.2SE_A}], \tag{5}$$

where f (unit: Hz) is the electromagnetic wave frequency; t (unit: m) is the shielding material thickness; r (unit: m) is the distance from the field source to the shielding material; μ_r is the relative magnetic permeability of the shielding material; and sσ_r is the relative conductivity of the shielding material.

As can be seen in the formulas, great thickness, outstanding magnetic permeability, and electrical conductivity of the chassis material enable the chassis to obtain a favorable ES effectiveness. Among the composite materials, carbon fiber has a resistivity of 1.3–1.9 × 10^{-5} Ω/cm, which shows good electrical conductivity, and the advantages of high specific strength, high specific stiffness, low thermal expansion coefficient, and remarkable damping performance. Therefore, it can be used as the

cover material of the chassis. Considering the lightweight requirements, the chassis wall is designed to have an A-sandwich structure configured with a honeycomb-structured interlayer. Aluminum honeycomb is selected as the sandwich material given the cost, shielding effectiveness, and superior conductivity of aluminum, in which resistivity can reach 4×10^{-4} Ω/cm. However, the A-sandwich construction consisting of carbon fiber and honeycomb-structured interlayer is not sufficient to produce the desired shielding effect. Among the existing shielding materials, metal conductive materials with certain magnetic properties represented by nickel can combine reflection and absorption loss, thereby surpassing other materials in electromagnetic wave absorption[4]. Based on the nickel ES capability, a layer of nickel mesh was added inside the chassis to enhance the chassis shielding effectiveness. The placement position of the mesh in the sandwich structure was determined through experiments. Finally, the chassis was coated interiorly with a layer of static conductive paint. All of these shielding components made up the shielding system of the chassis. Figure 3 shows the section view of the chassis wall.
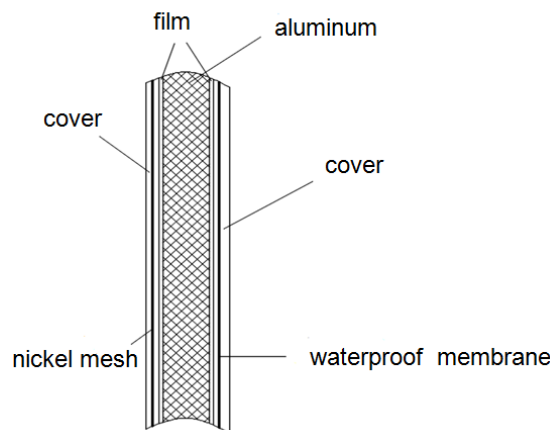

Figure 3. Section view of the chassis wall.

Meanwhile, a conductive rubber was added to each joint and connecting hole to avoid the risk of electromagnetic leakage in such a structure. For the large air vent for ventilation and heat dissipation on the chassis, a cut-off waveguide vent was used for ES protection when the conductive rubber was sealed on the air vent for transition. The ES application of the cut-off waveguide vent was well-established. Figure 4 shows the appearance of the vent-equipped chassis.

Figure 4. Cut-off waveguide vent used in the chassis air vent.

3.2 Weight reduction design
The total chassis weight should not exceed 10.5 kg (a body ≤ 8.5 Kg and an end cover ≤ 1 kg). By this criteria, we worked on the weight reduction design in combination with the chassis structure and material selections. An A-sandwich structurewasobserved in all chassis faces as well as internal vertical and horizontal partitions, which consisted of a carbon-fiber cover, an aluminum honeycomb panel, a film, a waterproof membrane, and a nickel mesh. The total weight of the single waterproof membrane and the individual nickel meshcannot be altered considering the roles they play; hence, the weight loss design focused on the carbon-fiber cover and aluminum honeycomb panel. According to the target shielding frequency, analuminumhoneycombpanel consisting of 2 mm cells was selected given the relationship between the size of the aluminumhoneycomb cell and the target shielding frequency as well as the honeycomb strength andpurpose of weight reduction. Moreover, in view of the material strengthandthe weight of each module to be installed inside the chassis, the minimum thicknesses of the cover and the honeycomb panel in the A-sandwich structure were confirmed by a simulation analysis to reduce weight (Figure 5).
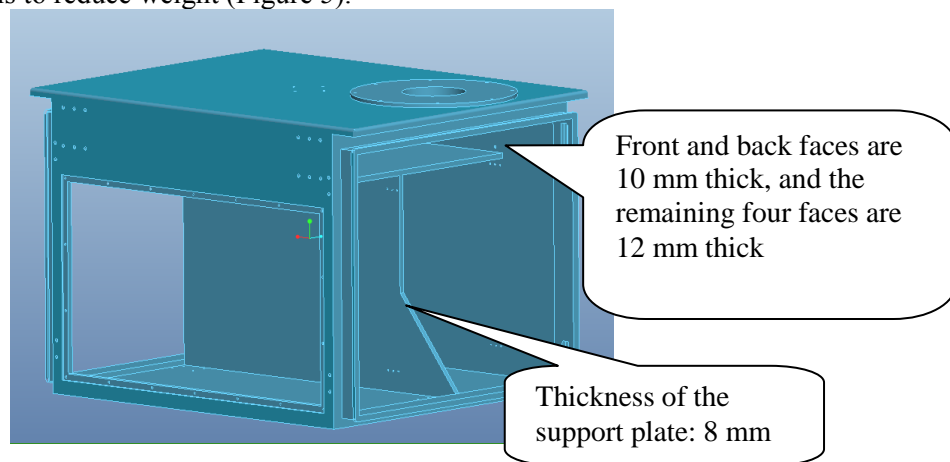

Front and back faces are 10 mm thick, and the remaining four faces are 12 mm thick

Thickness of the support plate: 8 mm

Figure 5. Chassis weight reduction design.

Many mounting interfaces can be found on the chassis, which depend on embedding aluminum blocks with threaded holes in the composite structure. A total of 130 embedded parts are included; hence,the aluminum-embedded parts also take up a considerable percentage of weight. Based on the premise that the strength of each embedded part met the design requirements, the size of the embedded parts was optimized to minimize weight, thereby decreasing the total chassis weight.

4. Chassis molding process
The various materials to be used in the chassis were determined according to the ES design discussed in the previous section. Table 1 presents the list of materials.

Table 1. List of composite materials for ES chassis manufacturing.

#	Name and model	Specification	Purpose	Manufacturer
1	Carbon-fiberprepreg	MTM28/CF0300-42%	Cover	Shanghai Kangzhan Composites
2	Aluminium honeycomb panel	95-2-0.05 (LF2Y)	Interlayer material	AVIC Composite
3	Film	J-272	Adhesion of honeycomb	Heilongjiang Petrochemical

4	Shielding mesh	Nickel mesh	Shielding	Heilongjiang Petrochemical
5	TEDLAR film	TDS15BL3	Surface film	DuPont USA
6	Static conductive paint	Polyurethane static conductive film	ES	Jiangsu Jinling Special Paint Co., Ltd.

The composite chassis molding is mainly based on the overall strength of the chassis and the ES effectiveness.If a gap exists between two adjoining faces, electromagnetic leakage will occur because the chassis has many individual faces. On the contrary, if molded as a whole, the chassis will have excellent mechanical strength. Therefore, we decided to fabricate it using the integral molding technique. In addition, a process path was eventually established given the difficulty of demolding: integrally mold five faces of the chassis; separately mold the top plate; and finally assemble both of them. An autoclave molding process with a higher molding pressure was also adopted considering the bonding strength between the prepreg layers and between the cover and the honeycomb[5]. Figure 6 shows the process flowchart.
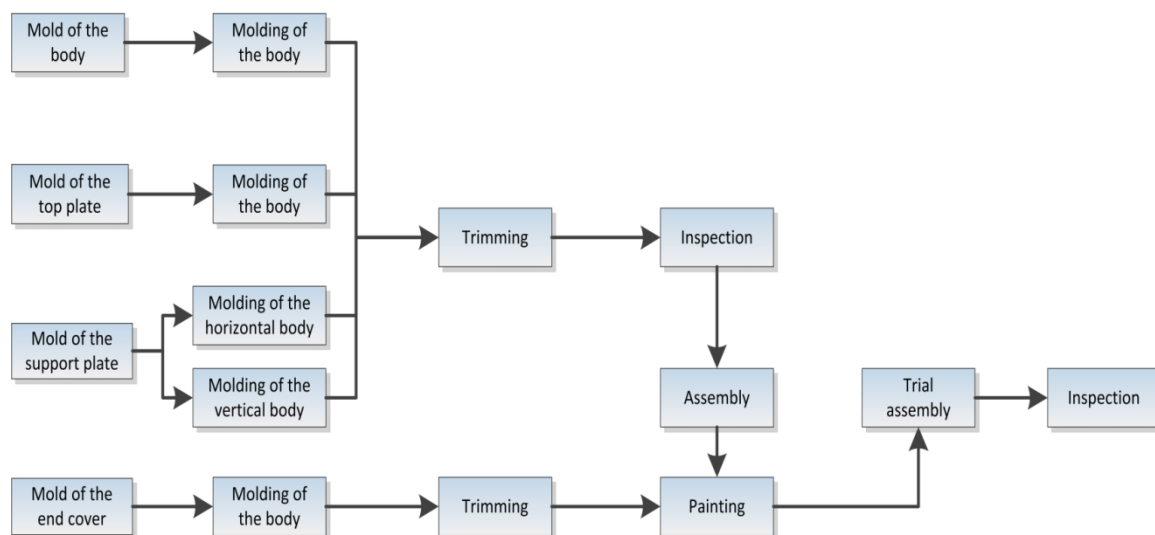

Figure 6. Flowchart of the chassis molding process.

The mold was designed to be a five-face male mold, on which the integral molding of the chassis would be performed. The layup design mainly draws on the design principles of composite materials, including "zero coefficient of linear expansion" and "isotropy," to stabilize the molded chassis. The layup procedure was performed as follows according to the thickness of different areas: lay up four or two layers in a "rotating" way; ensure that the front and back cover layers are symmetrical; and lay the wovencarbon-fiberprepregin the order of 0°/30°/60°.Pay attention to staggering the overlapping positions and reinforcingthecorner overlapping positions. It is a molding process involving a male mold. Therefore, the flange frame used to connect the end cover on the outer surface was separately fabricated and assembled after the inner cover was laid in the chassis. The outer cover was finally laid to shapethe chassis as a whole. The top plate was assembled with the molded five-face body through the blind holes of the angle supports. A conductive sealant was coated on the joint surface at the same time. After the aluminum honeycombpanelwas laid, all the embedded parts were buried in the corresponding positions and fixed using stop pins and holes on the mold for positioning. According to theresinproperties of the selected prepreg, the curing temperature curve was made based on the material parameters and experiment results (Figure 7).
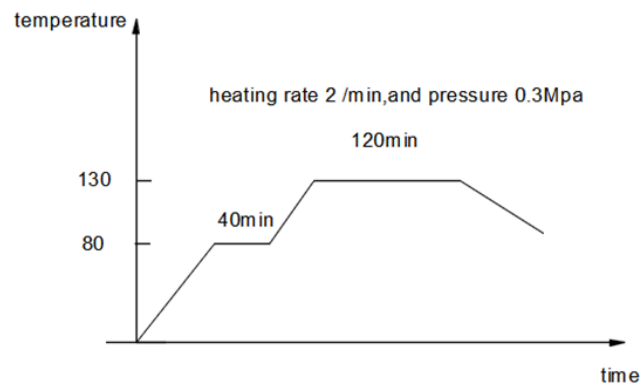
Figure 7. Curing temperature curve of the chassis molding

5. Verification of the chassis technical criteria

5.1 Weight verification
During the molding process, the body and the end covers were weighed and re-weighed after the chassis was assembled and painted. The results indicate that the chassis total weight and the weight of each component met the design criteria. Table 2 presents the weight and the corresponding criteria.

Table 2. Chassis weight verification.

Name	Actual weight	Criteria	Conclusion
Body	8.43 kg	≤8.5	Accepted
End cover 1	0.96	≤1	Accepted
End cover 2	0.98	≤1	Accepted
Total weight	10.37	≤10.5	Accepted

5.2 Verificationof the electromagnetic shielding effectiveness
The shielding effectiveness of the chassis was tested in conformity with the methods specified in GJB 151B-2013 (*Electromagnetic emission and susceptibility requirements and measurements for military equipment and subsystems*) (Figure 8).

Figure 8. Chassis ES effectiveness test.

Four frequencies (i.e., 1 GHz, 2 GHz, 3 GHz, and 4 GHz) were selected as the experiment frequencies according to the target shielding frequency. With each frequency, six faces of the chassis were subject to tests. Table 3 shows the results.

Table 3. ES Effectiveness test results of the composite chassis

	Top plate	Bottom plate	End cover 1	End cover 2	Air vent	Chassis wall
1 GHz	45	43	42	41	41	46
2 GHz	45	43	41	41	41	45
3 GHz	44	42	41	40	41	45
4 GHz	42	41	40	39	40	43

The test results indicate that the chassis can basically meet the product shielding requirementswith the target frequency. The chassis shielding effectiveness decreased as the frequency increased because the magnetic permeability of the nickel mesh used as a shielding material gradually declined with the frequency increase. This is aninherentproperty of the nickel material. Thus, itsshieldingeffectiveness tapered off.

5.3 Environmental adaptability verification
The environmental adaptability was verified according to the chassis environmental criteria through the damp heat test, high and low temperature test, vibration test, and rain test in conformity with GJB 150A. Table 4 presents the results below.

Table 4. Chassis environment tests.

No.	Test name	Test details	Test results
1	Damp heat test	Temperature: 35 ℃; humidity: 95–98%; and service duration: 48 h	Accepted
2	High and low temperature test	Stored at high temperature (+70 ℃) for 12 h and worked for 2 h Stored at low temperature (−45 °C) for 12 h and worked for 2 h	Accepted
3	Rain test	Raindrop diameter: 3 mm; wind speed: 16 m/s; and duration: 5 h	Accepted

As indicated in the environment test results, the chassis made of the ES composite is accepted and meets the product environmental adaptability criteria.

6. Conclusion
The electromagnetic environment of the modern radar equipment has become increasingly complicated. Meanwhile, the requirements for the radar electronic chassis are more stringent because of the increasingly demanding requirements for radar use. The chassis requires not only the electromagnetic shielding capability meeting certain criteria, but also a light weight. As a result, composite materials have been used for chassis fabrication. The carbon-fiber composite material with a satisfactory electrical conductivity was chosen as the cover material after selection. Additionally, the weight was reduced using an A-sandwich structure with an aluminum honeycomb-structured interlayer and the optimization of the prepreg thickness. The chassiselectromagnetic shielding

requirements were satisfied by laying a single nickel mesh inside the chassis. Moreover, an integral molding method was employed to eliminate the electromagnetic leakage risk of the joints and holes in the chassis: the five-face body of the chassis was first molded as a whole, then the top plate was assembled afterwards, followed by a conductive sealant used on the edges of the end-cover mounting face, vent mounting area, and through holes. Under this procedure, the air vent was sealed using the electromagnetic shielding technique of the cut-off waveguide vent. The conformity of the chassis to the design criteria was substantiated through the verification of weight, electromagnetic shielding, and environmental adaptability of the molded chassis. The successful development of the chassis provides an effective alternative for the design of a similar electronic chassis.

Acknowledgments

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