The use of plastics in fabricating enclosures for electronic and electrical assemblies has increased substantially recently. Enclosures made from such engineering thermoplastics as Noryl, Lexan, and Valox, as well as from many thermosetting plastics, including polyester fiberglass, epoxy fiberglass and similar materials, are considerably less expensive and more desirable in performance than metal cabinets, particularly in such mass production applications as business machines, computer terminals, and automotive body parts.

However, these plastics, being extremely good insulators, do not provide any resistance to the flow of electromagnetic radiation, and will not shield electronic assemblies inside from its effects. Similarly, they will not absorb the radiation that the devices themselves emit. Metal enclosures, will, of course, act as effective shields for most RF radiation because of their inherent conductivity.

Transition From Metals To Plastics

At this point, it might well be asked why one should be concerned with shielding of plastics, as it might be argued that a designer could select metal cabinetry whenever a shielding situation might be anticipated. The answer to this lies in recent cost trends, not only in basic materials costs of metals vs. plastics, but also in such related areas as finished part costs, lifetime costs, and social costs. This economic viewpoint, identified by economists as holistic analysis, can be stated simply by saying that a material should be evaluated not just in terms of basic mechanical properties and price per volume, but in the important terms of its contribution to the entire system. Factors to consider then, would include the following:

Finished-Part Costing—Weight savings and assembly time, as well as number and complexity of components, play an important part here. A current example is a polycarbonate air conditioner grille molded in one part, replacing grilles of welded wire; elimination of the welding operation, as well as weight savings, contributed to the lower finished cost of the product.

Lifetime Costing—After a product gets into service, operation and maintenance costs are often very significant factors. The superior corrosion resistance of plastics vs. metal is one example of a reduction in operation and maintenance costs as a result of using plastics.

Social Costing—The flexibility available in manufacturing polymers and plastics to specific end products at minimal capital investment cannot be overemphasized. Metal extraction, manufacturing, and fabrication processes are essentially based on cumbrous, energy intensive, or environmentally threatening processes—mining, smelting, heat-treating, finishing, etc.—which make the petrochemical process, from well-head to finished product, appear streamlined and clean.

Figures 1 and 2 indicate the emerging trend of plastics replacing metals in many areas.

FIGURE 1
Plastics Move Toward Cu-In Dominance Over Steel

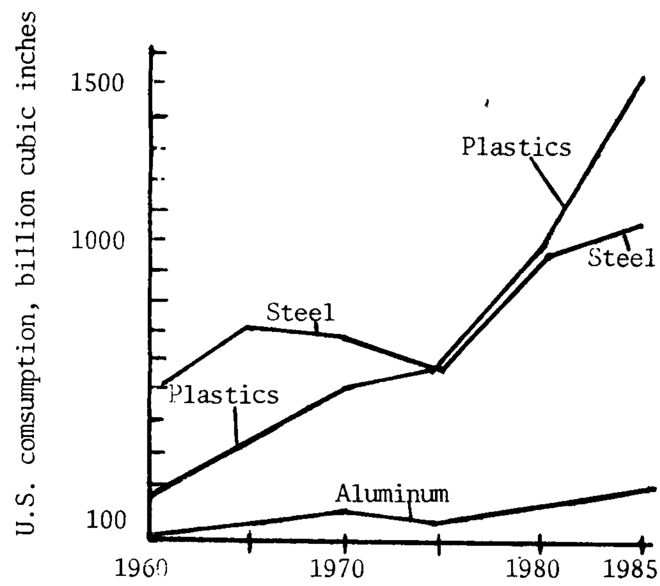
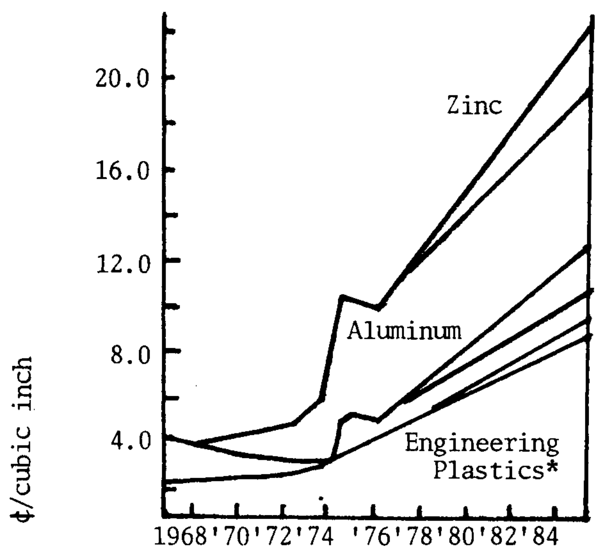


FIGURE 2
How Engineering Plastics Prices Compare with Die-Case Metal



Source: DuPont
*Includes unreinforced

Problems with Plastic Enclosures

As indicated above, plastics, by themselves, do not have the capability to shield adequately against radiation which may be generated within a device, or stray radiation from outside which may affect operation of the device. Therefore, even though economics now dictate strongly the use of plastics in virtually all cabinetry with relatively complicated designs and high volume production, one must be cognizant of the problems involved, and the most practical means of solving them, within reasonable economic limits. For example, a major problem relating to the burgeoning use of plastics, along with the new and varied consumer electronic devices on the market, is that of stray radiation from one device causing malfunction of another. There have been several reported instances of electronic devices being affected by radio transmissions, such as that from police or citizens band radios. Potentially serious consequences can result from such incidents—it is easy to imagine the effects of an electronic braking system malfunctioning at high speeds in heavy traffic. These problems, and others involving communications interference, have led the FCC and other Federal agencies to take steps to control the amount of radiation emitted by electronic equipment.

Static Discharge—An additional problem resulting from the use of plastics in these applications is that of static electricity. While the metal cabinets formerly used provided effective protection against static buildup because of their natural conductivity, plastics will not do so. The tendency of plastics to accumulate static charge buildup, much like a capacitor, may result in wiping out a computer memory, for example, when the buildup is abruptly discharged by grounding.

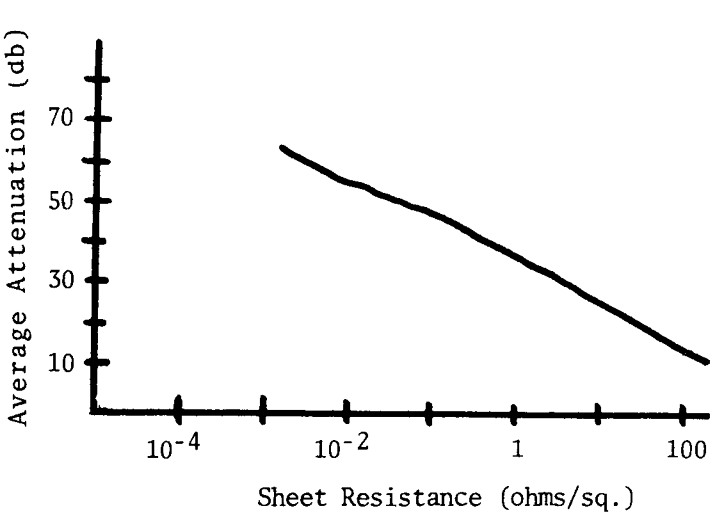
As a significant number of electronic assemblies require shielding from such outside electromagnetic interference as radio waves, static electricity, and the like, how can the problem of shielding plastic enclosures be solved?

The degree to which electronic devices requires shielding varies greatly. Most often, effective RF shielding requires surfaces with relatively high conductivities (low resistivities). Usually a metal is necessary to provide this degree of conductivity. The relationship between sheet resistance and attenuation at 100 megahertz, for example, is shown in Figure 3.

Highly conductive materials tend to reflect radiation, much like a mirror reflects visible light, so that the logical solution would be to provide a metallic shield, or "coating", on the plastic. Effective shielding usually requires lining the inside of the cabinet with a metal, in order to get sufficient conductivity to dissipate the interference. However, techniques such as foil lining have been generally unsatisfactory, particularly with the complex shapes of many newer packages. Methods which have proven acceptable to date include vacuum metalizing, flame spraying, plating, and metal filled coatings. Some of these procedures, however, are very costly, and processes must be selected carefully to provide the degree of electrical stability and adhesion required over conditions encountered during the life of the product.

FIGURE 3

Average Attenuation vs. Sheet Resistance*



*Reciprocal of conductivity at constant thickness

Common Shielding Methods

Vacuum Metalizing: This technique involves deposition of a metal film (usually aluminum) directly onto the plastic substrate by vacuum, resulting in a thin—typically 20-50 microinch—film on the plastic. In addition to the large amount of equipment required, the process is slow and tedious, and presents adhesion and resistance problems when subjected to environmental cycling.

Flame Spraying: This method of shielding involves the spraying of a molten metal, such as zinc, directly onto a plastic substrate. Shielding is usually excellent, as a 1-2 mil film of relatively pure metal is deposited. However, adhesion is poor in many cases, and the plastic is often deformed by the process. The flame spray process is slow, and presents health and safety problems to personnel.

Plating: It is possible to deposit metallic films on plastics by a technique known as electroless plating. It usually involves sensitizing the substrate with a suitable reducing agent, or catalyst, and then chemically reducing a metal salt, so that a film of metal is deposited on the plastic. While it is possible to get excellent shielding with this technique, a multi-step process, plus expensive masking, is usually involved. One commercial variation of this technique utilizes a multi-headed spray system, which reduces silver from solution prior to contact with the part, thus reducing masking requirements somewhat. Overall, costs associated with application appear to be the major drawback to plating techniques.

Coating: Perhaps the least expensive, and most adaptable, method of shielding complex plastic enclosures is to coat either inside or outside surfaces with an electrically conductive coating. Most coating processes are readily adaptable to high speed production, and do not require a great deal of specialized application equipment. Often, conventional spray equipment requires little or no modification to spray conductive coatings effectively.

Types of Coatings

Silver-Coatings—One of the most reliable processes used to date has been coating plastic enclosures with a silver filled conductive coating, optimizing conductivity and adhesion. These coatings often require the use of an undercoat to promote adhesion to the plastic substrate, and/or an overcoat to preclude the possibility of removing the coating by abrasion. As silver filled coatings are usually formulated in thermoplastic vehicles such as acrylics, their chemical resistance may be poor. However, they usually provide excellent shielding, and should be strongly considered in applications where materials costs are relatively insignificant in relation to the total cost of the system. As silver will provide conductivity in virtually any type of vehicle, a wide range of formulating latitude is available; silver coatings may be custom formulated to adhere well to almost any substrate, and to maintain conductivity and shielding in the most adverse environments.

Base Metal Coatings—The use of base-metal filled plastic systems as substitutes for silver filled systems has been considered in the past, as utilization of a base metal for all or part of the silver in a coating would obviously reduce the cost. However, the tendency of virtually all base metals to be subject to some sort of chemical change (usually oxidation) in either application or aging has precluded their use in systems where low and stable resistance must be maintained. For example, copper—a logical choice since its inherent electrical conductivity is very close to that of silver—could not be used because of its tendency to form an oxide coating with a very high electrical resistance.

Copper-Filled Coatings—An approach that may have overcome the tendency of copper to oxidize upon aging involves the use of vehicles which, when cured, would tend to reduce the oxide layer which is always present on copper particles used as conductive fillers in paint systems, and at the same time, encapsulate the reduced particle in a tight, environmentally resistant matrix which would keep the system conductive when exposed to harsh environments.

In its development, several resin systems were selected as candidates, including acrylics, polyolefins, acetals, epoxies, polyamides, phenolics, and polyimides. Many were eliminated either because they did not have sufficient environmental resistance to keep the copper in a reduced state (thus maintaining shielding integrity of a coated part), or could not provide a reducing atmosphere upon curing. A thermosetting epoxy copolymer, appeared to provide the best balance of physical and electrical properties. A typical coating made from the above referenced resin system, containing copper with an average particle size of about 10 microns, has an average resistance of less than 0.5 ohms per square at a dry film thickness of 2-3 mils, resulting in attenuation of greater than 40 dB at most frequencies.

Other Base Metal Coatings—A limited amount of work has been done in the area of coatings formulated with base metals other than copper, including nickel, tin, and aluminum. It was difficult, however, to achieve satisfactory conductivity with any of these systems, probably because their specific resistances, in most cases, are considerably higher than that of copper. Aluminum, which has a very low specific resistance, was found to be totally ineffective when used as a filler in these systems, because it forms a non-conductive oxide coating which is almost impossible to remove. Resistances of other base-metal filled systems were no better than 50 ohms per square.

Graphite Filled Coatings—Graphite, with a specific resistance of 800 ohm-cm, and a sheet resistance of about 0.3 ohms/square/mil, should provide adequate shielding in many applications if it could be applied in a continuous film. In actual practice, however, considerable binder must be used to obtain adhesion to a substrate, resulting in a relatively high ohmic value. Typical resistance readings obtained with graphite filled coatings range upward from 150 ohms per square, making them essentially useless for shielding at frequencies above 5 megahertz. Graphite coatings, however, are useful for many electrostatic discharge applications where a relatively high sheet resistance can be tolerated.

Selecting The Best System

It is very difficult to select any one material as best for a given shielding problem, since there are a multiplicity of variables affecting each application. Among factors influencing shielding effectiveness are conductivity, thickness and density of the barrier, and frequency of the electromagnetic radiation involved. One of the first factors to consider in selecting a shield is to determine the amount of shielding effectiveness required. Shielding effectiveness (decibels) is a ratio of field intensities before and after shielding, and is defined by the following equation:

$$SE = 20 \log \frac{E_b}{E_A}$$

Where E_b = electric field strength before shield is installed.

E = electric field strength after shield is installed.

The best way to determine the required shielding effectiveness is to test the device to failure in an EMI enclosure, and be thoroughly conversant with requirements of the FCC and other governmental agencies insofar as allowable emissions are concerned. Given the required field strengths, shielding effectiveness can be calculated from the above equation.

Once the required level of shielding effectiveness is determined, a metalizing technique can be selected with the following factors in mind:

(1) Electrical Conductivity—The higher the conductivity, the closer the metalizing will behave compared to a pure metal. Effective conductivity of a pure metal coating—flame spray, for example—can be less than ten per cent of the pure metal because of air entrapment.

(2) Thickness—In addition to conductivity, it has been found that the thickness of the metalizing has an effect on shielding. Thicker sections generally provide better shielding.

(3) Density—Higher density metalizing generally provides better shielding than lower density ones, because of the greater mass of metal available.

(4) Adhesion and Integrity—The metalizing must adhere to the substrate and remain intact throughout the expected life of the product, under specific environmental conditions.

(5) Grounding and Sealing—The package should be grounded and sealed in a manner that will provide maximum shielding.

Testing Resistance—The sheet resistance concept is usually used in measuring the resistance of a coated plastic substrate. Assuming that the coating thickness over a one square area (ohms per square—the size of the square does not matter) is constant throughout the part, one may measure ohms per square over several areas of the part, using an inexpensive attachment to a standard ohmmeter. If the part is to be overcoated with a non-conductive coating, ohms per square may be determined by reading resistance over a pre-determined number of squares on the part, the overcoat, of course, being removed in areas where the probes contact the part.

Adhesion & Integrity In addition to conductivity requirements, adhesion of the shielding to the substrate is very important. For example, if matalizing lost integrity and adhesion as a result of thermal cycling encountered during operations, it is possible for conductive materials to come into contact with system components, possibly causing a short circuit or other malfunction.

As a general rule, conductive coatings will adhere to plastic substrates better than direct metalizing, since the interface between the metal and plastic is less abrupt, due to the organic component of the coating. In addition to promoting adhesion under ordinary ambient conditions, the organic binder of the coating provides a buffer during thermal cycling, as its coefficient of thermal expansion is much closer to that of the plastic substrate than pure metal. Adhesion before and after environmental cycling should be tested. Common methods include a "cross-hatch" test, a tape pull test, and a mandrel test, depending upon coatings and substrates used.

The above article was condensed from "Conductive Coatings—A Practical Low-Cost Solution to Radio Frequency Shielding Problems" by John J. Reilly, Electro-Kinetic Systems Inc. It was presented at the IEEE MIDCON and reprinted by permission of the IEEE and Mr. Reilly.