EMI/RFI Shielding of Plastics

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By R.M. Gresham

Various methods of coating plastics to prevent electromagnetic and radio-frequency interference are surveyed. The dominant finish today is the nickel-laced, conductive organic coating, but electroless copper/nickel plating is becoming important for high-performance products such as those used in security and military hardware.

The fabrication of plastic cabinets for electronic equipment has been one of the fastest-growing industries in the American economy, resulting in tremendous growth potential for resin suppliers, molders, and coaters. Even though the industry has gone through a recent downturn, the direction of future growth will continue to depend on the need to shield parts or fully assembled units from electromagnetic interference (EMI). Electromagnetic radiation is one of the unfortunate byproducts of the rapid proliferation of electronic devices. EMI can interfere with the functioning of simple household appliances such as garage door openers and microwave ovens (Table 1) and also generate disastrous results in large-scale computers, aircraft guidance systems, and medical equipment such as pacemakers.

Table 1
Common Sources and Receptors of EMI[1]

Sources	Receptors
Televisions and radios	CB receivers
Radar transmitters	Remote-control units
Video cassette recorders	Sensitive test instruments
TV games	Telephones
CB transmitters	Microprocessor-containing equipment
Electric motors	Radio and television receivers
Relays and circuit breakers	Cardiac pacemakers
Engine ignition systems	Computers and large calculators
AC power-line leakage and corona	Navigation equipment
Induction heating units	Audio and high-fidelity equipment
Paging systems	Cash registers
Electronic calculators and computers	Duplicating equipment
Static electricity	
Remote-control units	
Mobile communication transmitters	
Arc welders	
Electrical appliances	
Lightning	

In 1983, the Federal Communications Commission (FCC) issued regulations on EMI shielding, and more stringent ones are expected to follow. The impact of the legislation has posed serious problems for producers of electronic equipment utilizing plastic cases or cabinets. The industry has had to develop methods of shielding while maintaining an attractive exterior, durability, and protection of the electronic devices within.

Electronic cabinetry has been produced largely from injection-molded and structural-foam-molded plastics, which have provided design engineers with lightweight, versatile, aesthetically pleasing packaging for their products. Plastic enclosures have been steadily replacing metal cabinets for items such as typewriters and CRT terminals. Unlike conductive metals, though, plastics cannot be grounded to provide electrostatic control and EMI shielding. However, even metal enclosures pose the possibility of EMI at joints and apertures (Fig. 1).[2]

Vent holes, cables, gaskets, and assembly techniques all play a role in developing an effectively shielded cabinet. The result is that no one form of shielding will dominate the market and metals will not be completely replaced by plastic cabinetry. However, as is the case in all industry, the most cost-effective means of controlling EMI for a specific design and application will become dominant. All producers in the chain must therefore maintain an awareness of new shielding developments as well as a high level of flexibility in their production facilities.

There are several basic approaches design engineers can use to control EMI in plastic-enclosed equipment: (1) redesign the electronic equipment to reduce the strength of the electromagnetic energy or signal emitted to levels below the regulations; (2) shield the electronic equipment directly to reduce or attenuate the signal emitted at the source through internal shielding enclosures or similar electronic devices; or (3) shield the plastic cabinet or enclosure.

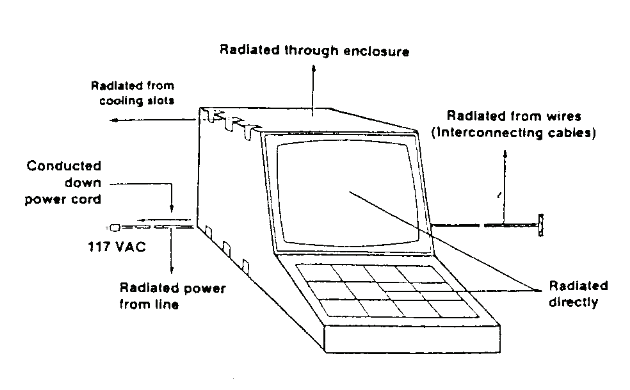

Fig. 1—EMI leakage areas.

The first option involves controlling noise generation and is the least attractive because it affects the ultimate performance of the product and can influence susceptibility. Options 2 and 3 have received the most attention, but the former tends to be relatively expensive. The third option appears to be the most popular because the packaging decision has the least effect on the circuitry and design of the specific electronic equipment. Differences in the geometric configuration and electrical output of equipment as well as the length of the production run for building the cabinet itself call for different shielding approaches. Furthermore, each shielding technique has inherent strengths and weaknesses that also affect selection.

Some of the technologies that have been promoted for shielding plastic parts include arc and flame spray, vacuum metallization, conductive paints, electroless plating, ion plating, conductive-filled plastics, and inherently conductive plastics (Table 2). However, the market is currently dominated by zinc arc spray, conductive coatings (e.g., nickel-, copper-, graphite-, or silver-based paints), and electroless plating.

The EMI Problem[1]

Electromagnetic interference can emanate from any circuit or man-made device that carries electrical current as well as from lightning, solar energy, or any of a number of other natural resources.[3] However, the most commonly experienced electromagnetic radiation is generated by man-made sources. Electromagnetic radiation is composed of electrical and magnetic fields oriented at right angles to each other (Fig. 2).[4]

For electronic cabinetry, shielding of the magnetic component is generally not a concern. At frequencies greater than 1 mHz, the main concern is with radio frequency (RF) energy, which is attenuated by three basic mechanisms—absorption, reflection, and re-reflection (Fig. 3).[5] RF energy that is not attenuated is transmitted. The mechanisms can be added albegraically when using units of decibels to determine total attenuation. Absorption takes place when the energy enters the shield and is converted to thermal energy, as occurs in a microwave oven. Reflection is similar to that of light or sound waves; the energy is reflected off the shield on the source side. Re-reflection is reflected energy reflected from a second side of the shield. All of these mechanisms are reasonably predictable; the degree to which each contributes to

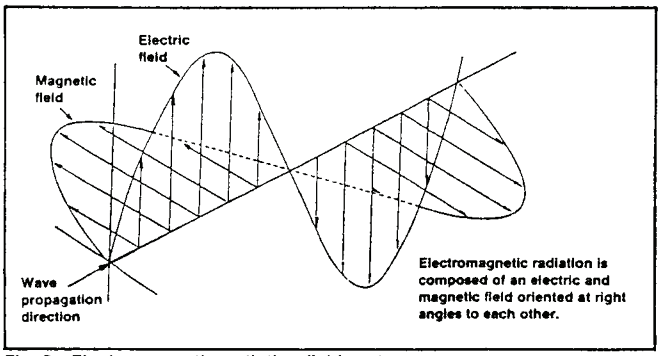

Fig. 2—Electromagnetic radiation field vectors.

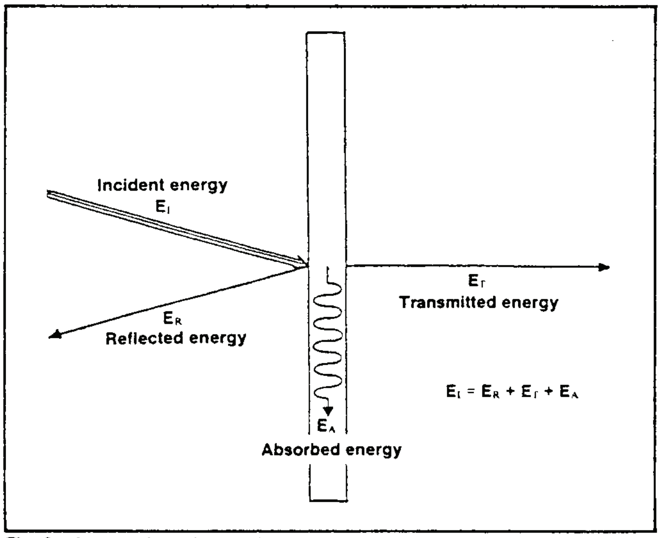

Fig. 3—Attenuation of radio-frequency energy.

Table 2
Electrical Properties of Selected EMI Shielding Methods[1]

Method	Thickness, μm	Resistivity, ohm/sq.	Attenuation, dB
Zinc arc spray	12-25	0.03	50-60
Zinc flame spray	25	4.0	50-60
Nickel-acrylic paint	50	0.5-2.0	30-75
Silver-acrylic paint	25	0.04-0.1	60-70
Copper-acrylic paint	25	0.5	60-70
Graphite-based paint	25	7.5-20	20-40
Cathode sputtering	0.75	1.5	70-90
Electroplating	0.75	0.1	85
Electroless plating (Cu/Ni)	1.25	0.03	60-70
Silver reduction	1.25	0.5	70-90
Vacuum metallizing	1.25	5-10	50-70
Ion plating	1.0	0.01	50
Conductive plastics*	—	75-100	40-60

*Forty percent carbon-filled nylon 6/6, LNP Corp., Malver, PA.

attenuate RF energy depends on the shielding material, source distance, frequency, and shield thickness. Shielding effectiveness is measured in decibels and is related to the level of attenuation (Fig. 4).[1]

FCC Regulations

In 1983, the FCC published a technical standard that applies to all devices manufactured after October 1, 1983.[6] The rules stipulate that "any apparatus which generates a radio-frequency (10 kHz to 3 million mHz) electromagnetic field at any point at a distance of $\lambda/2\pi$ from the apparatus shall not exceed 15 mV/m." Subpart J defines a computing device as "any electronic device or system that generates and uses timing signals or pulses at a rate in excess of 10,000 pulses (cycles)/sec and uses digital techniques; inclusive of telephone equipment that utilizes digital techniques or any device or system that generates and utilizes radio-frequency energy for the purpose of performing data-processing functions such as electronic computations, operations, transformations, recordings, filing, sorting, storage, retrieval, or transfer."

The regulations list the following examples: business and personal computers, data-processing equipment, digital weighing scales, switching power supplies, electronic games (including the coin-operated variety), electronic cash registers, digital watches, pocket calculators, and digital clocks. The list is not meant to be inclusive. The computing devices are divided into two categories: Class A for use in commercial or business environments and Class B for personal use in residential areas.

Restrictions on Class A business systems have actually been relaxed by the rules as the incidence of interference has been found to be minimal. For self-protection and security, business machines are normally shielded from outside interference (Table 3). Limits have been made more

Table 3
Radiation Limits for Computing Devices by Class[6]

Class	Frequency, mHz	Distance, m	Field strength, mV/m
A	30-88	30	30
	88-216	30	50
	216-1000	30	70
B	30-88	3	100
	88-216	3	150
	216-1000	3	200

strict on Class B computers for personal use as the commission considers them to be more apt to disrupt reception without built-in safeguards. A Class A computing device must be tested and verified by the manufacturer as complying with FCC regulations and must bear a warning as to the potential for interference if used in a residential area. By contrast, Class B personal computing devices require FCC certification and provisions for providing pertinent information to the user.

Shielding Effectiveness

Due to the relative high cost and technical difficulty of EMI testing, attempts have been made to relate measurements of surface resistivity to RF attenuation. Resistivity measurements unfortunately give only an average value for system conductivity, which is not necessarily related to shielding effectiveness. It is not truly an effective quality-control tool, either. Depending on the conditions of frequency and source to shield distance, thin coatings on areas of the system applied to the plastic could pass a high proportion of the incident energy.

In comparing samples having equal amounts of metal, those in which the metal is evenly dispersed will result in higher attenuation than where uneven dispersions prevail. However, either type of sample could result in essentially equal resistivity measurements.

Resistivity is therefore not recommended for determining the degree of attenuation of a system although it is widely

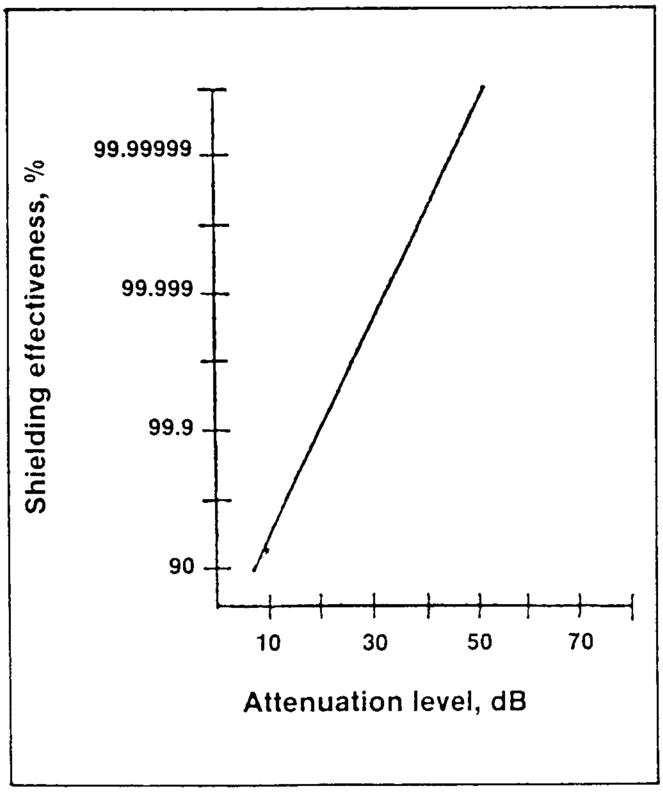

Fig. 4—Shielding effectiveness vs. attenuation level.

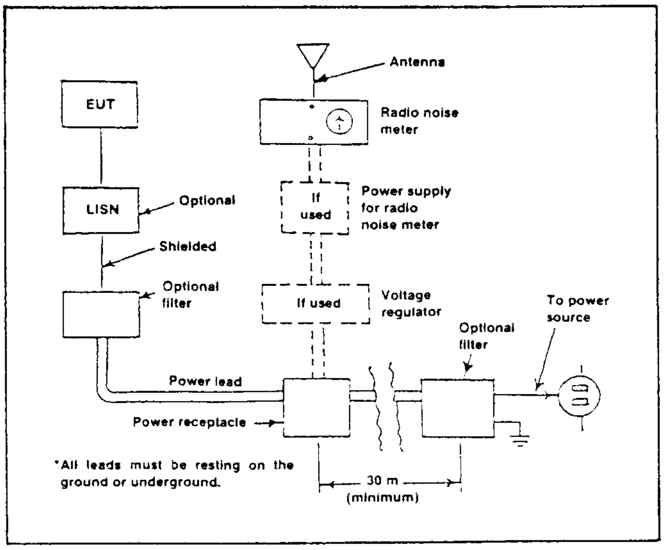

Fig. 5—Suggested layout for open-field tests.

used in the industry because the test equipment is relatively inexpensive and lends itself to on-line quality control. To put it simply, "It is the only game in town." The conductivity test is performed according to ASTM D-257. To eliminate some of the variability, both customer and vendor must measure conductivity in the same location on a part using like brands of volt-ohm meters and electrodes.

Compliance is determined by testing in open-field FCC test equipment (Fig. 5).[6] The electronics under test are located in a shielded environment and operated under normal conditions. An antenna is located at a specified distance from the equipment to monitor RFI emissions. The electronic equipment is considered to comply if the emissions fall within the specified requirements. The FCC regulates total RF emissions and is not concerned with the effectiveness of a given shielding system. Only enough shielding to reduce the emitted signal to the required level is needed. Thus, designers of components, cabinetry, and shielding systems have a high degree of flexibility in fabricating the total product. To produce the most cost-effective product, manufacturers must interplay various design considerations.

Therefore, ASTM Section D9.12.14 was established to develop a test method for the industry. An emergency standard, ES7-83, has been approved. The method, which initially incorporated a dual-chamber apparatus, compares parts being tested against appropriate standards. It is satisfactory for providing data on relative attenuation but does not necessarily provide absolute values. Although less expensive than many electronic procedures, it is still relatively expensive for the molder or coater and therefore has not had wide industry acceptance.

Any system for metallizing plastic substrates should conform to the requirements of Underwriters Specification 746-C,[7] which requires removal of no more than 5 percent of the metallized material when a tape is applied to a cross-hatched section of the coating (per ASTM D-3359) following thermal cycling, temperature, and humidity tests (Table 4).

Table 4
Environmental Test Method[7]

Procedure*	Conditions
Conditioning	40 hr at 23.0 ±2.0° C and relative humidity (RH) 50 ±5%
Thermal cycling	1 hr at 85° C 1 hr at 23.0 ±2° C and RH 50 ±5% 1 hr at 29.0 ±2° C 1 hr at 23.0 ±2° C and RH 50 ±5% Repeat cycle 3 times
Temperature exposure	85° C for 56 days
Humidity conditioning	35 ±2° C and RH 90 ±5% for 56 days

*Samples tested for adhesion (ASTM D-3359B) after treatment.

The final key test performed on shielding coatings involves thickness measurement. Coating thickness of conductive paints can be measured conveniently with a micrometer or Tooke gage. These are also applicable to zinc arc spray. However, electroless copper/nickel plating, by virtue of its extreme thinness (normally less than 100 μin.), requires more sophisticated techniques (e.g., beta backscatter per ASTM B-567). These methods require careful calibration but provide outstanding data readily amenable to plant operation and statistical process control.

Shielding Systems

There are seven relatively common systems proposed for EMI/RFI shielding. However, only conductive organic coatings, zinc arc spray, and electroless copper/nickel plating have emerged as commercially significant.

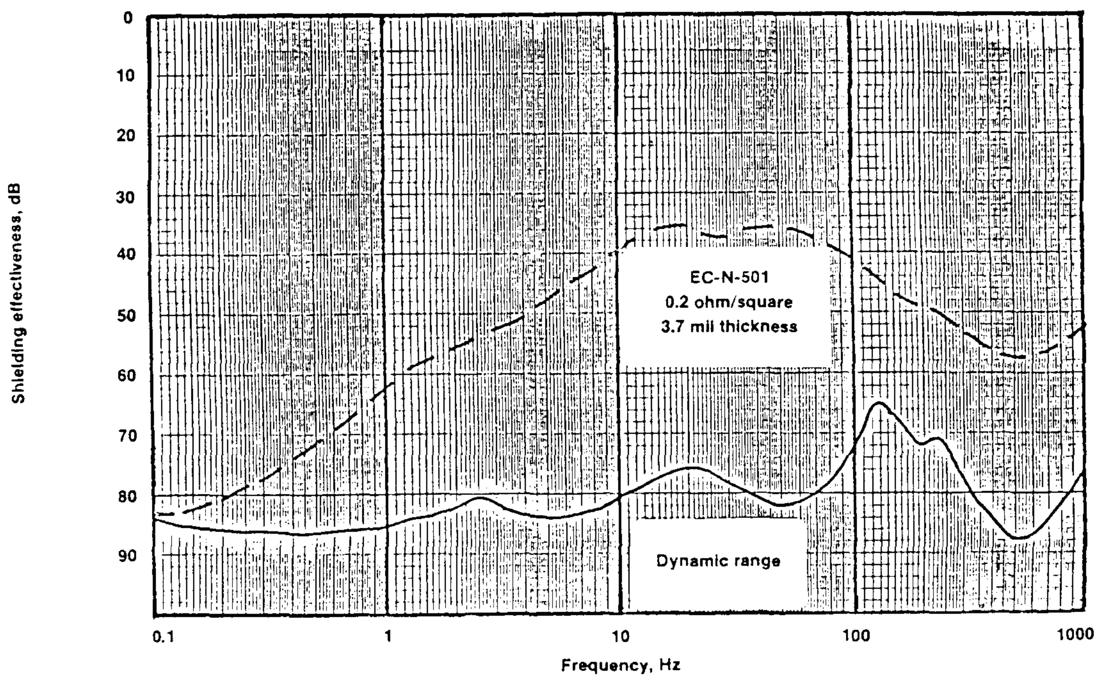

Fig. 6—Shielding effectiveness of nickel acrylic conductive coating in electric field.

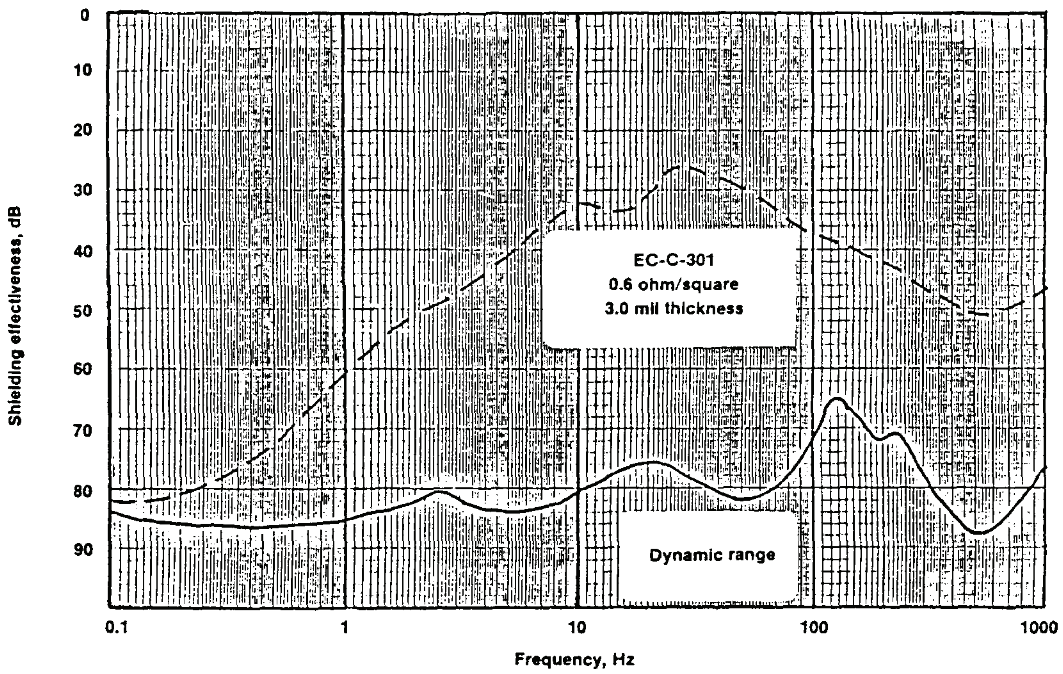

Fig. 7—Shielding effectiveness of copper acrylic conductive coating in electric field.

Conductive coatings are heavily filled with nickel, graphite, copper, or silver particles. These products include solvent-based or waterborne systems, which may contain an acrylic, polyurethane, or epoxy binder. Nickel is the most common material used in these coatings. The coatings provide an excellent shield that is environmentally stable. Acrylic binders are most commonly used with nickel and generally provide the most cost-effective shielding. Depending on the application technique and quality of the coating, shielding performance can range from 30 to 60 decibels. Figure 6[8] shows the shielding effectiveness of a conductive nickel-based organic coating, the dominant shielding product used today.

Graphite-containing conductive coatings are generally used against electrostatic discharge (ESD) due to the less effective conductivity of graphite and its lower shielding capability. In some low-power applications, the graphite coatings can provide adequate EMI shielding. Graphite has the advantage of superior environmental stability.

Copper-containing coatings provide excellent shielding

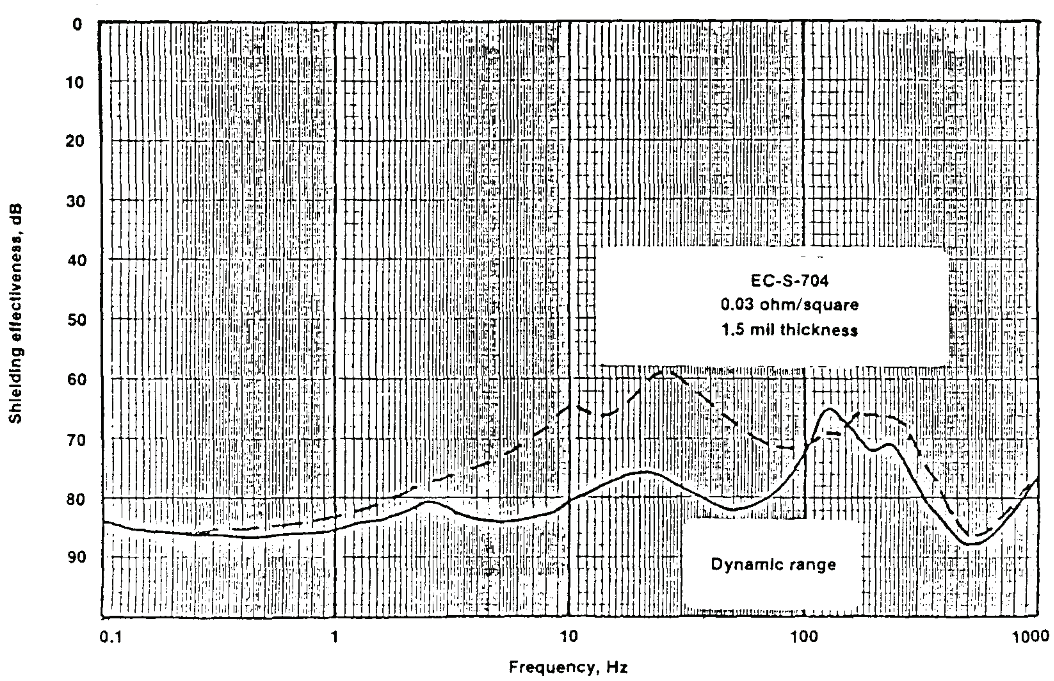

Fig. 8—Shielding effectiveness of silver acrylic conductive coating in electric field.

against EMI (Fig. 7),[8] but copper is readily oxidized and therefore not environmentally stable. New technology has greatly improved the environmental stability of these coatings. Nevertheless, copper-conductive coatings have not been used in great volume.

Silver-containing coatings provide superior shielding and environmental stability. Shielding can be as high as 70 to 80 decibels, but, because of the high cost of silver, this type of coating is used only in rare applications requiring extreme shielding not achievable by other methods (Fig. 8).[8]

Application of any conductive coating is critical to the success of the overall system. The first step, surface preparation, is of key importance. The surface of the part must be clean and free of grease and contaminants. The coating is most commonly applied via spray, with special attention to assure the paint is properly mixed because the conductive pigments tend to settle rapidly. A preferred system is a propeller-agitated pressure pot.

After application, the coating should be allowed to cure for at least 30 min before testing. Acrylic coatings usually develop their full shielding and conductivity capability after 24 hr. Urethane coatings can take as long as three to seven days.

In general, surface resistivity is used as a measure of quality control. The criteria are generally agreed upon between purchaser and vendor. High surface resistivity generally indicates inadequate coating thickness, poor paint mixing, or dry spray application. Poor adhesion is generally due to surface contaminants or improper selection of solvents. Cracking and similar discontinuities in coatings are generally caused by improper solvent selection or excessive film thickness. Quality control should therefore include checks for coating adhesion and, of course, visual inspection for cracks, crazing, and similar indications of a non-continuous coating.

Shielding is also provided by zinc metal, which is deposited on the prepared substrate by flame or arc-spray methods. In the case of zinc arc spray, the most common, two metal wires are fed through an electric arc, which melts the ends, causing a layer of metal to be sprayed on the part. Flame spray involves a metal powder or wire that is melted by contact with superheated inert gas and, using a special spray gun, atomized on the part. Flame or arc spray provides good conductivity and a hard, dense coating and is effective over a wide frequency range (Fig. 9).[8] However, poor coating adhesion caused by differences in the thermal expansion coefficients of plastics can result in flaking of metal on the electronic components beneath. Careful attention to the application technique and the end use the electronic device can effectively control this problem.

Electroless plating involves autocatalytic deposition of a metallic material on the surface of the plastic cabinet. Most commonly, a layer of electroless copper is plated on the

Table 5
Shielding Characteristics and Properties Of Electroless Cu/Ni Coatings

Properties	Type 1	Type 2	Type 3
Attenuation (FCC)	70-80 dB	>90 dB	>90 dB
Copper thickness, μm	0.625	1.25	2.5
Nickel thickness, μm	0.25-0.38	0.25-0.38	5.0
Surface resistance, ohm/sq.	0.01-0.06	0.01-0.06	0.04-0.08
Taber abrasion resistance	N/A	N/A	17 mg
Solderability	N/A	N/A	Yes
Primary application	Business machines	Military/ security	Military/ security/ extreme environment

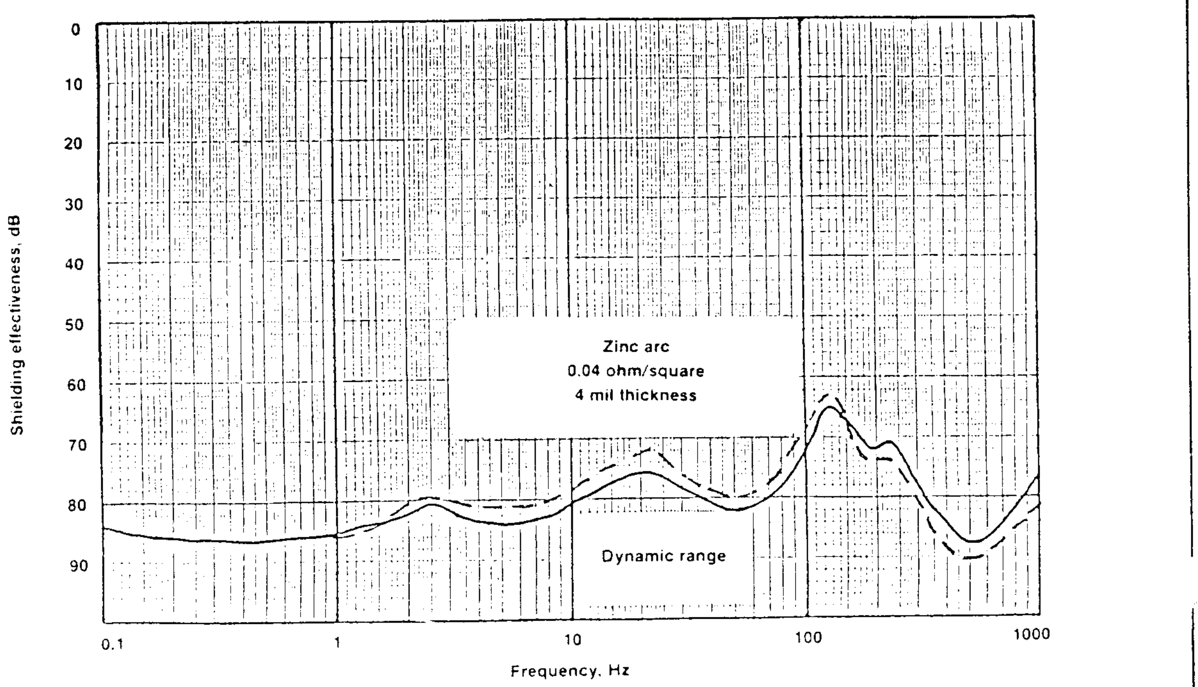

Fig. 9—Shielding effectiveness of zinc arc spray in electric field.

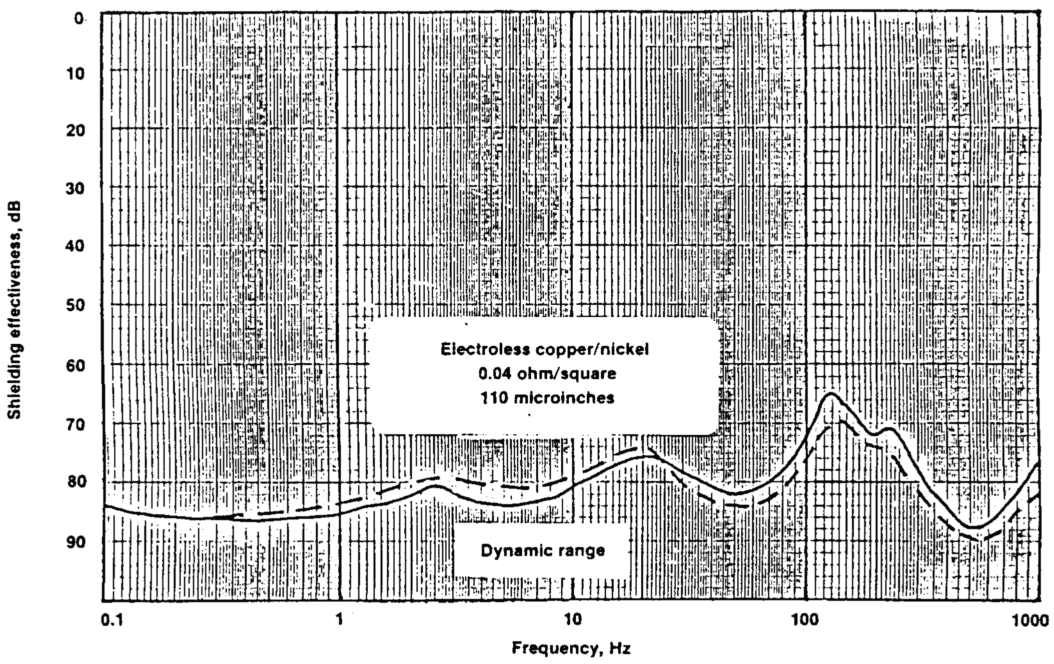

Fig. 10—Shielding effectiveness of electroless copper/nickel coating.

plastic to provide the primary shielding metal. This process is usually catalyzed by palladium and is the result of the chemical reduction of cupric ions by formaldehyde. This reduction is followed by additional catalyst and chemical reduction of nickel ions using hypophosphite. The nickel layer is added to provide environmental stability and, in some cases, wear resistance and solderability. In most cases, all surfaces of the plastic are plated. A number of techniques have been developed for masking these parts; however, some result in large increases in unit costs, often with little practical advantage.

The electroless copper/nickel plating technique appears to be the most promising emerging technology, particularly for high-performance products requiring extreme shielding. Plating baths can be controlled so that as much copper as necessary is deposited to shield whatever signal is encountered. Therefore, electroless copper/nickel plating is used in security and military applications as well as the production of business machines.

Figure 10[8] shows the shielding effectiveness of an electroless Cu/Ni combination with a total thickness of 2.75 μm (110 $\mu in.$). Table 5 shows the shielding effectiveness and properties at three different electroless Cu/Ni thicknesses.

Summary

There are a variety of commercially available shielding techniques. It is incumbent on the OEM supplier to develop working relationships with molders, platers, painters, other finishers, and assemblers to develop the most cost-effective product.

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