EMI Shielding by Electroless Plating of ABS Plastics

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Electronic equipment, especially computers, needs to be shielded from stray electromagnetic interference (EMI). Most equipment is contained in plastic housings, so is transparent to EMI. Plating on plastics offers a method for economical and reliable EMI shielding. This review explains the plating process and compares the capabilities of shielding techniques. Theoretical principles of shielding theory are also discussed.

Electromagnetic interference (EMI) is the unwanted energy emitted in the frequency range from below 60 Hz to more than 1,000 MHz (see figure). Radio-frequency interference (RFI) is the portion of EMI in the range of 0.01 to 1,000 MHz. Electromagnetic waves in this range can interfere with radio communications. Many electronic devices emit noise in this range that will be picked up directly by other devices or by conduction through power lines that act as antennas. Electronic noise is caused by rapidly changing voltage and is found in radio signals, video games, lightning, static electricity, computers, calculators, motors, etc. Electronic noise is both natural and man-made and can wipe out computer memories or cause arithmetic errors in computers, just as power surges and outages do.

Shielding Theory

Shielding effectiveness (SE) in decibels (dB) is a measure of the reduction of electromagnetic field achieved by a coating and is defined as:[1]

$$SE = 20 \log \frac{E_0}{Et} = 20 \log \frac{Ho}{Ht} \text{ (dB)} \qquad (1)$$

where E_0 and H_0 are the electric and magnetic field intensities incident on the coating and E_t and H_t are the transmitted signals intensities. Attenuation is achieved by absorption and deflection of the incident radiation and can be written as:

$$SE = A + R + B \qquad (2)$$

where *A* is the absorption loss, *R* is the reflection loss and *B* is a correction factor to account for multiple reflections. Although only the total of these terms is usually measured, it is important to appreciate the significance of the individual components.

Absorption Loss

When an electromagnetic wave passes through a medium, it loses energy because of interaction with the electrons and atoms of the material. If the initial intensity of the wave is given by E_0, its intensity, E_1, at a distance *t* in the material is:

$$E_1 = E_0 e^{-t/\delta} \qquad (3)$$

where δ is the distance required for the wave to be attenuated to 1/e or 37% of its original value, and is called "skin" depth. It is given by the equation

$$\delta = \frac{1}{\pi f \mu \sigma} \qquad (4)$$

where f is frequency in Hz, μ is the permeability of free space and σ is conductivity.

For copper, $\mu = 4\pi \times 10^{-7}$ H/m, $\sigma = 5.82 \times 10^{7}$ S/m. Accordingly,

$$\sigma = \frac{6.6 \cdot 10^{-2}}{\sqrt{f}} \qquad (5)$$

and for any material:

$$\sigma = \frac{6.6 \cdot 10^{-2}}{\sqrt{f}} \times \frac{1}{\sqrt{\mu_r \sigma_r}} \qquad (6)$$

where μ_r is the relative permeability and σ_r the conductivity relative to the copper.

Absorption loss (A) in decibels (dB) can now be written:

$$A = 8.69 \left(\frac{t}{\delta}\right) = 1.317\, t \sqrt{\mu_r \sigma_r f} \qquad (7)$$

where t is the coating thickness in meters.

It is shown in Eq. (7) that A is directly proportional to the thickness, and inversely proportional to the skin depth (δ) of the shielding material. The skin depth corresponds to an attenuation of 8.7 dB. Therefore, several skin depths are needed in order to achieve significant attenuation by absorption. Table 1 shows skin depth for several materials at different frequencies.[2] As can be seen, thick shields will be needed to attain modest shielding

Deposit thickness,

Table 1
Skin Depth (δ) for Various Materials

Frequency Hz	Copper µm	Aluminum δm	Steel δm
10	20.88	26.72	2.09
30	12.04	15.42	1.20
100	6.58	8.43	0.66
500	2.95	3.78	0.29
1000	2.09	2.67	0.21

Table 2
Electromagnetic Interference Guide

Frequency MHz	Type of radiation
0.01–0.1	Maritime communications
0.1–1.0	AM radio
Approx. 1–100	Short wave
Approx. 100–1,000	Television and FM radio
1,000–10,000	Radar, microwaves

by absorption alone. For example, about 40 µm of copper would be needed to absorb 30 dB of radiation at 30 MHz. Absorption, therefore, will not contribute significantly to the total attenuation for the most practical shielding processes.

From Eqs. (2)-(7), it follows that reflection is the predominant mechanism for attaining effective shielding in a practical manner. Therefore, the most effective shield must be made from materials with high conductivity and low permeability.

Cost Comparison

Electroless copper has less than one-sixth the resistivity of electroless Ni-P layers of equal thickness, and has 30 to 50 dB more attenuation, depending on frequency. Total attenuation is readily increased with thicker copper layers.

The data for composite coatings of electroless nickel on electroless copper or electroless copper on electroless nickel show that shielding levels are controlled by the copper layer.[3-6] The electroless copper dominates the system and the electroless nickel contributes only 1 to 2 percent additional shielding, at best. This allows a convenient way to achieve tailored shielding efficiencies at relatively low cost, because only the less expensive electroless copper layer needs to be varied in thickness.

Comparison of Other Coatings

Of the various types of coatings for EMI/RFI shielding, plated plastics and zinc arc-spray can give 60 to 120 dB attenuation or more; copper-based paint and conductive fillers, 30 to 70 dB; and nickel-based paint 20 to 60 dB.[25] Very thin copper coating, less than 1 µm, can give plane wave shielding efficiencies of more than 50 dB when using magnetron sputtering.[1]

All plated plastics process costs are based on coating both the inside and outside of the part. Consequently, costs are in terms of 2 ft^2, where all other coating methods are for 1 ft^2 only, (*e.g.*, the inside of the part), except for conductive fillers that are based on total plastic volume. The relative costs of these coatings are: Plated plastics, 1.0; silver-based paint, 9.7; copper-based paint, 1.9 to 2.5; nickel-based paint, 2.6 to 2.9; zinc arc spray 2.75; and conductive fillers, 3.

For plated plastics, the plastic part is completely coated with an adherent layer of electroless copper. The copper thickness is a function of the shielding requirement (dB attenuation) of the end product (*i.e.,* the thicker the copper, the better the attenuation). A "typical" copper thickness range would be about 0.5 to 2 microns. The higher figure would be sufficient for almost all current needs.

Uniformity of electroless coatings compared with nickel paint and zinc arc-spray have a particular advantage. Nickel paint and zinc arc-spray coating uniformities depend upon the accuracy and skill of the person applying the coating. In addition, blind holes, bottoms of parts, and odd configurations can have nickel paint or sprayed zinc thicknesses significantly different from flat, uniform surfaces. Electroless nickel, electroless copper, and electroless multilayer deposits have completely uniform coverage, regardless of the part configuration. Electroless coatings can be economically applied by bulk processing methods rather than one-at-a-time, as with nickel paint or zinc arc-spray. Electroless coatings deposit on both the inside and outside of a part to provide a continuous metal layer, which in case of rupture of one side, still has the other for shielding protection. Nickel paint and zinc arc spray are normally applied only to the inner surface.

Thin electroless films do not easily rub off from parts and such films are integrally bonded to a part. They are continuous and coherent and will pass tape adhesion testing. EN has very high abrasion resistance; no coating loss will be evident upon rubbing or handling. The weight gain of electroless deposits is normally very minor. Most deposits are in the range 0.5 to 2.0 µm thick, which corresponds to an increase in weight of only 10 to 20 g/m^2.

Composites of electroless copper with electroless nickel have about the same shielding efficiency as electroless copper. The only time this might not be true is when the electroless copper layer is less than 10 percent of the total film thickness. The common practice, however, is to use a layer of electroless copper at least 25 to 50 percent of the total film thickness.

When the two coatings are combined, the composite of electroless copper overcoated with a layer of electroless nickel offers superior RFI shielding. The shielding efficiency is as high as that of electroless copper alone, but the corrosion resistance, wear resistance, and general durability are much increased. Electroless copper oxidizes readily and is a soft, ductile metal, less expensive than electroless nickel. Electroless nickel does not oxidize readily, is very wear-resistant, is a good paint base, and provides stable contact resistance. Consequently, the ratio of Cu/Ni thickness should always be optimized for a particular application.

Shielding efficiency of electroless copper is much higher for a given thickness than for electroless nickel—as much as 25 to 50 dB greater. For 0.75 µm of electroless copper, shielding efficiency can be 65 dB at 1 MHz, increasing to over 100 dB at 1,000 MHz. Most electroless coppers give essentially the same results, inasmuch as a pure copper film is usually deposited.

Cu-Ni composite gives a shielding efficiency which can be the same as electroless copper. The shielding efficiency varies only with the thickness of the copper layer for practical multilayer films. Over a range of 0.5 to 2.5 µm of electroless copper, it will vary from 60-85 dB at 1 MHz to 90 to 120 dB or more at 1,000 MHz. This can be explained as follows: Decibels of shielding efficiency is a logarithmic term; simple addition of two decibel measurements cannot be used. If an electroless copper film provides 65 dB of shielding and is coated with an electroless nickel film providing 40 dB of shielding by itself, the total shielding efficiency is 65/.01 dB. The relevant equation is:

$$SE = 10 \log \frac{R_1}{R_2} \quad (dB) \qquad (8)$$

where R_1 is the RF transmission without any shielding and R_2 is the transmission with the shielding in place.

Electroless nickel alone has somewhat better shielding ability than nickel-filled paint at a fraction of the thickness of a nickel paint layer (0.5-2.5 µm vs. 25-50 µm). Electroless nickel films are much better than conductive fillers, but zinc arc-spray has much higher shielding values.

On the other hand, electroless copper offers about the same shielding ability as zinc arc spray, at much lower thicknesses. Electroless copper of 2.5 to 5.0 µm total thickness should equal or exceed the shielding efficiency of zinc arc-spray at 25 to 50 µm. Electroless copper has 40 to 60 dB (or more) greater shielding ability than nickel paint or conductive fillers. A 40-dB difference means 10,000 times more shielding ability.

The conductivity of the outside film bears a direct relation to EMI shielding—the more conductive the coating, the better the shield against EMI. Conductivity is easily measured in terms of ohms/square. From the above, it can be concluded that electroless coatings are more conductive than any other EMI method except zinc arc spray.

Representative shielding abilities *vs.* thickness for the case of EN can be explained as follows: Shielding ability (and conductivity) varies with phosphorus content, with metal film thickness and with the frequency of radiation. Typical shielding abilities are 40 to 50 dB at 1 MHz for a 0.75-µm film. The shielding efficiency increases with frequency, so that at 1,000 MHz, typical shielding efficiencies increase to the range of 60 to 80 dB. Higher-phosphorus alloys are, however, less conductive, but more corrosion resistant and, in certain cases, this can be an important factor to consider.

Having two coatings in a form of sandwich offers additional protection. When one coating is scratched or removed from one side, the coating on other side still possess enough conductivity for proper shielding efficiency. Moreover, electroless Cu and/or Ni metallic coatings are excellent bases for subsequent decorative painting without prior surface treatment, and they ensure an integral bond between molded-in metal inserts needed for electrical grounding.

Plating of Plastic for EMI Shielding

Successful electroless plating on plastic is a complicated process, both chemically and technologically. Its practical use depends on the optimized interaction of six separate complex chemical solutions.
The process steps are defined as:

1. Pre-etch
2. Etch
3. Neutralization
4. Catalysis
5. Acceleration
6. Electroless plating

Each solution used is an integral part of the operation, and each has its own complexity. Although the bulk of plating on plastic is done on ABS, other resins can be processed for electroless plating: PBT/polycarbonate blends, PET, polyester, PVC, polyurethane, polyphenylene sulfide, polyetherketone and some liquid crystal polymers. Steps 1 and 2 are different for these plastics.

Pre-etch
This step consists of treating the plastic with a solvent blend formulated to soften the surface chemically to allow more efficient subsequent etching. ABS plastic does not need this step but most other platable plastics do.

Etch
Etching is accomplished with the well-known solution of chromic acid dissolved up to saturation in concentrated sulfuric acid. A simplified description of the process is that the etch will oxidize the acrylonitrile-styrene (AS) portion of ABS selectively, and more slowly, than the polybutadiene (B) portion and chemically roughen the surface. The overall reaction is given by:

$$2C_{15}H_{17}N + 81H_2SO_4 + 54CrO_3 \rightarrow 30CO_2 + 2NO_2 + 98H_2O + 27Cr_2(SO_4)_3 \qquad (9)$$

Neutralization
Neutralization removes and reduces the Cr^{+6} to Cr^{+3}, because hexavalent chromium acts as a poison for catalytic and electroless plating steps.

Catalysis
Almost universally, the tin-palladium catalyst solution is used. It serves only to initiate electroless copper or nickel plating. As soon as the initial catalytic sites are covered with Cu or Ni, the newly deposited metal will assume and continue the catalytic function.

Accelerator
The accelerator provides activation of the catalyst by removal of excess tin from the surface to have fresh Pd atoms ready for their catalytic role.

Electroless Plating
Two steps are used in electroless plating for EMI shielding. The first step is electroless copper plating—a thick layer of copper is deposited, using formaldehyde in a special plating bath. The general reaction is given by:

$$CuSO_4 + 2HCOH + 4NaOH \rightarrow Cu^0 + H_2 + Na_2SO_4 + 2NaCOOH + 2H_2O \qquad (10)$$

The highly electrically conductive electroless copper does the actual EMI shielding. The thickness used depends on the exact shielding densities. Typically 0.5 to 2 µm are sufficient. The two-sided coating gives double shielding protection—if the product exterior should become scratched, the interior coating will shield the product satisfactorily. Another advantage of copper is its relatively low cost.

Copper has some disadvantages, however. It has low wear resistance, it oxidizes readily, giving it high electrical contact resistance, and it has relatively poor corrosion resistance. Layers of oxidation products at enclosure mating surfaces, for example, will allow large amounts of RFI leakage.

As mentioned earlier, the reason for a combination with electroless nickel (EN) is to coat copper with a corrosion-resistant layer. A low temperature plating bath, based on hypophosphite as a reducing agent for nickel, is needed to deposit Ni-P alloy, which is more corrosion resistant than pure nickel. The EN plating reaction is also a dehydrogenation and is given by:

$$Ni^{+2} + H_2PO_2 + H_2O \rightarrow Ni^0 + H_2PO_3 + H_2 \qquad (11)$$

One unique property of electroless plating explains its superiority to conventional electrolytic plating for EMI shielding and that is, its ability to plate uniformly over complicated and irregular configurations. The advantages of copper and nickel enhance the appeal of the process; the disadvantages of each metal are overcome by the advantages of the other. Because it is an all electroless process, it allows bulk plating to be used in processing. This means that line throughput is high because there are no electrolytic steps.

Recently, as an alternative for the Cu-Ni duplex layer, an alloy bath, Cu-Ni-P, was reported.[7] By using low current densities, the copper layer can be plated first, then by raising the current density, a copper alloy with high Ni content was obtained. The number of plating steps is thus reduced without loss of shielding capacity. Practical aspects (*e.g.,* coating distribution on deep, recessed areas) must be considered.

There is another method of plating on plastics which has *no* preplate cycle. A metal coating is deposited on the mold by accelerated electrodeposition. This creates a smooth metal surface on the side touching the mold and a rough surface on the opposite side. Molten polymer is then injected into the mold, forming a bond with the rough side of the metal. At this stage, a final decorative finish can be applied.[23]

Summary

Electroless copper offers far more shielding capacity than electroless nickel because of its higher conductivity. The ideal combination, however, is a composite coating of both. The superior corrosion and wear resistance of nickel, its pleasing aesthetic appearance and ability to be an excellent paint base and to have stable contact resistance offer distinct advantages. The plating cycle is very close to the standard preplate cycle used in electrolytic plating on plastic systems.

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