ELECTROLESS PLATING FOR EMI SHIELDING

Electroless plating is a method for coating non-conductive materials with a continuous metallic film using relatively simple chemicals in aqueous solutions. It differs from two other processes, electrolytic plating and immersion plating, in significant ways. Electrolytic plating uses an external electron source, such as direct current from a rectifier, to plate metal on top of a conductive surface. This process cannot be used directly to plate non-conductors such as plastics and ceramics. Immersion plating does not use an external electron source. However, it depends on the replacement of a metal of higher electromotive potential by a metal of a lower electromotive potential on the surface of an article. Thus, it is only applicable to an already metallized part. Immersion films of copper on steel and immersion films of tin on copper are typical immersion coatings.

Electroless plating is significantly different from both of the above processes. These aqueous solutions contain a mixture of reducible metal and reducing agents. The electroless plating reaction only occurs at the surface of the part where a deposit of metal is needed. Thus, no conductive surface need be initially present. Instead, a suitably prepared plastic or ceramic article can easily and cheaply be coated with a continuous film of conductive metal. The most common metals plated by this process are copper and nickel.

Electroless copper gives deposits of almost pure copper. These deposits have been used for many years in the printed circuit industries to connect two sides of double-sided printed circuit boards by application to the bare epoxy in drilled holes. Electroless nickel is used in several different modifications in the industry. It is used in the electronics industry in the form of nickel/phosphorus or nickel/boron layers, in order to inhibit diffusion of gold into the underlying copper on printed circuit taps. The largest applications, however, are in the plating on plastics industry and in the functional plating industry where electroless nickel solutions deposit a corrosion resistant nickel/phosphorus alloy.

Table I shows the basic steps in any electroless plating method. An electroless coating of copper or nickel/phosphorus can be built up to any practical thickness, for example 1 mil or more. Often, however, this is combined with a cheaper electrolytic plating step if thick coatings are needed. Composite coatings of electroless copper with overcoats of nickel/phosphorus for increased corrosion resistance and wear resistance are also available.

Etch Non-Conductive Surface
Neutralize Etchant
Apply Catalyst
Activate Catalyst
Deposit Electroless Copper or Nickel/Phosphorus

Table I. Basic Steps for Electroless Plating.

Electroless coatings are unique in several respects. They can cover a complex part with a completely uniform metal film, regardless of the part configuration. Classical electroplating techniques work best for flat or simple parts. All complex parts will give differential coating thickness when electroplated unless special masks, shields, and/or auxiliary anodes are used. Deep recesses and other low current density areas can have almost no plate. This means that if electroplating is used for RFI shielding, the metal thickness and thus the shielding efficiency will vary greatly from area to area on the part. This leads to over-plating in order to get minimum thickness in the low current density areas.

Among the advantages of an all-electroless system is the fact that no expensive plating rectifiers are used. Process tanks need only heaters and filters. The throughput is extremely high on an electroless plating system due to the speed of deposition and high tank loadings. Because the conductivity of electroless copper is so high, the actual coating thicknesses applied are very thin. Typically a maximum of 50 millionths of an inch of electroless copper is used. RFI shielding ability is uniform and reproducible over the whole part.

Why Use Plastics?

People are increasingly turning to plastic enclosures for electronics equipment because of its numerous advantages over formed metal parts. Unfortunately, plastic is transparent to electromagnetic radiation so that a separate shielding step may be necessary when plastics are used. The advantages of plastics to designers, though, are very great. Plastic is relatively low in cost, easy to process, durable, light in weight (especially when foamed plastics are used), has a high toughness and a pleasing appearance. Designers work with solid plastics, structural foam engineering plastics, and fire-retardant grades of plastics.

The techniques for plating on plastics have been worked out in detail and are commercially used in a large number of plants throughout the world. Not all plastics are plateable, but a large number of large volume plastics are regularly plated. Table II shows a list of commercially plateable plastics. This is not an

ABS
Noryl™ (polyphenylene oxide polymers)
Epoxy
Polysulfone
ABS/Polycarbonate
Fire Retardant ABS
Foamed ABS
Foamed Noryl™
Foamed Polystyrene

Table II. Plateable Plastics.

all-inclusive list, but it does show the main types plated. It is important to know the type of plastic as the details of the processing cycle can differ. Unlike many competing shielding processes, electroless plating is designed for application to large quantities of parts simultaneously, i.e. bulk application. Furthermore, no skilled labor is needed to apply electroless coatings to parts. Many large production lines are in operation. An advantage of electroless plating is that all surfaces are plated, both inside and out. This gives a double layer of protection and helps minimize any problems caused by scratching or abrasion.

Available Coatings

A large number of metals can be applied by electroless or electrolytic plating. The relative conductivities of many of the common shielding metals are shown in Table III. This table also shows whether or not the material can be deposited by electroless or standard electrolytic plating techniques. An advantage of electroless plating, followed by electrolytic plating, is that a very large possible variety of coatings can be applied. This is of little help to the designer who is often bewildered by the large number of choices available. Many designers have little understanding of the processing differences between an electroless and an electrolytic system, let alone a hybrid plating system. Some simple guidelines are outlined here which may be of help to those who are less than expert in this field.

Electroplating

Electroplating is limited for use to materials which are already electrically conductive. Thus, a steel article can easily be electroplated with copper. Special racks are needed so that the electricity can be applied to the part, the parts can be held in a preferred orientation, and the correct part density is maintained. The throughput on an electroplating line is often limited because the number of square feet of parts that can be plated at any one time is relatively low. Finally parts which have a very great depth or a very complicated shape, such as computer housings, often are impossible to plate with a uniform thickness. The low current density areas tend to have very thin or no plate at all. With electroplating, though, any combination of metals which can be electroplated can be put on a part so that multiple coats of different metals are not only available but commonly used.

Electroless Plating

Electroless plating has a great advantage over electroplating in that a non-conductive part can be coated with a metal. Unlike standard electroplating, though, the initial choice of metals for deposition is limited to essentially two, a nickel alloy or pure copper. These are the only two large-scale commercial processes in operation. Electroless silver and gold are occasionally used but are much more expensive than any of the others, with little incremental advantage. Some of the advantages for a straight electroless deposit include the fact that no expensive rectifiers or slow electrolytic plating steps are needed. An all-electroless system has a much higher throughput of plated parts than an electrolytic or a combination electroless and electrolytic system. Because the electrons are supplied by the solution itself for the reduction of the metal, there are no thin spots and no problems with applying the metal coating to every exposed and catalyzed surface of the nonconductor. As with electroplating, multiple coats of different electroless deposits are feasible.

Plastic parts can also be electrolytically plated with many metals once the initial conductive electroless layer is in place. This can be advantageously used when a very thick deposit of a metal must be put on the part, for example 2 mils or more of copper. Electroless baths can also give such thicknesses. However, they are relatively slow and expensive in this regard compared to electrolytic coatings. Thus, it can be advantageous to use an electrolytic final step, but this suffers from the same drawbacks as straight electrolytic plating, primarily the lack of uniform deposition between high current density and low current density areas of the parts. This often leads to massive over-design, as for example when ½ mil minimum is needed in the low current density areas. Often 2 mils or more may be plated in the high current density areas in order to meet the minimum. With a straight electroless system, you would get ½ mil everywhere upon the part.

Immersion Plating

Immersion plating is a third process related to the above two. It is not as commonly used as either electroless or electrolytic plating, but it is often referred to as a type of electroless plating even though it is not. Immersion deposits are limited in thickness and are rarely of good quality for corrosion resistance or other purposes. Immersion coatings form by dissolving part of

		Available by	
	Conductivity	**Electroless**	**Electroplating**
Silver	1.08	Yes	Yes
Copper	1.00	Yes	Yes
Gold	0.70	Yes	Yes
Aluminum	0.66	No	No
Zinc	0.30	No	Yes
Nickel	0.22	No	Yes
Steel	0.17	No	No
Tin	0.15	No	Yes
Nickel/1% Boron	0.10	Yes	No
Nickel/2.1% Phosphorus	0.057	Yes	No
Nickel/7% Phosphorus	0.024	Yes	No
Stainless Steel	0.02	No	No

Table III. Relative Conductivities of Shielding Metals (Copper = 1.0).

the metal surface while another metal simultaneously deposits. Because of the nature of the coatings, they are usually not very adherent and they have excessive numbers of pinholes. Typical coatings are immersion copper on steel, immersion tin on copper, and immersion zinc on aluminum. While some of these are useful for special purposes, they do not seem to be particularly suitable for EMI shielding.

Test Results

The primary factor in picking an electroless coating for EMI shielding is its shielding ability. Almost equally important is the question of whether this coating will maintain long-term shielding integrity. Electroless and electrolytic coatings have the great advantage of depositing a film of pure metal or alloy. Thus, the shielding efficiencies per unit thicknesses are much higher than for most competing processes. Unlike materials such as metal filled paints, there is no non-conductive polymer mixed in. Likewise, the shielding efficiencies of flame sprayed metals is much less than for the same bulk metal due to the inclusion of oxides, voids, and inhomogeneities.

Figure 1 shows how the shielding efficiency of pure electroless copper films varies with both the frequency and the thickness of the copper deposited. A corresponding curve for electroless nickel would be similar, but the shielding efficiency in decibels would be very much lower for corresponding thicknesses. These data were developed using the transfer impedance test method.

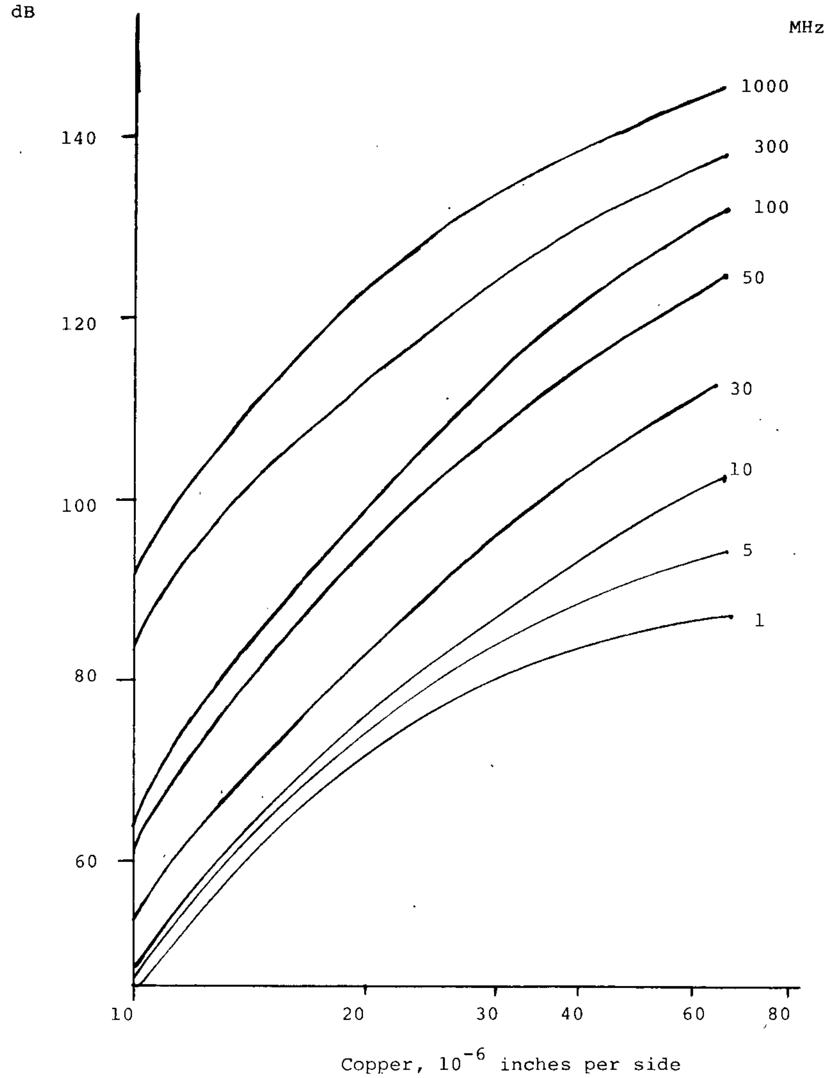

Figure 1. Shielding Efficiency vs. Copper Thickness

Figure 2 shows a comparison of the shielding efficiencies over the entire frequency range for different coatings and thicknesses. Line A shows a nickel/7% phosphorus coating which is 28 millionths of an inch thick. All these test panels were coated equally on two sides. Thus, the coating thickness is only 14 millionths of an inch per side. Even at this low thickness, the shielding efficiency is very close to what one would expect for nickel filled paint. When one increases the thickness to 48 μ in. total (line B), the shielding efficiency greatly increases. Lines C and D show the shielding efficiency for two different thicknesses of electroless copper. These panels were coated on two sides with a total of 48 or 98 μ in. of copper. At 48 μ in. of copper, the shielding efficiency is 30-50 dB or 1,000 to 100,000 times greater than 48 μ in. of electroless nickel. Line E is the same copper thickness as D, with the addition of a thin electroless nickel coating. The electroless copper shielding efficiency is so high that it dominates the system, showing no increase from the electroless nickel. The shielding efficiencies of these coatings are excellent.

A large number of all-electroless and composite coatings have been tested and recommended in the literature. These include straight electroless nickel, straight electroless copper, electroless copper with an immersion coat of tin, electroless copper with an electroless nickel overcoat, electroless copper with an organic coating, etc. Grounding can most easily be done to molded-in conductive inserts. These are integrally plated to the conductive electroless coating during the standard plating cycle to provide excellent grounding without fear of degrading the coating.

One coating for general EMI shielding purposes appears to be a layer of electroless copper overcoated with a layer of electroless nickel/phosphorus. Electroless copper cannot be easily used by itself because of its oxidation, softness, and low wear resistance. This leads to fast corrosion and inconsistent contact resistance which seriously compromises its shielding ability. Electroless nickel does not give very high shielding efficiencies when compared to electroless copper. However, its corrosion resistance is very good. It has high wear resistance and a very stable contact resistance. A combination of electroless copper for high shielding efficiency with an overcoat of electroless nickel for high wear resistance, corrosion resistance and stable contact resistance appears to be the optimum coating.

When composite coatings are tested, such as electroless copper overcoated with a layer of electroless nickel, one finds that electroless copper dominates the system for EMI shielding. As most of the shielding efficiency is due to reflection from the outermost layer, additional plating provides absorption loss relative to its conductivity, permeability, and thickness. As this is minimal in thin-plated metals, composite plating provides little, if any, additional shielding efficiency.

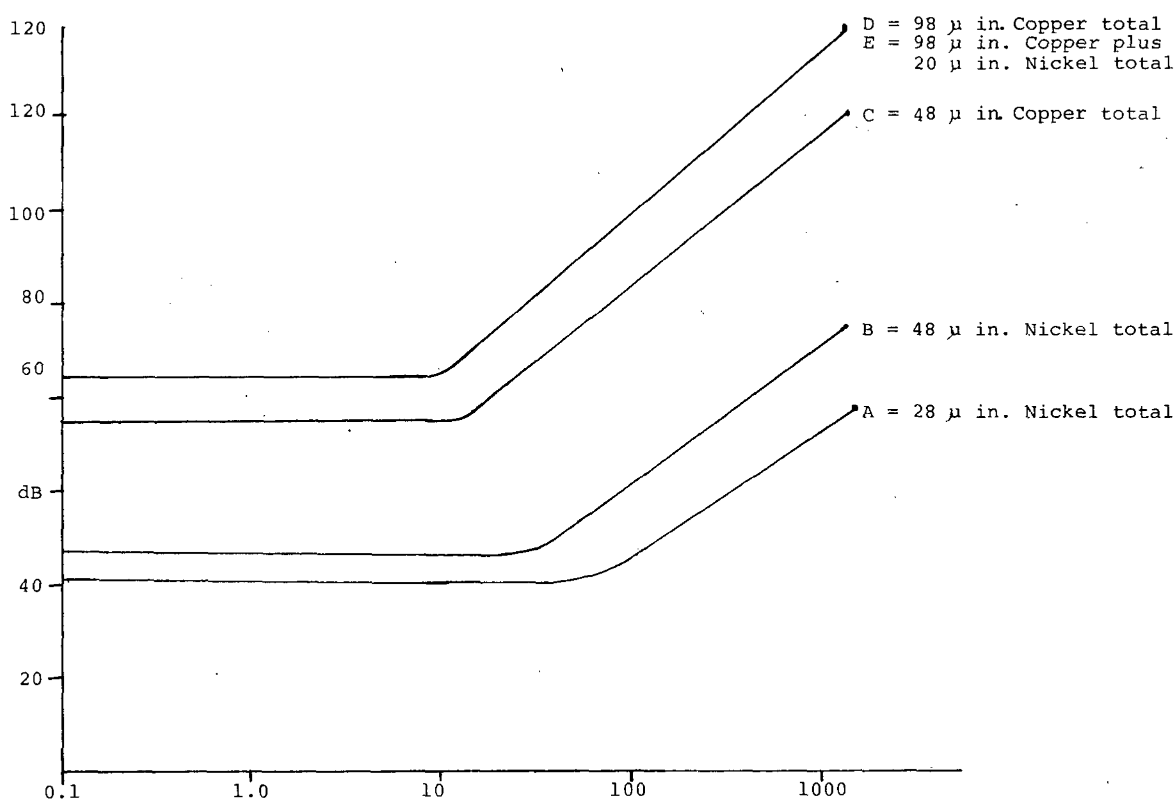

Figure 2. Shielding Efficiences of Electroless Coating

The great difference in shielding effectiveness between electroless copper and electroless nickel is very advantageous. It allows the custom tailoring of the final film to give any practical level of shielding efficiency, corrosion resistance, and durability. If the sole need is for electrostatic discharge protection, just use a very thin layer of nickel/phosphorus. If the need is a normal commercial level of 30-50 dB of shielding effectiveness, 25 millionths of an inch of copper would provide this. If one needed much higher levels of shielding efficiency, for example 80 dB or above, you would merely increase plating time in the electroless copper bath until the final coatings thickness has been applied which will meet the requirements. A thin (10-30 millionths of an inch) layer of electroless nickel over the electroless copper will provide excellent corrosion and wear resistance.

Coated plastic panels have been tested in various accelerated regimes, such as salt spray and humidity cabinets. The humidity testing is more indicative of what would occur in real life situations. However, the salt spray results are informative in that a very short time in salt spray testing shows a very great difference in the durability of various coatings.

Table IV summarizes some salt spray results. An ABS plastic panel coated on both sides with electroless copper shows a shielding loss of 9-47 dB over the range of 1-800 MHz after only 72 hours in salt spray. The electroless copper on the uppermost exposed area is almost completely eaten away and only the electroless copper remaining on the underside, which had less salt spray exposure, is responsible for what little shielding remains. Electroless nickel panels tested in the same manner show a drop of 10-26 dB after 72 hours in salt spray testing. Both initial and final shielding levels were lower than for straight electroless copper. The performance of straight electroless nickel is dependent upon the phosphorus content or the boron content of the electroless nickel. Higher phosphorus contents give better corrosion resistance though shielding efficiency per unit thickness decreases. Finally, a composite of electroless nickel over electroless copper shows only a 2-3 dB drop after 72 hours of salt spray over the range of 1-800 MHz.

	dB Decrease		
MHz	Copper*	Nickel*	Nickel Over Copper**
1	-9	-10	-2
10	-11	-10	-2
100	-33	-13	-2
800	-47	-26	-3

*15 x 10-6 inch of each per side
**15 x 10-6 inch of each per side

Table IV. Change in Shielding After 72 Hours Salt Spray.

An identical test series was run for 336 hours in humidity testing. Table V shows the results. Electroless copper was completely oxidized on both top and bottom surfaces. It lost all shielding ability. Both electroless nickel and the composite of electroless nickel over electroless copper showed essentially no change in shielding ability. Either of these two coatings would be expected to perform well for long periods in commercial use.

The Underwriters Lab test method for EMI shielding coatings is found in UL 746C, the standard for brittle coatings. The UL test specifies less than 5% loss on taping cross-hatched areas as received, after heat aging, after humidity aging, and after thermocycle. With proper preparation, all of the electroless coatings can meet the UL standards. Final cabinets coated with electroless coatings of copper, of nickel, and of copper plus electroless nickel have been found to meet the UL requirements.

	dB Decrease		
MHz	Copper*	Nickel*	Nickel Over Copper**
1	-55***	<2	<2
10	-60***	<2	<2
100	-80***	<2	<2
800	-100***	<2	<2

*15 x 10-6 inch per side
**15 x 10-6 inch of each per side
***These figures represent complete loss of shielding efficiency

Table V. Change in Shielding After 336 Hours Humidity

An additional advantage for electroless coatings comes in the area of foamed plastic parts. Various arc spray methods are available for applying thick metal films to foamed parts. However, unless the deposition parameters of the sprayed metal are rigidly controlled, the temperature of the foamed part can become excessive, leading to warpage of the large cabinets and loss of adhesion. When compared with painting of nickel filled paint on foamed plastics, electroless offers further advantages. Many solvents commonly used in painting of plastic enclosures will attack foamed plastic, leading to poor surface finish or alternatively to poor adhesion. Thus, any details which are molded into the plastic surface can be altered or completely covered up by the nickel filled paint coating. An electroless coating is so thin that there is essentially no change of the surface finish of the part. Likewise, the foamed surface itself is now coated with metal, so standard paints can be used to give the final overcoat of paint without fear of attack of the foamed plastic. Most electronic enclosures are painted at least on the outside for appearance's sake. Because the electroless coating is on both the inside and the outside of the part, it is easily processable by standard electrostatic spray equipment using reusable shields or masks for the uncoated areas. Extensive testing of painted parts in both humidity and salt spray testing have shown that these electroless coatings are an excellent substrate for painted electronic housings.

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