A Comparison of Conductive Coatings for EMI Shielding Applications

EDWIN BASTENBECK, BRIAN JACKSON, PETER KUZYK and GARY SHAWHAN
Enthone-OMI

INTRODUCTION

The increasing importance of conductive coatings for EMI shielding has resulted from the greater use of plastic materials in product design. Because plastics are nonconductors and are transparent to electromagnetic waves, the incorporation of a conductive coating has become an important method of providing EMI shielding to digital electronic products manufactured using plastic enclosures. Choices of conductive coating materials are based on electrical, design and reliability issues and manufactured cost issues (Table 1).

The principal types of conductive coatings used to achieve EMI shielding include electroless plating, conductive paints, and vacuum metallization. Within each of these three types of coatings there are several variations (Table 2).

An effectiveness assessment of alternative coatings must address variables of product design.

CONDUCTIVE COATING TECHNOLOGIES

ELECTROLESS PLATING

Electroless shielding is based on an autocatalytic, chemical plating process which produces a pure, continuous and uniform coating of metal to achieve EMI shielding of electronic enclosures. These coatings are duplex coatings consisting of a layer of electrolessly-deposited pure copper with an overcoat of electrolessly-deposited nickel-phosphorus alloy (4 to 10% P). Each layer provides specific performance benefits and contributes in a synergistic manner to the overall effectiveness of the shield. The thin, highly conductive layer of copper provides excellent conductivity for E-field and plane wave shielding effectiveness. The primary function of the electroless nickel-phosphorus top coat is to protect the copper sub-layer from oxidation and corrosion. Additionally, the nickel top coat provides abrasion and wear resistance due to its high as-plated hardness. Furthermore, the electroless nickel coating functions as an excellent paint base when required in post-finishing operations.

Electrical Issues	Design and Reliability Issues	Manufactured Cost Issues
• Increasing fundamental frequencies of operation • Harmonics associated with increasing clock speeds • Increased requirements for power supplies • Increased density in electronic circuitry and electronic packaging, creating more problems with crosstalk during use • Closer proximity of electronics due to size reduction	• Miniaturization/size reduction due to more portable products • Increased complexity in molded plastics to reduce cost through the incorporation of more designed-in features • Increased use of thin-walled molded product • Increased number of digital products in industry • Globalization of EMI regulations • Growing importance of immunity in the global marketplace	• Basic cost of materials • Secondary costs in assembly and production

***Table 1**. Factors Contributing to the Need for Conductive Coatings.*

Electroless shielding processes can be applied over the entire part to achieve complete metallization of an enclosure (Figure 1), or selectively, to metallize only specified areas. For the selective process, a special conductive organic coating is applied by spraying those areas of the plastic part where plating is desired. The balance of the part is masked to insure precise definition between those surfaces which are intended to be plated and those which are not. Selective plating then proceeds in the same manner as the conventional double-sided process, but plating only takes place on those areas where the basecoat has been applied (Figure 2).

The shielding effectiveness and inherent conductivity of the part, whether it is processed selectively or by conventional means, are primarily functions of the thickness of the copper. Surface resistivity or impedance is also influenced by the smoothness of the surface for a given copper thickness. For most applications, the copper and nickel thicknesses necessary to meet normal FCC performance requirements are in the ranges given in Table 3.

Increased shielding performance, in both E-field and plane wave, can be achieved by incorporating additional copper thicknesses. Electroless copper can be applied commercially and economically up to approximately 200 µin (5 µm). Beyond this range, electroplated copper can be used to supplement the process and achieve greater thicknesses if required. However, electroless plating is not capable of providing significant levels of H-field shielding. Even with increased thicknesses of nickel, it has limited absorption and permeability.

In the case of electroless nickel, a thickness of 10 to 25 µin (0.25 to 0.6 µm) is normally sufficient to provide protection to the underlying copper film and also to provide adequate durability. Increased thicknesses of electroless nickel can be achieved readily through longer immersion times. In some cases, greater thicknesses of nickel are desired to accommodate certain attachment procedures, such as soldering, or to further improve corrosion and wear performance. Nickel thicknesses of 200 to 500 µin (5 to 12.5 µm), for example, can be achieved when needed. Other metals, such as tin, can also be plated onto the nickel if desired.

Conductive Paints

Conductive paints have traditionally been used to coat plastics to achieve EMI shielding. This technology is based on the incorporation of a conductive filler and pigments into a resin binder. In general, the alternative types of conductive fillers used in today's conductive paints include copper, silver, graphite or nickel. The primary binder systems used in the formulation of these products include vinyls, acrylics, polyurethanes and epoxies.

The most commercially significant conductive paint technology today is based upon copper. This may or may not include the use of silver-plated copper fillers to enhance copper conductivity and to assist in protecting the copper film from oxidation when exposed to corrosive conditions. Conductive copper and silver paints are primarily suited for addressing the requirements for shielding in the E-field and plane wave applications. They possess no significant capability to provide H-field shielding. Permeable materials like mu-metal are best suited for these situations.

Silver-based conductive paints offer excellent conductivity and can be applied at lower dry film thicknesses while still providing effective shielding. However, the very high material costs associated with silver paint tend to restrict its use.

Nickel conductive paint has been a traditional shielding choice for plastic parts, but its lower level of conductivity has

Electroless Plating • Double-Sided Plating • Selective Plating
Conductive Paints • Silvered Copper Paint • Copper Conductive Paint • Nickel Conductive Paint • Silver Conductive Paint
Vacuum Metallizing

Table 2. *Principal Conductive Coatings.*

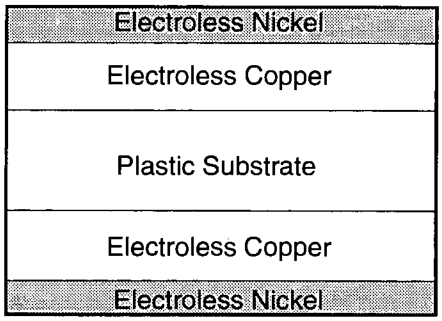

Figure 1. *Double-sided Plating Process.*

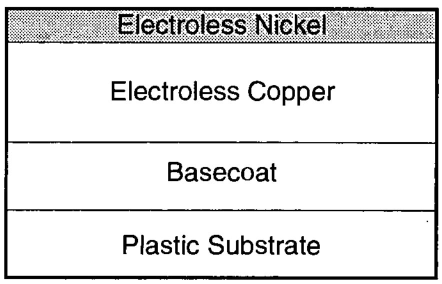

Figure 2. *Selective Plating Process.*

	Copper	Nickel
Double-Sided	40-80 µin	10-25 µin
	1-2 µm	.25-.6 µm
Selective Plating	80-100 µin	10-25 µin
	2-2.5 µm	.25-.6 µm

Table 3. *Typical Plating Thickness.*

begun to limit its use for many of today's electronic products. Although the performance of nickel paint, in most applications, is not equal to that of copper paint, electroless plating or vacuum metallizing, it continues to meet the needs of the market when shielding requirements are more modest and the environmental resistance of the coating is not a significant issue. One advantage of nickel paint over copper or silver paint is its durability, due to the hardness of the nickel. In addition, as is the case with greater thicknesses of plated nickel, limited amounts of H-field shielding can be attained when nickel paint is used.

Conductive paints usually involve high solids, solvent-borne processes, although some water-borne processes are also used commercially. The paints themselves are applied through a variety of conventional spray techniques, and as such, can be processed at a number of commercial operations. High-volume, low-pressure (HVLP) equipment is most often selected for conventional spraying operations. HVLP equipment improves the transfer efficiency of the paint as compared to traditional high-pressure spray equipment (air atomizing or airless). Typical over-spray losses for conductive paints are in the range of 30 to 40%. For parts with less complex geometries, over-spray losses can be less than 30%. In contrast, with more complexity incorporated into the designed-in features, additional passes are necessary to avoid flooding in some areas and/or leaving voids in others. Thus, over-spray losses tend to increase under these circumstances. In high-volume production, robotics and HVLP equipment are employed to improve uniformity and consistency in the application of the paint.

Conductive paints, by the very nature of the process, are selective to the areas where they are applied. As such, they use masking techniques similar to those employed for selective plating. The shielding performance of conductive paints varies with the thickness of the dry paint film and with the inherent conductivity of the paint, which is a result of the filler used and the uniformity of the conductive filler within the binder system. Surface resistivity is also influenced in the same way and is further affected by variations in the uniformity of the paint film over the entire surface of the part. In cases where the paint is flooded onto the part, settling of the conductive fillers in the paint film may result, reducing conductivity in that area.

Typical thicknesses used to achieve adequate EMI shielding from conductive paints are summarized in Table 4.

Copper Paint	2-3 mils 50-75 μm
Nickel Paint	2-3 mils 50-75 μm
Silver Paint	0.5-1.5 mils 12-37 μm

Table 4. *Typical Application Thicknesses (Dry Film).*

Vacuum Metallizing

Vacuum metallizing for EMI shielding is principally based upon vacuum-deposited aluminum. In the application of the process, parts are masked and placed on fixtures which rotate inside the vacuum chamber where the deposition takes place. During the deposition of the aluminum, the vacuum chamber is pumped to a low enough vacuum to vaporize the aluminum which is deposited onto the plastic part as it rotates in the chamber. Pure aluminum is sited in the chamber on the electrically-heated evaporator unit (located in the center of the chamber). An aluminum vapor radiates like a cloud out from the center of the chamber, condensing onto the plastic parts as well as onto the chamber itself.

Vacuum deposition is a batch process that is best suited for small-to-moderate size parts with limited complexity. The typical thicknesses applied for EMI shielding are 0.1 to 0.25 mils (3 to 6 μm). Commercially, thicknesses of up to 0.5 mils (12 μm) have been used for EMI applications.

Masking of the parts is accomplished using conventional hand-masking methods or in conjunction with the actual fixtures used to hold the parts in the chamber. The vacuum process can require a surface preparation step, such as plasma, to aid in the adhesion of the vacuum-deposited aluminum to the plastic. Since vacuum deposition is a batch process, it is most cost-effective when the part size and design allow for an increase in the number of parts in the chamber while simplifying the masking that is needed.

As with any spray coating process, vacuum deposition is a line-of-sight dependent technology. Thus, masking and fixturing become more important elements in the successful, cost-effective application of the coating as the design complexity increases.

PERFORMANCE CONSIDERATIONS

ELECTRICAL PROPERTIES

The conductivity of coatings can be measured using several different methods. The two most common means of determining conductivity include the ohms-per-square test method and the point-to-point measurement (Tables 5 to 7).

In the case of conductive shielding materials which are designed to address E-field and plane wave shielding, the importance of high surface conductivity increases significantly with the fundamental frequencies of device operation. In addition, the effects of the harmonics associated with

	Conductor Thickness	Conductivity
Double-Sided Plating	50-80 µin 1.2-2.0 µm	0.01-0.02 Ω/sq.
Selective Plating	80-100 µin 2.0-2.5 µm	0.02-0.03 Ω/sq.
Silvered Copper Paint	1.5-3.0 mils 37-75 µm	0.03-0.05 Ω/sq.
Copper Paint	2.0-3.0 mils 50-75 µm	0.2-0.5 Ω/sq.
Nickel Paint	1.5-3.0 mils 37-75 µm	0.5+ Ω/sq.
Silver Paint	0.5-1.5 mils 12.5-37 µm	0.03-0.05 Ω/sq.
Vacuum Deposition	200-300 µin 5-7.5 µm	0.1-0.2 Ω/sq.

Table 5. *Conductivity of Alternative Shielding Methods According to Ohms-per-Square Measurement.*

	Ω	Ω	Ω
Double-Sided			
A-B	0.17 (1.6 µm)	0.04 (3.2 µm)	0.03 (4.0 µm)
A-C	0.21 (1.6 µm)	0.06 (3.2 µm)	0.04 (4.0 µm)
Selective Plating			
A-B	0.25 (1.6 µm)	0.07 (4.0 µm)	0.03 (8.0 µm)
A-C	0.14 (1.6 µm)	0.09 (4.0 µm)	0.04 (8.0 µm)
Silvered Copper Paint			
A-B		0.65 (80 µm)	0.34 (120 µm)
A-C		0.72 (80 µm)	0.34 (120 µm)

Table 6. *Conductivity Measured According to Point-to-Point Method. Measurements made on laptop computer top cover, as coated. Approximate 12" horizontal distance point-to-point.*

	Point-to-Point Ω		Ω/Sq.
	A-B	A-C	
Double-Sided (3.2 µm Cu)	0.04	0.06	0.02
Single-Sided (4.0 µm Cu)	0.07	0.09	0.02
Silvered Cu Paint (80 µm)	0.65	0.72	0.03

Table 7. *Conductivity Measurement Techniques Compared.*

these fundamentals increase the importance of determining both the conductivity of the coating and the uniformity of the conductive film across the entire surface of the part.

In production, conductivity testing becomes an important means for quality control of individual parts as well as for part-to-part testing of assembled enclosures. For plated coatings, ohms-per-square testing can also be used as an effective check on the actual thickness of plated metal films, due to the uniformity and conductivity of the metal film itself.

OHMS-PER-SQUARE TESTING

Ohms-per-square testing involves the placement of a probe on the surface of a part. This probe has two outside blocks of equal geometry and a space of equivalent dimension between the blocks (Figure 3). In general, the ohms-per-square test produces relatively ideal results for a given coating in that the proximity of the measurement is very close. Variability in readings will result from differences in the pressure applied to the surface by the inspector. In addition, variations in the surface topography due to variability in the conductor thickness, discontinuities in the coating, or as a result of part roughness will also affect the final result.

On plated parts, the test is useful as a quick quality control check to verify that a minimum thickness of metallic copper has been deposited. The ohms-per-square method can also be used during processing of the copper plate to check an intermediate point for work in progress to confirm the actual metal thickness on the part in relation to a customer's specification. In the case of conductive paint, the ohms-per-square method is only capable of verifying that there is sufficient film thickness to achieve a given resistivity value.

The ohms-per-square test is also an effective means of ranking alternative materials. This method, however, is not very effective for assessing the overall conductivity of a coating across an actual part, or part-to-part. The part geometry, the size, and features such as vents, card guides, standoffs, ribs, bosses, etc. can have a significant influence on conductivity measurements and will contribute to impedances due to variability in the thickness of some conductive coatings during application.

POINT-TO-POINT TESTING

Point-to-point conductivity testing is the most common means of evaluating the actual conductivity of shielding materials on production parts (Figure 4). This method utilizes two spring-loaded probes that are placed at designated positions on the part or between two areas on mating parts (part-to-part conductivity). The conductivity between these two points is then taken as the measurement.

Point-to-point testing is an effective means of evaluating the consistency of a given conductive material across actual parts. Typically, three to five locations (e.g., A-E, A-B, A-C) are selected. These locations often include those areas of the part where there is concern over impedance due to variability in the actual coating. Thus, A-E might traverse bosses, supports, standoffs, etc. which represent line-of-sight concerns in the application of a given conductive coating. A-B might traverse areas where there is a very limited surface area through which current can be conducted. Distances that incorporate vent areas and card guides fall into this category. A-C might cover a measurement where contact at mating surfaces or point of contact (i.e., seams, joints, standoffs, etc.) is a concern.

SHIELDING EFFECTIVENESS

The shielding effectiveness (SE) of conductive coatings can be evaluated using a variety of different methods. These include the dual chamber and the transmission line methods and the newer coaxial transmission line test.

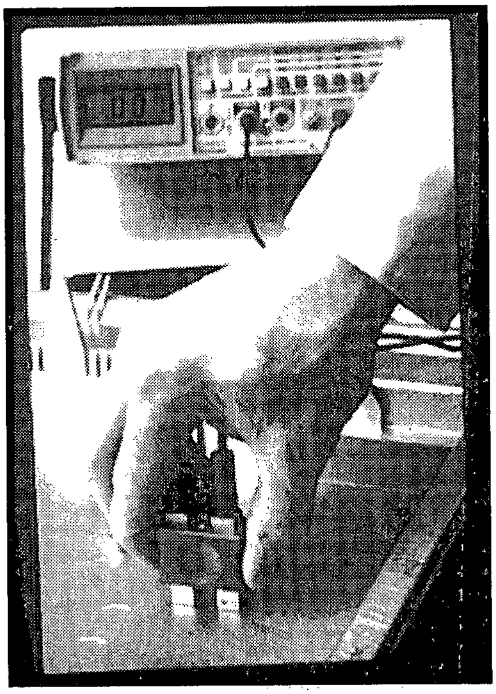

Figure 3. *Ohms-per-Square Testing.*

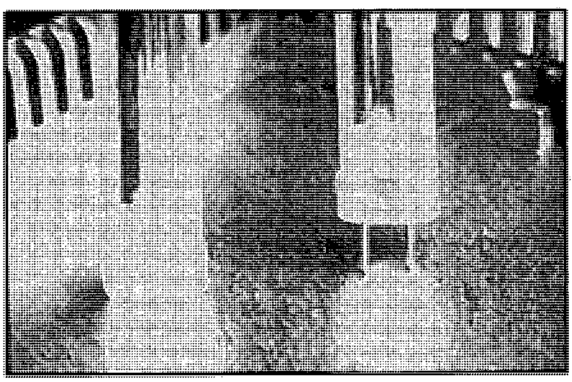

Figure 4. *Point-to-Point Testing.*

DUAL CHAMBER / TRANSMISSION LINE TESTING

Shielding effectiveness testing as defined by the ASTM ES7-3 Standard evaluates and ranks alternative shielding materials on flat or planar surfaces. In this standard, the near-field region is evaluated using the dual chamber test method. The far-field region is evaluated using the transmission line test method (Table 9).

In general, the far-field region is that region where the distance from the radiating device is greater than 5 λ. At this point, the ratio between the magnetic field and the electric field is equal to $\lambda/2\pi(377\ \Omega)$ which is the RF free-space impedance. The near-field and transition areas are those regions where the distance is less than 5 λ. The transition point between the near-field and far-field region is $\lambda/2\pi$. Below this transition point, both electric and magnetic fields need to be considered.

The test results from Tables 8 and 9 suggest several general conclusions on the relative SE of these alternative materials.

- Double-sided plating provides greater SE than alternative methods. This is partly due to the synergistic benefits of a coating on both sides of the plastic, increasing its ability to provide added reflected wave radiation.
- Far-field transmission line test results produce higher attenuation values, especially for plated metal coatings. A principal reason for this is the performance of more highly conductive coatings in E-field and plane wave conditions. The dynamic range for this test method is also higher, raising the attenuation values in general.
- At higher frequencies, currents tend to flow closer to the surface of the conductive film. Shielding effectiveness is partly affected by both the conductivity and the uniformity of the conductive coating.
- Near-field dual-chamber test results tend to produce lower values for each type of coating. In part, this is the result of the role played by magnetic H-field radiation under these conditions.
- The shielding performance of plated coatings is consistently higher than that of conductive paints. The differential increases at higher frequencies. The differential is also much greater under far-field test conditions. Copper paints are noticeably better than nickel paints, especially at higher frequencies. The performance of silvered copper paint (based on general information published separately) is somewhat greater than of standard copper paint, but poorer than of

Continued on page 278

plated coatings. Vacuum metallizing offers good shielding performance at relatively low thicknesses.

COAXIAL TRANSMISSION LINE TESTING

Comparative testing has also been performed according to the newer ASTM D-4935-83 test method. This method is designed to measure the SE of a planar material due to plane-wave and far-field EMI wave radiation.

Table 10 shows the improvement in as-coated samples when a silvered copper paint is used versus standard copper paint. It also shows relatively similar shielding performance between silvered copper paint and selective plating within traditional application thickness ranges. The traditional advantage of double-sided plating is shown.

LONG-TERM PERFORMANCE

Product reliability and quality demands in today's electronic marketplace have placed increasing pressure on the material selection process. In the case of shielding materials, a major concern exists with the ability of alternative coatings to maintain their adhesion, conductivity and resulting SE over extended periods of time. Furthermore, the rapid growth in portable electronic devices, such as laptop computers and hand-held portable products like cellular phones, pagers, sub-notebook products, etc. has increased the likelihood that a given product will be exposed to potentially aggressive environments.

Several test methods have been utilized to address this concern. These include the UL-746C accelerated temperature and humidity test, the 4/4/16 temperature humidity cycling test developed by IBM, the ASTM B-117 neutral salt spray test, environmental cycling tests that involve the introduction of bleed-in industrial gases to simulate different levels of aggressive industrial corrosive environments, and other types of accelerated tests that address very high and low temperature

	30 MHz	100 MHz	300 MHz	1000 MHz
Double-Sided 2.4 µm Cu Per Side	84 dB	75 dB	>94 dB	>74 dB
Selective Plating 5.2 µm Cu One Side	65 dB	53 dB	55 dB	64 dB
Nickel Paint 80 µm (Dry)	61 dB	49 dB	53 dB	33 dB
Copper Paint 80 µm (Dry)	62 dB	51 dB	55 dB	57 dB
Dynamic Range	90 dB	81 dB	94 dB	74 dB

***Table 8**. Shielding Effectiveness According to the Dual Chamber Test.*

	30 MHz	100 MHz	300 MHz	1000 MHz
Double-Sided 2.4 µm Cu Per Side	>99 dB	88 dB	>92 dB	>91 dB
Selective Plating 5.2 µm Cu One Side	83 dB	83 dB	80 dB	91 dB
Nickel Paint 80 µm (Dry)	43 dB	43 dB	39 dB	40 dB
Vacuum Metallizing (6 µm)	70 dB	68 dB	60 dB	68 dB
Copper Paint 80 µm (Dry)	57 dB	56 dB	50 dB	53 dB
Dynamic Range	99 dB	94 dB	92 dB	91 dB

***Table 9**. Shielding Effectiveness According to the Transmission Line Test.*

Frequency	30 MHz	300 MHz	600 MHz	1,000 MHz	1,200 MHz
Silvered Cu Paint					
37 µm	78	73	72	76	77
50 µm	82	78	75	81	85
75 µm	79	82	86	89	91
Copper Paint					
50 µm	65	63	59	62	61
75 µm	67	65	63	64	65
Selective Plating (Cu Thick. on One Side)					
2.0 µm	77	73	71	73	72
4.0 µm	82	81	83	83	81
8.0 µm	91	89	90	92	93
Double-sided (Cu Thick. on Two Sides)					
1.6 µm	90	108	104	104	98
3.2 µm	98	107	108	106	97
4.0 µm	96	109	109	104	98

***Table 10**. Attenuation (dB) According to ASTM D-4935-83 Coaxial Transmission Line Test.*

cycling. Testing such as the 4/4/16 method is designed to simulate product life performance. Thermal cycle and thermal shock testing is designed to assess coating adhesion.

Testing of various conductive coatings including electroless plating (both selective and double-sided), conductive paints and vacuum metallizing has been performed in a variety of these accelerated test methods. Since EMI shielding performance, which deteriorates with oxidation, is directly tied to the electrical conductivity of a given process, environmental test data offers a good comparison of current technologies after accelerated testing.

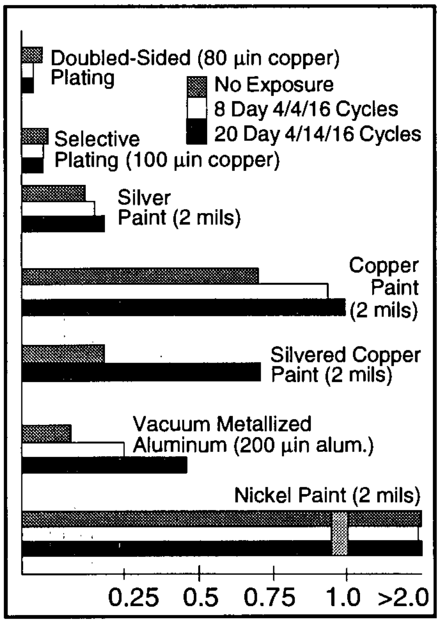

***Figure 5**. Point-to-Point Conductivity, Ω, According to Temperature Humidity Test Results.*

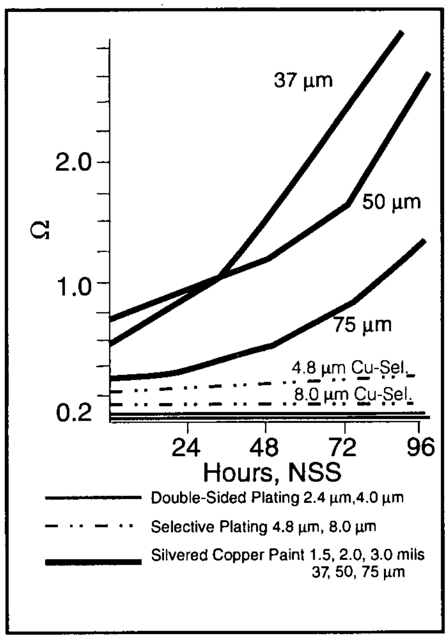

***Figure 6**. Point-to-Point Conductivity, Ω, According to Salt Spray Test.*

ELECTRICAL PERFORMANCE AFTER ENVIRONMENTAL CYCLING

Figures 5 and 6 provide a summary of the expected changes in electrical performance based on exposure to selected accelerated environmental test conditions. Test data is shown for copper paint, electroless plating and vacuum metallizing. Nickel paint is not included due to its significantly poorer performance in these tests.

ADHESION

The adhesion of conductive coatings on plastics for EMI shielding is normally guided by the UL-746C adhesion test method. This method uses the ASTM D-3359-83 crosshatch tape adhesion test method as the means of rating the adhesion of the coating over a range of 1 to 5. Typically, a rating of 3 or greater is necessary to be considered satisfactory.

Each of the principal conductive coating technologies easily passes the UL-746C test method when properly applied on resins that are suitable for the process selected. Not all resins are suitable for a given process. In this regard, discussions with the supplier or applicator of the process help to determine which resin grades can be expected to produce the best result.

The adhesion of double-sided plating to a given plastic is primarily determined at the beginning of the pre-etch and etch stages of the process. Certain grades of plastic within a particular family of resins are often designated as plating-grade materials. The bonding mechanism is principally mechanical and depends on the micro-etch porosity imparted to the plastic. Once the process is established for a given plastic, repeatability is excellent. Some of the more chemically-resistant engineering plastics may require special considerations to obtain reliable adhesion.

Conductive paints and the catalytic base coats used to facilitate selective plating employ a similar adhesion mechanism. In general, this is a mechanical bond achieved in part by the binder system but primarily through a controlled attack on the plastic by the organic solvent components of the formulation. Since there are both waterborne and solvent-borne processes associated with conductive paints and the base coats used for selective plating, there are also some fundamental differences from product to product that define the process window for obtaining adhesion to a given plastic. For many of the more commonly used resins, adhesion is good and very consistent. When more chemically-resistant engineering resins are used, adjustments to the solvents used in the coating to attack the plastic may be required to effect good adhesion.

Stresses imparted to the plastic during the molding process can also affect coating adhesion for all conductive coating processes, especially in areas where these stresses are concentrated. The solution to these adhesion failures is not normally found in the coating process, but in corrective action in the molding of the part. This includes attention

Continued on page 287

to melt flow, fill speeds and pressures, and part design.

COST COMPARISONS

The relative costs associated with alternative conductive coatings need to be examined from a process perspective (Figure 7). Cost differences are normally based on application-specific issues. One technology can be a little less expensive for a given part and more expensive for another. In this regard, it is important to identify the elements of process cost that can come into play in determining the total cost.

In general, the basic costs associated with conductive paints (except silver) and selective electroless plating are similar. The differences that might exist are most often related to the issues described below. Double-sided plating is the least expensive technology, but will normally require exterior painting on any enclosure parts that are not internal to the product. Selective plating and conductive paints can avoid this step, but in a number of cases an exterior color-coat of paint or a "soft touch" paint is applied to meet final customer requirements. Material costs for silver conductive paint are high, making it more of a specialty coating process. The cost competitiveness of vacuum metallizing in comparison to conductive paints or selective electroless plating varies with both part size and the level of complexity in the part design.

Factors such as material losses in manufacture, masking, process control, waste disposal, throughput and post-painting/finishing steps are also important considerations.

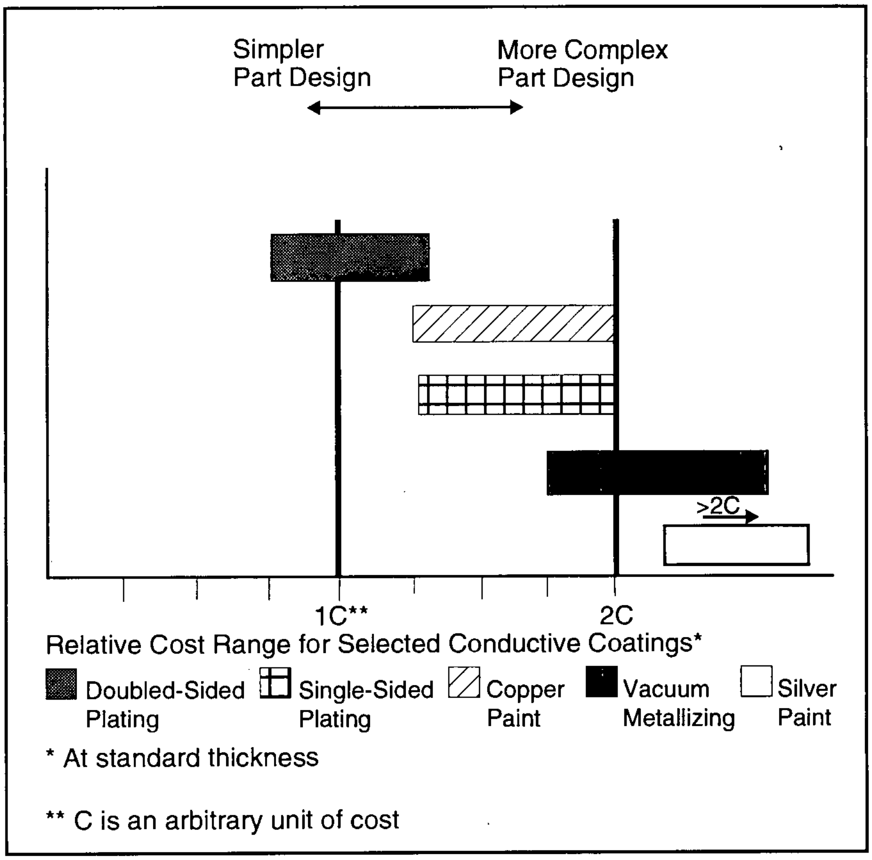

Figure 7. *Relative Costs of Conductive Paint and Plating Processes.*

SUMMARY

Conductive coatings technology has continued to evolve along with the changes in product design and the complexity of today's electronics. Any assessment of the current capabilities of conductive coatings must include not only the basic performance differences that exist between each coating type, but also the capability of the process to deal with key variables in product design. In addition, cost is always an important consideration in the selection process.

ACKNOWLEDGMENT

The authors would like to gratefully acknowledge the contributions of Apogee Plastics, Daytona Beach, FL, in the development of some of the electrical and shielding performance data included in this paper.

EDWIN BASTENBECK *has been associated with Enthone-OMI since 1961, and is presently Research Manager in charge of research and development for plating processes. Mr. Bastenbeck attended the University of Connecticut and the University of Southern Connecticut. He holds four U.S. and international patents for plating on plastics, selective metal stripping, selective EMI/RFI shielding processes, and pre-etches for polycarbonates, and he has received several industry awards. (203) 799-4909.*

BRIAN JACKSON *is Marketing Manager for Enthone-OMI's electronics business in Europe. His particular specialty is electroless plating technology. He has been the architect of many product development programs and achieved much success with marketing Enthone-OMI's proprietary process for EMI shielding. Brian is a Fellow of The Institute of Metal Finishing. He is author of several articles and technical papers, and is active in various industry associations for the promotion of electroless plating technology. (203) 799-4909.*

PETER KUZYK *is International Marketing Manager for Enthone-OMI. He has been associated with the finishing industry since 1977 in various positions, including marketing of EMI shielding and electroless nickel technologies, sales, manufacturing and R&D. Mr. Kuzyk received a degree in science in 1977, and an MBA from Rensselaer Polytechnic Institute in 1985. He is an active member of the AESF, SAE and ASM, and is a past president of the Boston branch of the AESF. (203) 799-4909.*

GARY J. SHAWHAN *is the Marketing Development Manager for non-PWB electronic applications at Enthone-OMI and has more than ten years of experience in electroless plating and plastics plating. He has worked with plated plastics for EMI shielding since 1983. He is co-chairman of the ASEP Electronics Industry Council and is a member of IEEE, SPE, and ISHM. (203) 799-4909.*