Performance characteristics of conductive coatings for EMI control

Conductive coatings can be compared in terms of shielding effectiveness when exposed to environmental tests, including thermal shock, temperature and humidity, and salt spray.

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There has been an increase in the use of plastics in the manufacture of electronic equipment, particularly in computers and telecommunications. This has been driven by economics and has allowed for increased miniaturization and more complex designs.

Due to the dielectric nature of the plastic, it has been necessary to develop shielding techniques to protect sensitive electronic devices from any external interference and to develop complete immunity.

In developing shielding techniques, it has been necessary to consider the advantages of using the full-function design flexibility of plastics for multi-site manufacture and assembly.

EMI-RFI shielding of plastics is achieved by the use of a conductive coating generally applied to the plastic substrate (Table 1). As an alternative, internal metal shields can be used, provided space permits.

Demands in the marketplace over the last 10-plus years have resulted in improved coating technology to meet the needs of the manufacturers of electronic products. Improvements have been achieved not only in performance, but also in application.

The key issues which determine the performance of the conductive coating when applied to the plastic are:

Adhesion
- Integrity of the coating before and after environmental cycling
- Ability to process an increasing number of engineering thermoplastics and thin-walled molded parts

Conductivity
- Highest conductivity point-to-point to meet the demands of today's electronics
- Faster clock speeds, harmonic effects, avoidance of part-to-part impedance
- Retention of conductivity after environmental cycling to ensure reliability of the final product in the field
- Uniformity of the conductive film to ensure current flows are flat

Uniformity/Dimensional Consistency
- Incorporation of more functionality into

Electroless coatings	Double-sided plating Selective (single-sided plating)
Electrolytic coatings	Double-sided plating
Conductive paint	Silver Silvered copper Nickel silver Nickel
Vacuum metallizing	Aluminium Other metals

Table 1. Key conductive coating processes.

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the design of injection-molded plastic places more emphasis on the tolerance of the process in accommodating the inclusion of added features
- Avoidance of line-of-sight dependence in coating applications
- Consistency in film thickness to ensure mating during assembly
- Reproducible coating thickness to ensure consistency in high volume production

Durability
- Good abrasion and wear resistance to facilitate retention of the conductive film during mating and unmating of parts at snap-fits and during assembly

Corrosion and Oxidation Resistance
- Retention of the electrical conductivity over the expected life of a given product. This is especially important with the increased number of hand-held, portable electronic products now in use.

Cost
- Cost competitiveness of the process with consideration to materials, material losses, throughput, yields, masking, final finish costs, etc.

Appearance
- Importance of uniform part appearance, even for internal areas.

Recycle/Reuse/Waste Treatment
- The ability of a given coating process to meet the needs of recycling and reuse with regard to the finished part
- Waste treatability of the technology within existing regulations

Gasket Compatibility
- Importance of form-in-place gasket compatibility, particularly in terms of good adhesion.

Since EMI/RFI is achieved via a conductive coating mechanism rather than the bulk absorption properties of the coating, it follows that the more conductive the coating, the better the shielding performance.

In Table 2, silver is shown to have the highest conductivity, and as such would be expected to provide the greatest shielding effectiveness. Copper, however, the basis for the plated coatings, is a close second and with its lower cost, has many attractions.

Silver	1.08
Copper	1.0
Gold	0.7
Aluminium	0.66
Zinc	0.3
Nickel	0.22
Tin	0.15
Electroless Nickel 2.1-percent Phosphorus	0.057

Table 2. Relative conductivity of shielding metals.

ELECTROLESS COATINGS

Electroless coatings are deposited onto the plastic substrates by either all-over plating or selective plating. The all-over plating process involves etching the plastic, usually with chromic acid, and activating with a palladium catalyst, whereas the selective plating process involves coating selectively with a base coat to provide a catalytic surface. The base coat is applied by spraying, preferably using robotics.

After a catalytic surface is applied, parts are coated with high conductivity copper, followed by nickel for corrosion and wear protection.

The deposition by immersion of copper and nickel is achieved by the autocatalytic chemical reduction of metal ions from solution. The thickness of the deposited metal is dependent upon the duration of immersion.

For all-over plating, 1 µ to 1.5 µ copper and 0.3 µ to 0.4 µ nickel is generally sufficient for effective shielding, whereas for selective plating, 2.5 µ to 4.0 µ copper and 0.3 to 0.4 µ nickel would be used.

Although copper exhibits excellent conductivity, it readily oxidizes to a lower conductive state upon exposure to the environment; this significantly reduces its shielding effectiveness. It is for this reason that a nickel topcoat is applied over the copper layer to produce the duplex electroless coating. The electroless nickel top coat serves as a barrier layer to protect the highly conductive copper underlayer from environmental exposure, thereby preserving the conductive properties of the coating. The thin electroless nickel topcoat provides superior wear and abrasion resistance for snap fits and interconnect mechanisms. The electroless nickel also serves as an excellent paint base for subsequent decorative finishing.

These thin coatings obviously provide the benefit of low weight gain. The main benefit, however, of electroless coatings is the absolute uniformity and continuity of the coating over a complex shape, providing consistency of shielding effectiveness.

Electroless coatings are the only coatings that are independent of line-of-sight.

As with any selective process, the selective electroless process has the benefits of no finish painting requirement, and compared to all-over plating, it eliminates the need for chromic acid etching and palladium activation. Both processes can be readily automated.

The elimination of etching can be of benefit when using thin walled moldings, i.e., mobile telephones.

ELECTROPLATED COATINGS

Electroplated coatings utilize the same pre-treatment sequence as all-over plating electroless coatings and are used:
- To produce thicker coatings of copper
- To decorate finishes for aesthetic purposes

The thicker copper coatings can be required to improve the rigidity of the plastic for certain assembly requirements. Thicker copper coatings may also be used for ultra high frequency applications for military or microwave.

Electroplated coatings do not have the same absolute uniformity properties as the electroless coating process, due to current density variations over the part.

Electroplated decorative finishes are available in many colors or finishes; however, this is usually only a consideration on external components.

CONDUCTIVE PAINT

Historically, copper paint (for low cost) and silver paint (for high conductivity) have been used for coating plastic substrates.

In order to maintain lower cost levels, but to improve conductivity nevertheless, developments have included the introduction of silvered copper paints with varying degrees of silver content, i.e., 3 to 9%. However, coating thicknesses of 17 to 37 μ were still required to provide acceptable levels of shielding effectiveness, although environmental resistance was still poor.

Concurrently, the method of conductive paint application was being reviewed. Linked to the use of robotics, for improved definition, were HVLP guns, which use greatly reduced pressures to ensure good atomization. Reduced nozzle sizes were able to be used, ensuring improved transfer efficiency and providing better cost control. These improvements enable a more cost-effective use of the historically more expensive silver paint. With changes to paint formulations and application techniques, thicknesses of 5 to 15 μ of silver paint would provide effective shielding.

To improve the hardness and cohesion, and yet retain the high conductivity of the silver, a recent development has seen the introduction of a silver nickel paint, which requires a thickness of 5 to 25 μ to produce a similar conductivity to silver paint.

Nickel paint is still used to a lesser degree for low-frequency application and ESD.

Where thicker coatings of paint are required, this value clearly relates to a minimum thickness which can be a constraint on parts with a complex geometry.

To date, most conductive paints are based on solvent formulations with varying degrees of VOC content, but show a tolerance to humidity and have the ability to coat a wider range of plastic substrate. Aqueous-based alternatives are now being developed.

VACUUM METALLIZING

Traditionally, vacuum metallizing has used aluminium as the coating of choice. When applied in a thickness of 5 μ, the shielding effectiveness of aluminum was adequate. However, the coating resistance to environmental testing did show signs of deterioration. Thicker coatings can be applied with a double chamber application; this reduces the cost effectiveness and illustrates the fact that the process is a batch process.

Market demands have also led to new developments in the vacuum metallizing sector. To improve conductivity, vacuum coatings of copper are now being investigated by applying thicknesses of 3 to 4 μ. To improve environmental resistance, this is coated with nickel/chromium or 1.5 μ tin.

The vacuum metallizing process still relies upon line-of-sight issues, and therefore has penetration problems, especially in deep recesses such as venting slots. This is particularly the case with the nickel/chromium coating. Vacuum metallizing is generally used as a selective process.

Electrical and shielding performance comparisons of some of the coatings have been carried out. For the electrical and adhesion performance comparisons the following industry test methods were used:

- UL 746C Adhesion Test
- 4/4/16 Temperature/Humidity Test
- 5% Neutral Salt Spray
- Thermal Shock Test
- UL Humidity Test

Ohms-per-square and point-to-point electrical test methods were used as the method of measurement.

Ohms-per-square: Ohms-per-square results typically show only small differences between plating technology, conductive paints and vacuum metallizing.

	Thickness	Conductivity ohms/sq	Shielding Effectiveness, dB
Electroless Coatings			
All-over plating	1 to 2 μ per side Cu	0.007 to 0.02	90-110 dB
	0.3 μ per side Ni	0.01 to 0.02	
Selective plating	2 to 4 μ Cu, 0.3 μ Ni		80-100 dB
Electrolytic Plating			
All-over plating	up to 25 μ Cu	0.007 to 0.02	90-110 dB
Conductive Paint			
Copper/silver	18 to 37 μ	0.05 to 0.10	60-75 dB
Nickel/silver	5 to 25 μ	0.01 to 0.02	75-85 dB
Silver paint	5 to 17 μ	0.01 to 0.02	80-90 dB
Vacuum Metallizing			
Aluminium	5 to 10 μ	0.01 to 0.02	60-80 dB
Copper/Tin	3 to 4 μ Cu	0.004-0.02	60-75 dB
	1.5 μ Sn		
Copper/Nickel Chrome		0.004-0.002	60-80 dB

Table 3. Comparison of conductive coatings for thickness, conductivity and shielding effectiveness.

Specifying ohms-per-square is helpful in confirming the basic fingerprint conductivity at a given point on the part. However, ohms-per-square does not characterize the continuity of the conductive paint across the surface of a manufactured part. Further, ohms-per-square cannot be accurately measured on non-flat surfaces.

Point-to-point: Point-to-point does show differences for all the different conductive coating types based upon variations in the application thickness, part geometry and distance of measurement.

All-over electroless-plated coatings show little variation in point-to-point values due to the uniformity of the deposited copper film.

Selective electroless-plated coatings show minimal change in point-to-point values and values are slightly lower than for all-over coatings due to the subtle differences in the continuity of the copper film which is applied to the selectively-applied base coat.

Conductive paint technology will show variations in point-to-point readings primarily due to variations in application thickness. Increased control of paint thickness by the use of robotics, rotary console, etc., can reduce such variations.

As part geometries become more complex, the contribution of line-of-sight to lower point-to-point readings will increase. Specifying point-to-point conductivity for copper silver paints requires confirmation of attainable results based on specific part geometries and actual painting conditions.

All-over electroless coatings are virtually unaffected in its electrical and EMI performance by accelerated temperature/humidity (Table 4), thermal shock (Table 5) or salt spray testing (Table 6).

Also, selective electroless coatings were not significantly affected by accelerated environmental testing methods.

Silver and nickel-silver conductive paints maintain their conductivity very well after environmental cycling.

Silver-based paints can show a lowering of their resistance after the first test sequence period. This is attributed to further settling or orientation of the silver particles within the paint film.

Silvered copper paints are more vulnerable to deterioration when exposed to corrosive environments such as salt spray (Table 6). Attack of the exposed copper in the paint film produces non-conductive oxides.

Thermal shock has minimal effect on the electrical properties of the silvered copper paint (Table 5). It can clearly show differences in the adhesion and cohesion of all coatings.

Temperature/humidity testing (Table 4), shows differences among various products in their moisture resistance. It also identifies the cohesive characteristics of the paint film for a particular formulation and/or the conditions under which it was sprayed, with respect to humidity.

Shielding performance measurements were also carried out using the coaxial transmission line method (ASTM D-5935-89) for both the initially applied coating and following the same environmental test procedures:

- 4/4/16 Humidity/Temperature cycling
- Thermal shock
- Neutral salt spray

Again, the results were consistent and in line with the relative conductivity measurements expressed in Tables 4, 5 and 6.

In consideration of the performance—both electrical and shielding effectiveness—various conductive coatings offer different potentials to electronics design engineers. These considerations follow.

	Point-to-point, mohm		mohm/sq, ohms/square	
	0	21 Days	0	21 Days
All-over electroless 1.5 μ Cu/side	20 →	20	7 →	10
Selective electroless 2.5 μ Cu	30 →	35	16 →	16
Silver Copper paint 37 μ	600 →	850	80 →	90
50 μ	400 →	550	70 →	80
Nickel Silver paint 10 μ	230 →	180	38 →	31
Silver paint 5 μ	120 →	60	16 →	16

Table 4. 4/4/16 test results—21 days.

USE OF CONDUCTIVE COATINGS IN ELECTRICAL DESIGN

A major benefit of plastic is that design engineers can take advantage of its full function design flexibility including:

- Snap fit
- Bosses
- Card guides
- Stand offs
- Ribs
- Fasteners

However, even with this design flexibility, it is not practical to design a 6-sided enclosure and get it out of the mold. As an alternative, typical design calls for the molding of several subassemblies that are then assembled to provide a 6-sided box.

	Point-to-point mohm		mohm/sq. ohms/square	
	0	32 Cycles	0	32 Cycles
All-over electroless 1.5 μ Cu/side	20 →	25	8 →	8
Selective electroless 2.5 μ Cu	30 →	40	15 →	15
Silver Copper paint 37 μ 50 μ	600 → 400 →	850 600	90 →	100
Nickel Silver paint 10 μ	220 →	190	21 →	18
Silver paint 5 μ	110 →	70	16 →	15

Table 5. Thermal shock results—32 cycles.

The subassemblies usually consist of a base, top and often a bezel and utilize many functional design features including:

- Vents/apertures
- Fasteners
- Seams and snap fits
- Grounds
- Ribs, bosses and stand offs
- Card guides
- Waveguides

Although the use of these design features alleviates the problem of molding a 6-sided enclosure, their use significantly increases the complexity of achieving EMC using electrical design. Hence, including conductive coatings (shielding media) in electrical design to achieve EMC is important.

Since enclosures are not solid 6-sided boxes, the actual shielding effectiveness is usually determined by EMI "leakage" at seams, joints and holes, including vents, rather than by the shielding effectiveness of the shielding media alone. In other words, the conductive coatings must function as uniform and highly conductive coatings across all subassemblies so that, in effect, they will operate as one unit (i.e., 6-sided box) to ensure EMC.

BENEFITS TO EMC DESIGN ENGINEERS

Joints and Seams

One of the most important aspects of electrical design is the method of achieving acceptable part-to-part conductivity at overlapping walls and mating surfaces. EMI leakage between mating surfaces at joints or seams is the primary reason why shielding effectiveness is reduced. If a continuous conductive path does not exist between the mating surfaces, slot antennas can develop. The increased impedance created by reduced or lack of conductivity will result in EMI problems. Maintaining electrical continuity also aids in the dissipation of ESD that may build up.

The potential for slot antennas can be minimized by addressing the issue on two points: (1) properly designing mating surfaces to maximize electrical contact, (2) proper selection and integration of the shielding coating and (3) employment of sound gasketing media—e.g., form-in-place gaskets.

Technology Comparison:

- Conductive paints can cause problems with thickness variations—improvements in application techniques can reduce this.
- Mating surfaces can be thick, difficult to assemble, or thin, loosely fitting, and increase impedance.
- The highest conductivity paint should be used to reduce the required thickness and minimize the coating thickness variation.
- Vacuum metallizing offers uniform coating for part-to-part acceptance mating. However, increased impedance due to poor environmental resistance of aluminium can result.
- Electroless coatings provide uniform coatings for a good fit—good environmental resistance.

Snap Fits, Bosses and Contact Fingers

Mechanical Design: Ease of assembly is a key benefit when taking advantage of the full function design flexibility of plastics. Snap fits are a popular option elected by many design engineers. They allow for multiple site production of various parts and easy low-cost central assembly of the final enclosure. Snap fits may also be used for applications where entry and exit to the internal electronics occur with some frequency.

Electrical Design: The importance of maintaining a conductive path at the contact surface to avoid attenuation loss and slot antenna effects is clear. In addition to being used for mechanical design, snap fits and bosses, as well as contact fingers, are used to achieve EMC through electrical design. Maintaining pressure on the mating surfaces of snap fits provides for a continuous conductive path across mating surfaces.

Technology Comparison:

- Certain conductive paints can show weakness with respect to abrasion resistance. However, new paints such as nickel silver do more towards addressing this issue.
- Similarly, copper/nickel vacuum metallization has been developed to minimize abrasion wear compared to aluminium.
- Electroless coatings provide good

	Point-to-point mohms		mohms/sq, ohms/square	
	0	96 Hours	0	96 Hours
All-over electroless 1.5 μ Cu/side	10 →	15	8 →	15
Selective electroless 2.5 μ Cu	20 →	25	18 →	25
Silver Copper paint 37 μ 50 μ	600 → 300 →	2000* 2000*	50 →	700
Nickel Silver paint 10 μ	200 →	150	35 →	30
Silver paint 2.5 μ 20 μ 10 μ	120 → 70 → —	100 50 —	20 → 14 →	22 12

*2000 milliohms after 72 hours

Table 6. Neutral salt spray.

electrical conductivity across mating surfaces (part-to-part), even after environmental exposure. Electroless coatings also exhibit good wear resistance, primarily due to thin uniform copper/nickel coatings and also because of the high hardness (VH 650) of the nickel topcoat.

VENTS AND APERTURES

Vents and apertures are integral parts of enclosure designs utilizing the full function capabilities of plastics. Vents are typically incorporated into the design to provide for cooling of the internal electronics. Apertures are incorporated into part design to provide access ways in the enclosure for cabling and other electronic connections. Vents and apertures will be present in any array of different dimensions to ensure no EMI leaks and no slot antenna effect.

Technology Comparison:

- Conductive paints exhibit problems on small vents with increased wall thicknesses primarily due to line of sight limitations.
- Vacuum metallizing is satisfactory provided the recesses are not too deep.
- Electroless coatings are uniform on coverage of complex shapes.

GROUNDING

Adequate grounding has become a key requirement for achieving EMC through electrical design. This is because of the increased clock speeds used with modern digital electronics. With the increased clock speeds, electric fields build and fade at a rapid rate and set up current flows and the potential for electromagnetic interference. In the past, enclosures were larger and the distance from the enclosure to the internal electronics was greater, thus reducing the potential for electromagnetic interference.

However, given the trend toward smaller enclosures and more populous electronics, field interactions are a necessary concern and grounding is required to avoid conducted EMI. In addition, the shift toward higher density circuits using surface-mount components and advanced packaging concepts places a significantly increased level of functionality on a single board layer. Circuit lines are much closer together and field interactions are a very significant issue to electrical design. Adequate grounding is necessary in dealing with this phenomenon.

Technology Comparison:

- Certain conductive paints such as copper silver and aluminium vacuum deposition are susceptible to environmental oxidation, resulting in increased surface resistance and higher impedance across the ground. Silver and nickel/silver paints are less susceptible.
- Electroless coatings maintain their surface conductivity due to the corrosion resistance of the electroless nickel deposit.

SUMMARY

Several conductive coatings can be used for EMI/RFI shielding of electronic equipment using plastic housings.

Each will have a place in the market. Electroless coatings technically provide the best shielding compatibility for the following reasons:

- They use high conductivity copper.
- They offer absolute uniformity and continuity.
- There are no line-of-sight issues.
- They offer environmental stability.

Conductive paints, particularly silver-based products, offer good conductivity, and with improved application techniques, can reduce variations in coating thickness.

Vacuum metallizing is a batch process and is also governed by line-of-sight issues. Aluminium does not stand up to environmental testing, and copper nickel coatings are susceptible to throwing power problems on complex shapes.

ACKNOWLEDGMENTS

Our thanks to E. Bastenbeck and V. Pannecassio for their work in helping us to prepare this paper.

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