PRODUCT LIFE PERFORMANCE OF CONDUCTIVE COATINGS FOR THE ELECTROMAGNETIC SHIELDING OF PLASTICS

Various conductive coatings commonly used on engineered plastic resins are tested to show general performance trends when exposed to temperature and humidity variations.

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INTRODUCTION

The responsibility of electronic equipment manufacturers is ever-increasing to meet stricter electromagnetic emissions control and susceptibility requirements and maintain high product quality standards. As these electronic devices enter new domains, the performance characteristics of electromagnetic (EMI) shielding materials must also adapt to new challenges. The challenges of shielding a device employing denser circuitry, faster clock speeds and advanced chip technology, coupled with quicker concept-to-market introduction, are readily apparent to the EMC engineer. However, the broader use of electronic devices in industrial environments, such as process control equipment on the manufacturing floor, has brought to light a new concern relating to the long-term EMC performance of shielding materials.

Various commonly used conductive coatings on engineered plastic resins were tested to show general trends in their performance when exposed to temperature and humidity. Conductive coatings tested included electroless copper/nickel plating, vacuum deposited aluminum, copper-filled conductive paint and nickel-filled conductive paint. Shielding effectiveness and surface resistivity before and after environmental exposure were evaluated.

EXPERIMENTAL PROCEDURES

In today's industrial applications which use electronic devices, the environment can vary considerably. For example, the atmospheric composition in pulp and paper processing environments can include high temperatures and high humidity containing trace elements of sulfides and chlorides in acidic conditions. For the purpose of the general characterization of the conductive coatings in question, a mild environment of temperature and humidity were used only for exposure testing. The temperature was cycled from 23°C to 66°C while relative humidity ranged from 47.5 percent to 93.5 per-

Plastic Substrate	Total Metal Thickness per Side Cu/Ni (microinches)	Shield Efficiency (dB) 30 MHz DR = 105dB	100 MHz DR = 102dB	300 MHz DR = 106dB	1000 MHz DR = 112dB
Polycarbonate	40/15	>105	>102	>106	88
Polycarbonate	65/15	>105	>102	>106	95
Foamed PPO	65/15	>105	>102	>106	92
ABS	65/15	>105	>102	>106	88
ABS	100/10*	>105	>102	>105	72
ABS	80/10*	>105	>102	>104	68

*One Side Application Only

Table 1. Shielding Effectiveness of Electroless Copper/Nickel Coatings, Dual Chamber Method (ASTM ES 7-83).

cent. One complete cycle represented 24 hours in the above temperature/humidity conditions. Coated specimens were monitored at eight days and at the completion of 20 days of temperature/humidity exposure.

Samples of the conductive coatings were obtained from commercially available sources. Conductive coating applications were performed in manufacturing facilities on test plaques and actual production components. Coated plaques were used for shielding effectiveness in the near-field dual chamber test method (ASTM ES 7-83). Production samples were used for surface resistivity (ohms/square; point-to-point).

Thicknesses of the conductive coating were recommended by the manufacturer and/or commercial applicator of the technology with the exception of selective electroless copper/nickel plating. Due to the low dynamic range of the dual chamber unit for testing, the total metal thickness in the electroless copper/nickel duplex coating was 55 microinches versus a recommended thickness of 100 microinches. Previous testing of double-sided (total coverage) and selective electroless copper/nickel plating for typical production thicknesses are given in Table 1.

SHIELDING EFFECTIVENESS

Figure 1 shows the various conductive coatings tested in the as-applied condition. At all frequencies tested, 30, 100, 300 and 1000 MHz, selective electroless plating demonstrated the highest shielding effectiveness, even at lower than recommended thickness levels. As the frequency increased from 300 to 1000 MHz, shielding efficiencies for all conductive coatings tested showed a decline. This is characteristic of the transition at higher frequencies; the absorption component in shielding attenuation becomes more apparent in the shielding material capabilities. As the coatings were expos-

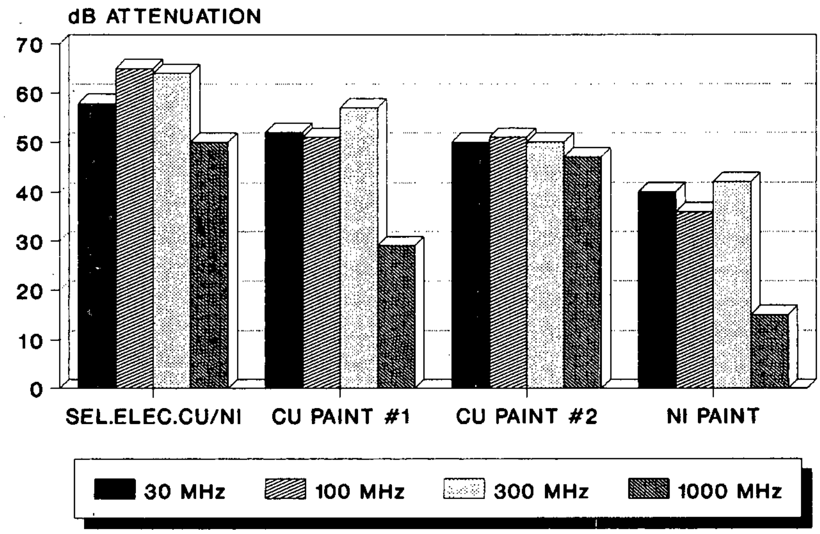

Figure 1. Shielding Effectiveness of Various Conductive Coatings: Dual Chamber Method.

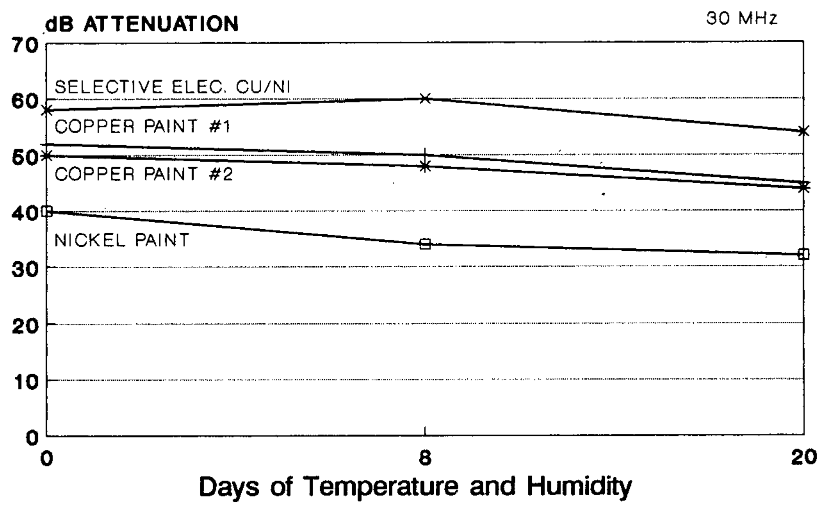

Figure 2. Shielding Effectiveness: Dual Chamber Method at 30 MHz.

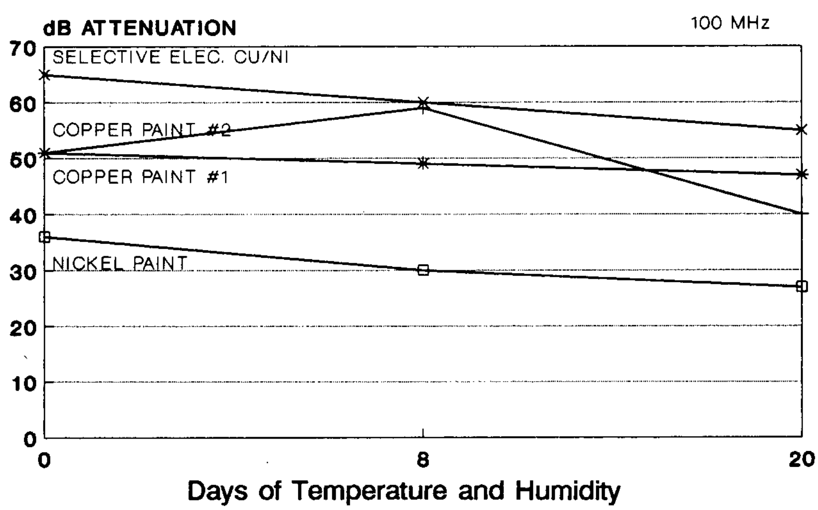

Figure 3. Shielding Effectiveness: Dual Chamber Method at 100 MHz.

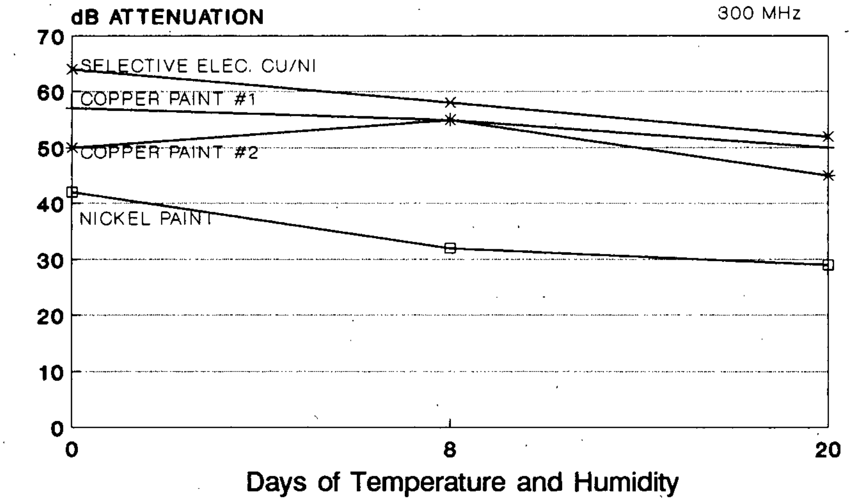

Figure 4. Shielding Effectiveness: Dual Chamber Method at 300 MHz.

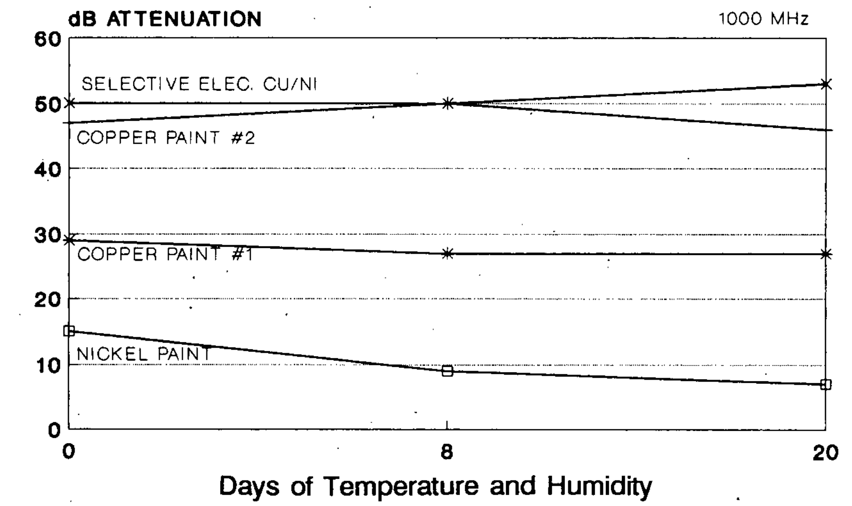

Figure 5. Shielding Effectiveness: Dual Chamber Method at 1000 MHz.

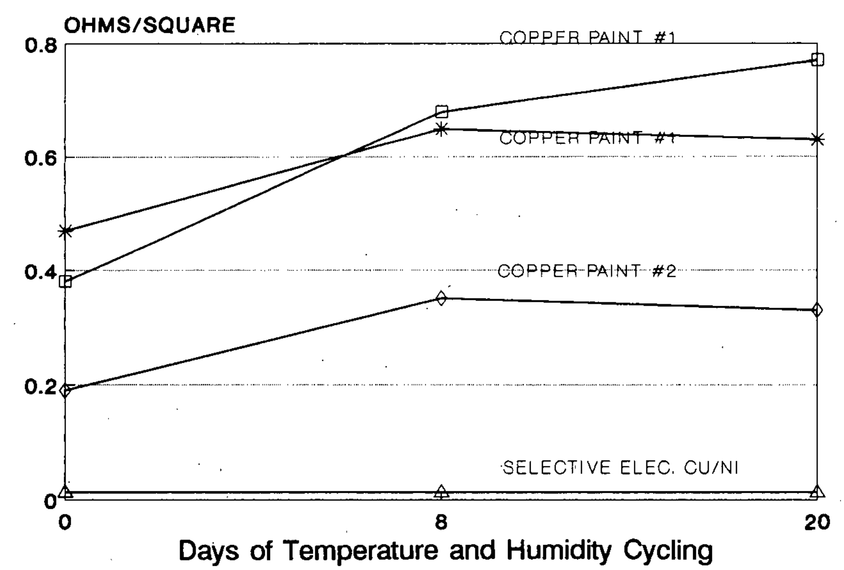

Figure 6. Resistivity of Copper Paint.

ed to a maximum of 20 cycles (20 days) in temperature/humidity, slight decreases in shielding effectiveness were observed (Figures 2, 3, 4 and 5).

The largest negative slope for all coatings appeared at 300 MHz (Figure 4). At 1000 MHz, the shielding effectiveness (Figure 5) from 0 to 20 cycles exposure were virtually unchanged with the exception of nickel-filled conductive paint. This was expected since the absorption factor for shielding materials begins to become a factor. Below 1000 MHz, surface conductivity plays an extremely important role in shielding attenuation. As the absorption factor is considered above 1000 MHz, conductivity of the material with relation to thickness plays a more dominant role than surface conductivity. Thus the degradation of the coating surface due to oxidation and/or corrosion during temperature/humidity exposure is of very little importance in the idealistic testing of flat plaques in the dual chamber test method.

RESISTIVITY

Shielding effectiveness is dependent upon the surface conductivity and thickness of the material providing the EMI attenuation. The importance of surface conductivity becomes evident as the design of electronic housings which incorporate the multiple parts that make up an assembled unit is considered. Here the surface conductivity must be as low as possible and remain relatively unchanged in its product life to avoid impedance changes as energy is moved across part interfaces. Increases in impedances due to loss of surface conductivity, i.e., corrosion and/or oxidation, can create localized radiating antennas.

Testing the various conductive coatings revealed some very surprising results from the as-applied conditions to 20-day temperature exposure conditions (Figures 6 through 12). In Figure 6, two different types of copper-filled conductive paint were evaluated on test plaques. The initial surface conductivities of the different compositions varied considerably in the as-applied conditions, and ranged from 0.2 to 0.5 ohms/square. All copper paint samples demonstrated a very quick increase in surface resistivity, but reached a steady state by the eighth cycle of temperature/humidity exposure.

The nickel-filled conductive paint in Figure 7 did not fare well in the presence of temperature/humidity. Samples tested consisted of both commercially available solvent-based and water-based formulations. Significant differences in the as-applied surface conductivity were observed. The water-based formulation showed the lowest initial surface conductivity at 0.19 ohms/square with solvent-based chemistry varying from 1.4 to 4.9 ohms/square. Samples from water-based and solvent-based formulations rapidly lost surface conductivity as they were introduced to temperature/humidity. The loss of surface conductivity continued as the exposure was concluded at 20 days. One sample of the solvent-based nickel paint formed a very heavy oxide layer that did not allow any surface conductivity measurement to be taken without penetrating the oxide layer.

Vacuum deposited aluminum (Figure 8) was tested on several production samples -- a medical instrument housing, a telecommunication headset and a bar code scanner housing. Surface conductivity measurements for the as-applied condition ranged from 0.18 to 0.5 ohms/square. Vacuum deposited aluminum showed the greatest negative effect when exposed to environmental conditions. In several of the production housings tested, a significant loss of metal, which resulted in exposing the base plastic substrate, was observed. Areas of the remaining metal that could be tested again varied considerably. Several samples formed a heavy aluminum oxide layer, which

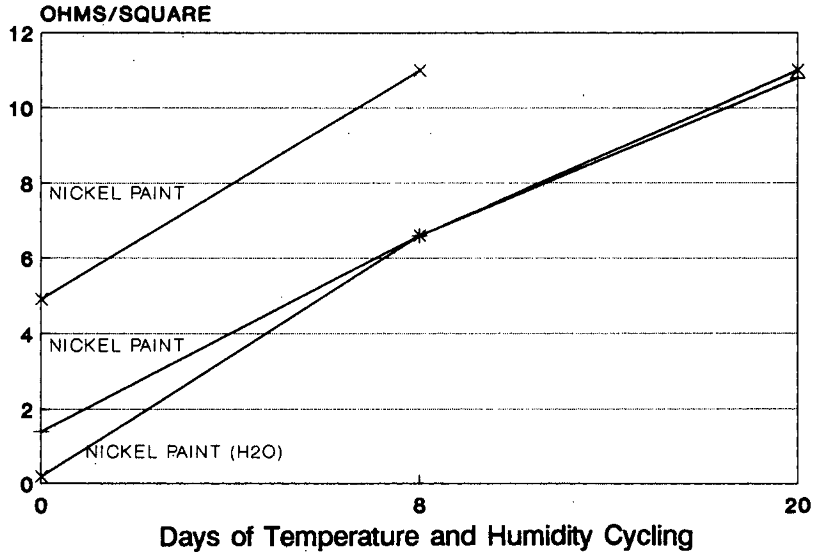

Figure 7. Resistivity of Nickel Paint.

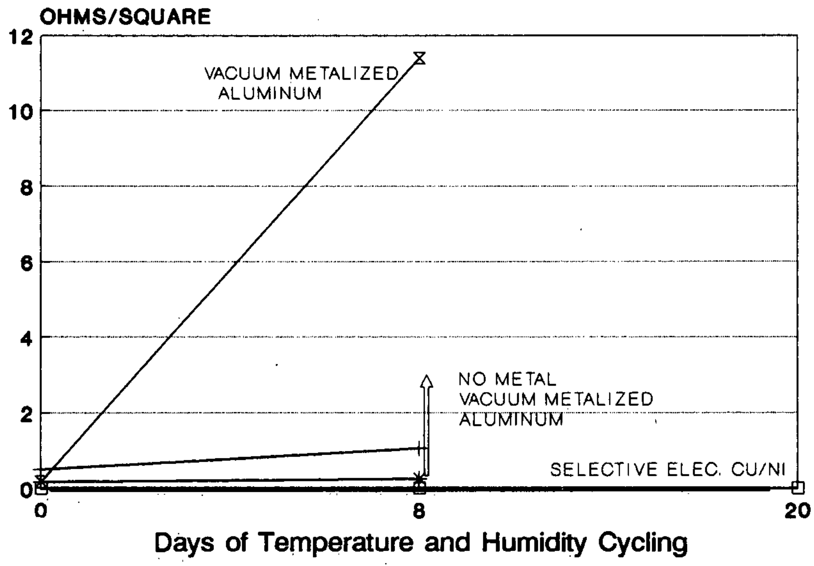

Figure 8. Resistivity of Vacuum Metallized Aluminum.

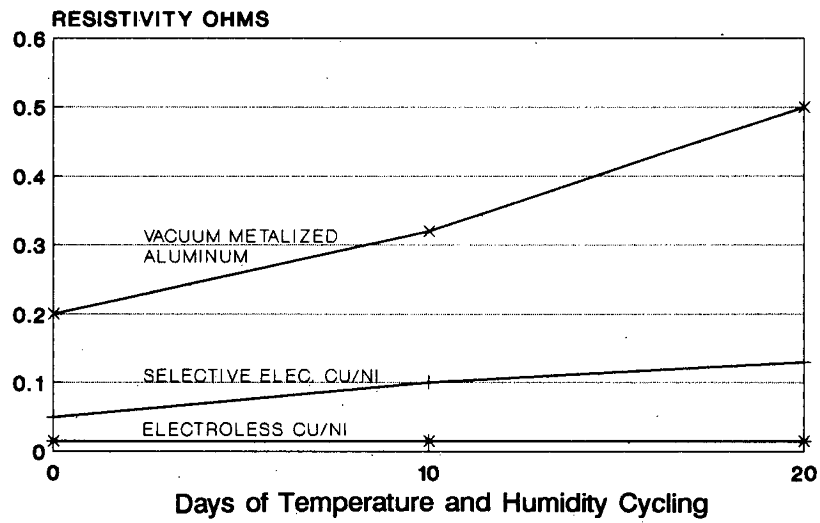

Figure 9. Point-to-Point Resistivity: Part #1.

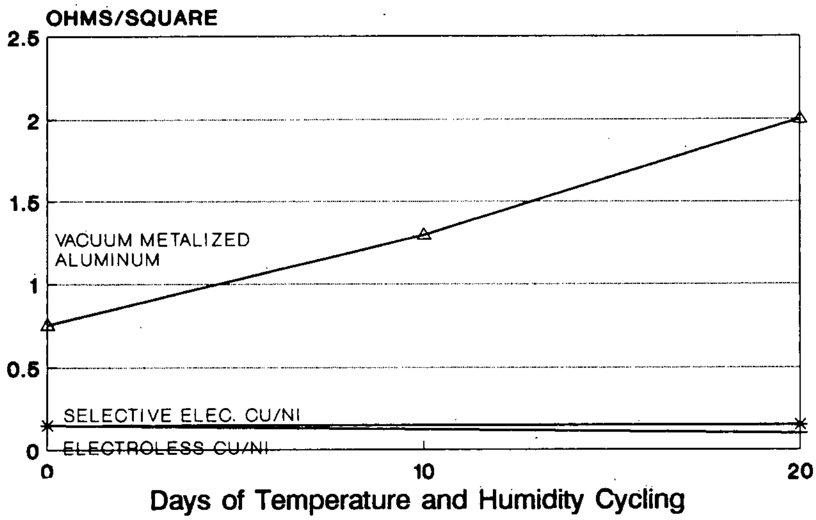

Figure 10. Resistivity: Part #1.

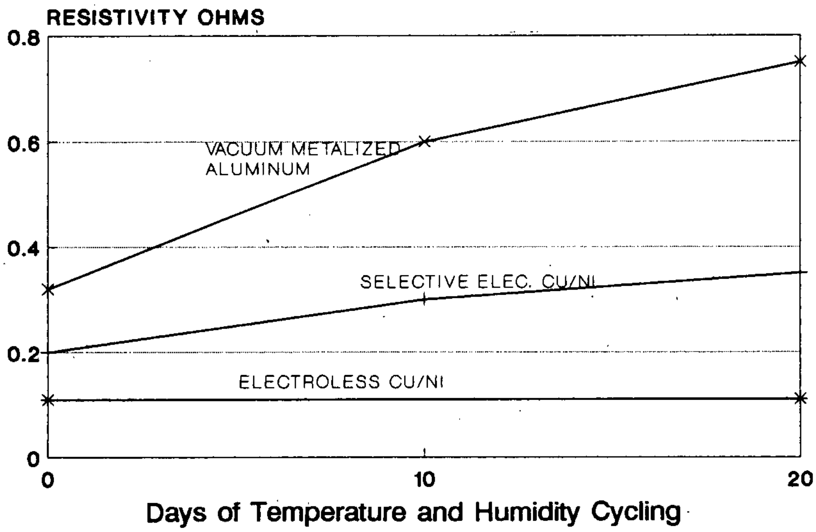

Figure 11. Point-to-Point Resistivity: Part #2.

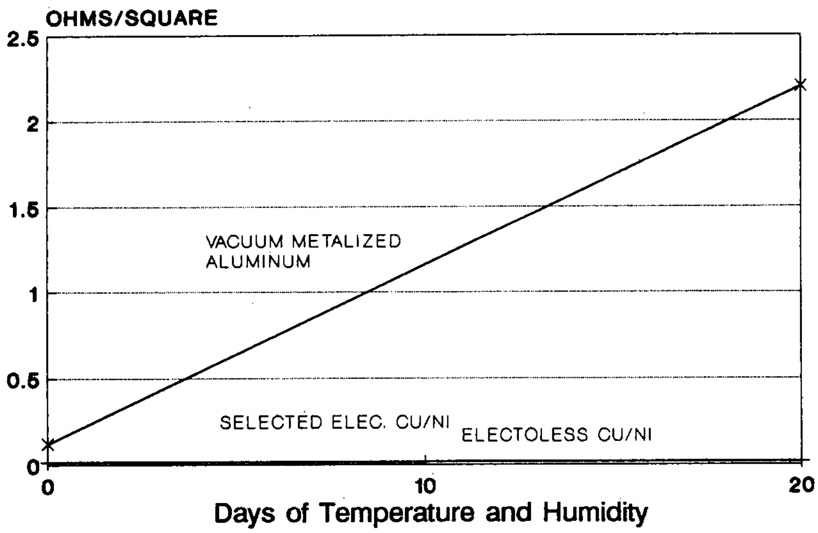

Figure 12. Resistivity: Part #2.

resulted in very high resistance values at the eight day exposure check. Other samples appeared unchanged in their bright appearance and remained relatively free of oxide. However, slight increases in resistivity were recorded. These samples also showed between 25 to 50 percent loss in total metal coating. At the conclusion of the 20-day temperature/humidity exposure, two scenarios existed -- no aluminum coating was present to test, or the oxide layer formed and prevented any surface conductivity from being measured.

Understanding that differences in vacuum deposited aluminum techniques are being commercially promoted, a production computer housing was provided to compare the vacuum metallized samples discussed in the previous paragraph. The computer housing, consisting of base and top cover, utilizes a vacuum deposition technique which allows for greater thickness build-up of the aluminum than the previously tested parts. Two uncoated housings were also provided. These "raw" samples were processed with both selective electroless copper/nickel (one side only) and double-sided electroless copper/nickel plating. The electroless coatings were tested simultaneously with the vacuum deposited aluminum production housing (Figures 9 through 12).

In Figures 9 and 11, resistivity measurements were taken using a Fluke meter at the greatest distance within each part. Lower resistivity measurements were obtained by both electroless copper/nickel coatings with double-sided electroless coatings offering the highest conductivity. Introducing the coating to temperature/humidity resulted in vacuum deposited aluminum to show the same increase in resistivity as previously observed. At the conclusion of the 20-day exposure, double-sided electroless copper/nickel remained unchanged. Vacuum deposited aluminum showed the greatest change, but more significant is the fact that no steady state for surface conductivity was reached at the conclusion of the test. Selective electroless copper/nickel showed a slight increase in surface conductivity. However, the slope of the change illustrates a favorable trend toward a steady state near the conclusion of the 20-day exposure.

The surface conductivity in ohms/square of the electroless coatings and vacuum deposited aluminum are given in Figures 10 and 12. Surface conductivity of 0.014 ohms/square for electroless copper/nickel remained unchanged during temperature/humidity exposure, as tested using the two-point probe method. Vacuum deposited aluminum increased from 0.050 ohms/square to a high value of 2.2 ohms/square. The slope of the vacuum deposited aluminum shows an unfavorable condition of increasing surface resistivity relative to time of exposure to temperature/humidity. Weight loss measurement for either shielding system was not monitored.

GENERAL CONCLUSIONS

Electroless Copper/Nickel

Electroless copper/nickel coatings applied selectively or to completely cover components surpassed all coatings tested in relation to surface conductivity and shielding effectiveness under temperature/humidity exposure.

Nickel-filled Conductive Paint

Nickel paint demonstrated the lowest shielding capabilities over the regulated FCC frequency range. As the frequency increased above 300 MHz, shielding performance rapidly diminished. Exposed to mild environmental conditions, nickel-filled conductive paint performed considerably worse than all coatings evaluated. At frequencies above 100 MHz, coupled with environmental exposure, nickel paint offered little EMI shielding protection.

Copper-filled Conductive Paint

Differences between copper paint manufacturers were noticeable. Shielding effectiveness and surface conductivity were adversely affected by temperature/humidity exposure. Steady state was being approached at the conclusion of the 20-day temperature/humidity exposure.

Vacuum Deposited Aluminum

The technique for depositing aluminum and the resultant thickness can be critical when exposed to environmental conditions. Relatively thin coatings of aluminum offered no protection from temperature/humidity exposure. Vacuum deposited aluminum showed an unfavorable trend of increasing surface resistivity during temperature/humidity exposure in proportion to the length of exposure.

SUMMARY

The testing conditions of temperature/humidity were extremely mild compared to the actual industrial environments to which the new breed of electronic devices will be subjected. These environments include not only temperature and humidity variations, but extremely corrosive atmospheres containing chlorides, sulfides, acidic fumes and/or other chemical compounds. The shielding performance in the as-applied state, as well as the long-term performance of these coatings, is important. Even more critical is the effect of these atmospheres on the surface conductivity of the shielding systems as it relates to the EMC design. Changes in surface impedance from part-to-part within the EMC schematic can be worse than when no shielding coating is present.

All coatings systems tested have a proper application and use in defeating the EMI problem. The brief exposure to mild temperature/humidity environments illustrates the need for the coating system used to be life-cycle tested to the worst case condition in order to determine its integrity in the intended use. Of the commercial coatings tested in this experimental procedure, electroless copper/nickel coatings appear to offer the best protection and integrity during environmental exposure. ■