Vacuum Evaporated Aluminum for Selective Shielding of Plastic Housings

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A study of the far-field properties of simply shaped coated housings considers the effect of geometry on shielding performance.

INTRODUCTION

Electronic equipment contained in injection molded plastic housings may cause electromagnetic interference to nearby electronics (via radiated emissions) or may receive radiated disturbances (electromagnetic susceptibility). Thin metallic coatings deposited onto the plastic surfaces provide efficient shielding and are used in numerous applications, including equipment for information technology, measurement and control.

The most common coatings on the marketplace are conductive nickel (Ni) and copper (Cu) paints, electrolessly deposited Cu/Ni layers, either double-sided or single-sided (selectively), and vacuum evaporated aluminum (Al).

The latter is often referred to as vacuum deposited or vacuum metallized Al. The designation originates from coating light reflectors with thin Al layers. Here the demands are different from shielding: about 0.1 micron of Al on a smooth surface reflects light to a high degree but does not shield a three-dimensional housing.

In terms of EMI control, several microns of evaporated Al are considered state-of-the-art. The method of deposition of thick Al layers in a mass production process will be explained. Electrical properties, shielding effectiveness and long-term stability will then be compared to the other metallizations.

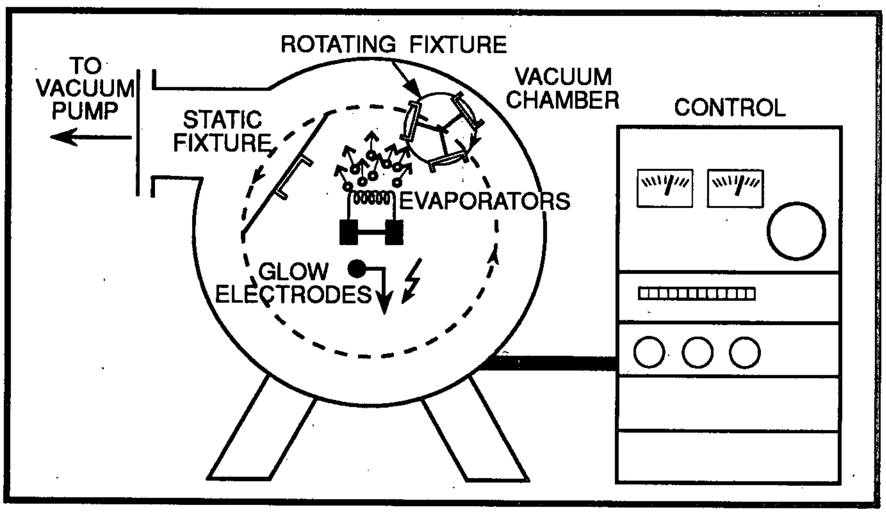

FIGURE 1. Vacuum Evaporation Plant for Coating Plastic Parts.

ALUMINUM EVAPORATION UNDER VACUUM

Vacuum evaporation of metals is based on creating such a low residual gas pressure in the recipient unit that the vapor pressure above the molten metal yields a high deposition rate. As a result, selective deposition of thick Al layers (several microns) on plastics can be carried out in a batch-type process. The equipment consists of a vacuum chamber, typically 1.9 m diameter by 1.9 m length, a pumping unit and the associated instrumentation. The evaporation unit is installed along the center line of the chamber. Pure Al is fed into the resistance-heated sources without breaking the vacuum. The Al vapor propagates radially from the center and condenses on the plastic parts.

The parts are mounted on a cage, rotating around the evaporators. A planetary motion of the parts is also possible (Figure 1). The total cycle time is about 30 to 40 minutes, including about 10 minutes for deposition. A glow treatment takes place at a medium pressure, at about 10^{-2} Pa (10^{-4} mbar), before evaporation begins.

The fixtures for the parts also hold the masks in place. Depending on the housing design, precision machined components can be inserted. Though a thermal process, the temperature of the substrates is kept far below the deformation limit.

Aside from line-of-sight propagation of the Al vapor, there is residual gas molecule scattering.

Hence, the sidewalls of a three-dimensional part are coated sufficiently, but compared to the floor, a lower thickness results.

Note that there is no solvent or chemical etch pre-treatment of the plastic surface. Hence, the effect of Al evaporation on impact strength of the polymer is negligible. Because of masking during evaporation, coated areas are sharply separated from uncoated areas. This is known as selective coating.

DESCRIPTION OF TEST SAMPLES

Rectangular shaped plastic housings, consisting of bottom and top parts, were metallized. The dimensions after bolt-mounting the cover and bottom are 360 mm by 200 mm by 150 mm.

Before shielding measurement and aging treatment, each individual part was characterized in accordance with the layer's sheet resistance, R, and its thickness. As in ASTM F 390-78, a four-point probe is used to pick up the resistance which is then transformed into sheet (surface) resistance by a correction factor of 4.53. The local distribution of test points inside the parts is shown in Figure 2.

Table 1 summarizes the metallizations under test. According to one coating procedure, thicknesses on wall sides differ somewhat from the thickness on the bottom faces. For comparison, only the bottom values, locations (1) and (2) in Figure 2, are represented in Table 1.

Paint thicknesses were determined optically on a cross-section of substrate plus layer. While for Cu paint the spread of values was acceptable, this was not the case for Ni paint. The interface between Ni and the embedding material was too irregular to assess the thickness. The true value was roughly estimated to be in the range of 20 to 90 microns. For Cu/Ni layers, x-ray spectroscopy can be used to analyze the thicknesses of both deposits. Beta backscattering is the appropriate method to analyze Al thickness on polymers. For each type of deposit only typical values are given in the resistance column.

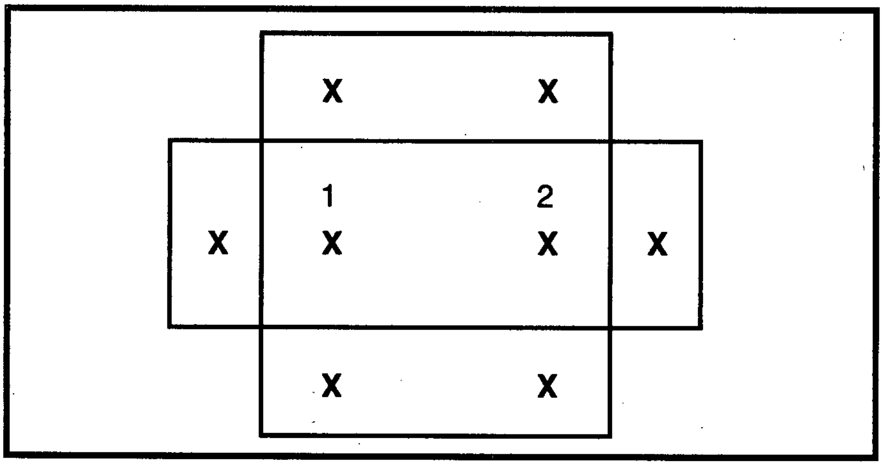

***FIGURE 2.** Locations of Sheet Resistance Measurements Inside a Housing.*

COATING	DESIGNATION	THICKNESS (μm)	R (mΩ/□)
Ni paint	Ni-p	?	400
Cu paint	Cu-p	100	130
Electroless Cu/Ni, double-sided	Cu-Ni	1.8 Cu/0.8 Ni per side	55
Electroless Cu/Ni, selective	Cu-Ni sel.	3.0 Cu/0.3 Ni	45
Evaporated Al	Al Al Al	3.0 6.0 12.0	35 10 8

***TABLE 1.** Coatings Under Test.*

COMPARISON OF SHIELDING EFFECTIVENESS

After installation of a pick-up antenna into the interior of the housing via a BNC feed-through in one of the front sides, the box was closed. A conductive gasket between the top and bottom provided electrical contact along the seam line. The aim was to counter the influence of the contact on the shielding measurement. As long as an efficient mechanical connection between the three integrated parts — groove in the bottom part, gasket, wall of the cover part — could be made, the results did not depend on the type of gasket. A filled silicone gasket, filled silicone hollow strip, and nonconducting elastomeric core with conductive fabric performed equally well. If, for comparison, the gasket was removed, the frequency dependency of shielding efficiency (SE) was strongly altered; above 100 MHz the SE decreased substantially.

The measurements were carried out in an anechoic chamber in accordance with the German stan-

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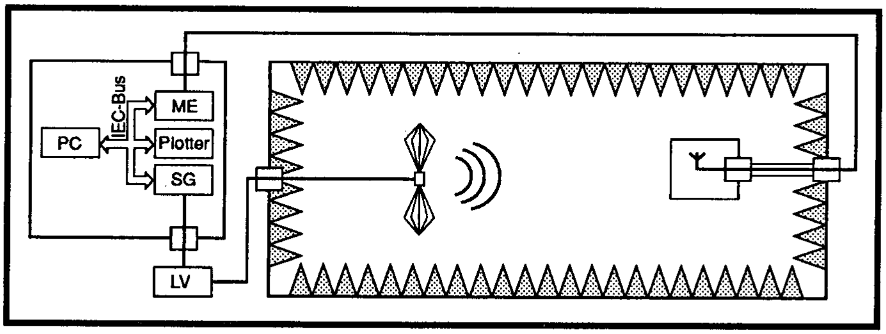

FIGURE 3. Measurement Setup for Shielding Efficiency of Housings (courtesy of Universitat Karlsruhe, Institute für Elektroenergiesysteme und Hochspannungstechnik).

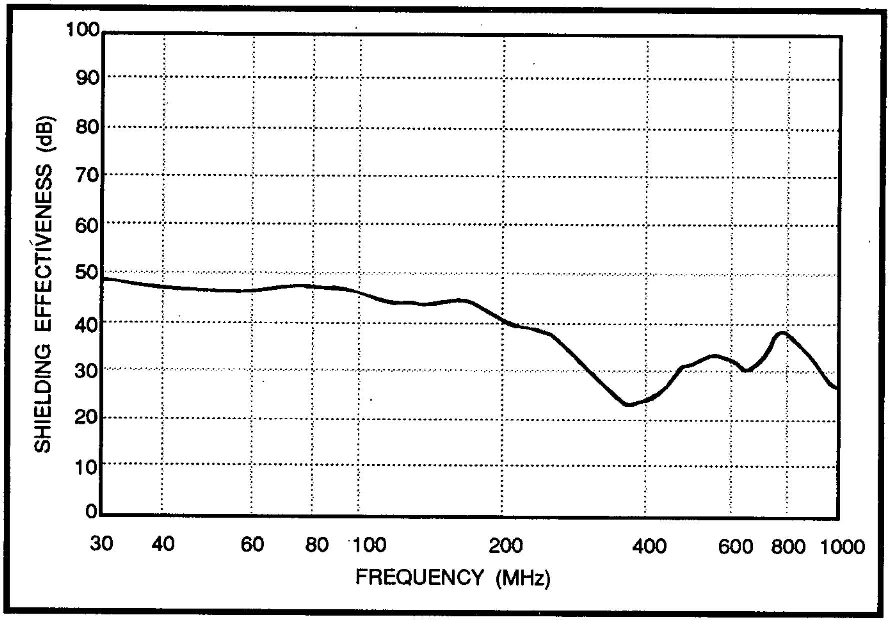

FIGURE 4a. Far-field Shielding Effectiveness (SE) of Ni Paint.

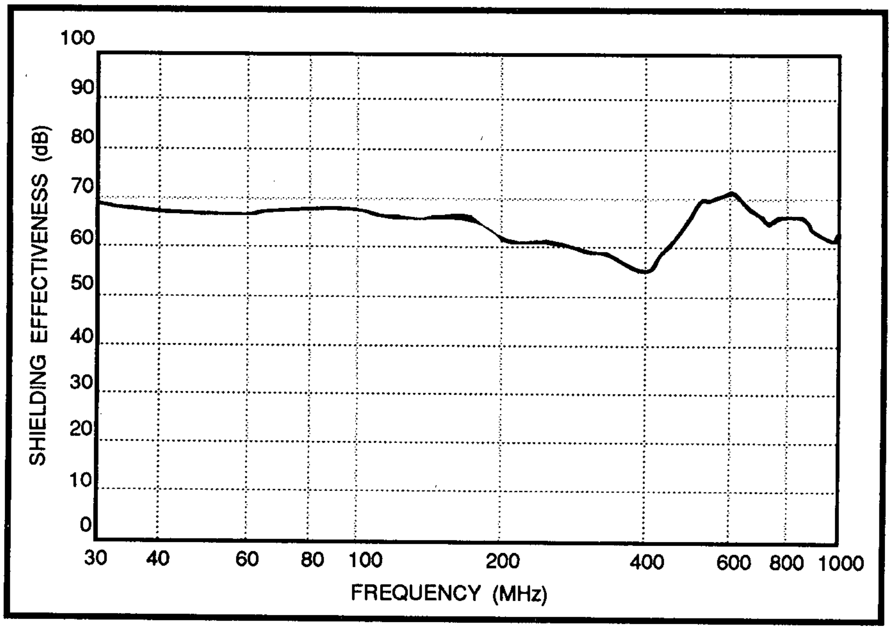

FIGURE 4b. Far-field Shielding Effectiveness (SE) of Cu Paint.

dard VG 95373/15. In the frequency range 30 to 1000 MHz, a rod antenna placed in parallel to the longest edge of the box received the electrical field in the interior.

The housing, positioned upright, was illuminated by an emitter radiating at a distance of 3 m. For 30 to 300 MHz a biconical antenna was used; beyond 300 MHz a logarithmic periodic antenna was substituted. The experimental setup is shown in Figure 3.

Because of the distance between source and coated housing, far-field conditions are assumed valid for the whole frequency range. In Figures 4, 5 and 6, results on SE are represented as the difference between field strengths with and without a shielded box surrounding the rod. The dynamic range is larger than 95 dB. The raw spectrum is given only for Cu/Ni; the other curves are corrected for experimental errors.

Compared to Cu paint, the Ni paint displayed less efficiency in the whole frequency range (Figure 4a). A difference of 20 dB was found below 200 MHz, and a 30 to 40 dB difference was found for higher frequencies. The Cu paint under test with about 100 microns thickness yielded efficiencies from 55 to 70 dB (Figure 4b).

Non-selective Cu/Ni provides the highest SE of all samples — 50 to 95 dB — depending on frequency (Figure 5a). The curve representing single-sided Cu/Ni is shifted downwards by 10 to 15 dB (Figure 5b). But from 600 MHz on, the situation is reversed; selective Cu/Ni provides 15 to 20 dB of excess SE. The reason for comparatively low shielding at high frequencies could be that after coating both sides with Cu/Ni, small cracks in the plastic housings could be observed. The cracks, which originate from chemical pre-etch before activation of the plastic surface, are

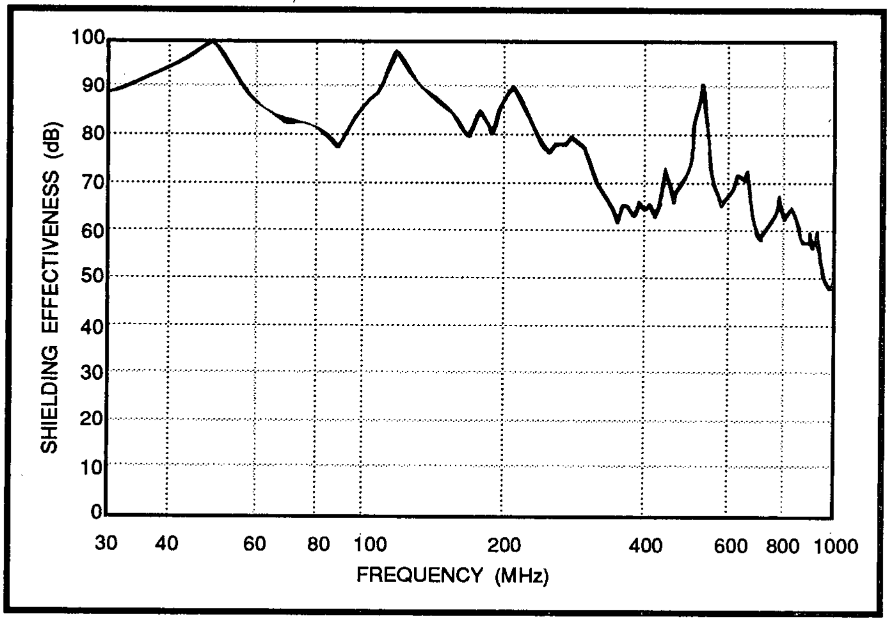

FIGURE 5a. Far-field Shielding Effectiveness (SE) of Electroless Cu/Ni.

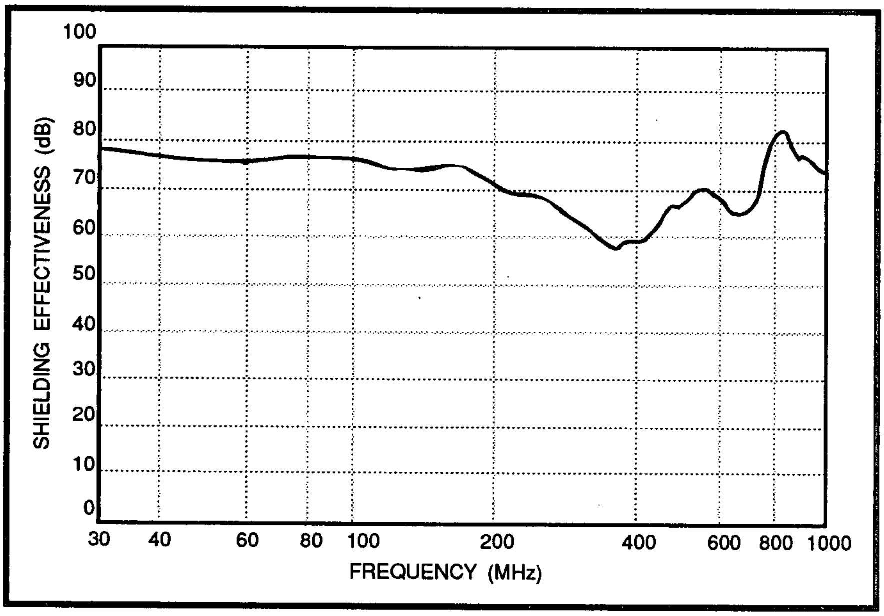

FIGURE 5b. Far-field Shielding Effectiveness (SE) Achieved with Selective Coating with Electroless Cu/Ni.

located in areas of high internal stresses, especially near the bolt holes. Though the conductive gasket is surrounding these holes, high frequency leaks can build up in the wall if the cover is mounted to the bottom half.

The shape of spectra recorded for thick Al layers is similar to those of conductive paints and selective coating with Cu/Ni (Figures 6a, 6b, and 6c). The type of Al coating with the largest thickness (12 microns) is characterized by a spread in SE from 60 to 80 dB. About 10 dB has to be subtracted from these results for lower Al thicknesses. This relationship holds for frequencies less than 700 MHz. Beyond this point, lowest thickness correlates with highest shielding levels and vice versa. This relationship should not be over-emphasized however. First, this is a region of resonances which can distort the shielding result. Secondly, a high level of shielding is maintained if compared to the low frequency part of the spectra. In contrast to double-sided Cu/Ni where a decrease from 95 dB (30 MHz) to 50 dB (1 GHz) occurred, any kind of leakage can be excluded.

Given a measurement uncertainty of 6 dB, the curves of the two Al samples with lower thicknesses more or less coincide. Because of different preparation methods (2.5 µm Al on a rotating fixture; 5 µm Al on a static fixture) differences in thicknesses and square resistances are of less importance for the SE results. Thickness distribution inside the housing is the main criterion.

From Figure 6c it can be deduced that the orientation of the box with respect to the source is of minor importance. If one analyzes a double-sided Al coating (2.5 µm per side), a gain in shielding is found with respect to single-sided 2.5 µm coating. The difference is most pronounced above 100 MHz; at least 15 dB higher efficiency results if both sides are metallized.

LONG-TERM STABILITY

Besides thickness, the most important parameter in the shielding effectiveness of a thin conductive barrier of non-magnetic material is sheet resistance (skin penetration depth larger than thickness of shield). Hence, sheet resistance was chosen as an indicator of the coating's behavior after temperature-humidity cycling tests.

The test specifications were as follows:

- 4 hours at 25°C, 50-percent relative humidity
- 2 hours ramp to 66°C, 95-percent relative humidity

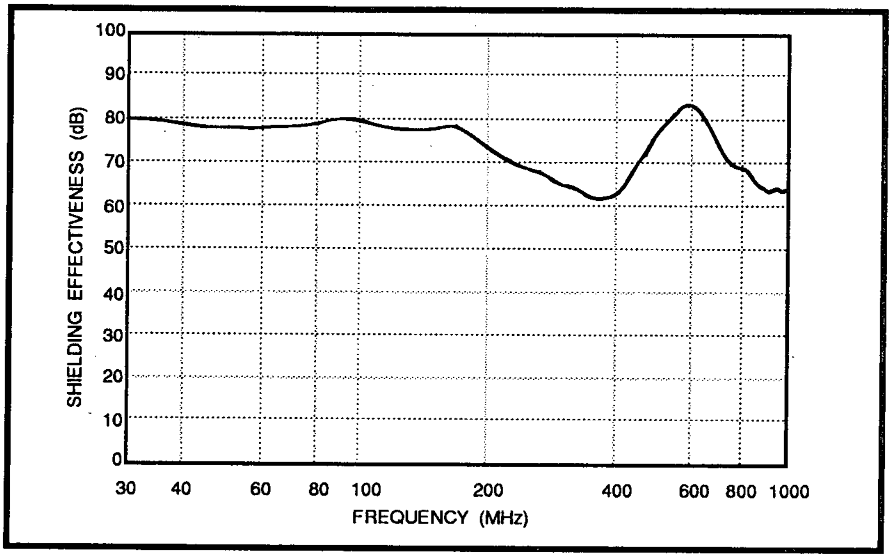

FIGURE 6a. *Far-field Shielding Effectiveness (SE) of Evaporated Al, 12 Microns.*

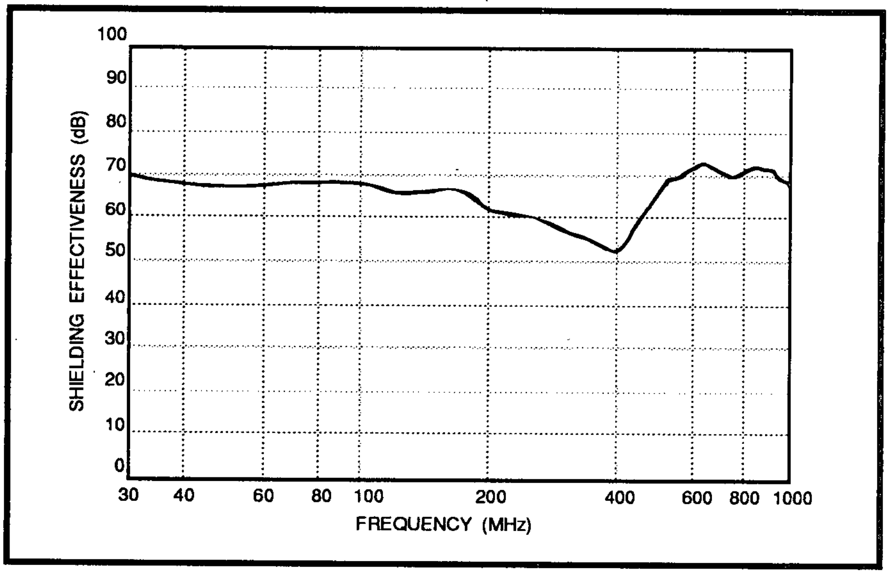

FIGURE 6b. *Far-field Shielding Effectiveness (SE) of Evaporated Al, 6 Microns.*

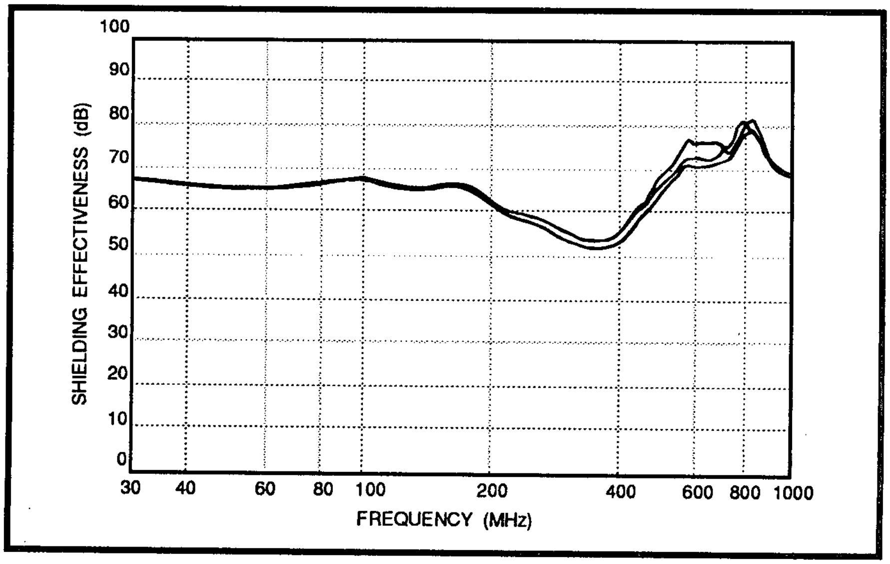

FIGURE 6c. *Far-field Shielding Effectiveness (SE) of Evaporated Al, 3 Microns, Bottom, Top and Sidewall of Housing Directed Towards Emitting Antenna.*

- 4 hours dwell
- 1 hour ramp to 50-percent relative humidity
- 11 hours dwell
- 2 hours ramp to 25°C
- 1 cycle within 24 hours

As outlined above, sheet resistance was recorded at eight different locations inside the coated plastic part. Measurements were carried out at intermediate stages until the total number of cycles, 40 and 50 respectively, was completed.

Based on the test results, Ni paint proved to be the most unstable layer because no saturation was observed. Cu paint revealed an increase in resistance which leveled off at about 20 cycles. A similar behavior was found for selective Cu/Ni with an initial increase and a stabilization beyond 20 cycles. Both Cu/Ni double-sided and Al maintained their as-deposited resistance. The deviations correspond to measurement uncertainties.

Considering the eight locations described in Figure 2, the different metallizations are ranked in Table 2 (according to minimum and maximum derivation out of eight with respect to as-deposited sheet resistance). The percentage increase in sheet resistance reported for nickel paint does not represent a steady state.

Only in areas with fingerprints before cycling does the resistance of Al coatings increase by orders of magnitude. The cracks in the double-sided Cu/Ni-coated housings grew during environmental testing.

CONCLUSIONS

Instead of comparing the shielding efficiency of metallized plastic

Al, 6 µm	0 - 30%
Al, 3 µm	0 - 30%
Cu/Ni	0 - 30%
Cu/Ni selective	30 - 100%
Cu paint	30 - 225%
Ni paint	160 - 1000%
(Al, 12 µm, was not tested)	

TABLE 2. *Ranking of Metallizations.*

plaques, the far-field properties of simply shaped coated housings were investigated. The results are of more practical value, because geometry is taken into consideration.

The shielding results can be classified as follows. Ni paint results in low shielding effectiveness, while the highest SE can be obtained by double-sided Cu/Ni. The reason is not only the high electrical conductivity provided by Cu, but also the double barrier action, if coated non-selectively. For instance, if a housing is metallized by evaporation of Al on all sides, a pronounced increase in SE is found, when compared to the same thickness deposited only on inner faces. So this type of layer is rather exceptional, because all of the competing coatings were selective ones.

Between the two extremes — Ni paint and Ni/Cu — are Cu paint and Al and Cu/Ni selective coating. These are characterized by SE values which are rather close. The thickest Al layer under test (12 µm) is next in the ranking.

In the case of Cu paint, an unusually large thickness (~100 µm) was included in the test. Under normal production conditions, only half of it is usual (~40 to 50 µm). Then Cu paint would be clearly separated from the middle group.

Additionally, long-term stability of the coatings on plastic housings was investigated. Again, Ni paint came out with the worst result, because no stable sheet resistance could be detected after completion of temperature-humidity cycling. Even if resistance increases at the beginning stages of aging, the final result is a steady state for all other layers under test.

There is a higher increase in resistance for selective application of Cu/Ni than for double-sided Cu/Ni, although the type of electroless Cu and Ni is principally the same. The only difference is the preconditioning of the plastic: etch and activation in the former case, spraying a paint-type primer before activation in the latter. Whether a different microstructure of the Cu layer because of the primer, or the primer itself, is responsible for higher resistance changes is not clear.

Besides thickness, the most important parameter in the shielding effectiveness of a thin conductive barrier of non-magnetic material is sheet resistance.

Within the scope of the applied cycling conditions, evaporated Al of several microns thickness offers long-term stable electrical resistance.

A general comment on the shielding results should be added: one should not be misled by the absolute figures of SE (Figures 4, 5 and 6), because they resulted from more or less ideal conditions: boxes of simple geometry consisting of only two parts, electrical contact via a conductive gasket, and no openings in the walls. Real applications look quite different. They are characterized by:

- more than two parts
- construction so that a line-shaped contact is not given
- inability to accept gasket
- many openings for cables, keys, ventilation.

In summary, these items drastically pull the reported SE values down, irrespective of coating method. In this sense, 20 dB for an electronic instrument has to be considered a good result.

ACKNOWLEDGMENTS

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