# Comparative magnetic field Shielding Effectiveness of thin conductive coatings

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## 1) Introduction

### *1.1 Conductive coatings*

This investigation served to analyze the magnetic field shielding effectiveness of several conductive coatings now available.
The conclusion from this report is that conductive coatings vary greatly in their shielding effectiveness and that some coatings are nearly as effective as solid aluminum.

### *1.2 Summary conclusion to this report*

The conclusion from this report is that a class of electroless copper coatings with copper electroplate and nickel finishes provide the best shielding effectiveness; almost as effective as a 1mm aluminum plate.
In a companion report the question was asked "Can MIL-STD-461 EMI requirements be met with a conductively coated plastic enclosure"? This report was aimed at very small enclosures with dimensions of typically 11cm x 7cm x 5.5cm designed to be worn by personnel.
Since that report EMI qualification testing was performed on equipment containing RF and digital circuits which were housed in a 42cm wide by 14cm deep by 50cm tall plastic enclosure. The enclosure was plated inside and outside with electroplate copper and bright nickel plate. This equipment met the most stringent RE102 limit for Navy Mobile and Army equipment.

### *1.3 Why is magnetic field shielding effectiveness important?*

Conductive coatings are typically effective at shielding against electrostatic fields and also electromagnetic fields which have a wave impedance close to 377Ω, however they are much less effective at shielding against magnetic fields.

The fields very close to the surface of a PCB containing logic are predominantly magnetic and the fields close to switching power supplies are also typically magnetic. Switching power supplies operate at frequencies as low as 100kHz and, although clocks are typically at a higher frequency, data can contain frequency components at very low frequency. Thus for small enclosures, where the source of the field is close to the inside surface of the enclosure, the level of magnetic field shielding effectiveness is very important even down to frequencies as low as 100kHz.

## 2) Thin coating types

The plaques were supplied by manufacturers with their conductive finish added, but in one case non-conductive plastic plaques were supplied to the manufacturer for plating. Where possible the thickness of the coating is described, as this is an important parameter. However for some samples this data was not available and in on one plaque the coating was so thin and uneven that when held up to the light, it shone through in certain areas. As expected this material performed poorly.
We had no control over the quality of the plating, but manufacturers were told to supply, where possible, the very best finish they could, i.e. thickest practical coating.

A list of the types of coating, finish and plating tested is describes as follows:

**Aluminum coating**

Vacuum deposited aluminum coating, 0.0005” thick.

**Electroless copper coatings**

Electroless Copper followed by copper plate, then nickel plate. The five combinations tested are as follows

Electroless Cu +

- Flash electroplate Cu + bright Ni plate 0.001”
- Flash electroplate Cu + bright Ni plate 0.002”
- Flash electroplate Cu + electroless Ni plate 0.001”
- electroplate 0.001” Cu + Ni flash 0.0002”
- electroplate 0.002” Cu + Ni flash 0.0002”

**Conductively loaded plastic**

An even dispersion of long, interlocked nickel-plated carbon fibers in a thermoplastic resin, 0.09” thick, 30% solids by weight.

**Conductive silver paint #1**

Sprayed silver conductive paint, <0.5 mil thick, with 47 ± 1.5% solids by weight.

**Conductive silver paint #2**

Sprayed silver paint, 0.4 – 1.0mil thick, with 47% solids by weight.

**Silver conductive coating**

Sprayed silver conductive paint, 0.5 - 1.5mil thick, with 50.8 ± 0.5% solids by weight. Low volatile organic chemical (VOC) content.

**Silver-plated, copper conductive EMI coating**

Sprayed silver-plated copper conductive paint, 0.6 – 0.8mil thick, with 35% solids by weight.

**Silver-coated copper conductive paint**

Sprayed silver-coated copper paint, <1 mil thick, with 29 ± 1.5% solids by weight.

**Nickel paint**

Sprayed nickel flake paint, unknown thickness, 19% nickel, 27% solids by weight.

**Tin/zinc alloy conformal coating**

High purity 80% tin/ 20% zinc alloy applied as a molten metal and cools to a laminar film with low porosity, 0.001" thick.

## 3) The tests performed

The tests were of the IEEE-STD-299 type in which the radiated H field from an enclosure with an aperture is compared to the radiation with the aperture closed by a conductive plaque. However, because the plaques provided were small, a smaller enclosure (8.5" x 4.5" x 3.5") than that specified in IEEE-STD-299 was used. Using a small enclosure also made it easier to achieve higher current flow on the inside of the enclosure. The measurements are comparative and the measurement without plaque is referred to as the reference measurement. The shielding effectiveness in dB is the difference between the reference measurement, measured in dBμV, and the measurement with the plaque, again measured in dBμV. Photo 3.1 shows the metal enclosure with its aperture closed by one of the test plaques.

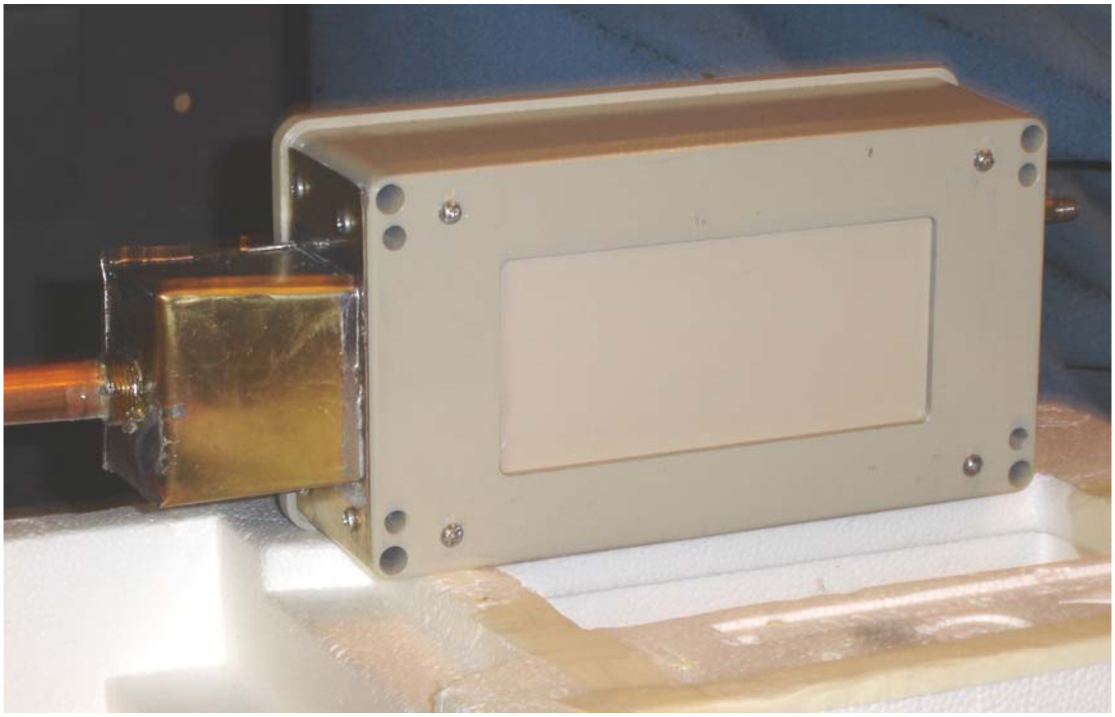

Photo 3.1 The enclosure with its aperture closed by one of the plaques under test.

Two sets of measurements were made, over the lower frequency range from 100kHz to 10MHz and from 10MHz to 156MHz using different receiving antennas for the two ranges. The IEEE-STD-299 test is not of an intrinsic electromagnetic parameter, such as transfer impedance, instead the test method affects the results. For example using a small loop transmitting antenna inside a small enclosure the internal current flow on the enclosure affects the magnetic field generated by the loop. Thus we expect the field generated by the loop to be slightly different with the aperture open and with the aperture closed by a plaque. Also it is to be expected that the performance of the receiving antenna is dependent on the type of antenna used and its proximity to the enclosure with plaque, versus enclosure without plaque. Reproducibility in this comparative type of test is very important. It was found that the exact location of the transmitting loop and receiving loop was critical. See photos 3.2 and 3.3 for the positioning of the receiving loops.
The pressure between the plaque and the enclosure was kept as constant as possible from one test to the next as this was expected to change the test results.


Photo 3.2  Positioning for the balanced loop antenna

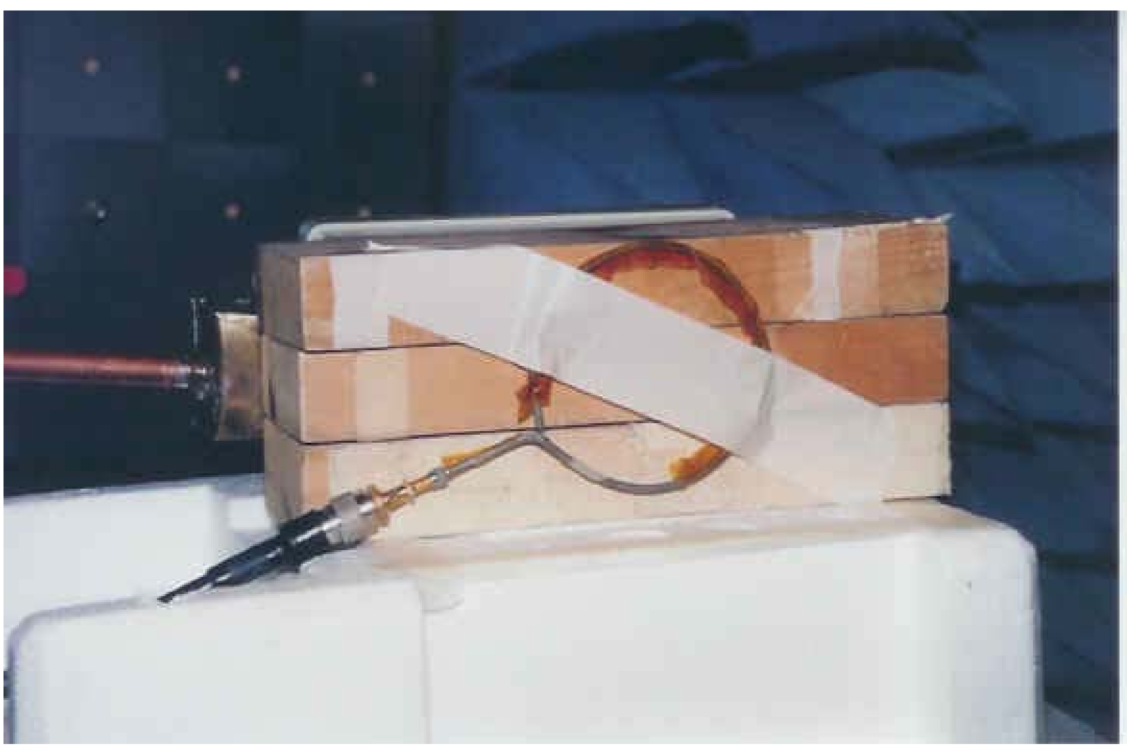
Photo 3.3  Positioning for the shielded loop antenna

To ensure repeatability the same plaque was measured three times and when comparing the results in the first group of plaques tested to the second group the correlation up to 80MHz was good. Above 80MHz the dips and peaks in shielding effectiveness (S.E.) occurred at different frequencies but the comparison between the S.E. for the different plaques in the same group were valid. Also group 1 could be compared to group 2 above 80MHz if a different frequency were chosen. For example the S.E. for silver coated copper paint was 47dB at 115MHz in the first group tested and 49.7dB at 100MHz in the second group. Table 1 shows a comparison of the test result for the silver coated copper paint between one test and the next.

Table 1 Comparison between test results on the same plaque

| $f$(MHz) | S.E. for silver coated copper paint in group 1 test | S.E. for silver coated copper paint in group 2 test | Δ (dB) |
|---|---|---|---|
| 1.0 | 20 | 18.5 | 1.5 |
| 10.0 | 39 | 36.9 | 2.1 |
| 80.0 | 45 | 44.1 | 0.9 |
| 115/100 | 47 | 49.6 | 2.7 |

Therefore below 80MHz the results can be trusted within a margin of error of maximum 3dB.
Thus if the S.E. between any two plaques is within 3dB, we must assume that the S.E. of the plaques are virtually the same.

## 4) Results

Group 1 test results showed that a 1mm aluminum plate provides a significantly better shielding effectiveness than any of the coatings tested. The maximum shielding effectiveness achieved using the aluminum plate was 74dB at 55MHz, which is 24dB higher than the maximum shielding effectiveness attained by any of the coatings. Even 0.15mm thick aluminum foil performs slightly better than the best conductive coating which was one of the conductive silver paints. Not far behind were the silver-coated copper paint and the Sn/Zn pure metal alloy coating. The worst coating was found to be the nickel paint, having a maximum shielding effectiveness of only 9dB. See figure 4-1 for a comparative shielding effectiveness plot of all the plaques tested in group 1.

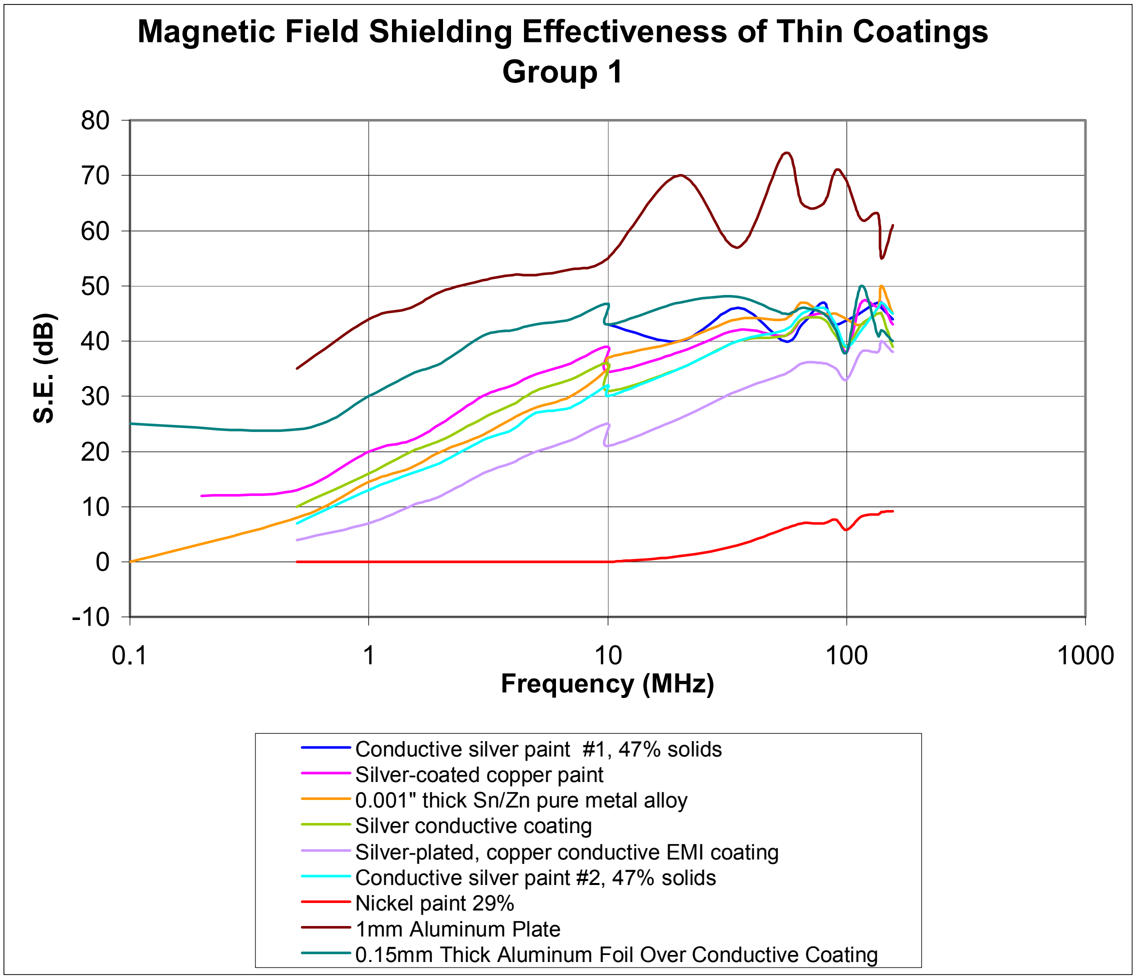


Figure 4-1. Magnetic shielding effectiveness of all plaques tested in group 1.

Eight new plaques were tested in the second group, along with three of the plaques tested in group 1, the 1mm aluminum plate, Sn/Zn pure metal alloy coating plaque, and silver-coated copper paint plaque. Comparisons of the group 1 and group 2 findings for the pure metal alloy and silver-coated copper paint, show reproducibility in the findings. The variation was 6dB up to 10MHz and up to 8dB above. This means that when comparing the group 1 to group 2 plaques that any difference less than 8dB is not valid.
See figures 4-2 and 4-3 for these comparisons.

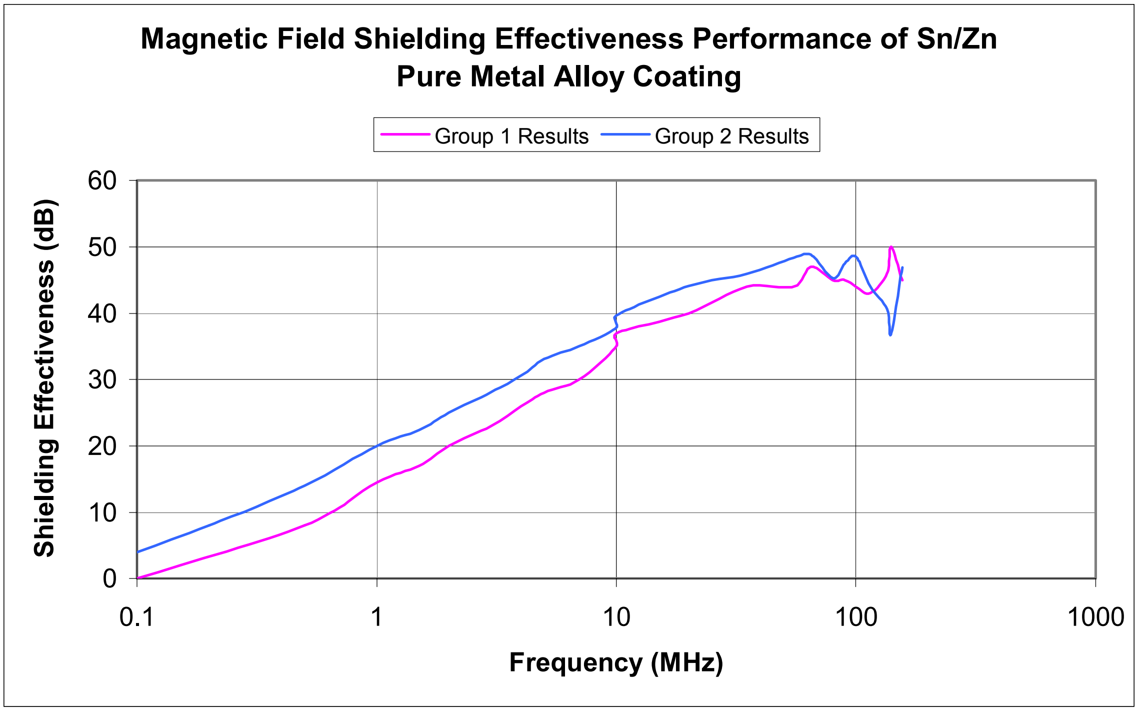


Figure 4-2 A comparison of Sn/Zn pure metal alloy coating S.E. results

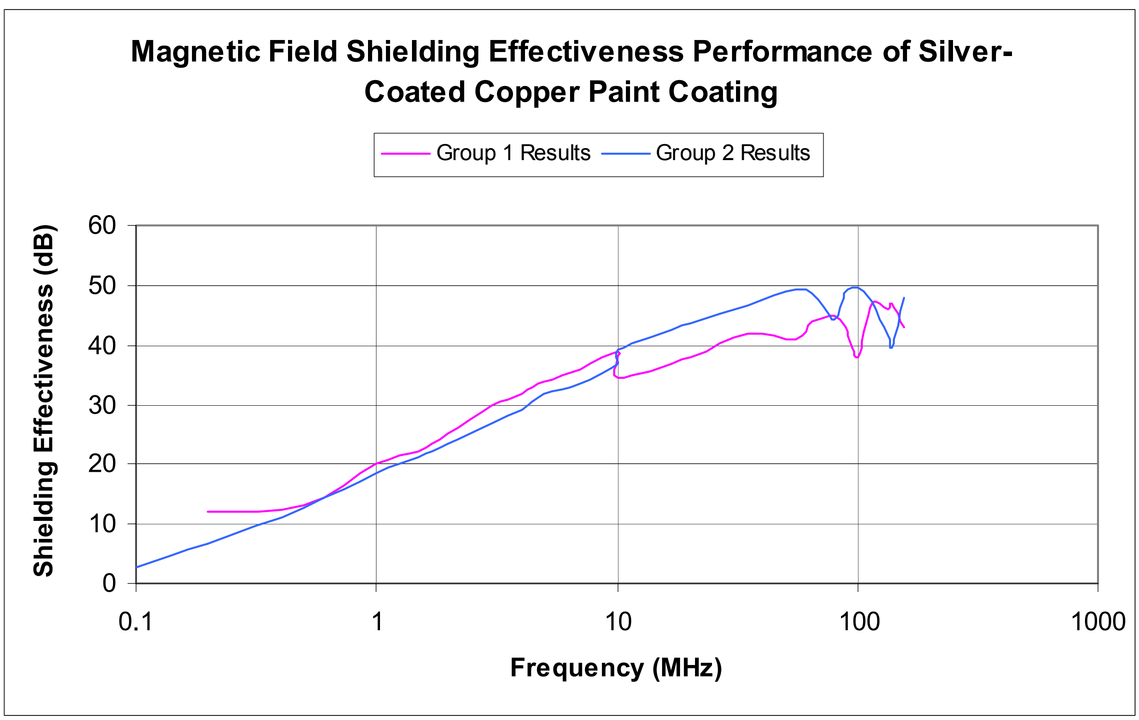


Figure 4-3 A comparison of silver-coated copper paint coating S.E. results

As shown in figure 4-4, the 1mm aluminum plate still achieved the highest shielding effectiveness of all plaques tested in group 2. However, there were some conductively coated plaques in group 2 that performed almost as well as the aluminum plate. Four of the coatings made with electroless copper, followed by copper plate and nickel, were as good, if not better than the aluminum plate at low frequency (up to 1MHz). At high frequency all five of these electroless copper coated plaques provided at least 50dB of shielding effectiveness, and one provided as much as 63.5dB at 65MHz. Differences in the shielding effectiveness existed between the electroless copper coated plaques as well. Refer to figure 4-5 for a comparison between the different electroless copper, copper plate, nickel plate plaques. While 0.002" copper electroplate with flash nickel plate is best at low frequency, flash electroplate copper with 0.002" bright nickel plate is most effective at high frequency. Looking at figure 4-6 we can also see that bright nickel plating is more effective than electroless nickel plating below 20MHz.

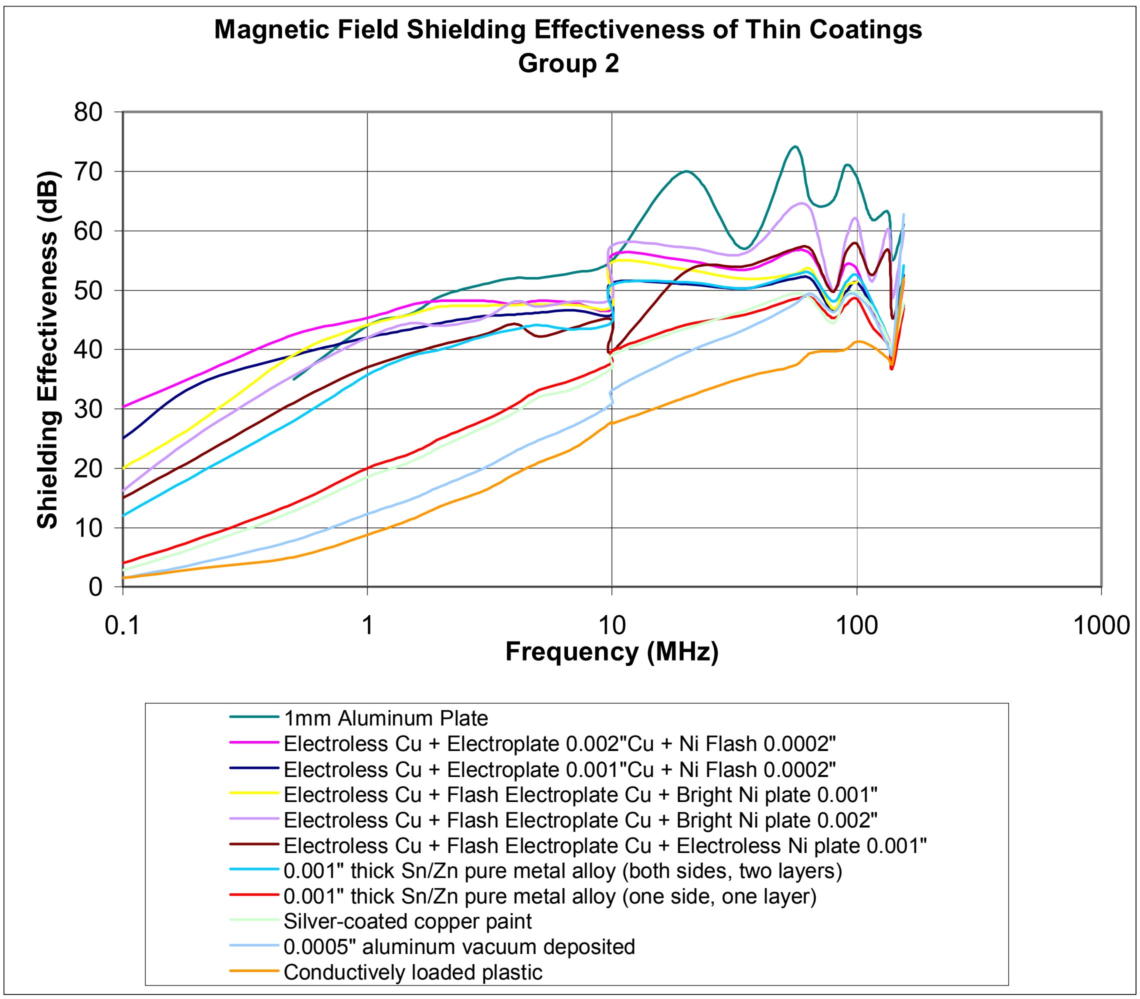


Figure 4-4 Magnetic shielding effectiveness of all plaques tested in group 2.

The worst conductive coating from group 2 was the conductively loaded plastic, with a peak shielding effectiveness of 41.3dB at 100MHz. This is what we would expect since this plaque is lacking a conductive metal surface for making good electrical contact at the interface with the enclosure.

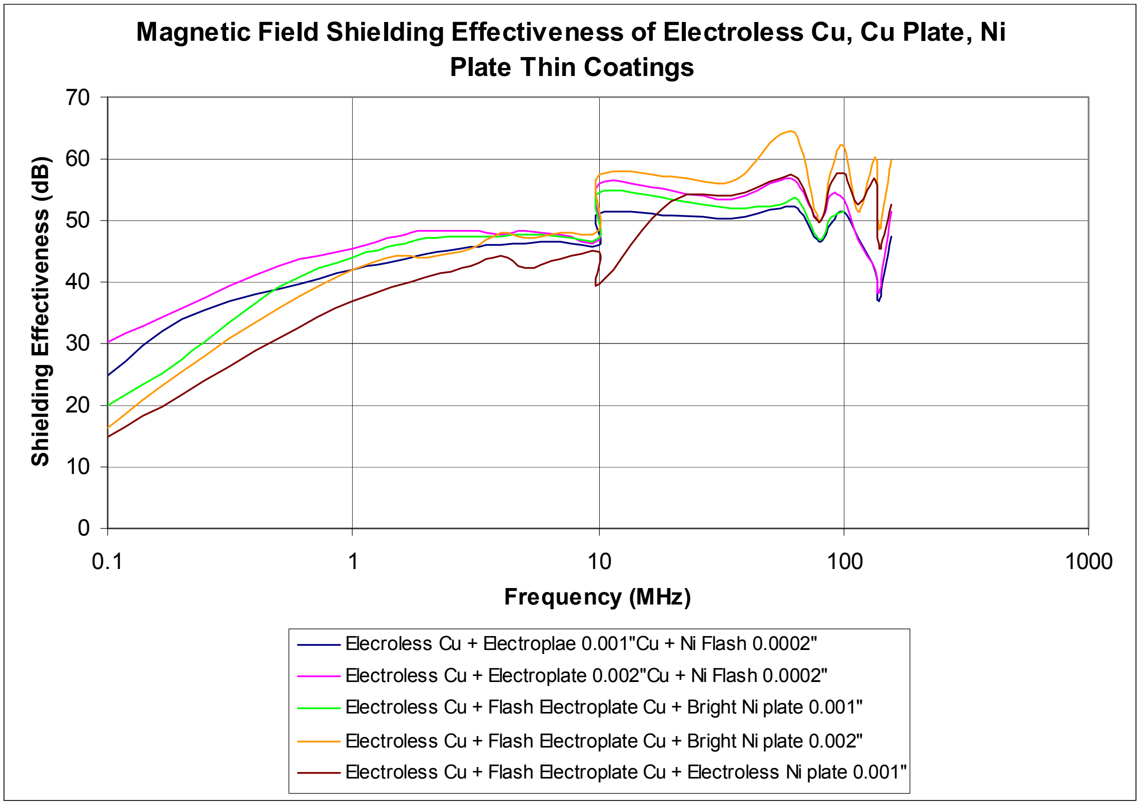


Figure 4-5 Magnetic shielding effectiveness differences between the electroless copper, copper plate, nickel plate plaques.

Figures 4-7 and 4-8 demonstrate an important point about the shielding effectiveness of a plaque. That is that thicker applications provide more attenuation. In figure 4-7 the difference of 0.001" in thickness of the copper electroplating on the second layer, increases the shielding effectiveness of the plaque by as much as 5dB at some frequencies. Figure 4-8 shows an even more dramatic improvement in shielding effectiveness when a double layer of the tin/zinc alloy coating is applied. At 1.5MHz the improvement in shielding effectiveness was as high as 16dB.

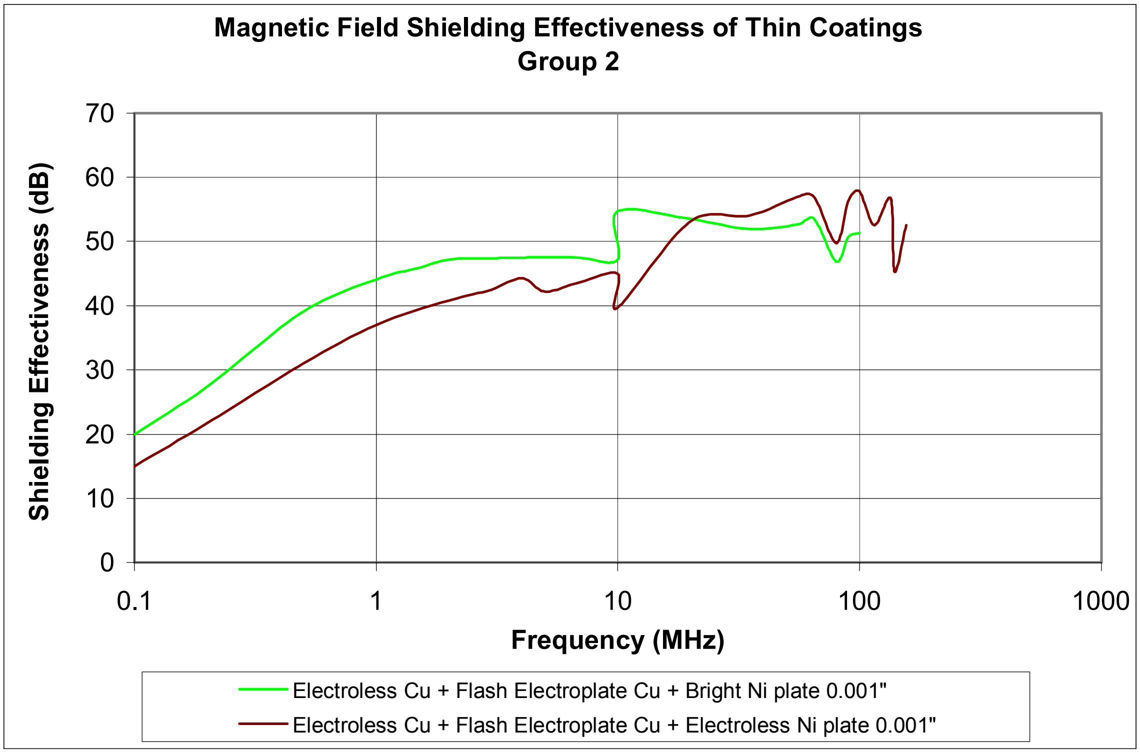


Figure 4-6 Comparison between the shielding effectiveness of bright nickel plating and electroless nickel plating on electroless copper, flash electroplate copper plaques

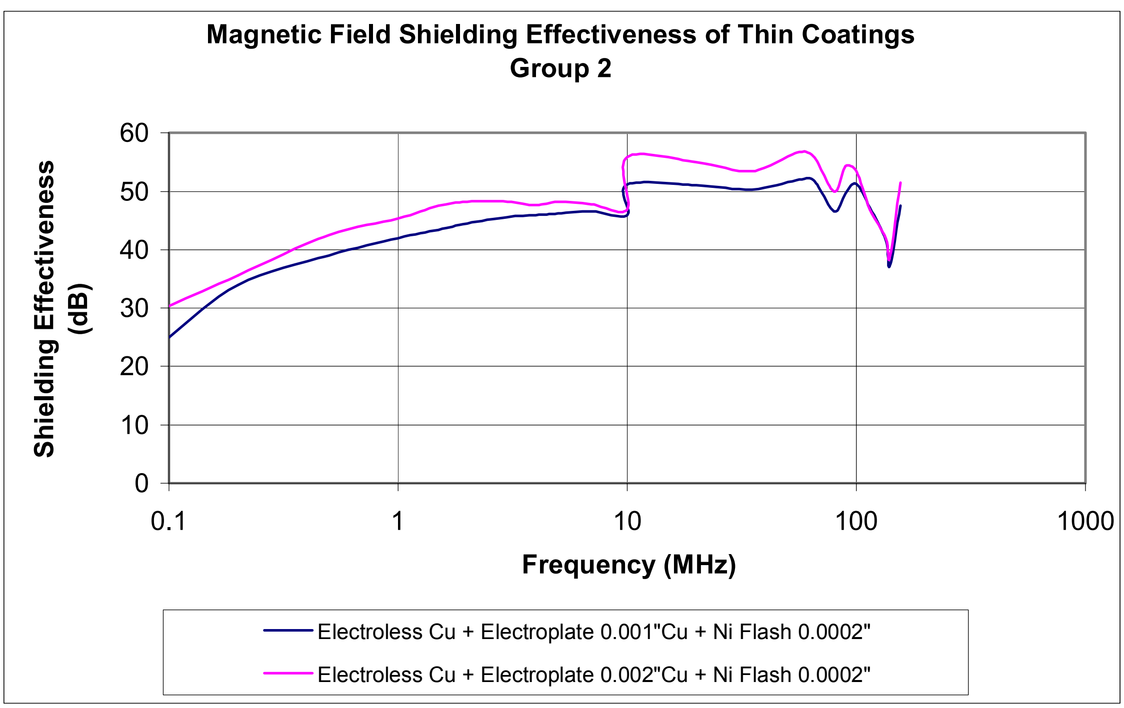


Figure 4-7 Effect of copper electroplate thickness on shielding effectiveness

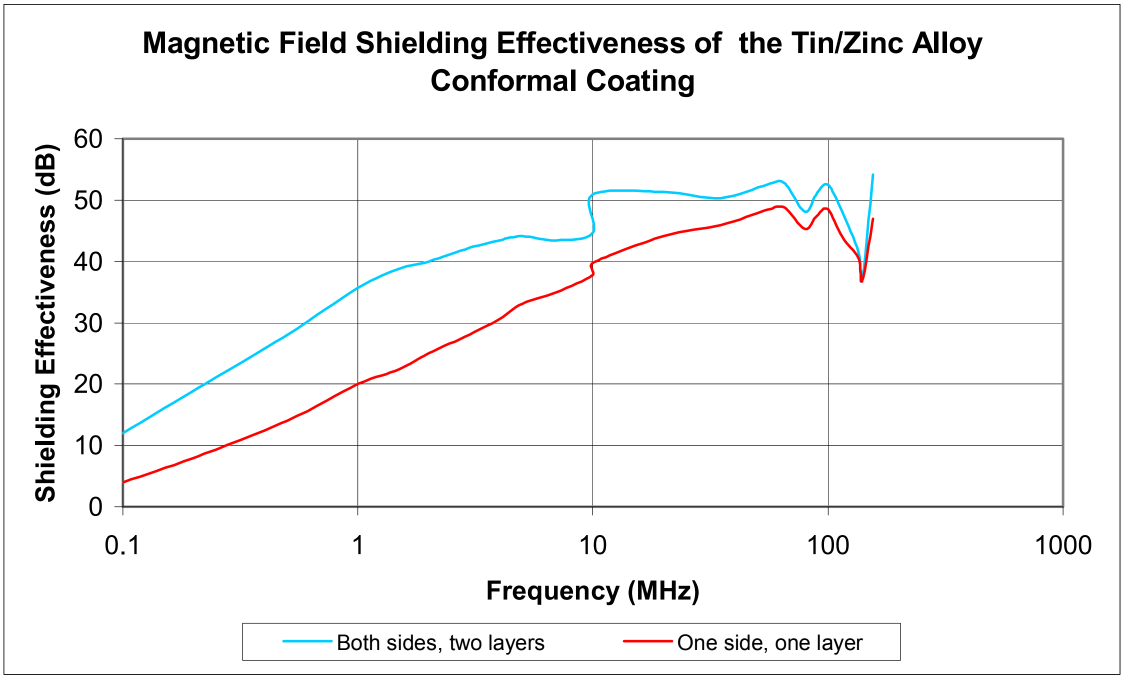


Figure 4-8 Effect of tin/zinc alloy coating thickness on shielding effectiveness

When selecting a coating for EMI shielding it is also important to keep in mind the susceptibility of the material to chemically degrade. Over time some metals will oxidize, changing the shielding properties of the material. As shown in figure 4-9, clearing away the oxidized surface on an aluminum plate using steel wool, improves the shielding effectiveness significantly. This underlines the importance of selecting a chemically stable material for plating.

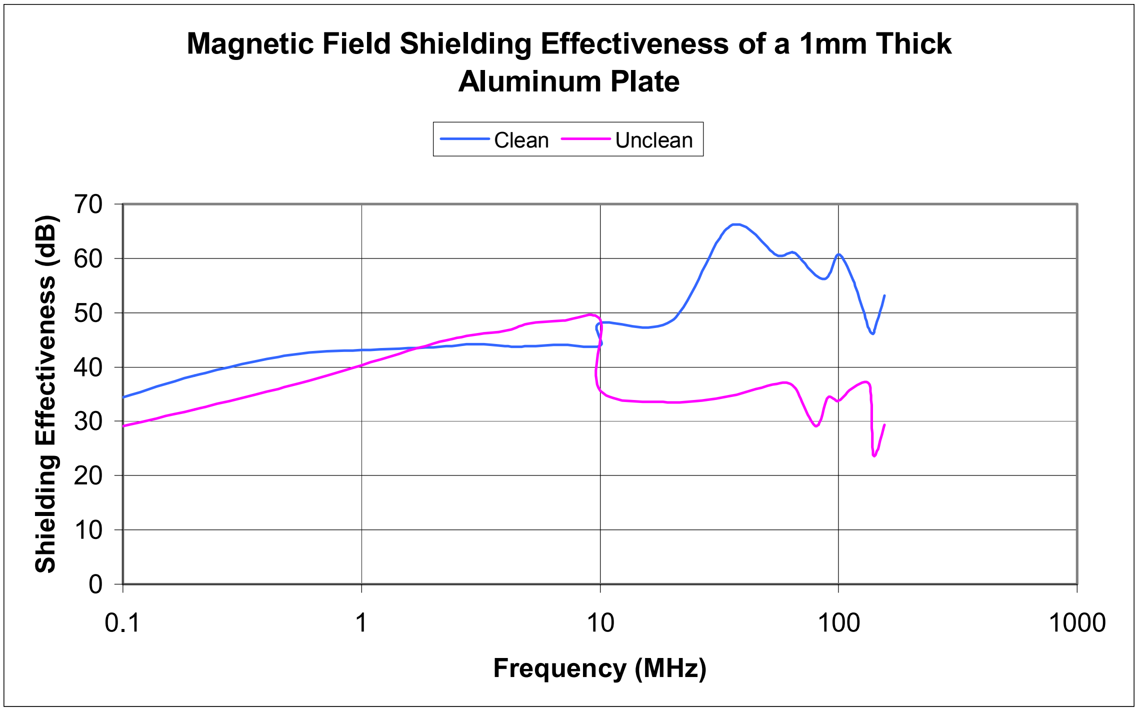


Figure 4-9 The effect of buffing the oxidized surface on an aluminum plate

## 5) Correlation between S.E. and surface resistivity.

The shielding effectiveness tests described here require great care in the execution, a shielded room and test equipment. Measurements of the surface resistivity of a material and the S.E show a close, but not perfect, correlation. Thus manufacturers can perform the much simpler surface resistivity test and obtain a good idea of how effective a material will be.

Table 2 compares the surface resistivity and the shielding effectiveness of different materials at 1MHz

Table 2 Comparison between S.E. and surface resistivity

| Material | Surface resistivity ($\Omega$/sq) | S.E. at 1MHz (dB) |
|---|---|---|
| Spayed silver-coated copper paint | 10m | 20 |
| Conductive silver paint #1 | 52m | 7 |
| Silver-plated, copper conductive EMI coating | 23m | 16 |
| Conductive silver paint #2 | 26m | 13 |
| Aluminum foil | 3.3m | 30 |
| 1mm aluminum plate | 33μ | 44 |
| Sprayed nickel paint | 11 | 0 |