Shielding a room using aluminum foil

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1) Introduction

A local hospital was interested in shielding some sensitive equipment and contemplated installing a shielded room. The room under consideration was the typical laminated wood core panel with galvanized steel on both surfaces, with a RF shielded door, honeycomb air vent panels and filters for ac power, telephone and any other signals, meeting the shielding effectiveness requirements of MIL-STD-285 or IEEE 299-1997.

As schedule was important, a room was purchased and installed. However two interesting questions have been raised 1) How much shielding effectiveness (S.E.) was actually required and 2) Could the existing room be converted to a shielded room and if so would it be less expensive than the conventional shielded room within the room. This report does not set out to answer the first question as factors such as the level of electromagnetic ambient and sensitivity of the equipment to power line conducted noise, E fields, plane waves or magnetic fields remain unknown. Another deciding factor is the frequencies at which the equipment is susceptible. Instead the conceptual design for a room covered in thin aluminum foil is described and the predicted shielding effectiveness for magnetic fields, plane waves and E fields are measured and predicted.

Some estimated costs are provided although the final cost must depend on the size of the room, the cost of local labor and the type of finish required on the walls and ceiling. It is worth reiterating that whether the level of predicted shielding achievable with this type of room is adequate depends on the level of the electromagnetic ambient to be shielded against and the susceptibility of the equipment to be shielded. This may be determined by localized shielding of sensitive equipment using aluminum foil or by analysis, although this is more difficult. This susceptibility will almost certainly vary with the type of field and the frequency. One word of warning, medical equipment is often susceptible to the emissions from fluorescent lights and if either the conventional shielded room or aluminum foil shielded room is provided with fluorescent lights it is important to also include alternative lighting such as filament lamps and to use a separate switched circuit for the fluorescent lights.

Apart from cost, the aluminum foil has the advantages of being potentially aesthetically more pleasing than a typical shielded room and in fact if the walls are properly covered and the floor covered in tiles, it will not be obvious that it is a shielded room. Another advantage is that any size room may be shielded without reducing its size, which typically
happens when a standard shielded room is placed within an existing room. Also the existing room may be any shape and size and still be shielded.

If the highest level of shielding is required and cost is not a major concern then the conventional shielded room would be the obvious choice.

Another alternative is a sound absorber drywall, which contains a steel plate and is sold as an RF panel. The available test data for this type of panel shows plane wave shielding effectiveness for a 24” x 24” panel in the wall of a large shielded room. The plane wave shielding is almost identical to the 1m x 0.7m x 1m aluminum foil room with stapled joint presented in this report. Unlike the test data provided in this report no shielding effectiveness for magnetic fields is provided for the drywall material. Reference 1, reference 2 and reference 3 as well as this report, show that the field, either plane wave or magnetic field shielding effectiveness is a strong function of the joint impedance and not of the conductive material of which the wall is made and so the mounting technique for this drywall material would be critical. This material should not be ruled out as a possibility for an inexpensive shielded room but if magnetic field shielding is a concern some additional tests on either a room or small box constructed from these panels would be recommended.

2) Conceptual design of a room

An existing room could be shielded by adding thin aluminum foil to the walls and ceiling. The foil could be glued in place. At the seams the foil would be overlapped at the edges. One option is for joints to be stapled at 3.5cm (1 3/8th of an inch) intervals and sealed with packing tape. This type of joint would be better if the foil is glued to plywood, into which the staples are firmly embedded. The foil could then be covered in either drywall or decorative panels. Alternatively, a thin or thick aluminum or plated steel strip would be used to apply pressure at the seams. If the thin strip is used (0.7mm thick), then to ensure adequate pressure at the seams, the joint should be over wooden strapping or battens. In the sample tested here, the fasteners were at 15.24cm (6” spacings) over the wooden frame of the enclosure. The implementation of this may involve taking down the dry wall and adding additional strapping, or plywood at additional cost. The measurements presented in this report do not show a significant difference in shielding effectiveness between the stapled joint and the joint with the metal strip.

The floor cannot be thin foil due to problems of tearing and wear. One recommendation is to place thin aluminum panels on the floor, in which case the foil on the wall would be in contact with the panels around the periphery of the room. The aluminum panels would use aluminum or plated steel strip either side of the joints, which would not need to be overlapped to ensure a good contact as the strips are on both sides of the panels. Around the bottom of the walls the foil would be placed over the top of the aluminum panel and clamped by the upper strip on the floor. Tiles placed over the floor would then protect this joint.

An option for the door, or doors, is the type of shielded door used in MRI shielded rooms. This will not have the highest level of shielding effectiveness but it looks like any normal door and so is aesthetically pleasing. The approximate cost for such a door is $5000 to $6000 CAN and a 12” x 12” air vent filter is approximately $480 CAN.
The conceptual design is shown in Figure 2.1.

The aluminum foil described in this report is 0.003” (0.076mm) thick. For a roll 100” long and 48” wide the cost is $119.66 US. For a 20’ x 8’ x 20’ room the approximate cost of the foil would be $360 US. The aluminum or plated steel strips may have to be custom made.

Once the aluminum foil is on the walls and ceiling it may be covered with decorative panels or painted. The decorative panels would be aesthetically more pleasing and provide protection against damage to the thin aluminum foil. If the area under the aluminum panels on the floor, between the aluminum strips is covered by a filler material with the same thickness as the strip and glued in place, then the floor tiles would be glued onto the floor. Figure 2.1 shows this thin filler on top of the aluminum between the upper metal strips.

The local labor cost is very approximately $3500 CAN. The total cost for a 20’ x 20’ room with one door and two ventilation panels, but excluding power line and signal filters is then approximately $12,000 to $14,000 CAN. However this estimate will vary depending on local labor cost, the cost of having aluminum strip manufactured (if used) and the type of floor tile and wall covering. The cost of floor materials and manufacture are not included in the above estimate.

An architect or mechanical engineer may suggest an alternative design, including the RF drywall material or may even say that the proposed design is impractical!

In contrast, the typical cost for a typical galvanized steel panel 20’ x 20’ shielded room meeting the shielding effectiveness specified in MIL-STD-285 or IEEE 299 is $45,000 CAN and so even with a well decorated room the cost of the aluminum room is likely to be much lower than the typical room.

To evaluate the performance of such a room a 1m x 0.7m x 1m version was built and tested. The test results from the small room were used to predict the performance of the 20’ x 20’ room.
Figure 2.1 Conceptual design of room

3) The enclosure under test

A wooden frame was built in the form of a square box with the dimensions 1m x 1m x 1m. Later this box was cut down to 1m x 0.7m x 1m as this was a more convenient size. This box is covered in 0.076mm thick aluminum foil. On one side of the box the foil is covered in a brass plate. A rectangular aperture is placed in the brass and foil, and this is covered by a door. The door has a Spira gasket around all four sides. Although this door was found to be a significant weak link in the plane wave S.E. measurements on a soldered up
copper box, described in reference 3, leakage from the seams is still considered to be the predominant factor in the test data presented here.

In the shielding effectiveness tests, the magnetic field loop and the E field transmitting antenna were oriented so that the current flow on the face of the box close to the transmitting antenna was vertical. I.e. the current flowed over the top of the box and returned on the underside of the box. A companion report entitled “An explanation for the “magic” low frequency magnetic field shielding effectiveness of thin conductive foil with a relative permeability of 1” available on www.magma.ca/~emccons has been published and will be referred to as reference 2. In reality, current also flows down the sides of the box but this does not generate an internal field as described in reference 2. Also, the receiving loop antenna inside the box was oriented to pick up the field generated by the current flowing up the face of the box. Only one seam, in which the foil was overlapped, was placed in the current path. However the vertical seams, which were stapled and taped, may also contribute to the leakage. A 4cm wide plated steel strip (used as a corner reinforcement in drywall) was placed over the seam and held in place by screws at 15.24cm spacing. An alternative seam was manufactured in the 1m x 0.7m x 1m version of the box using 8mm (5/16”) staples into the underlying wooden frame at 3.5cm (1 3/8”) intervals and, as described later, this was found to be similar to the metal strip.

Photo 3.1 shows the 1m x 1m x 1m room with door.
4) DC resistance of seam

The magnetic field shielding effectiveness of an enclosure is a strong function of the dc resistance of the seam/s in the enclosure. As described in section 6, the theoretical magnetic field S.E. of a thin aluminum foil enclosure without a seam (an impractical configuration as welding is not possible on such thin material) is incredibly high. Reference 2 reports the magnetic field S.E. on an aluminum foil enclosure with the lowest practical seam impedance. The dc resistance of the 1m long seam in the 1m x 1m x 1m aluminum foil enclosure in this report was measured, using a four wire technique, at 0.31mΩ/m. The dc resistance of the stapled seam was measured at 80µΩ/m. The joint with a drywall reinforcement strip has a dc resistance 3.9 x higher than the best practically achievable joint and the degradation in measured magnetic field S.E. is almost as predicted based on the dc resistances. A comparison is provided in reference 2. In plane wave measurements the difference in attenuation between the two seams is very dependent on frequency but on average is virtually the same. This is not explained by the ratio in the dc resistance of the joints which is approximately 12dB. This indicates that the total seam impedance and not only the dc resistance is the important parameter in plane wave S.E.

5) E field and Plane wave shielding effectiveness.

For E field measurements a biconical antenna was used to generate fields from 30MHz to 200MHz. The receiving antenna was a short monopole antenna mounted on a small PCB ground plane that could be inserted into the door of the box. A log periodic antenna useable from 200MHz to 1000MHz was used as the transmitting antenna with a bow tie antenna useable from 30MHz to 1000MHz as the receiving antenna for the plane wave measurements. The center of the biconical and the tip of the log periodic were located 0.5m from the front face of the shielded room. The antenna was oriented vertically so that the current induced into the face of the box was also vertical and flowed up the front face over the seam at the top of the box, across the top of the box, returning on the under surface. How this current changes due to the location of the antenna is discussed for magnetic field loops in reference 2. For the log periodic antenna, especially at low frequency, the current density is assumed to be relatively constant on the front surface of the enclosure. Inside the enclosure is a small bow tie antenna also oriented vertically and at 0.5m, i.e. equidistant, from the front and rear walls of the enclosure.

Shielding effectiveness is defined as the ratio of signal picked up on the receiving antenna without the box and with the box. Thus if the level received by the bow tie antenna without box is +6dBm and the level with the bow tie inside the box is –39dBm the S.E. is +6dBm –(-39dBm) = 45dB.

As with any shielding effectiveness measurement there is a limit to the level of S.E. that can be measured. In the test set up described here the cable connecting the bow tie to the spectrum analyzer outside of the anechoic chamber is run in a copper pipe. This pipe is connected at one end to the brass plate on the side of the box and at the other end to the
shielded room wall. The short length of cable outside the room is covered in an overbraid which is clamped to the shielded room wall as well as to the BNC connector on the pre-amp. Thus any pick up on the receiving antenna cable is expected to be very low. Measurements were made of the pick up with the bow tie removed from within the enclosure and replaced with a 50Ω termination. The level received in this ambient test was much lower than the level induced into the bow tie antenna and thus the bow tie measurements are validated.

Figure 5.1 is a plot of the E field and plane wave shielding effectiveness of the 1m x 0.7m x 1m box with one stapled seam as well as the plane wave shielding effectiveness of the box with metal strip seam.

![E field and plane wave S.E. of 1m x 0.7m x 1m aluminum room](image)

**Figure 5.1 E field and plane wave SE of box with stapled seam and metal strip seam.**

The weak link in the E field and plane wave shielding effectiveness of the box is not the aluminum foil but rather the stapled or metal strip seam. This is effectively demonstrated in a companion report entitled “seams as the weak link in E field and plane wave enclosure shielding effectiveness”, reference 3. This report describes measurements on a fully soldered up copper enclosure also 1m x 0.7m x 1m in dimension. The S.E. for this seamless box versus the same box with a seam in the copper and the copper seam replaced by aluminum are described in the report.

This report also describes a method for modeling the seam in an enclosure using the 4NEC2d MOM analysis program. Using the same impedance for the seams in the proposed 20ft x 8ft x 20ft room and assuming equipment is located at a minimum distance of 30cm from the wall, the E field and plane wave shielding effectiveness of the room was calculated using 4NEC2d. The room is much larger than the 1m x 0.7m x 1m box tested...
and contains seams at 0.81m intervals. However as the worst case (highest E field) is close to the seams (when the point for analysis is only 0.3m from the inside of the wall) the predicted shielding effectiveness is very similar to that for the 1m x 0.7m x 1m box. Thus the predicted shielding effectiveness for the 20’x 20’ x 8’ room is the same as shown in figure 5.1.

6) Magnetic field shielding effectiveness.

That a low permeability thin conductive foil provides any level of magnetic field shielding effectiveness at low frequency is to many counter-intuitive and a mystery. Many analyses based on a simple transmission line impedance approach and on skin depth predicts a very low level of S.E. for thin materials at low frequency, as well as a dependency on the proximity of the transmitting antenna. However an analysis technique validated by measurements is provided in reference 1 and this is further described in reference 2. This approach predicts a high level of magnetic field S.E., which is validated by the measurements. It also shows no dependency on the distance between the tx loop and the enclosure.

Reference 1 defines the magnetic field S.E as the ratio between the current flowing on the outside of the box to the current flowing on the inside. Two sets of measurements were made, one with the box inside the shielded room and one outside. Reference 2 also describes tests made on the far field range with the box on non-conductive trestles and the antenna on a wooden mast. In this test set up metal objects are kept very well away from the set up. A multi-turn transmitting antenna used in RS101 type measurements and the 13cm RE101 type of shielded receiving loop antenna were used. In this set up a reference measurement was made with the transmitting antenna at a fixed distance from the receiving antenna and without the presence of the shielded box. The second set of measurements has the receiving antenna located inside the shielded box. To ensure that the cable attached to the receiving loop did not pick up a signal and invalidate the shielded measurement the cable was run in a copper pipe from the box to the measuring equipment. A background measurement was made with the receiving loop replaced with a 50Ω load. The level of signal received with the 50Ω load termination was much lower than with the loop ensuring that the measured signal was well above the ambient.

Another set of measurements was made with a 560 turn surface current probe. The surface current probe was located on the outside wall directly facing the transmitting antenna. A second measurement was made with the surface current probe at the same relative location but on the inside wall of the box. The surface current probe measures the magnetic field on the surface of a conductor. It will also measure the magnetic field in space. A comparative measurement was made between the signal picked up by the current probe placed on the outside of the aluminum foil box versus the signal picked up at the same location in space with the box removed. At 400Hz and above the signal with the probe on the surface of the box was between 4 – 6dB higher than in space. This is to be expected as the current flowing on the outside surface of the box due to the incident magnetic field sets up a field which is in phase with the incident field and which adds to it. This is further discussed in reference 2. The plot in Figure 6.1 compares the S.E. obtained
from the current ratio and the magnetic field S.E. and it shows a good correlation from 10kHz to 70kHz. From 400Hz to 7kHz the difference between the two measurements is worst-case 8dB, which is acceptable. The theoretical is also within 8dB of the measured magnetic field and it may be that the dc resistance of the seam is slightly higher than the 0.31mΩ measured.

Figure 6.1 also shows that the location of the source loop does not alter the level of magnetic field shielding effectiveness as expected.

Photo 6.1 shows the multi-turn RS101 type transmitting loop 0.5m from the shielded room wall and photo 6.2 shows the 13cm RE01 type shielded loop antenna inside the enclosure.

Photo 6.1  Transmitting loop 0.5m from box wall.
Photo 6.2 Receiving antenna inside box.
Figure 6.1  Measured magnetic field shielding effectiveness versus theoretical and the ratio of external to internal current flow on the enclosure.

As expected the magnetic field shielding effectiveness of the foil box is not high at the power line frequencies of 50, 60 or 400Hz but neither is a traditional shielded room, which may exhibit approximately 20dB of S.E. at 60Hz. From 50kHz, and above, the S.E. is higher and so magnetic field broadband emissions from switching power supplies, some types of turbines used in HVAC and heavy machinery will be attenuated. The predicted S.E. for a 20’ x 20’ x 8’ aluminum foil room with at least 18 seams in the current path is provided in section 7.0 of this report.

7)  Predicted shielding effectiveness of a 20’ x 20’ x 8’ shielded room using aluminum foil on the walls.

The analysis tool described in reference 1 and used to predict the theoretical S.E in Figure 6.1 may also be used to predict the magnetic field S.E. of a larger room with multiple joints. If we use a dc resistance of 1.2mΩ/m and a contact impedance value of 2.2μΩ/m, which matches the measured S.E for the 1m x 0.7m x 1m box with the stapled seam, we arrive at 200μΩ dc resistance and 0.366μΩ for the contact impedance for the 6m wide seam in the room. If we assume ten such seams in the current path and a room 20’ wide 8’ tall and 20’ in depth the predicted magnetic field S.E. is shown in figure 7.1.
Figure 7.1  Predicted magnetic field SE of aluminum foil covered room with stapled seams.

8) Conclusions

This report shows the approximate level of E field, plane wave and magnetic field shielding effectiveness of a room 20ft x 8ft x 20ft covered with thin aluminum foil. Although it is beyond the scope of this report to determine if the level of predicted S.E. is high enough it does show that a significant level of shielding can be achieved. Table 8.1 compares the specified S.E. of a typical shielded room versus the predicted S.E. of the 20’ x 20’ x 8’ room. The level of S.E. at 1MHz was not measured but based on the 100dB achieved at 30MHz this should be possible.
Table 8.1 Comparison between a standard room and the aluminum foil lined room.

<table>
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<th>Frequency</th>
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<th>Predicted performance of aluminum foil room (dB)</th>
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<td>42</td>
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<td>E</td>
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<td>100?</td>
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<tr>
<td>1000MHz</td>
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<td>100</td>
<td>42</td>
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</tbody>
</table>
References


2) An explanation for the “magic” low frequency magnetic field shielding effectiveness of thin conductive foil with a relative permeability of 1. D. A. Weston and K. McDougall. 31-7-2006. Available on the EMC Consulting Inc. website www.magmacom.com/~emccons

3) Seams as the weak link in E field and plane wave enclosure shielding effectiveness D. A. Weston. 19-7-2006. Available on www.magmacom.com/~emccons