Shielding

A Low Tech, Low Cost Method for Building Shielded Enclosures

A Discussion of a Low Cost Technique for Constructing a Shielded Enclosure Using Common, Inexpensive Materials

By Ken Javor

This article describes a construction technique for economically building shielded enclosures using materials available at building supply stores. The technique is roughly comparable to the foil lined chamber of NACSEM 5204 Appendix C, *National Security Agency Specification for Foil Shielded Enclosure*. A normal size shield room providing an ambient suitable for testing to the radiated emission limits of MIL-STD-461C may be built at a cost of roughly $1.00 per surface square foot for material and 48 manhours of labor. Detailed construction techniques, material lists and costs are given. Possible applications for shielded structures of similar "off the hardware store shelf" construction are also presented.

Construction

Basic Six-Sided Room. With the foil lined chamber of the Tempest document as a point of departure, a change in siding material is made to save labor costs. The siding under this new technique is aluminum foil coated insulating building siding. This siding is more expensive than drywall ($7.77 vs. $2.98 at a local retail building supply store), but saves the labor of stapling the foil to the drywall. The panel seams may be sealed either with conductive EMI tape, or, as shown in Figures 1 and 2 below, sealed with a combination of aluminum flashing and ordinary metal tape with a nonconductive adhesive.

It is important that the foil on the siding material have a conductive finish. This can be checked using an ordinary VOM, but using pennies as pads to protect the foil material from excessive contact pressure from sharp probes. The contact pressure should approximate that available from the construction technique in order to be a useful measurement. One product which meets the requirement is Celotex Tuff-R brand insulating sheathing. This is a polyisocyanurate foam board with aluminum foil facers on both sides.

The method of seam dressing as shown in Figures 1 and 2 is much less expensive in materials than using conductive EMI tape. EMI tape will cost roughly twice as much as the combination of ordinary metal tape and aluminum flashing as shown in the figure. The author was initially skeptical of the sealing method of Figure 1. The concern was that using tape to hold down the edges of the flashing would apply no direct contact pressure between flashing and siding and thus no controlled ohmic bonding. But a room built with a similar technique performed more than adequately to provide a reasonable RE02 ambient. This seam dressing technique, aside from saving a great deal of money, allows the room to be built entirely from common building materials found at local building supply stores.

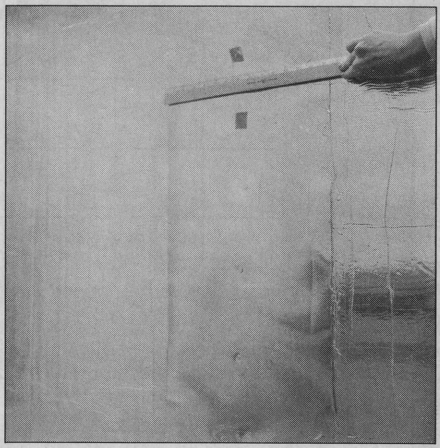

Figure 2. Photograph of seam treatment.

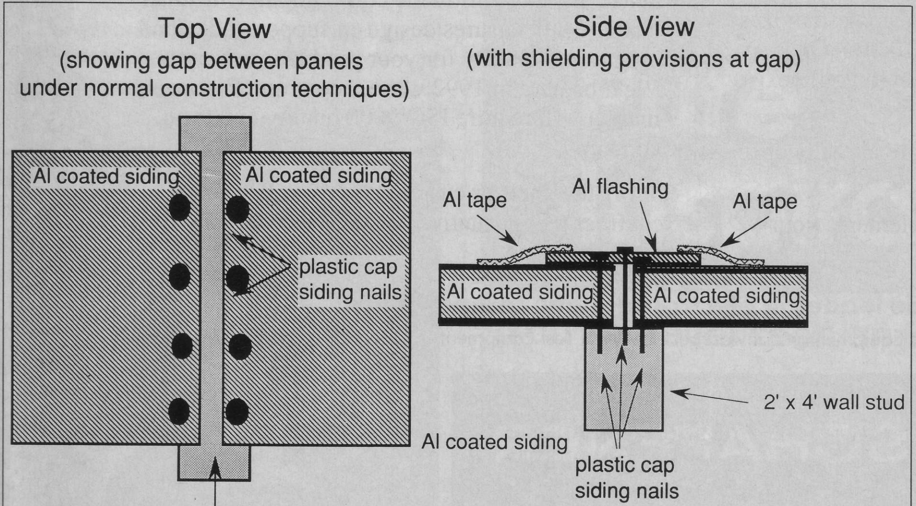

Figure 1. Construction details, siding treatment (exaggerated seam gap, not drawn to scale).

Concluding description of the six-sided room construction, the ceiling is built exactly like the walls. The floor is galvanized sheet panels taped together (see Figures 3 and 4, respectively). Aluminum flashing is used at the enclosure edges to make the ohmic seam between the six enclosure surfaces. The same metal tape is used to seal these seams.

Access to Room. Depending on the purpose, access into the chamber may be implemented in various configurations. A very simple method will be described for which RF attenuation data exists. A 2 ft. ×

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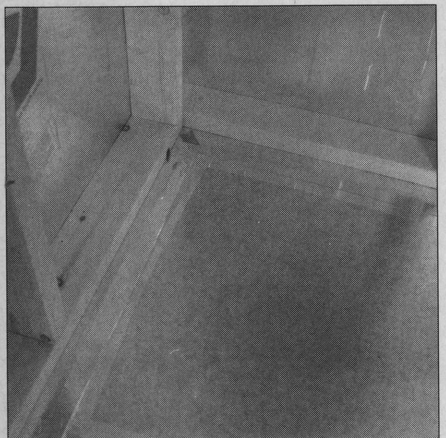

Figure 3. Floor details.

Figure 4. Photograph of ceiling with seams.

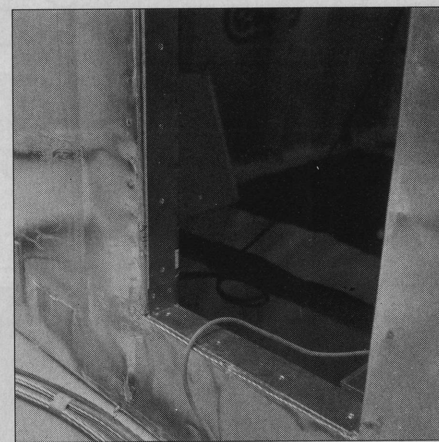

Figure 5. Photograph of personnel doorway close up.

4.5 ft. personnel access door was cut into an enclosure built with similar techniques to those discussed. Figure 5 is a close up of the access treatment showing aluminum plate over aluminum flashing lining the access way penetration. The plate acts as both protection for the weaker flashing and as shim stock. Figure 6 is the door itself. The door is not hinged and is completely removable, as shown. As can be seen, the door was a 2 in. × 4 in. frame with metal sheeting of sufficient size that there was an overlap between the enclosure surface and the door shielding material. Metal to metal contact was achieved by use of metal weather stripping visible on the outer side of the door frame. There was no mechanism for producing contact pressure between door and enclosure. However, there was enough pressure generated by the metallic weather stripping against the shimmed door frame to hold the door in place. This door although of simple design, provided the necessary attenuation.

Penetrations. EMI testing and general shield room activities typically will require interface(s) with the world outside the chamber. Electrical/electronic interface cabling may be routed through either stuffing tubes or bulkhead panels. An inexpensive method for building stuffing tubes is to use aluminum ductwork available at building supply stores. Figure 7 shows a combination stuffing tube and bulkhead plate made of welded steel pipe and plate. Steel stuffing tube/bulkhead panels must be mounted against a 2×4 box built into the wall framing as one would do around a window, since the foil clad foam siding is not strong enough to support the mass of the metal bulkhead. Wood screws are used to pull the bulkhead plate in against the siding. In this figure

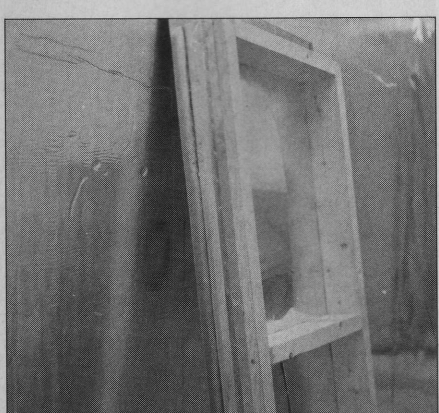

Figure 6. Photograph of personnel door.

some cables were removed from the stuffing tube and provided bulkhead feedthrough type connectors because the nonconductive cloth cable covers made it difficult to ground the cable overshield adequately as it penetrated the stuffing tube. The empty volume of the stuffing tube may be filled with steel wool, per common practice. In order to determine the quality of the shielding termination shown in Figure 7, current probe measurements were made on all cables inside and outside the enclosure. Noise reduction was achieved on all cables.

Another penetration frequently necessary is for a coaxial cable between EMI sensors and receivers. This will consist of a bulkhead plate with a single coaxial type bulkhead feedthrough connector.

In addition to electrical/electronic interfaces, there is usually a need for HVAC penetrations. HVAC dedicated to a single piece of equipment may be routed through a stuffing tube.

HVAC for the general chamber may be routed into the enclosure through a stuffing tube and/or aluminum screening peripherally bonded to the foil backed siding with tape. As will be shown, a screened penetration on the ceiling and a complementary penetration near the base with an outside mounted fan appropriate for the heat load will suffice.

Grounding and Groundplanes. Any such chamber must be single point grounded to avoid fields produced by ground currents circulating on the chamber. Figure 8 shows an attachment to the outside of a room similar to that described. Normal good practice for optimum SE is for the outer grounding attachment not to penetrate the enclosure. Grounding of equipment inside the enclosure should be to a groundplane

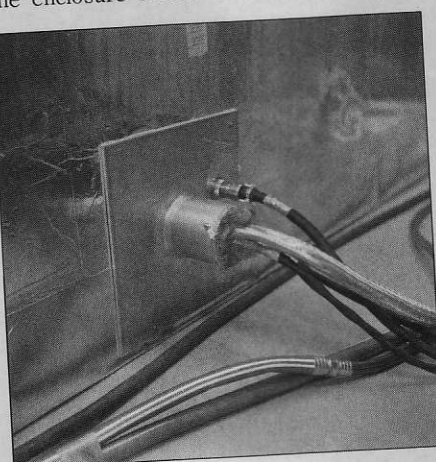

Figure 7. Photograph of bulkhead penetration for electrical support equipment.

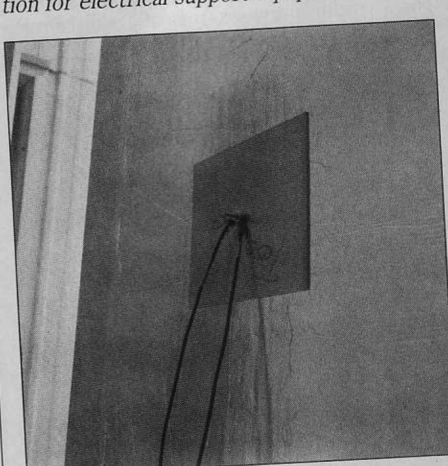

Figure 8. Photograph of shield room outer ground connection.

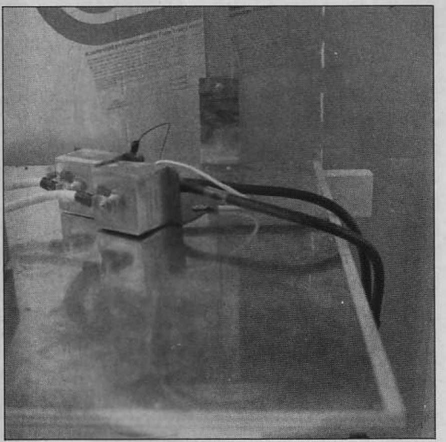

Figure 9. Shieldroom equipment ground and groundplane.

which is itself electrically bonded to the enclosure at prescribed intervals (viz. MIL-STD-462 basic 1967 release, paragraph 4.2.1.2). However, in the case of a foil room the author questions whether using the enclosure structure for a safety ground path is allowable. The effects of a fault would be better controlled if a fixed fault current path of known current carrying capability was designed. To this end, the penetration shown in Figure 8 on the outside may be connected to a copper strap on the inside which drops down to a groundplane surface (similar to Figure 9.) The equipment inside the room itself is bonded to the groundplane surface.

Purpose	Material	Price Each	Quantity	Size	Price Subtotal
Siding	Celotex Tuff-R siding	$7.77	20 sheets	4'x8'x0.5"	$155.40
floor	galvanized sheet	$53.99	1.5 rolls	31 ga 20"x50'	$81.00
framing	lumber	$1.74 $3.92 $1.39	44 8 20	10' 2x4 16' 2x4 8' 2x4	$76.56 $31.56 $27.80
siding seam	aluminum flashing	$25.33	6 rolls	50'x14"	$151.98
treatment	aluminum tape (Thermwell Products Co. Frost King repair tape)	$1.97	20 rolls	10 yd. x 2"	$39.40
fasteners	nails (not added into total) plastic cap siding nails (not added into total) wood screws (if necessary for mounting penetrations)			#16 7/8"	$0.37/lb. $3.34/lb. not added into total
miscel-laneous	steel wool (#1)	$0.92/each			not added into total
	aluminum ductwork and screening				not added into total
Total					**$563.70**

Table 1. Materials Parts List and Cost

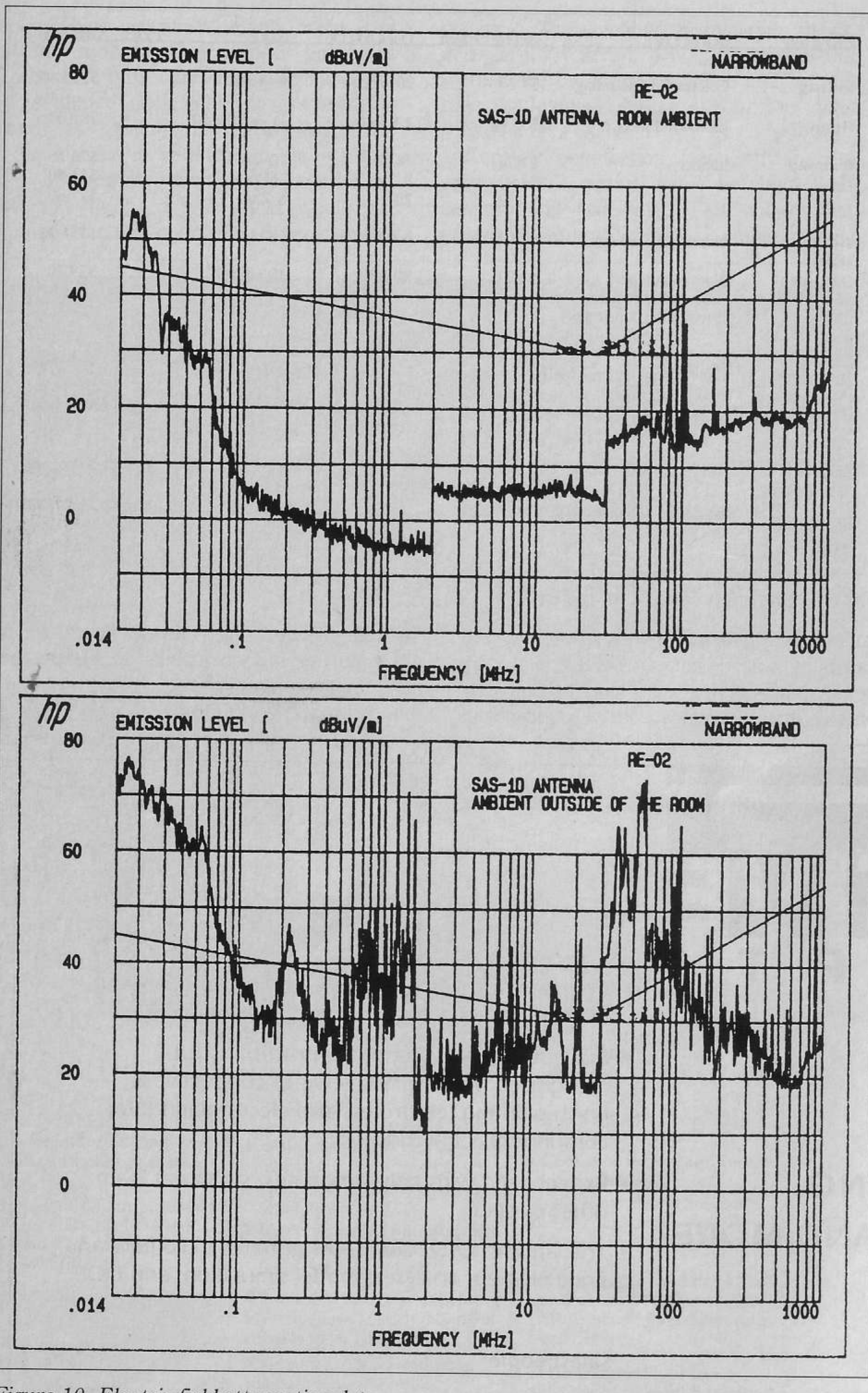

Figure 10. Electric field attenuation data.

Economics

An enclosure of size 16 ft.L x 8 ft.W x 8 ft.H may be constructed for roughly $1100 in material and 40 manhours of labor. This size is picked for ease of estimation purposes. Prices are from local retail building supply stores as of July 1991. The enclosure material cost is broken down as shown in Table 1. A 40 manhour estimate is based on a three man crew assembling a considerably larger room of similar construction technique in under two days (author's recollection.)

Enclosure Performance — Shielding Effectiveness

Actual RF attenuation data attributable to these techniques is available. The photographs in this article are of a room built with similar, but not as good construction techniques as described herein. This room was built to provide a radiated emission (RE) ambient 6 dB below the RE02 limit. Achievement of this goal was an end in itself; no SE measurements per se were made. Thus the attenuation values claimed for the room are not in accordance with the industry standards, MIL-STD-285 and NSA 65-6.

E-field. Figure 10 shows a comparison of radiated electric field intensity measurements made inside and just outside the chamber. Fortuitously, the EMI test team provided emissions measuring equipment much better than necessary for making RE02 measurements below 1 GHz. The measurement system with antenna inside the room consisted of the Antenna Research Associates SAS-1D antenna, an Electrometrics preamplifier BPA-1000 (F<7 dB, G=26 dB), and an HP8566B spectrum analyzer with the HP8565A preselector. With this set up, the measurement noise floor over the entire frequency range is dominated by the sensitivity of the SAS-1D, the first element in the series, as is proper. Outside the room, the BPA-1000 was removed from the measurement set up to avoid possible overload.

There are three areas of interest in Figure 10. Below about 25 kHz, the room ambient was slightly over the limit. This anomaly was never fully explained. The ceiling of the shielded room was only two feet below the ceiling of the building enclosing the shield room. The ceiling was almost totally composed of fluorescent light panels. No 60 Hz wiring was in the room during the measurement.

In the AM broadcast band the results are most gratifying. As much as 75 dB attenuation is evident at just over 1 MHz. It should be mentioned that the SAS-1D is an electrically short E-field probe below about 60 MHz so that only E-field attenuation can be claimed at this frequency.

In the FM broadcast band, where the antenna approximates a passive quarter wave stub and thus has an appreciable effective aperture, the attenuation is still respectable. At just over 100 MHz, attenuation is 30 dB. At 890 MHz (cellular telephone) attenuation is 20 dB. Recall the simplicity of the door. The door height must be over a quarter wavelength at 100 MHz. It was not checked, but it is reasonable to assume that a better door seal would greatly increase the attenuation at these frequencies.

B-field. See Figure 11 for magnetic induction intensity data between 20 Hz and 50 kHz. Although an inside/outside comparison was not made, it is apparent that quite low levels are measurable in the room. (This test was performed to the obsolete MIL-STD-461A RE04 limit.) Compare these levels to the present day limits of requirement RE01. There were no unusual sources of 60 Hz magnetic fields in the building; however, there was a small power substation less than 100 meters from the building. Measurements at 60 Hz did increase when the loop probe was moved outside the room, but the increase was not recorded. An Electrometrics EMC-11 with the AT-205 type loop (as defined in MIL-STD-461 basic and revision A, paragraph 5.2.1) was used to make these measurements.

Reliability Observation. As mentioned above, the method of fastening the panels together and sealing the gaps does not force any metal to metal contact under pressure. In some areas, the aluminum flashing will make direct contact with the Celotex siding. In the room of the photographs, casual inspection revealed a large amount of bowing between flashing and siding. This would lead to the conclusion that tape to flashing/tape to siding capacitance might be responsible for the attenuation noted. This capacitance would not be expected to degrade over time, as the aluminum oxidizes, at least to the extent that an ohmic connection would.

Possible Improvements. The door is the most obvious weak link in the shielded enclosure. A hinged metal door hung on a proper frame with better "finger" contact between door and frame would probably help considerably. Power into the room must be either dedicated to the room or filtered (as would be necessary for any 60 Hz piped into the room.)

Finally, a note of academic interest. The double sided Celotex paneling would lend itself naturally to a double electrically isolated (DEI) enclosure configuration a la Lindgren RF Enclosures technology. Lindgren literature shows 34 dB improvement in 14 kHz magnetic performance and 20 dB improvement in electric and plane wave SE due to DEI construction (using a single layer of copper screen as a baseline.) The construction techniques changes would be limited to the following.

1) Predrilling oversize holes for nails. The purpose here is to avoid allowing a nail to provide ohmic contact between the aluminum foil coatings on either side of the panels. 2) Laying up of flashing material on inside of enclosure panel gaps as well as the outside. The oversize holes would have to be drilled through this flashing material as well. See Figure 12 below (contrast with Figure 1.)

Applications

There are many cases where on-site EMI testing is preferable to shipping the test unit to a remote facility. The ability to provide a clean radiated ambient is crucial for the success of the test. Besides schedule, complexity of test item/support equipment or a need for special support personnel and facilities are all possible reasons for performing an on-site test.

Besides EMI testing there are several reasons for using shielded enclosures. The point of departure for the room described here is the Tempest shielded enclosure referenced previously. If the construction techniques described above provide satisfactory SE per the methods of NSA 65-6, then this technique may well be an economi-

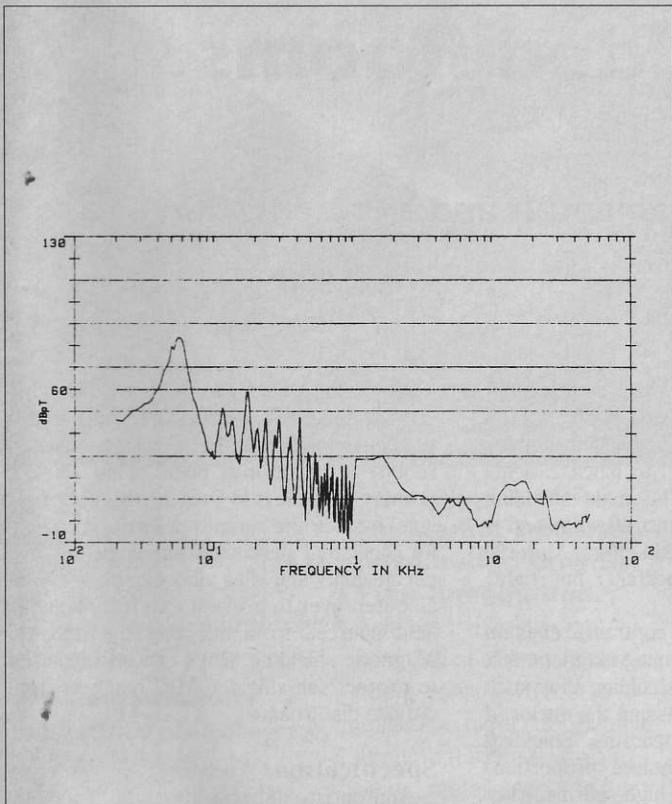

Figure 11. Magnetic induction intensity in shield room.

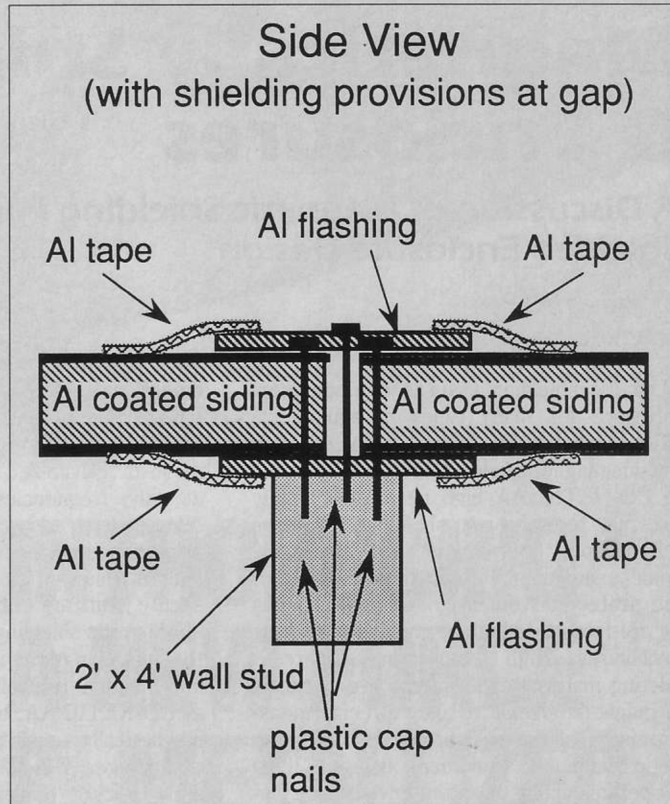

Figure 12: Construction details, double electrically isolated siding seam treatment (exaggerated seam gap, drawing not to scale).

cally advantageous replacement for the current foil lined chamber.

Taking this approach one step further, it may be desirable to build an entire shielded building per the methods described above. This construction technique could vastly reduce the cost of providing the required attenuation. The foil lined Tempest chamber referenced previously is described as a free standing enclosure erected inside another building as the need arises to process classified data. The room described herein was likewise built inside of a laboratory building. But if the need for shielding is apparent before a building goes up, for Tempest, EMI or perhaps safety reasons, then the techniques described herein allow for shield room like performance with insignificant extra cost for materials. Only the ceiling and sealing of the gaps and metallizing the floor requires extra material and labor.

Another use for an inexpensive shielded room is as an electrically quiet environment for the checkout, troubleshoot and general testing of sensitive electronic instrumentation.

Safety was mentioned as a possible reason for shielding an entire building. There is growing concern about the biological effects of radiated electromagnetic fields, from 60 Hz through the microwave bands. The heating effects of electromagnetic radiation and the limits on such radiation are the subject of ANSI C95.1. There are probably very few buildings outside of airport flight lines and aircraft carrier decks which require SE to meet C95.1 levels.

However, there is a more recent and currently controversial topic related to the effects of power frequency (50/60 Hz) electric and magnetic fields on human health. One main concern is the electric field from the power company overhead transmission lines. Depending upon the nominal amount of power delivered by the overhead line, the voltage between each phase and ground can easily number in the hundreds of kilovolts, while the current flowing is less than 10 Amps. Such fields have been shown in the laboratory to cause irregular behavior in cells.

The author feels that the use of aluminum clad building siding, bonded together per the instructions above, would be more than adequate to shunt the electric fields away from the interior of the building. The impedance of the field in the immediate vicinity of the overhead line is to a first approximation the ratio of the voltage to the current in the line. For a 1 MW line running at 500 kV and 2 Amps, the impedance of the field would be 250 kΩ. Given such a high impedance field, it should not be necessary to seal all the building joints and seams, but merely to provide a DC path between all metal surfaces, as one would do for lightning (without, however, the need to carry lightning magnitude currents). A 1Ω path to ground from any portion of the building surface would suffice to attenuate the field inside by the ratio of the voltage divider formed by 1Ω shorting out a 250 kΩ source impedance, or 108 dB. If the overhead lines were 10 meters above ground, the field strength would be (again, a simplistic assumption for the purpose of illustration) 500 kV/10 m or 50,000 V/m. Inside the building the field would be 0.2 V/m.

Achnowledgement

The author would like to thank the EMI test engineers, Mr. Richard Aldridge and Mr. George Williams, for the extra time and effort they took to gather the attenuation data included in this article, and also for their superb measurement facility allowing the full attenuation of the room to be measured.