SHIELDED ROOMS & ENCLOSURES

Introduction

An RF shielded enclosure is any container which is made up of continuously conducting walls and whose seams and openings are especially treated to minimize RF leakage. In the context of this paper, a shielded enclosure is an especially designed room in which man and equipment can be placed. It has an access door, ventilation openings, power entrance, and the RF environment inside is significantly different from that outside of the enclosure's walls. Figure 1 is a picture of a typical shielded room.

Generally, a shielded room has four walls, a roof and a floor. Some designers try to eliminate the shield floor of rooms which are resting on earth by extending the walls into the earth. This is a very flakey practice, however, since the RF shielding effectiveness of the earth is, at best, variable depending upon the consistency of the soil. In a practical sense, it is better to include the shield floor than to go to the expense of an elaborate and untested design to eliminate it.

There are several types of shielded rooms. Most are semi-permanent structures designed so that they may be dismantled and moved to another location and reconstructed. Thus, they are either bolted together or welded in a way that the weld may be removed and then rewelded. The shielding which is built into the architectural structure of the building is, of course, fixed, and intended to be permanent in nature. There are also a large number of a third type of shielded rooms, that is, mobile shielded enclosures built into a van or truck such as that shown in Figure 2. Sometimes the entire van is built as a shielded enclosure.

Shielded rooms should not be confused with anechoic rooms. An anechoic chamber is made of microwave absorbing material designed to minimize internal reflections by simulating the impedance of free space in the direction of propagation and along the walls. Since an anechoic room will leak RF energy, it is often desirable to build an RF room around the chamber. There are many RF shielded anechoic chambers in existence today.

Why You Need a Shielded Enclosure

An RF shielded enclosure works in both directions; it keeps internal radiated energy in and external radiated energy out. It should be remembered that the shielding is not absolute, but usually a very high order of magnitude, such as 100 dB over a finite frequency range. Thus, when you need a shielded enclosure, you should know how much shielding effectiveness (or attentuation) you require as a function of frequency.

Shielded enclosures are used for many purposes. The most common usage is as a test chamber in which to perform EMI measurements or to test sensitive and high power equipment. The need for a shielded room in which to perform EMI measurements on government contracts is straightforward; it is required by military EMI specifications. Here, noise radiation limits are very low and are usually substantially below the ambient radiation levels in the normal laboratory environment. Thus, the shielded enclosure keeps out the high ambient and provides a quiet zone in which the low levels of the specification can be measured. On the other hand, the specifications require that high levels of radiation be generated (10V/m and greater) to which equipment is subjected. The shielded rooms keep this energy contained, preventing its interaction with other unprotected equipment in the laboratory, and avoiding violation of FCC radiation regulations.

Other typical applications include:

- Building shielded rooms around control and communications equipment at radar sites.
- Building shielded rooms around computer hardware installations to keep out industrial noise.
- To house the performance of biological effects of electromagnetic radiation experiments.
- To house equipment to prevent electronic easesdropping.
- To house electronic equipment developed as part of DOD and industrial classified projects.
- To provide a radiation free laboratory in which to tune sensitive electronic equipment.

Figure 1: Typical Shielded Room (Solid)

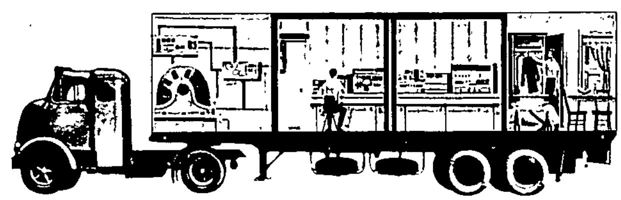


Figure 2: Mobile Shielded Enclosure

Types of Construction

The first of the modern shielded enclosure construction methods was developed, to a great extent, at the Johnsville, Pennsylvania, U.S. Naval Air Development Center. This room was made with two layers of copper screen, separated by an inch or so.

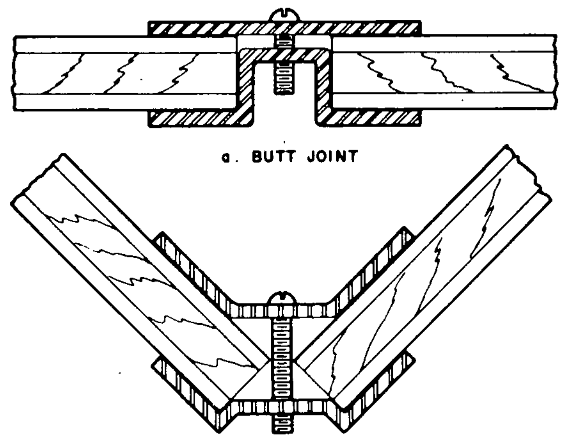
The room was constructed of several panels, called cells, each one 8 feet by 4 feet in dimension. The individual panel edges butted together and were bolted through the wood framing that provided the shape and strength for each panel. One of the features of this room was that it could be disassembled, moved, and reassembled at a second location without major modification.

The door for this room was also framed with wood, but well-braced and covered with either copper or copper screen. The periphery of the door was furnished with two sets of spring fingers, one to provide contact with the inner edge of the doorjamb and sill, with the outer set to push against the outside of the door frame. This second set of spring fingers actually overlapped the door frame opening.

A similar enclosure construction is the cell type with only a single layer of screening or sheet. This method is not widely used since it is almost as expensive as the double-layer cell-type, and has poorer performance.

For double-layer enclosures, or the so-called double-shielded room, a fairly simple method has been developed. This is the sandwich panel, with two steel sheets bonded to a 3/4-inch plywood core. The panels are not butted together all the way, but are clamped on each edge by special continuous channels and strapping. The method of joining panels along the sides of a room and at the corners is shown in Figure 3. Machine screws pull the channel and strap together every few inches.

Another type of construction makes use of a single sheet of steel on a metal framework. The sheet is under some tension from the way it is welded to the frame, and the frame or panels are welded together.

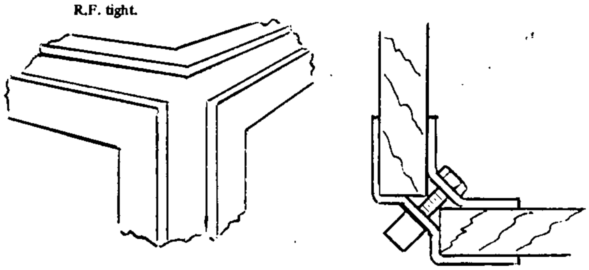


b. CORNER JOINT (VERTICAL OR HORIZONTAL)

Figure 3: Methods of Joining Sandwich-Type Panels

Variations are used by several manufacturers of shielded enclosures. Some newer developments in clamp design by Lectro-Magnetics (LMI) include a preassembled (welded) and interlocking three way corner which eliminiates common three way corner leakage problems. Also incorporated in the design is the use of a closed threaded insert to eliminate RF leakage and pentration at each of the clamping bolts. Typical features of this design are shown in Figure 4.

Note: Corner seams are welded R.F. tight.



Shielded non penetrating theaded blind insert.

OUTSIDE CORNER CLAMP

Figure 4: Alternate Methods of Joining Panels

Filters

Part of the job of providing attenuation for a shielded enclosure is accomplished by the structure itself, i.e., the wall sections, seams, and door. But these are of no value, no matter how well designed, if the room is penetrated by any unfiltered lines or wires. For this reason, the power-line filters are an integral part of the enclosure.

The basic requirement for the filters is that they provide a certain minimum attenuation over the frequency range of the room, usually from approximately 14 kHz to 10 GHz.

The difficult problem is to determine how much attenuation the filters must offer to complement a particular room design or application. The degree of attenuation that must be furnished by the filters is only roughly related to the attenuation of the room.

The usual solution to the problem is to provide filters with attenuation capability somewhat less than that of the room. For example, if the room offers attenuation of 120 db over most of the frequency range, filters offering 100 db should prove adequate. If the required enclosure performance exceeds the RF Power Line filter capability, the filters may be enclosured in a shielded electrical panel cabinet to increase the low frequency magnetic isolation. Normal installation practice places the filters outside the enclosure, with the line coming through pipe nipples into the room.

The mechanical design of high-attenuation filters is quite an important factor in their performance. To reduce coupling between the input and output of the separate sections, well designed compartments are required. The buyer of power-line filters must be cautious in his selection, since a variety of sizes and qualities of shielded enclosure filters are available.

Cost

Cost considerations are very important and should be resolved at the earliest possible point when a new shielded enclosure is being considered. Cost and performance are interlocking features.

As a rule of thumb, if performance is secondary, for smaller enclosures and up to a size of approximately 24 ft x 30 ft, the modular room is less expensive in its initial cost. The environments of useage and maintenance must be considered to determine the end cost. If performance, and/or environments are most important, the all welded room is less expensive both initially and in the end cost.

An exception to this rule of thumb is in the case of large structures that are appreciable in size than stated above, and in particular when such structures must pass building codes and other environmental factors, wherein the all welded enclosure is generally less expensive regardless of the degree of shielding effectiveness required. In such applications, the modular rooms are not self supporting and require considerable framing. The all welded rooms are in accordance with the Uniform Building Code and are self supporting. An important cost and weight advantage is also in favor of the all welded room due to the elimination of plywood in the total structure.

Additional Penetration

Additional penetrations of the enclosure walls may be necessary to provide other services. Gas, water, and compressed air may be furnished through steel or copper piping. If the pipe is joined to the enclosure wall in a clean, tight connection, the attenuation of the room will not be appreciably affected.

The same method must be used to bring coaxial lines through the wall of the enclosure. In this case, special coaxial fittings are available that are similar to a threaded pipe nipple, except they have the suitable coaxial construction and fittings at each end.

The use of coaxial cables can, in some cases, reduce the shielding effectiveness of an enclosure by providing a path of entry for high-level signals. These high-level signals can penetrate the cable shield and be conducted into the enclosure. For this reason, double-shielded coaxial cables should be used for these connections if high ambient signals are known to exist.

Checkout

A newly installed shielded enclosure usually receives a thorough check of its attenuation to determine if it performs to specification. Often these tests are performed in accordance with MIL-STD-285, which prescribes test frequencies and equipment, as well as antenna separation distances. The testing of an enclosure is basically a near-field measurement which means that the results may vary widely as a function of distances, antenna types, and frequency. For this reason, it is important that the methods indicated in MIL-STD-285 (if it is the test specification) be followed as closely as possible so that meaningful and repeatable results may be obtained.

Testing of an enclosure should be accomplished periodically to verify that its attenuation still meets the original specification. In this respect, the enclosure may be considered as an item of equipment in the laboratory inventory, and placed on the periodic calibration schedule. After the initial checkout, the enclosure should be checked at least every other year. Interim spot checks may be desirable in conjunction with special interference tests as a validation move, or in the event degradation of enclosure attenuation is suspected for any reason.

Ventilation

Shielded enclosures of all types require some means of force ventilation, especially the solid-wall enclosures. This service must provide moving air without affecting the shielding effectiveness of the walls. The standard method of achieving this requirement is to utilize the waveguide-beyond-cutoff principle and there are several physical satisfactory configurations.

The finished unit, sometimes termed "honeycomb," may have the appearance of an automobile radiator. The placement and size of these air vents will depend on the individual room requirements, as will the size and type of blower. If the room is to contain large amounts of equipment and/or personnel, air conditioning must be furnished.

Basic Shielding Theory

The first precise treatment of shielding theory is due to Schelkunoff. He developed the plane-wave theory of shielding which is still used today. Other researchers, particularly Jarva, Vasaka and Schulz, working primarily from experimental data, adapted the work of Schelkunoff to the prediction of shielding effectiveness for practical shielded enclosures.

A rigorous dissertation on shielding theory must include the treatment of plane wave, electric field and magnetic fields separately, plus an examination of wave impedence theory. We shall leave this detail to the textbooks such as Everett (1), and deal only with the simple case of a far field plane wave, in order to make our point about double isolated shielded enclosures.

In discussing shielded rooms, we must adopt the concept of a physical barrier between two regions. Then there are two main means by which the barrier may effect shielding. They are absorption and reflection.

eq. (1) $$SE = A + R$$

where

A – absorption loss
R – reflection loss

The barrier or shield may be made out of either a dielectric or conductive material. A pure dielectric shield will give limited shielding due to reflection because the dielectric constant of most materials differs very little from that of air. Conductors, however, make excellent shields, because they can reflect a great deal more energy than dielectrics, as well as absorb much of the energy.

It can be shown quantitatively that the amount of energy incident upon the barrier or shield that is transmitted into it is dependent only upon the ratio of the electric to magnetic field strength at the surface of the shield. This ratio is just the impedance of the barrier when the absorption loss of the barrier is high, such as 10 dB or more. If the absorption loss is low, such as 1 dB, then the actual impedance at the barrier surface is highly affected by the reflected wave from the far side of the barrier shield and thus the correction term (C) may be added to equation (1). Shielding effectiveness against a plane wave can then be stated as:

eq. (1) $$SE = A + R + C \quad (dB)$$

where

eq. (2) $$A = 131\,\ell\sqrt{f\mu_r g_r} \quad (dB)$$

eq. (3) $$R = 168 + 20\log\sqrt{g_r/f\mu_r} = 20\log\frac{(\eta + Z_s)^2}{4\eta Z_s} \quad (dB)$$

eq. (4) $$C = 20\log\left[1 - 10^{A/10}(\cos .23A + j\sin .23A)\right] \quad (dB)$$

eq. (5) $$Z_s = (1 + j)\left(\frac{\pi f \mu_r}{g_r}\right)^{1/2}$$

It can be seen from equation 2 that when the absorption loss A is larger. C is small and can be ignored.

μ_r = relative permissibility

g_r = conductivity relative to copper

f = frequency in Hertz

η = 377 Ω Intrinsic impedance of free space

ℓ = meters

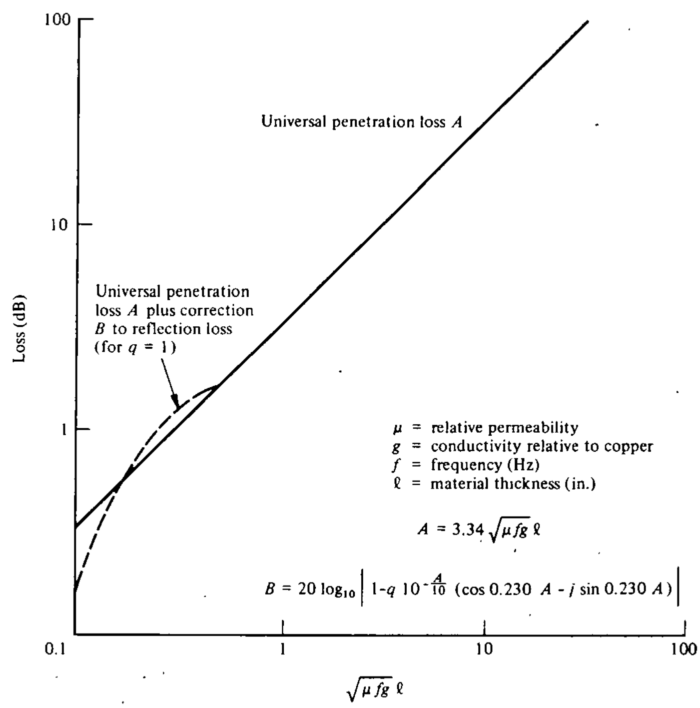


Figure 5: Universal Penetration-Loss Curve

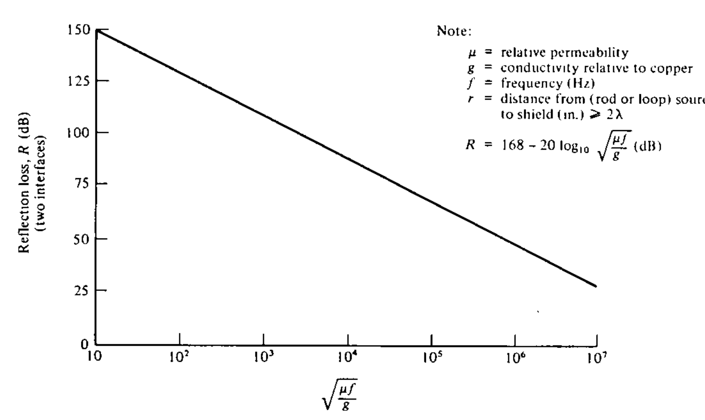


Figure 6: Universal Reflection-Loss, R, for Plane Wave Source

ELECTRICALLY ISOLATED DOUBLE SHIELDED ROOM

(Another school of thought)

There has been a long-standing controversy over the advantage of completely separate layers, electrically isolated, in the double-shielded room as opposed to the cell-type room. Some think that the test reports which show no difference in attenuation factors between an Electrically Isolated Room and the Not Isolated Room made of exactly the same materials, are both misleading and a misrepresentation of test results. One point which is almost universally agreed upon is that regardless of the type of construction, no shielded room is better than the effectiveness of its filter, door and seams.

Whenever specialists or "experts" on RF shielded enclosures congregate, you can expect endless discussion on the test methods. There is a standing argument that you might conceivably leave the subject of test methods, test procedures and instrumentation where it was 20 years ago because what was true in 1951 is still true today, that is; "The test is only as good as the skill and integrity of the engineers who conduct the test." One should not make the mistake of comparing a 0.015 inch thick copper screen Double Electrically Isolated room with a plywood room laminated with two layers of 18 guage or 24 guage steel, or comparing a plywood room with a single layer 0.125 inch thick solid steel room having welded seams and joints. Illustrations of the three types of rooms are shown in Figure 4.

Qualities of Double Isolated Rooms

The shielding of the electrically isolated double-wall depends not only on the wall material and seams, but also on the spacing between the walls. It turns out that a given thickness of metal divided into two walls gives more shielding than the same metal in a single wall due to the spacing. When the inner and outer walls are conductively connected at only one point or completely isolated, the walls are effectively decoupled, for there is no low impedance "return path" for the conduction of currents. If connection is made between the inner and outer wall at two or more points, the same currents can flow in both walls. Thus, the increased shielding gained due to the separation of the walls is lessened. This theory is substantiated in the Stanford Research Institute report (reference 2).

Comparison of Solid Metal Enclosures

The shielding action of a double isolated enclosure may be described as follows. The reflection loss which is the predominant part of the shielding in general as

eq. (6)

$$R = 20\log\frac{(\eta + Z_s)^2}{4\eta Z_s} + 20\log\frac{\left[Z_s + \eta\dfrac{(Z_s + j\eta\tan\beta_e)}{(\eta + jZ_s\tan\beta_e)}\right]^2}{4Z_s - \eta\dfrac{(Z_s + j\eta\tan\beta_e)}{(\eta + jZ_s\tan\beta_e)}} \quad \text{(dB)}$$

assuming that the absorption loss in each wall is greater than 10 dB. Here, β_e is the distance between the walls measured in meters. This can be compared to the shielding effectiveness of a single wall where (from equation 3):

eq. (3)

$$R = 20\log\frac{(\eta + Z_s)^2}{4\eta Z_s} \quad \text{(dB)}$$

Therefore, the big difference in shielding and the advantages obtained with the double isolated room is the second term of eq. (6). If we connected the two walls at more than one point, or moved the two close together such that they were touching (either case simulating other types of shielded room constructions) then tan β_e would approach zero as would the entire second term. Thus, the presence of this additional term is evidence that the double isolated rooms inherently provide greater isolation than do the other standard construction designs.

There are some high frequency phenomena which can be referred to as resonant effects that also influence the reflection losses in the double isolated concept. For instance, when the spacing between the walls, $\beta_e = n\pi$ (n=1,2 . . .) the second term of eq. (6) also goes to zero. However, this can be ignored since the spacing between the walls is usually much less than one half wave length (π) in most applications. Under such unusual circumstances, there is also a condition for maximum reflection loss. This is when the spacing is an odd number of quarter wave lengths, that is $\beta_e = \pi/2\ (2n+1)$ where (n=1,2. . . .). In this condition β_e approaches infinity as eq. (6) becomes

eq. (7)

$$R = 20\log\frac{(\eta + Z_s)^2}{4\eta^2 Z_s} + 20\log\frac{\left((Z_s + \dfrac{(\eta)^2}{Z}\right)^2}{4\eta^2} \quad \text{(dB)}$$

Comparison of Wire Mesh Enclosures

The same approach can be used to show the superior inherent qualities of a double isolated room made of wire mesh when compared to a cell-type, non-isolated shielded enclosure. Again, the reflection loss (which is the predominant property) for other double isolated rooms is given by the equation (8) (reference 2).

eq. (8)

$$R = 10\log\frac{\left(\eta + \dfrac{Z_m Z_{mt}}{Z_m\ Z_{mt}}\right)^2}{4\eta\dfrac{Z_m Z_{mt}}{Z_m + Z_{mt}}} \bullet \frac{(Z_m + Z_{mt})^2}{4Z_m Z_{mt}} \quad \text{(dB)}$$

where

$$Z_{mt} = \eta\frac{(Z_m + j\eta\tan\beta_e)}{(\eta + jZ_m\tan\beta_e)}$$

Z_m = mesh impedance

In comparison, the equation for the non-isolated case is:

Eq. (9)

$$R = 10\log\frac{\left(\eta + \dfrac{Z_m}{2}\right)^2}{2\eta Z_m} \quad \text{(dB)}$$

If we allow the two mesh walls to make electrical contact at more than one point, then equation (8) will reduce to equation (9).

The resonant phenomena at high frequencies are still present as they were for the solid room case. Here, when the spacing between the meshes is an odd number of quarter wave lengths, that is:

$\beta_e = \frac{\pi}{2}(2\eta + 1)$, Eq. 8 becomes

Eq. (10)

$$R = 10\log\frac{\left[\eta + \dfrac{\eta^2}{Z_{mt}\cdot\dfrac{\eta}{Z_m}}2\right]^2}{4\eta\dfrac{(\eta)^2}{Z_m + \dfrac{\eta^2}{Z_m}}} \bullet \frac{Z_m + \dfrac{\eta^2}{Z_m}}{4\eta^2} \quad \text{(db)}$$

The condition where a combination metal sheet and mesh walls is used can be presented in a similar manner. However, since this is not a common application, the reader may refer to the referenced Stanford Research Institute Report for the appropriate equations. He will then find that the same type result will be obtained in the comparison of the equations.

REFERENCES

1. *Inter System Electromagnetic Compatibility* by W.W. Everett, Jr. 1972 Holt, Rhinehart & Winston
2. *Principles Covering the Construction of Shielded Rooms* by Edward M.T. Jones, Tech. Report No. 1, SRI Proj. 336 Stanford Research Institute, April 12, 1951