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 ...e 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.

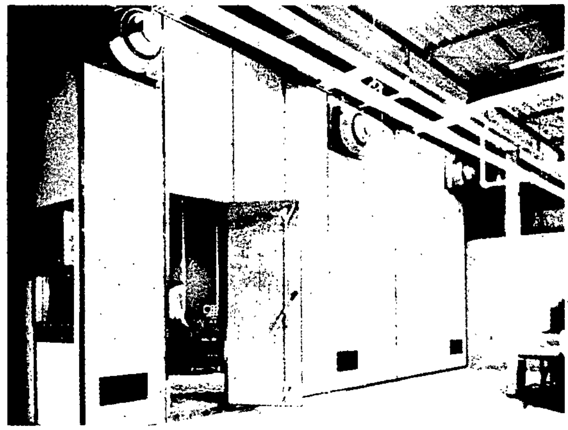

Figure 1: Typical Shielded Room (Solid)

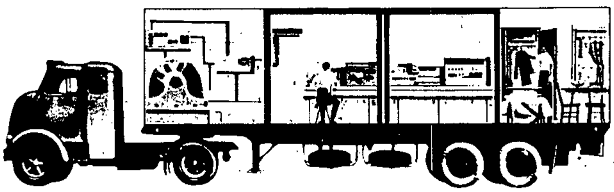

Figure 2: Mobile Shielded Enclosure

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.

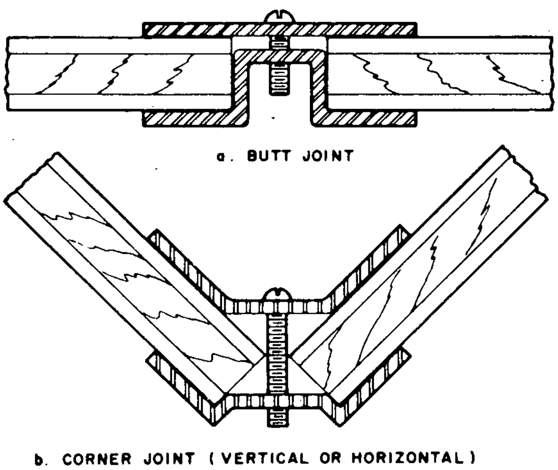

Figure 3: Methods of Joining Sandwich-Type Panels

Variations are used by several manufacturers of shielded enclosures. Some newer developments include a preassembled (welded) and interlocking three way corner which eliminates 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.

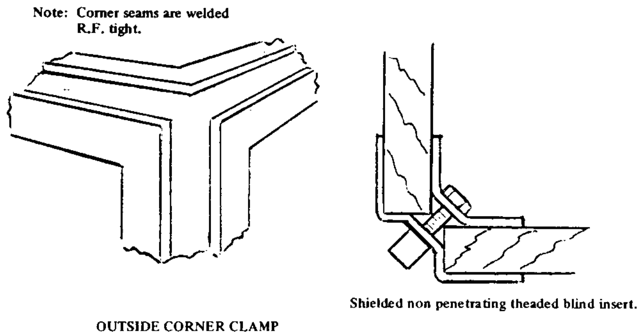

Figure 4: Alternate Methods of Joining Panels

SELECTING AN ENCLOSURE

With the electromagnetic frequency spectrum becoming more and more crowded, electronic engineers are increasingly called upon to design equipment that does not cause electromagnetic interference. To do this, an interference-free environment is essential to allow the engineer to conduct various tests to evaluate his designs. An interference-free environment is brought into the laboratory by using a shielded enclosure. Often the electronic engineer is called upon to specify the type of enclosure required.

Shielded enclosures are of varied construction and materials. Various parameters have a bearing on the attenuation afforded by the enclosure. Knowledge of them is essential in evaluation of an enclosure. These parameters are: (1) frequency range through which the tests will be made; (2) ambient levels of interference present and their frequency range; (3) possible future sources of interference with estimates of frequency and intensity; (4) practical materials available for shielded enclosures; (5) power requirements; (6) various signal and metering input circuits; and (7) ventilation and lighting requirements.

INTERFERENCE SURVEY

An EMC consultant is extremely valuable in determining the first three parameters, for he has both the equipment and experience for providing an intelligent answer. A radio-frequency interference survey is normally performed at the proposed shielded-room site between the frequencies of 0.014 and 1000 MHz. Normal sources of radio-frequency interference include radio broadcast stations, radio beacon signals, ignition interference, oscillations from adjacent test equipment, and any other r-f source which can interfere with measurements being made on the equipment under test. Specific equipment in the plant, such as dielectric heaters, induction furnaces, transmitting equipment, and other sources of high-powered r-f interference should be energized and the field strength measured at the shielded-room site. Should any electrical or electronic equipment capable of producing r-f energy intentionally or unintentionally be planned for future installation, estimates of its interference capabilities should be considered. The survey determines the minimum attenuation required of a shielded enclosure to permit operation of a low-level r-f test.

CONSTRUCTION

Once a frequency range and attenuation level are determined, examination of the types of construction and materials available is next. The three popular types of construction (each successive type normally having increased shielding with a given material) follow:

1. single-layer shielding
2. cell-type shielding
3. double-layer insulated shielding

Commercial enclosures are generally made in sections so that they can be shipped easily and also moved should the occasion arise. Cross sections of the three types are shown in Figure 5.

PRACTICAL MATERIAL

Materials which provide sufficient effectiveness at various frequencies are copper, bronze and galvanized sheed iron. Copper and bronze screening are available, but a mesh less than 18 x 20 should not be used and wire diameter should be a minimum of 0.011 in. The lowest frequencies at which a given shielding effectiveness is required normally determine the type of material to be used. Ferrous materials produce more shielding effectiveness at low frequencies are netic and co-netic materials, while galvanized sheet iron has medium shielding effectiveness at the lower power frequencies. The accompanying table shows shielding effectiveness of a given material at a given frequency.

Non-ferrous materials are used to attenuate magnetic fields at higher frequencies. Here, shielding effectiveness is dependent upon thickness and must be related to the frequency.(1)

When a given material is decided upon, an increase in shielding effectiveness may be had by increasing the thickness of the material. However, doubling thickness will only increase shielding effectiveness by 6 dB. To increase shielding effectiveness and still not materially increase thickness of the material required, multiple-shielded enclosures are used. If, instead of doubling thickness of the single shield, another shield of the same thick-

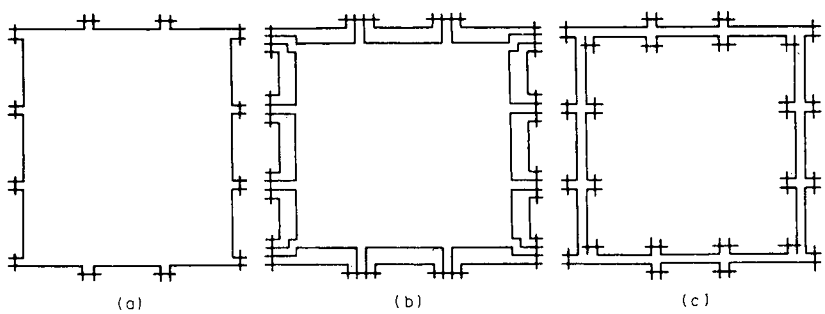

Figure 5: Three types of shielded enclosures used to provide an interference-free test environment: (a) single-layer shielding; (b) cell-type shielding; (c) double-layer insulated shielding.

ness, as the first is placed around the second, with a spacing of approximately 2 in. and isolated electrically from the first, shielding effectiveness of the room should theoretically be increased by the same amount as the shielding effectiveness of the first shield. Distance between the two shields and discontinuities in the shield will decrease total shielding effectiveness slightly. Magnetic field test results of single and double electrically isolated enclosures of copper screening and 3-oz. copper foil are shown in Figure 6. Placing both layers of this material one on top of the other would have resulted in only a 6-dB increase in shielding effectiveness.

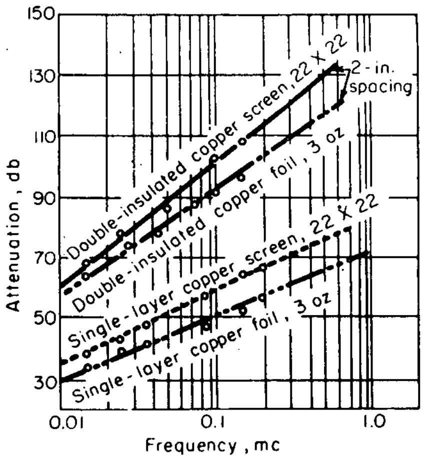

Figure 6: Results of magnetic-field tests on materials for electromagnetic shielding.

POWER REQUIREMENTS

When bringing a-c power into a shielded enclosure, a line filter must be employed which will allow power frequencies to enter but attenuate all other undesirable frequencies. Standard commercial line filters are available with attenuation on the order of 100 dB. These filters are normally placed outside the shielded enclosure. At times, 100-dB attenuation is insufficient to remove the unwanted signals from the power line. These line filters are divided into two sections. One section is used outside the enclosure and the second section inside. Each filter section has a minimum attenuation of 80 dB through its effective frequency range. Placing both filter sections in series gives a theoretical attenuation of 160 dB or more (Figure 7). Filters made in this manner can be used on all types of enclosures. When line filters are to be used at frequencies of 400 Hertz or more, an investigation should be made into the amount of reactive power drawn by the filter. Many filters may draw more current than the 400 Hertz generator can handle. Power factor correction coils should be used to prevent problems of this type.

METERING AND INPUT CIRCUITS

Another shielding discontinuity is introduced by insertion of an r-f feed-through. An important requirement of the feed-through connector is that it must allow a specific r-f current, if required for testing, to enter or leave the shielded enclosure with minimum loss.

The UG-30/U Type N feed-through adapter exhibits a nominal impedance of 50 ohms and can be used as a feed-through connector. This feed-through is ideal for single-shield bulkhead mounting. When multiple shields are used, a special panel must be installed to provide a single shield at the point of r-f connector

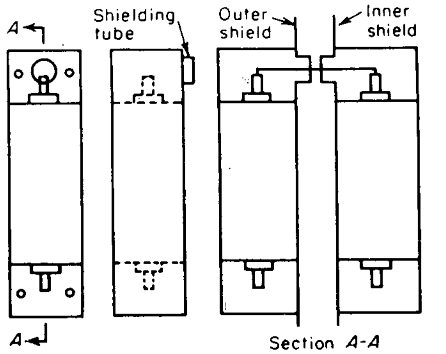

Figure 7: Double-section r-f line filter for shielded test enclosure. A small tube is connected to each of the filters, as they enter the shielded enclosure, to prevent radiation from leaking around the filter. In the double electrically insulated enclosure, the tube prevents multiple conducting paths which tend to reduce enclosure shielding effectiveness.

entry. In double electrically insulated enclosures, there may be a decrease in attenuation because of the single layer plus associated multiple connections between inner and outer shields. To alleviate this situation a special r-f feed-through connector has been designed to maintain isolation between both inner and outer shields, and still present a nominal impedance of 50 ohms. Use of a ferrite sleeve over the coaxial conductor also prevents intense external high-frequency radiation from entering the shielded enclosure. UHF connectors of BNC connectors are not recommended if a minimum VSWR is desired of the r-f feed-through connector.

VENTILATION

Ventilation openings, if improperly designed, could cause a serious reduction in shielding effectiveness. The amount of air entering or leaving the enclosure is based upon the amount of heat that must be extracted from the room due to electronic equipment in operation, plus the number of operators present during testing.

Another ventilation consideration is the amount of r-f attenuation presented by a particular opening. Screened openings usually have to be extremely large in area to permit sufficient air to flow through the fine mesh required to prevent r-f leakage. When frequencies about 1000 MHz need not be attenuated to a high degree, a multi-layer opening of 1/4 in. copper mesh is satisfactory. At frequencies above 1000 MHz, the multi-layer 1/4 in. mesh rapidly decreases in effectiveness. A ventilating opening must then be designed as a waveguide attenuator operating below cutoff at its lowest propagating frequency. In this manner, shielding efficiencies of up to 100 dB can be obtained at frequencies of 10,000 MHz. A 1/4-in. diameter tube, 1 inch in length would have approximately 102-dB shielding effectiveness at 10,000 MHz. A 1/2 in. diam tube, 2-1/4 inches long would give approximately 100-dB effectiveness at 10,000 MHz. Openings 1 inch or more in diameter would have little or no attenuation at 7000 MHz. (2) To obtain an opening of sufficient size to admit the required volume of ventilating air, these tubes are placed side by side until sufficient air flow is achieved.

See LMI on back cover.

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.

MAINTENANCE

Shielded enclosures require a certain amount of maintenance if they are to retain their designed attenuation. The vulnerable areas of a shielded enclosure are the joints and seams of bolted structures, and the door. The fastenings between panels must be kept tight; the enclosure manufacturer usually gives a torque rating on the fasteners. No maintenance is required on all welded enclosures.

The finger stock along the edge of the door must be kept in good condition. If any fingers are damaged or broken off, a new section of fingers may be soldered on as a replacement. These fingers provide a good connection between the enclosure and the door by sliding, for a short distance, along the door frame. To maintain this good connection, the door frame must be kept smooth and clean. One exception is the pneumatic door, which does not use fingers.

LIGHTING

Lighting must be provided for the enclosure. This should in all cases be incandescent lighting, since other types of lighting usually involve ionization processes and subsequently produce RF noise. There exist some fluorescent fixtures which have RF suppression built into the unit. While this type of lighting may be of benefit to lower the RF ambient in a laboratory, they generally are not suitable for shielded enclosures. Any other services to be provided in addition to lighting, such as electric heating should be installed in such a way that it cannot produce any RF signals.

PERFORMANCE-SHIELDING EFFECTIVENESS

The end shielding effectiveness per MIL-STD-285, or similar specifications such a USAF Class I Shielding, or NSA 65-6 must be well defined before the selection of the type of shielded room or enclosures. Size is also an important factor as shown in the cost section.

The well designed and installed shielded rooms of the modular clamp together shielded rooms as shown in Figures 3 & 4 conform to well known shielding requirements of MIL-STD-285 and others as previously mentioned. The shielding effectiveness of the modular rooms, using two sheets of 24 gauge steel on ¾ inch plywood is typically shown in Figure 8.

The performance of all welded rooms is shown in Figure 8 for the different classes of shielded rooms based on the thickness of the shielding steel used. The performance of the all welded rooms follows the theory of design in the magnetic field attenuation, while the slope of the magnetic shielding for the modular room follows a curve that is the result of the properties of the materials used plus a proven derateing necessary for the magnetic seam impedance of the clamping arrangement.

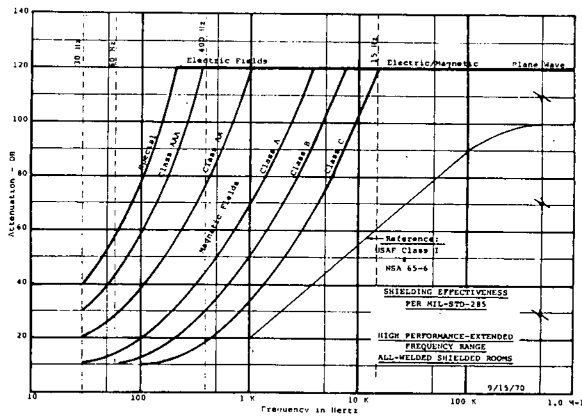

Figure 8: Shielding Effectiveness Curves

SHIELDED EFFECTIVENESS is the total capability of a given material to prevent propagation of electromagnetic energy, and it is represented schematically in Figures 9 & 10.

Expressed mathematically: $SE = R + A + B$ eq. (1)

where: SE = Total shielding effectiveness in (dB)

$R = R_1 + R_2$ = Reflection radiated power loss in (dB) (first and second boundary)

A = Absorption power loss (dB)

B = B–factor (dB) (omit if A is greater than 10 dB)

P_1 = Incident radiated power (dB)

P_2 = radiated power thru the shield (dB)

Expressing in terms of the law of conservation of energy:

$$P_2 = P_1 - (R_1 + A + R_2 + B)$$

$$P_1 - P_2 = R_1 + R_2 + A + B = R + A + B$$

$$SE = R + A + B = 10 \log \frac{P_1}{P_2}$$

These equations are expressed in terms of incident and emitted power. However, at low frequencies it is more convenient to work with electric or magnetic field intensities, thus the equation becomes:

$$SE = 20 \log \frac{E_1}{E_2} = 20 \log \frac{H_1}{H_2} \qquad \text{eq.(2)}$$

Reflection and absorption losses are a function of frequency, thickness of shielding material, resistivity, permeability and conductivity. Reflection loss is caused by a difference in characteristic impedance between the incident field and the shield and may also vary with distance. When the impedance of the incident field is much higher or lower than the impedance of the shield, the reflection loss is very high.

At all frequencies, magnetic fields are low impedance and electric fields are high impedance. Generally, for most materials, the impedance is low at low frequencies and high at high frequencies. Therefore, magnetic reflection loss R_h is small because there is a good match between the impedances of field and shield. For this reason, magnetic shielding depends primarily on absorption loss. For good shielding effectiveness ferromagnetic materials are the most suitable, and as the frequency increases, the impedance mismatch widens with the consequent increase of R_h.

Electric fields are readily stopped by metal shields because high reflection loss RE is easily obtained due to the mismatch between field and shield is always large.

The total reduction in field intensity is caused by reflection and absorption losses, therefore the shielding effectiveness of an enclosure is the sum of reflection and absorption losses. Reflection takes place at the surface of the shield while absorption is the dissipation of the signal as it passes through the body of the shield. (see figures 9 & 10).

In any a-c circuit there are two vectors: the electric field vector associated with the voltage and the magnetic vector associated with the current. If the field varies with time, the electric and magnetic components occur simultaneously. A field may be predominantly electric or magnetic if most of the energy is stored in the dominant component and will generally occur close to the generating source (within one wavelength). The ratio of the electric to the magnetic field is defined as the characteristic impedance. For a plane wave in free space the characteristic impedance is 377 ohms, for a magnetic field the impedance is less than 377 ohms and for an electric field it is greater than 377 ohms.

Basic Shielding Design Equations

The following equations are presented in a simplified form as an aid in designing RF shielded enclosures. All terms used are defined:

SE = Shielding effectiveness, representing reduction of electromagnetic energy in (dB). Measurements are made in power, voltage or current ratios.
R = Total reflection loss in (dB) from both surfaces of the shield.
A = Absorption loss inside the shield.
B = Positive or negative correction factor in (dB) (omit when A is more than 10 dB).
Z_s = Intrinsic impedance of the shield.
Z_w = Wave impedance of incident wave in space.
μ = Relative magnetic permeability referred to free space: 1 for copper, 1 for ferrous metals at microwave frequencies, and 200 to 1000 for ferrous metals at low frequencies.
μ_0 = Permeability of free space = 1.26×10^{-6} henrys/meter.
ξ = Permittivity of free space = 8.85×10^{-12} farads/meter.
G = Relative conductivity referred to copper (1 for copper, 0.61 for aluminum, 0.17 for iron).
V = Speed of light in free space = 3×10^8 meters/second.
f = Frequency in hertz/second.
λ = Wavelength in meters/hertz.
β = $2\pi/\lambda$
ω = $2\pi/f$
r = Distance from source to shield in meters.
r_1 = Distance from source from shield in inches.
t = Thickness of shield in mils.
T = Thickness of shield in meters.
E = Electric field component in volts/meter.
H = Magnetic field component in amperes/meter.
p = Plane wave.
α = Attenuation coefficient of metal in nepers/meter.

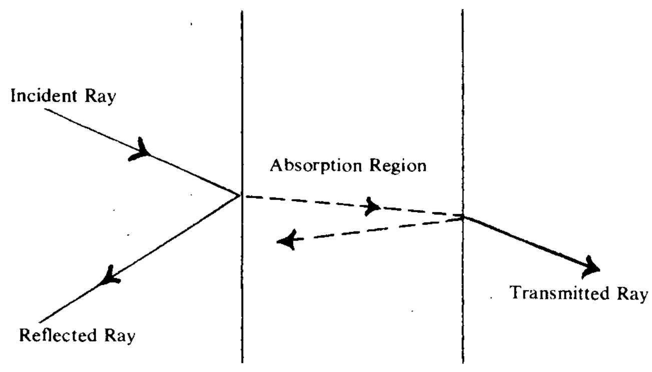

Figure 9: Reflection and Attenuation

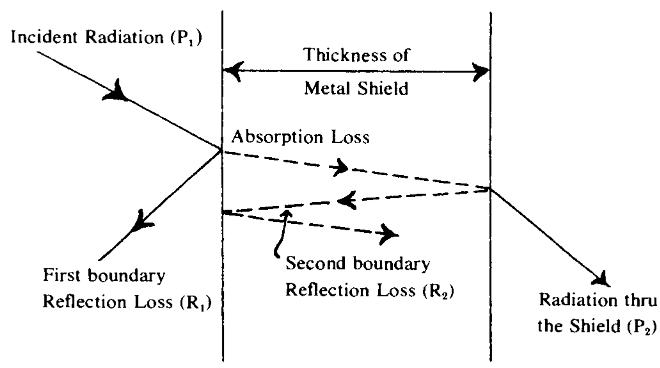

Figure 10: Factors Contributing to Total Shielding Effectiveness

$\sqrt{\frac{\mu_o}{\xi_o}}$ = Impedance of plane waves in free space = 377.6 ohms, approximately 120π

To compute R:

$$R = 20 \log_{10} \left[\frac{(Z_s + Z_w)^2}{4\, Z_s\, Z_w} \right] \text{dB} \qquad \text{eq.(3)}$$

$$Z_s = \sqrt{\frac{\mu f}{G}} \times 3.69 \times 10^{-7}$$

Values of R may be zero, positive or negative. In all cases R is positive at frequencies above 1 Khz. SE is always positive and in all cases greater than zero.

$Z_w = \frac{E}{H} = \frac{1}{\sqrt{\xi}} = 376.7$ ohms for high impedance electric fields, when $r > \lambda$ eq. (4)

$Z_w = -\frac{E}{H} = \sqrt{\mu_o} = 276.7$ ohms for low impedance magnetic fields, where $r > \lambda$ eq. (5)

To compute R for magnetic fields the given formula reduces to:

$$R_{(H)} = 20 \log_{10} \left[\frac{0.462}{r_1} \sqrt{\frac{\mu}{Gf}} + 0.136\, r_1 \times \sqrt{\frac{Gf}{\mu}} + 0.354 \right] \text{dB} \qquad \text{eq. (6)}$$

To compute R for Electric fields the given formula reduces to:

$$R_{(E)} = 353.6 + 10 \log_{10} \left[\frac{G}{f^3\, \mu\, r_1^2} \right] \text{dB} \qquad \text{eq. (7)}$$

To compute R for plane waves, where $r > \lambda$ the given formulas reduce to:

$$R = 108.2 + 10 \log_{10} \frac{G \times 10^6}{\mu\, f} \text{ dB} \qquad \text{eq. (8)}$$

To compute A:

$$A = 3.338 \times 10^{-3} \times t \sqrt{Gf\mu} \text{ dB} \qquad \text{eq. (9)}$$

To compute B:

$$B = 20 \log_{10} \left\{ 1 - \left[\frac{Z_s - Z_w}{Z_s + Z_w} \right]^2 \times 10^{-A/10} \times \left(\text{Cos. } 7.68 \times 10^{-4}\, t \sqrt{Gf\mu} - j \text{ Sin } 7.68 \times 10^{-4}\, t \sqrt{Gf\mu} \right) \right\} \text{dB} \qquad \text{eq. (10)}$$

NOTE: If A is more than 10 dB, B is neglected.

Grounding

After RF shielding, proper grounding is of outmost importance for two main reasons. First, improper grounding will cause electrical hazards whch are a danger to life and property. Second, improperly grounded RF shielded enclosures can result in loss or degradation of RF integrity, or excessive radiations within the enclosure that could raise the electromagnetic ambient to an intolerable level. The hazards are comprised of potential voltages

FREQUENCY	IRON		COPPER		ALUM.	
	G	μ_a	G	μ	G	μ
60 Hz	0.17	1000	1	1	0.61	1
1 KHz	0.17	1000	1	1	0.61	1
10 KHz	0.17	1000	1	1	0.61	1
10 KHz	0.17	1000	1	1	0.61	1
150 KHz	0.17	1000	1	1	0.61	1
1 MHz	0.17	700	1	1	0.61	1
3 MHz	0.17	600	1	1	0.61	1
10 MHz	0.17	500	1	1	0.61	1
15 MHz	0.17	400	1	1	0.61	1
100 MHz	0.17	100	1	1	0.61	1
1 GHz	0.17	50	1	1	0.61	1
1.5 GHz	0.17	10	1	1	0.61	1
10 GHz	0.17	1	1	1	0.61	1

which may exist between the enclosure and ground. When an enclosure is installed with multiple grounds, or partial grounds such as pipes, ducts, hangers from overhead structure, anchors, etc. in addition to the ground stud, then circulating ground currents will result.

The ground impedances at the various contact points are totally unpredictable and the obvious result will be ground loops between the multiple grounding points. When the currents circulate through the enclosure skin, the induced voltages will radiate both inside and outside the enclosure. If the impinging voltages stem from outside sources, the energy, in circulating through the enclosure walls could be transmitted inside, or viceversa. Either way, the RF integrity could be compromised.

It is recommended therefore, that a single point ground be used and that the grounding connection be made only at the ground stud provided for this purpose. Pipe penetrations, hangers, etc. should be isolated by means of dielectric fittings. Electrical conduit feeding the power line filters should also be isolated by means on non-conductive fittings. Use canvas boots or non-conductive flexible connections for ducts to or from the enclosure. The entire floor of the enclosure must also be insulated from the building slab.

The result of single point ground is that all equipment and instrumentation will be at the same potential within the enclosure and electrical hazards will be non-existent. During construction, a relay operating ohmmeter or a suitable monitoring device can be continually attached to insure against inadvertent grounding. After completion of the installation, the single point ground is connected before power hook-up.

Many installations require isolated power and in addition may require a ground detection system to monitor failure of the ungrounded circuits. Since all power line filters utilize large values of capacitance, approximately 40 microfarrads or higher between the lines and the gounded case, a certain amount of leakage current will exist which is sufficient to set off the alarm in the ground detector device. The solution to this problem is readily met by installing the isolation transformer within the shielded enclosure, thus isolating the wiring from ground after the filter. In other words, filter the primary, not the secondary of the transformer. The shielded enclosure still must be grounded regardless of isolated power within.