A PRACTICAL APPROACH
to
RF SHIELDED ENCLOSURE DESIGN

The general purpose of a shielded enclosure is to reduce the detrimental effects of broadband radio frequency emanations. They provide an RF interference-free environment in which accurate low level measurements can be made. Conversely, the shielded enclosure may be used to confine a source of radio frequency interference so that the surrounding external area will be free of its detrimental effects.

Ideally, a shielded enclosure should provide one or more layers of shielding media forming a six-sided continuum of solid metal or wire mesh screening. This objective is achieved in a practical manner, by tightly bolting together adjacent panels and by utilizing special electrical contact fingers around the shielded door to maintain continuous peripheral connection to the door jamb. It is not permissible to have electrically conductive materials pierce the shielding media, unless special precautions are taken to minimize the antenna effects of such penetrations. These effects would invalidate the design objectives of the shielded installation. The most prominent and certainly most important precautions concern radio frequency interference suppression filters, which must be used on all electrical wiring (including neutrals) penetrating the shield.

An engineer confronted with the problem of designing a shielded area must first ascertain the overall performance criteria. These criteria include attenuation characteristics, frequency range, electromagnetic environment, ventilation and adaptability for future physical enlargement or configuration alteration.

Attenuation is the ratio, expressed in decibels (dB), of the received power on opposite sides of a shield when the shield is illuminated by electromagnetic radiation. It is used as a figure of merit to designate the effectiveness of shielded enclosures. "Frequency range" refers to that portion of the electromagnetic spectrum over which the shield is to be effective.

The intensities of the various RF fields comprising the electromagnetic environment at the proposed installation site will determine, in part, the performance characteristics required for the installation. It is possible to measure the existing RF field at a certain location and if the ambient RF field within the shielding area is defined, the attenuation of the shielded area can be calculated by using the following formulae.

$$\text{Attenuation (dB)} = 20 \log_{10} E_1/E_2$$

Where E_1 = RF field intensity in terms of microvolts per unit of length on one side of the shielded area, and

E_2 = RF field intensity in microvolts per unit of length on the other side of the shielded area.

In a power relationship the formula then becomes

$$\text{Attenuation (dB)} = 10 \log_{10} P_1/P_2$$

Where P_1 = power density of the RF field in watts per unit of area on one side of the shielded barrier, and

P_2 = RF field density in terms of watts per unit of area on the other side of the shielded barrier.

This is the theoretical concept applied when a test is performed to determine the actual attenuation, or 'shielding effectiveness, of a shielded area. The test consists of setting up a transmitter and a receiver without the presence of a shielded barrier between the respective antennae for the purpose of determining a reference level in terms of dB or microvolts per unit of length. Once the reference level has been established, the receiving antenna is placed within the shielded enclosure, and the transmitting antenna is positioned on the exterior of the enclosure (or vice-versa), maintaining the same antenna spacings and configurations as set up for the reference measurements. This is basically the test procedure outlined in MIL-STD-285, which is generally used as the accepted standard for evaluating the shielding effectiveness of radio frequency shielded enclosures.

While the above description defines the physical test procedure to determine shielding effectiveness and the foregoing formulas provide a means for calculating shielding effectiveness, it is a difficult task to design a shielded enclosure on the basis of mathematical calculations.

It is possible to determine the ambient levels required within a shielded enclosure if the end use is known. However, the ability to determine the level of RF radiated energy outside the shielded area is rather difficult, since it is dependent upon many factors. The number and types of rotating electrical equipment within the area, overhead electrical wiring, and the multitude of various supplemental electrical and electronic equipment necessary to the proper operational functioning of the laboratory or production areas surrounding the installation site must all be considered.

One may well ask how much a problem can be solved. The answer lies in the ability of manufacturers and engineers who are constantly working with these radio interference problems. They have the capabilities for providing sound design criteria based on a strong background of working knowledge accumulated from past experiences. In short, designing a shielded area is an art, and should not be entrusted to the handiwork of the average carpenter or metalsmith.

The engineer's first task in the design of a shielded area is to determine performance criteria as specified by the user. The next step is to prepare a construction and performance specification which will guarantee desired performance criteria at the lowest possible cost, and yet maintain its usefulness for a prolonged period of time. The RF interference problem has become acute in the engineering laboratory, due to the utilization of highly sensitive measuring equipment which is susceptible to low intensity fields of broadband radio frequency interference.

The ideal situation would be to control or eliminate these RF emanations at their source by shielding, altering or redesigning the interference producing unit or circuit. This approach is usually a long, tedious procedure. From the standpoints of general economic and time schedule considerations, such remedial measures are not usually applicable.

When necessity dictates that a shielded area be provided in the laboratory, it is usually more economical to install a shielded enclosure in the immediate test area. Enclosures of this type are commercially available as prefabricated or built-on-site structures to provide various degrees of RF attenuation. Here again, the performance criteria must be defined by the user so that a structure with suitable attenuation characteristics can be provided. Generally, shielded enclosures for laboratory purposes are designed for minimum electric field attenuations of 100 dB from 150 kHz to 10,000 MHz.

Shielded enclosures are available in a wide variety of types and configurations to meet specific attenuation or structural requirements. Military applications often require completely shielded buildings. Generally, the requirement is to keep high powered RF energy from interfering with very sensitive electronic equipment and to minimize the biological radiation effects on personnel. This protection can be provided in several different ways. For example, it may be a completely shielded building of a 100 dB rating or a 50 dB building with additional attenuation provided by smaller shielded enclosures within the overall basic shielded building. Smaller shielded enclosures of higher attenuation characteristics within an unshielded building would also provide the required protection. It is the engineer who must decide which approach offers the best performance at the most economical cost.

To preserve the integrity of the shielded area, RF interference suppression filters are required on all wires of each electrical service entering the shielded area. As previously stated, any unfiltered wire penetrating the shield produces an antenna effect which will degrade the shielding performance. For this reason, the filters must have the same RF attenuation characteristics as those specified for the shielded enclosure.

Other penetrations, such as utility services which include water, gas, air, etc., must be rigidly bonded to the shield at the point of penetration. All penetrations should be confined to as small an area as possible on the shield.

In shielded areas where a steady flow of material and personnel are entering or leaving the shielded area, added protection can be provided by including a shielded vestibule (RF lock) as an integral part of the constructional features of the shielded enclosure. Electronic or electric inter-locks can be supplied so that both doors cannot be opened simultaneously. Since shielded doors are normally difficult to open and close, panic-type door hardware should be provided at all emergency exits.

Thus far, some of the basic problems which must be resolved prior to the actual design of shielded enclosures to satisfy general conditions have been discussed. From a commercial standpoint, standard levels of attenuation have been set, based on the electrical characteristics of the shielding media and construction features of various types of shielded enclosures. It is assumed that all commercial suppliers of shielded enclosures have the ability to provide a product which will provide a relatively interference-free environment. No compromises can be tolerated in shielding design and construction. All design parameters must be based on sound theoretical considerations and commercial shielding practices within limitations of the present state of the art.

The performance of a shield is affected by the impedance of the joint structure between adjacent panels. It is imperative that an electrically continuous mechanical bond of clean metal-to-metal contact surfaces under pressure be maintained to provide a low impedance path. Attenuation characteristics are also directly affected by the conductivity, permeability, and mass of the shielding media.

Conductivity refers to the ability of the shielding media to provide a highly conductive path. Materials commonly used as shielding media, in order of highest conductivity, are: copper, aluminum, brass, bronze, and steel. While steel has generally poorer conductivity than the other four metals, it provides superior attenuation characteristics to magnetic fields commonly found in the frequency region below 200 kHz, because of its natural permeability characteristics.

The shielded enclosure which has long been considered the electronic industry standard for research and industrial laboratories is the copper mesh, double-walled, cell type. Military specification MIL-E-4957A (ASG) sets forth construction details and performance criteria for this type of enclosure. The prefabricated interchangeable, modular panel type of construction described in this specification utilizes 40-inch panel increments in 8- and 10-foot lengths. The connection between the adjacent panels is achieved by an arrangement of mechanical bolting on approximate 12-inch centers. All assembly bolts are tightened to a torque of 140-inch pounds and, although MIL-E-4957A is based on the use of outside bolted panels, the bolts should be accessible from the interior of the enclosure to permit erection directly up against building confines.

Recent extensions and refinements of basic shielding concepts have resulted in and excellent design which makes use of a solid galvannealed steel sheet. This type of construction is basically referred to as the single-shield solid enclosure. The design utilizes a stressed panel under uniform tension in an all metal framework, providing an exceptional, rigid, low-impedance mechanical joint structure. In this instance, the assembly bolts actually penetrate from inside to outside through the framework. However, these bolts are an integral part of the overall RF shielding. This type of enclosure is a rigid, free-standing structure. Special applications may require additional structural steel supporting members to satisfy unusual load conditions. Enclosures of this type provide a higher attenuation to low-frequency magnetic fields, and to high-frequency microwave energy. This construction is particularly recommended for built-in type installations where periodic retightening of bolts becomes impractical in cases where plaster, sheet rock, or other aesthetic treatments have been applied.

Other extensions of basic shielding concepts utilize the plywood core sandwich (steel-plywood-steel) type of construction in the fabrication of RF shielded enclosures with reasonably good results, provided that the joint between the various panels can be kept RF tight for prolonged periods of time. In this construction, adjacent abutting panels are held together in a metal framework by a clamping action, with only the metallic interfaces of the panels making contact with the framework. Because plywood is a nutrient material, it is natually susceptible to environmental changes resulting in dimensional variations which could necessitate retightening the assembly bolts to restore the RF shielding integrity of the joint structures. Upon initial installation, shielded enclosures of this type provide levels of shielding effectiveness in the order of 100 dB from 150 kHz to 1000 mHz, but continued maintenance is required to preserve the pressure contact at the joint. The added weight of the plywood and steel panel may be a disadvantage of this type of enclosure in some applications.

Shielded enclosures are commercially available, which are fabricated in accordance with an early theoretical concept of RF shielding based on the isolated, double-wall type of construction. The theory dictates that the inner and outer wall must be kept electrically isolated from each other. From theoretical considerations, there are indications that the isolated double-wall shielded enclosure may possibly yield attenuation levels slightly higher than those provided by the other types of construction previously discussed. The transformation from the theoretical concepts to the practical aspects is not always an easy one. Such is the case with the isolated double-wall shielded enclosure. Commercially-available shielded enclosures of this type do have the isolated walls electrically connected together at a single point, usually at the filter entrance panel.

In many instances, the attenuation characteristics of any of the enclosure types mentioned (cell type, single solid shield, or double-wall isolated) are beyond the range of commercially-available instrumentation when measured in accordance with a military standard. Therefore, the actual numerical values of attenuation characteristics have never been determined throughout the complete frequency spectrum covered by the accepted specifications.

In addition to prefabricated modular enclosures, another type, known as built-on-site shielding, utilizes a soldered screen technique which can never provide attenuation levels as high as those achieved by prefabricated shielded enclosures which utilize a mechanical pressure joint construction. It does, however, offer the advantage of a permanent, maintenance-free, joint structure. This type of construction is generally more costly to build, and it should be field tested to ascertain its attenuation characteristics prior to the installation of all interior finishing materials. It should also be retested after the attachment of plaster, sheet rock, or other aesthetic finishes, or when the overall installation has been completed. Extreme care must be taken not to pierce the shield with nails, screws, or other mechanical anchoring devices, any one of which can act as a miniature antenna capable of transmitting RF energy through the shield. The possibility of introducing these antenna effects can be eliminated if these devices are soldered to the screening. In this type of construction, wood furring strips are secured to the wall in a normal fashion, then the screening is fastened to the furring strips with staples or other fasteners at the overlap joint of abutting sections of screening which have been pre-tinned. All abutting joints of the screening material should then be continuously seam soldered or welded. Closet-bolts may pierce the screening and screw into the furring strip. They must be continuously soldered to the screening material about their entire periphery at the point of penetration. A second layer of wooden furring strips which have been pre-drilled and counter-bored (to receive the holding nut) may then be anchored to the original furring. All interior finish materials, including piping, electrical conduits, etc., may be attached to this interior furring with wood screws of a selected length which will not pierce the screening material.

The use of insulating nylon (non-conductive) nails should be discouraged because the multiplicity of larger than basic mesh size openings produced by these nails will degrade the RF shielding properties of the shield.

When concrete flooring is required over shielding material, a protective layer of waterproof paper should be installed to minimize the effects of the galvanic action which will occur due to the alkaline content of the concrete mix. Copper screen in direct contact with concrete could disintegrate in a relatively short period of time. Concrete floors should be of sufficient depth to prevent equipment anchors from contacting the screen.

Access to a shielded area, regardless of the construction techniques used to erect the shield, presents a major problem. Special emphasis must be placed on the design and construction of the doors or other access ports into the shielded area. It is imperative that the overall shielding performance of the area be maintained at these very critical points. Shielded doors must be built in accordance with the same RF shielding construction techniques as the wall, floor, or ceiling components. Electrical contact around the entire peripheries of the doors must be maintained. Braided jumper straps across the hinge edge of the door are of little significance, since continuous peripheral contact must be maintained at all times about the entire door opening when the enclosure is in use. When contact strips are used, they should be arranged so that one set wipes the inner surface of the door buck and the other set is in compression against the exterior face of the door frame. This type of seal requires a 3 point wedge locking system capable of applying uniform pressure when the door is in its locked or closed position. Shielded doors of this type are commercially available as complete, factory aligned units (i.e., door and door frame assembly), and are not to be confused with standard hollow metal doors and metal door bucks. On standard prefabricated enclosures, since the panel module is 40 inches wide, the overall door frame dimensions are also in 40-inch increments.

Shielded doors should not be used as exterior entrance doors to a building. Shielded doors are difficult and costly to weatherproof. Without this added protection, they will be susceptible to the corrosive action induced by varying climatic conditions, which will seriously degrade their shielding effectiveness. The simplest solution to this problem is to protect the shielded door in a weather protective vestibule with its own weatherproof door.

The introduction of ventilation air into a shielded area is an important consideration, even on screen type shielded enclosures. A section of screening of a coarser mesh than the general shielding media will appreciably degrade the overall attenuation of the area. Increasing the number of such layers of mesh may increase the attenuation, but the addition of the added layers of screen will seriously impede the normal air flow. A realistic solution to this problem is the utilization of beyond-cut-off wave guide principles normally applied to the control of RF energy in microwave systems. In radar systems, RF energy is made to travel through silver-plated brass tubes, rather than along wires.

A characteristic of these tubes or wave guides is that the unattenuated passage of RF energy is determined by the cross-sectional dimensions, configuration, and length of the wave guide and the frequency of the RF energy. For a given cross-section, there is a frequency called the cut-off frequency below which no energy will pass through the wave guide. In the frequency range above the cut-off frequency, the attenuation characteristics are dependent solely upon the length of the wave guide. The wave guide type openings should be designed to have a cut-off frequency no less than the highest frequency designated in the shielded enclosure performance requirements.

In the manufacture of these wave guide type air passage fixtures, configurations of the wave guide cross-sections are varied to accommodate specific physical conditions, such as air pressure drop through the core, ease of cleaning, or cost considerations. Installation of the wave guide type air transmission fixtures (which may also be used as air exhaust penetrations) must be done in a manner that will provide a continuous electrical bond to the shielding media. For the cell type (double wall) construction, only one wave guide type air fixture is required at each air inlet or exhaust location, since it can be bonded to both layers of shielding media, which, in effect, only creates another cell. If this fabrication technique is applied to the isolated double-wall type of construction where only one cell is permitted, the air transmission fixture would further violate basic theoretical shielding concepts. In this case, a special design or two air transmission fixtures are required at each supply or exhaust point. One fixture should be secured in each layer of the shielding media to maintain electrical isolation. In addition, dielectric ducting should connect the two fixtures to prevent diffusion between the shield walls.

The attachment of external ducting to these fixtures should be made through a non-conductive flexible boot, so as not to introduce system vibrations into the shielded structure. Internal ducting connections do not require this degree of protection.

Power line filters should be attached directly to the wall or ceiling of the shielded enclosure. It is not good RF shielding practice to run conduits from the filters to the shielded room, since this will enhance the possibility of RF leakage along the conduit run. Good shielding practice consists of securing the filter to a power inlet supplied with the enclosure by means of a hex nut, which acts to ground the filter to the RF shielding and also seal off any RF leakage at the point of attachment.

On the interior of the enclosure, conduit can be run in accordance with local electrical codes. The only condition here is to insure that the fastening or anchoring devices do not penetrate the shielded media.

Lighting within the shielded area should be of the incandescent type since this type of illumination is basically interference free. Certain types of interference-suppressed, Cold Cathode, and fluorescent lighting fixtures have been developed. Although these specific types of fixtures comply with the requirements of MIL-STD-461, they do increase the RF ambient level within the shielded area and, therefore, are undesirable.

When the sole purpose of the shielded enclosure is to contain RF interference sources without regard to making low level RF measurements, any type of lighting, including fluorescent or Cold Cathode fixtures, may be used.

There are many opportunities for "short cuts" in the design and construction of shielded enclosures. Shielded enclosures are not inexpensive.

Before making a final decision on the selection of a shielded enclosure, it would be wise to have the answers to certain questions clearly defined.

1. What is the guaranteed *minimum* attenuation of the shielded enclosure?
2. Is this guarantee valid after the room has been erected on the installation site with filters, ventilation, and necessary services installed?
3. What frequency range does this guarantee cover?
4. Are these attenuation figures for magnetic fields, electric fields, or plane wave fields?
5. Does actual data support this guarantee?
   a) Who performed the tests?
   b) Were these tests performed in accordance with one of the accepted standards, such as MIL-STD-285?
6. What steps has the designer and/or supplier taken to insure stability of the attenuation characteristics throughout the guarantee period?
   a) Will the door or door jamb sag?
   b) Is there adequate mechanical/electrical bonding at all joint structures?
   c) Are the bolt diameters used sufficiently large and adequately spaced to provide the necessary degree of mechanical pressure?
   d) Can bolts be tightened to adequate torque ratings without physical damage to framing members?
   e) Are the assembly bolts readily accessible for ease of installation—and, in the case of the copper mesh cell type, retightening?

Throughout this presentation we have made continued reference to the term, "shielded enclosure." An older, but still used term is, "screen room." This new term is being widely accepted today and has come into use with the advent of the newer types of enclosures which are representative of extensions and refinements to the RF shielding concepts developed many years ago.

When confronted with the task of designing or purchasing a shielded enclosure, treat the procurement of the item with the same prudence exercised in selecting any other piece of electronic equipment. In actuality, the shielded enclosure is a precision electronic instrument, and as such, the performance characteristics will reflect the engineering talent put into its design and the production skill applied to its fabrication.

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