SPECIFYING A SHIELDED ENCLOSURE

Introduction

This article informs engineers how to specify a shielded enclosure; it also serves as a reminder to those already knowledgeable. It not only covers considerations of applications, performance, construction, quality assurance, and cost, but it also provides an outline of a model specification.

Applications

Shielded enclosures are used in many different applications, with shielding requirements being dependent upon the specific use. Some common applications are for:

1. COMMUNICATION FACILITIES
   Radio & Radar Duplexes
   Police Centers
   FCC Centers
   FAA Air Traffic Control
   Commercial Radio
   Mobile
   Teleprinters
   Secure Communications Facilities
2. HOSPITALS
   EEG Rooms
   Operation Complexes
   Electrocardiograph Laboratories
3. ELECTRONIC and TEST LABORATORIES
   Test Equipment
   Calibration
   Electronic Clean Rooms
   Acceptance Test Facilities
4. MOBILE COMMUNICATIONS and TEST UNITS
5. COMPUTER FACILITIES
6. EMP - NUCLEAR ELECTROMAGNETIC PULSE PROTECTION
7. SECURE CONFERENCE ROOMS

Performance

Performance is usually specified in terms of the shielding effectiveness (dB) for steady-state electric/magnetic fields over a desired frequency range. Other requirements may include anechoic (reflection-free) performance and electromagnetic-pulse (EMP) protection.

Shielding effectiveness provides a logarithmic measure of the ratio of electromagnetic fields incident upon a shield to those emerging from it. Values in dB should be specified (1) for the magnetic components below 1 MHz and (2) for electromagnetic plane waves above 1 MHz. Values obtainable depend upon both the materials and construction methods (see Construction section).

Shielding effectiveness is also dependent upon the frequencies for which performance is desired. It is controlled at the low-frequency end of the spectrum, say below 100 kHz, primarily by properties of the shielding materials used. Best results are obtained with good magnetic properties (high initial magnetic permeabilities μ), high electrical conductivities σ, and thick materials. For moderate performance, tradeoffs among these may be made. At the high-frequency end of the spectrum, say above the 100 MHz, shielding performance is controlled by construction details which permit varying RF leakage at seams around doors and between panel sections, and through holes that may be required for ventilation, cable pass-throughs, etc.

For standard materials and commercial constructions (Figs. 1 and 2), typical shielding-effectiveness values in the mid-frequency region might run as in Table 1.

Table 1. Typical Shielding Values (dB)

	Single	Double
Steel Plate	>120	
Galvannealed Steel Sheet	80->120	>120
Copper Sheet	80->120	>120
Copper Screening	40-60	70-100

At low frequencies, shielding performance is largely proportional to the product $\sqrt{\mu\sigma}$. Common conductive materi-

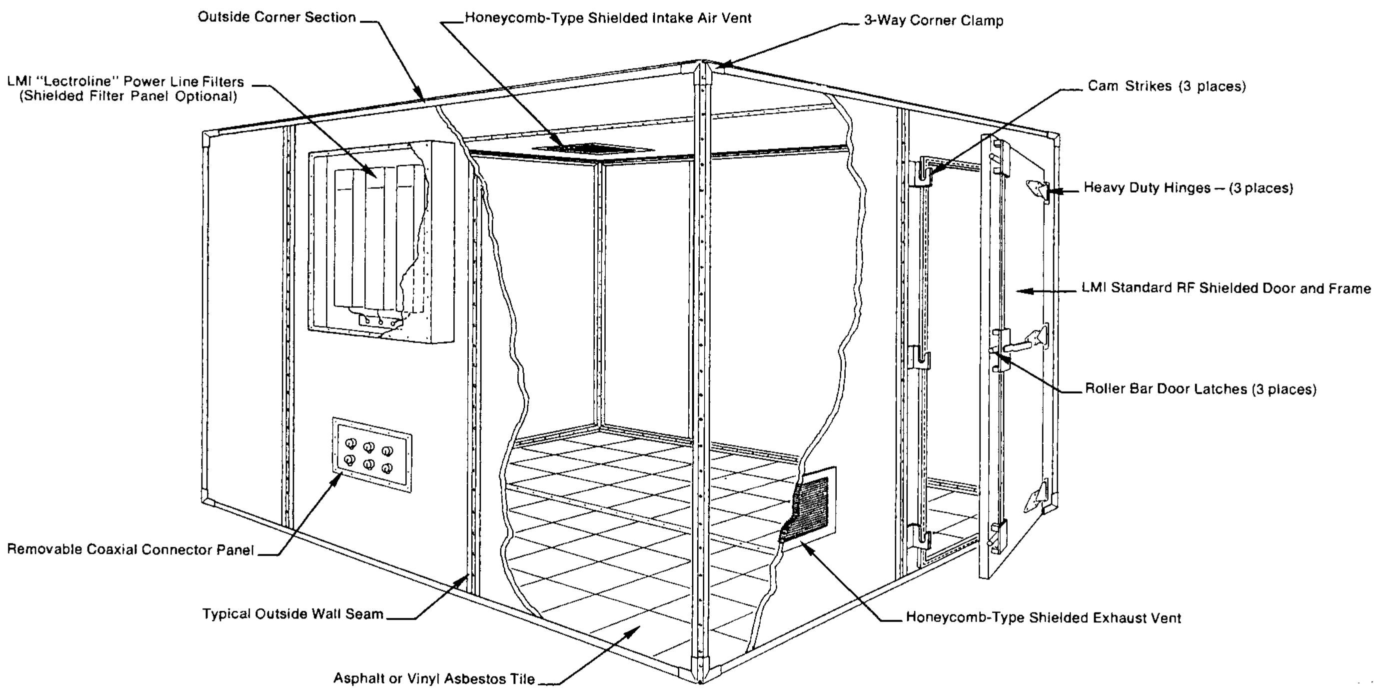


Fig. 1. Clamped-Together Type of RF Shielded Enclosure Courtesy: LectroMagnetics

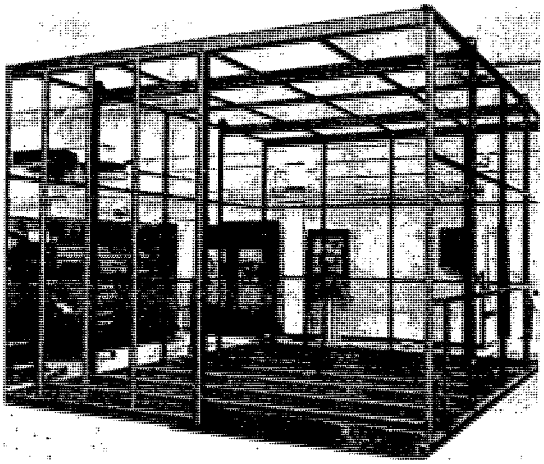


Fig. 2. Typical All-Welded Construction.
(Shielding skins are welded to this frame.)
Courtesy: Lectro Magnetics

als are ranked by performance in Table 2. (Some of the higher-performance materials are sensitive to shock, forming, etc.)

A performance difficulty is evident near those higher frequencies for which the enclosure acts as a resonant cavity (high Q's are common). Such resonances result in standing waves which make the shielded enclosure difficult to use as a laboratory item for repeatable measurements. One common (and expensive) solution is to line reflecting room surfaces, either in part or in whole, with RF-absorbing material to make an anechoic chamber (Fig. 3). This solution reduces working space inside the enclosure due to the required thickness of the RF-absorbing material; it is generally practical for frequencies above 200 MHz. Since the lower frequency resonances may occur down to approximately 40 MHz, depending upon room size, a frequency range of unsatisfactory performance still may exist, although it may not be critical for specific uses.

Other approaches to solving the standing-wave problem are used in specific installations, such as "tuning" the room for resonance or stirring the EM modes (1), but are not commercially available.

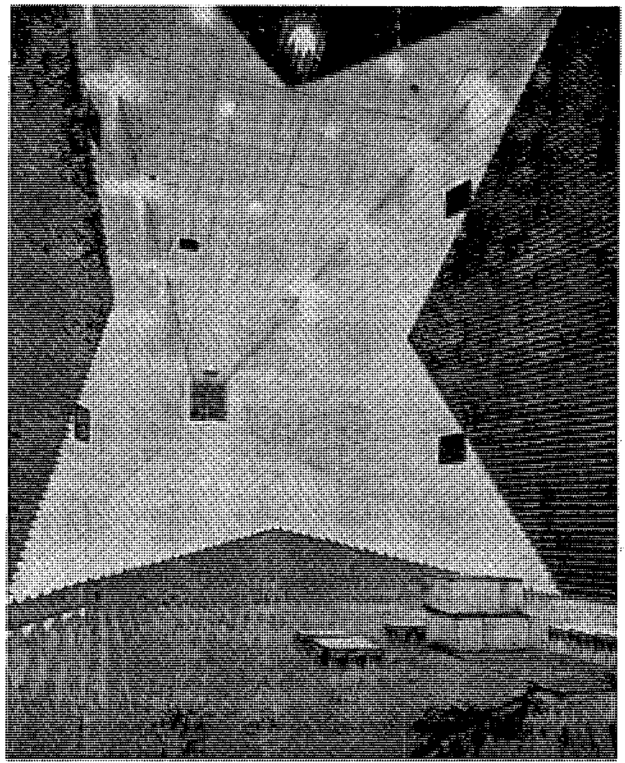


Fig. 3. Large Anechoic RF Shielded Enclosure
Courtesy: Ray Proof

Sometimes shielding performance is required, not for a steady-state source, but for a transient source, such as an electromagnetic pulse (EMP) which simulates the EM properties of a nuclear explosion. Performance is somewhat different from the steady-state case. The induced shielding currents again tend to create a field which opposes the incident field on the wave-emergent side of the shield, but it lags the incident field at initiation. Hence, the cancellation effect is low at *initial* incidence of a pulse and the initial shielding effect tends to be low. This effect may be lessened by providing extra-high-performance shielding at the lower frequencies.

Table 2. Low-Frequency Electrical Properties of Various Shielding Materials

METAL	RELATIVE CONDUCTIVITY σ_r	LOW-FREQUENCY RELATIVE PERMEABILITY μ_r	LOW-FREQUENCY PRODUCT $\sqrt{\mu_r \sigma_r}$	PRIMARY SHIELDING APPLICATION
Hypernik	0.06	80,000	69	Sheet
Mu-Metal	0.03	80,000	49	Sheet
Permalloy	0.03	80,000	49	Sheet
Iron	0.17	1,000	13	Plate
Steel, SAE 1045	0.10	1,000	10	Sheet
Silver	1.05	1	1.03	Contact Platings
Copper	1.00	1	1.00	Sheet and Screening
Gold	0.70	1	0.84	Contact Platings
Aluminum	0.61	1	0.78	Sheet
Magnesium	0.38	1	0.62	Cast Boxes
Zinc	0.29	1	0.54	Sheet Plating
Brass	0.26	1	0.51	Flanges
Cadmium	0.23	1	0.48	Sheet Plating
Phosphor-Bronze	0.18	1	0.42	Spring Contacts
Tin	0.15	1	0.39	Box Plating
Beryllium	0.10	1	0.32	With Copper in Springs
Monel	0.04	1	0.20	Gaskets

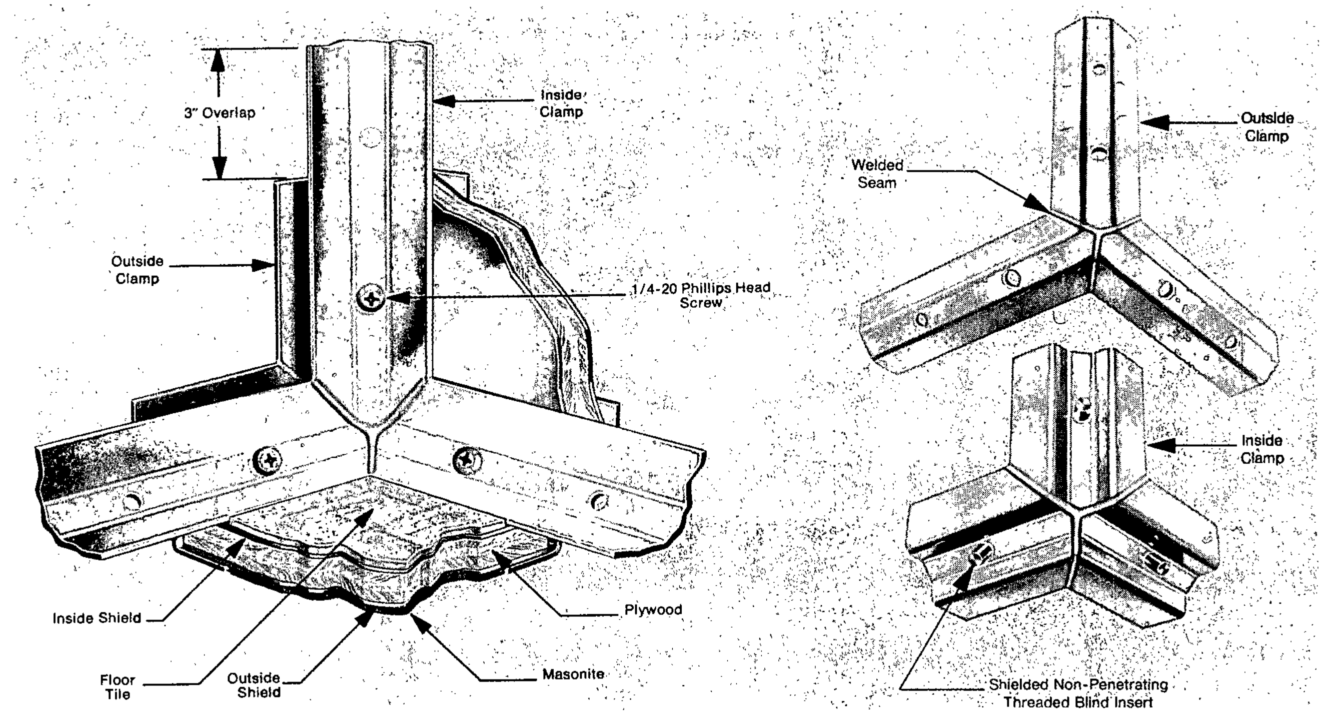


Fig. 4. Typical Corner Details
Courtesy: LectroMagnetics

Construction

Small construction details can have a large impact upon shielding performance, particularly at the higher frequencies. Attention to these details, such as corners (Fig. 4), as the result of experience, gives the commercial manufacturer a significant advantage over the individual constructor. Such details are associated with the items to be discussed.

Type Classification. Basic shielding construction may be classified in various ways. Most commercial rooms consist either of modular (pre-fabricated) panels clamped in an overall frame (Fig. 1) or of steel plates welded at the site of installation (Figs. 2 and 5). Thus, commercial enclosures may respectively be de-mountable (although not readily so) or fixed permanently in place (although movable by judicious welding). Both types are available from cabinet size to large-room size.

Shielded enclosures also may be classified as single or double shielding, with the latter available in either cell-type modules (conducting material surrounding entire panel) or double electrically-isolated modules (insulation between two sheilding surfaces); see Fig. 6. (Lines in this figure represent electrically conducting paths.) In some cases, a hybrid construction is used with double-isolated panels, but with periodic electrical conduction between clamping members of a frame. Joint details for various types of shielding are shown in Fig. 7.

other ways of classifying shielded enclosures are by the form of shielding material used: plate, sheet, or screening, or by the basic type of material used: steel (often plated), copper, aluminum, etc. (see Table 2).

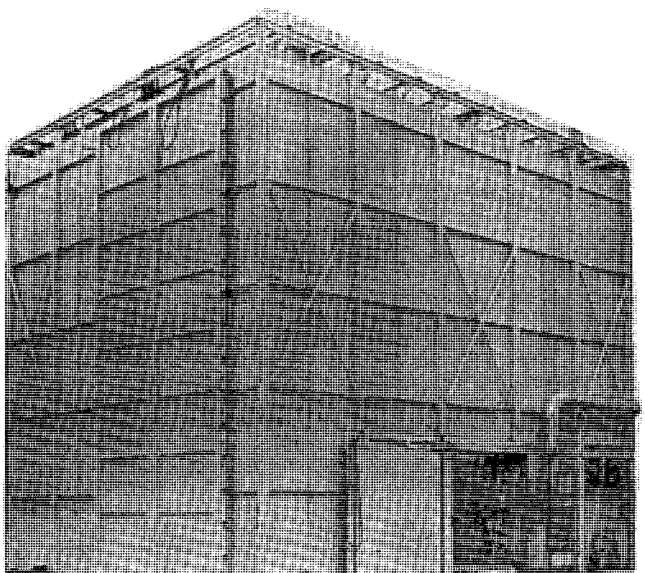


Fig. 5. Large Welded Shielded Enclosure
Courtesy: Ray Proof

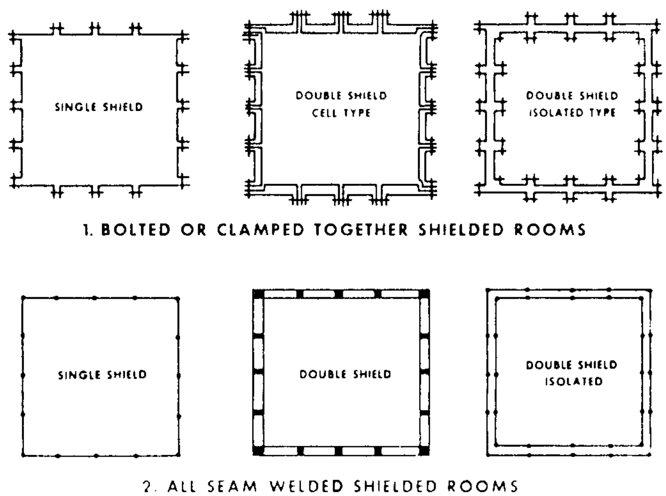
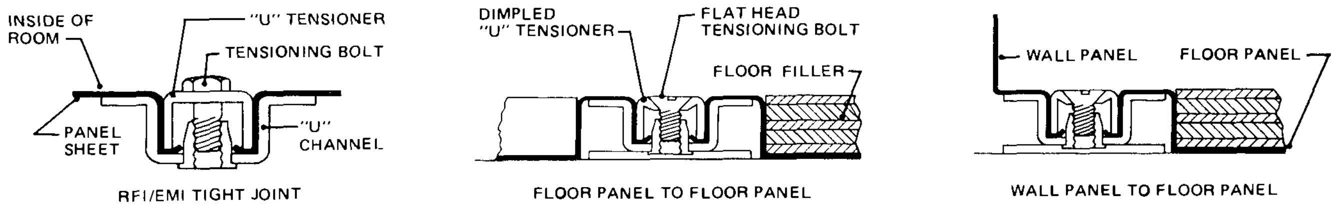
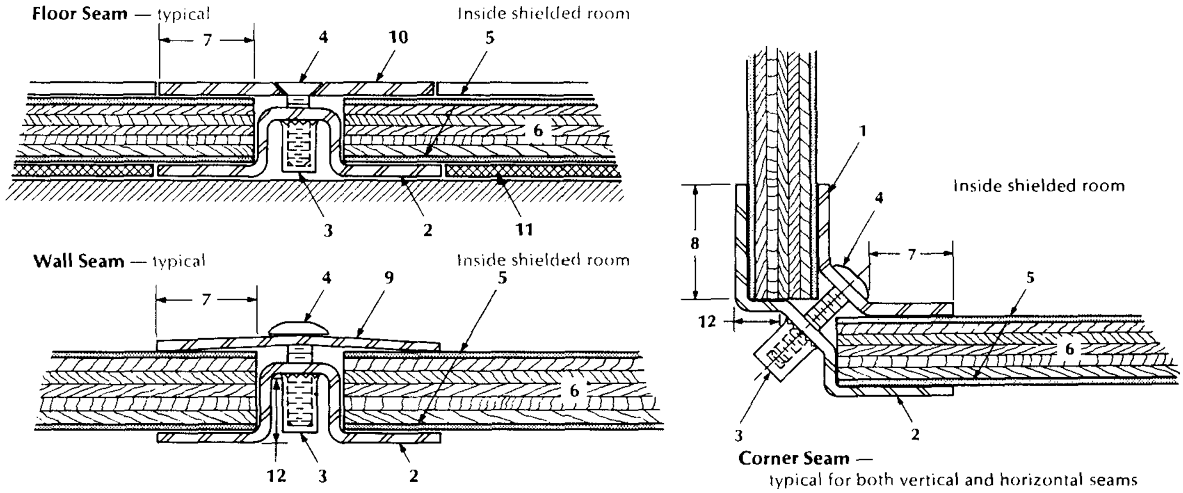


Fig. 6. Generic Types of RF Shielded Enclosures

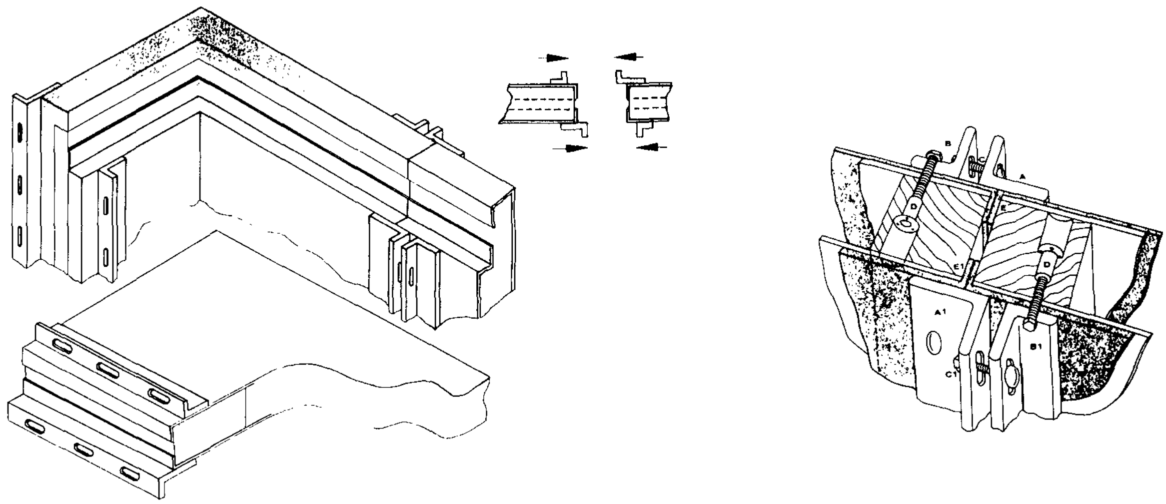


(A) Single Shield
Courtesy: ARK Electronics



1. Inside clamp — heavy duty, zinc plated steel — 0.125", nominal
2. Outside clamp — heavy duty, zinc plated steel — 0.125", nominal
3. Threaded blind insert — shielded, non-penetrating
4. Steel machine screw — ¼-20, torqued to 70 to 80 in. lbs.
5. Shielding steel panels — two, 24 ga., zinc clad
6. ¾" panel — plywood or particle board as specified
7. Overlap — 1.0" wide, nominal
8. Overlap — 1⅛" wide, nominal
9. Back-up plate, uncompressed — heavy duty, zinc plated steel — 0.125", nominal
10. Structural and Electrical Seam Clamp, compressed — heavy duty, zinc plated steel — 0.125", nominal
11. Masonite — under flooring
12. 5/8", nominal — for maximum structural strength

(b) Hybrid Double Shield
Courtesy: LectroMagnetics



(c) Isolated Double Shield
Courtesy: Erik A. Lindgren

Fig. 7. Typical Panel Seams

Doors. Types of doors used must, of course, be compatible with the type classification of the basic enclosure. A most critical item of construction is the door seal which provides electrical contact between the door and its frame. Contact should ideally be continuous around the periphery of the door for each layer of shielding provided. This ideal is never attained in practice and results in lower performance than theory would indicate. However, the best commercial door seals result in extremely good performance; standard seals provide fair performance. Some examples are shown in Fig. 8.

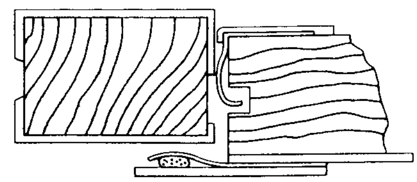
To provide the electrical contact, high-conductivity spring fingers are used around the door (or frame) in one or more rows. Such fingers are normally made of either beryllium copper or phosphor bronze; some manufacturers provide silver-plated surfaces. Contact fingers require a wiping action to remove poorly-conducting metal oxides and sulphides which form when a door is open. This wiping action varies considerably among styles of manufacture, the least effective resulting from a simple compressive action (points A and D of Fig. 9), although some wiping does occur in even this case. More effective wiping occurs when contact fingers are rubbed along the contacting surface by door actuation (point B of Fig. 9).

Simple doors can provide good wiping action along surfaces away from the hinged edge of the door (points A and B of Fig. 9) but, at the hinged edge, simple compression is used with little wiping (points C and D of Fig. 9). More complex doors are made with compound hinges that provide effective wiping action around the entire door. Another type of complex door provides excellent contact with only compressive action of the spring contacts by using high-pressure air to actuate them between the door and frame.

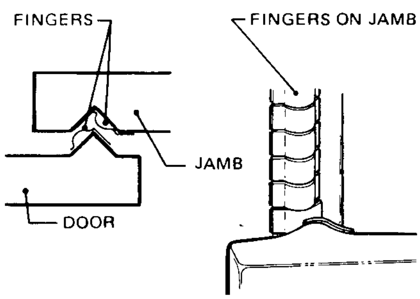
Several problems exist in the normal use of spring contact fingers. One relates to their accidental destruction, which may occur when they are exposed to damage in the door-open situation. They are then easily snagged and broken by either personnel or equipment moving through the doorway. Some designs have been developed to protect the fingers when the door is open (Fig. 8).

Another problem is concerned with maintenance. Naturally, broken fingers require replacement, but the job requires a person with special skills (usually from the manufacturer) to solder small spring contact fingers to a large door which conducts away the soldering heat and expands non-uniformly. To overcome this maintenance problem, at least one manufacturer supplies insertable replacement finger stock. (The effect on performance has not been ascertained by the author.) Even without breakage, a problem exists: fingers should be cleaned periodically, perhaps twice a year. (The cleaning cycle will depend upon how often the room is used and the atmospheric environment at its site.) Many special door latching provisions are also available, such as fully automatic floor-mat activators, photo-cell activators, door openers and closers, and interlocks.

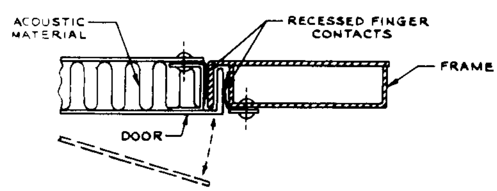
Filters. Powerline filters for shielded enclosures are required to prevent the transmission of RF signals along powerlines through enclosure walls. They are basically of the low-pass type with an extended rejection range, commonly from 10 kHz to 400 MHz, 1 GHz, or 10 GHz. Typical rejection values run over 100 dB for all frequencies, except possibly the low end, say below 100 kHz. (Values supplied by manufacturers are for standard test conditions: 50-ohm loads and [normally] no powerline current; installed operation is normally less effective than test values.)



(a) Double Fingers—Isolated Double Shield
Courtesy: Erik A. Lindgren

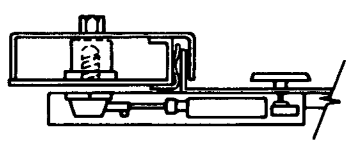


CONTACT FINGERS OF DOOR AND JAMB
Courtesy: ARK Electronics



Courtesy: All-Shield

(b) Double Fingers—Cell Type or Hybrid



Courtesy: All-Shield

(c) Single Fingers—Automatic Control

Fig. 8. Typical Details for Hinged Doors.
(Sliding Doors not shown.)

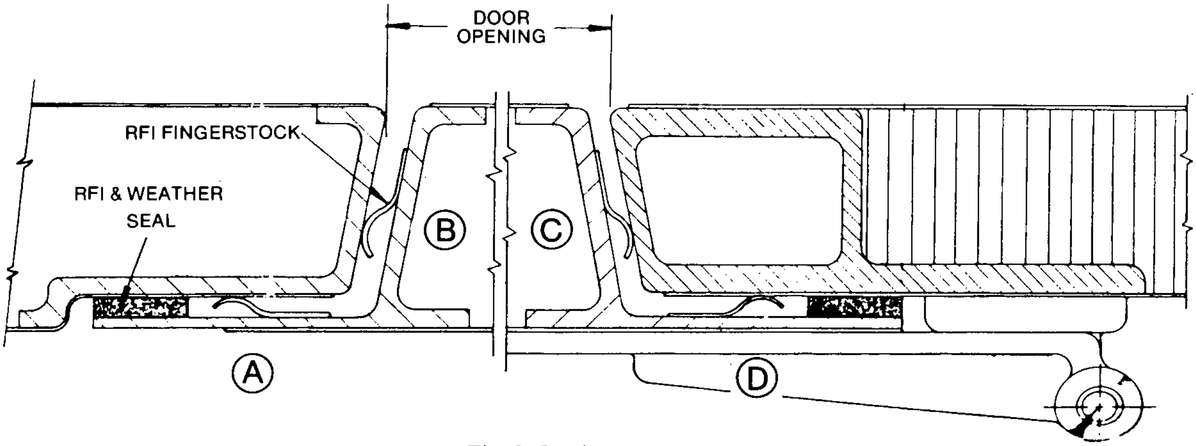


Fig. 9. Section at Door
Courtesy: Genisco

At the low end, performance decreases with frequency until, at 10 kHz, it may fall to the range of 40 to 50 dB. Various current-carrying sizes are available from approximately 30 amperes to 200 amperes, with 100 amperes being most commonly used. One such filter should be used in each power feed wire, whether grounded or not (to avoid circulating RF currents).

(CAUTION: Because of the large shunt capacitors used in powerline filters, an extreme shock hazard to personnel may exist unless the filter housings and the shielded room are properly grounded. Make certain that they are!)

These large capacitors in filters also may result in a poor electrical power factor. To prevent this situation, power-factor correction coils, also commercially available, should be used.

Less commonly used than powerline filters are telephone and intercom filters which provide the means for transmission of voice-frequency electrical signals through shielding walls. They also are commercially available.

Coaxial Feedthrough Connectors. Filters cannot readily be used when high-frequency signal lines penetrate shielding. Instead, co-axial feedthrough connectors are used, together with completely shielded coaxial cables within the shielding room, to prevent undesired RF coupling. Good conventional practice is to have the desired feedthrough connectors mounted on, and peripherally soldered to, a well-conducting panel in the enclosure wall. Such connectors may metallically join the inner and outer shields of doubly-shielded enclosures. No special location is required in the case of cell-type enclosures, but performance of the double-isolated enclosure may be degraded unless the panel location is at the room groundpoint, close to the powerline filters. This preferred location may be inconvenient to utilize in practice.

Whenever feedthrough connectors are not in use, they should be capped at both ends.

Air Vents. Inexpensive enclosures of screening material normally have no ventilation problem. On the other hand, ventilation provisions (intake and exhaust) must be made for solid-wall enclosures. Air is commonly moved through specially-built air ducts consisting of an assembly of waveguide-below-cutoff, tube-like structures, often honeycomb (Fig. 10). These permit air flow while still maintaining the shielding integrity.

Floor. Permissible floor loading may be considerably different for various styles of manufacture. Check with manufacturers to ascertain if they can meet your requirements (one typical maximum value might be 3000 lb/sq ft).

Floor finishes of various types are also available, the most common being vinyl or asphalt tile.

Quality Assurance

As a check on manufacturers' claims of shielding performance, reports of tests by an independent testing organization should be requested from the manufacturer before placing an order. Organizations that have their own testing capability may wish to verify performance of the enclosure(s) received. Others may consider the performance to be sufficiently crucial to their operations in order to have an independent testing organization test their received room(s). Most commonly, testing arrangements are made by the room supplier and tests are witnessed by the purchaser.

Test procedures should be consistent with a standard for the application, such as MIL-STD-285 for military applications and IEEE Standard 299 for commercial applications.

Specification Outline

Many different ways exist for specifying shielded enclosures, just as there are many variations to be specified. Some assistance in such an effort may be obtained from the sample outline provided. (In this sample, words and numbers within parentheses and above dashed lines are illustrative only.) It should be used only as a general guide to defining specific requirements. In doing so, be sure to specify performance adequate for your needs. Be equally sure not to overspecify requirements with associated unnecessary costs.

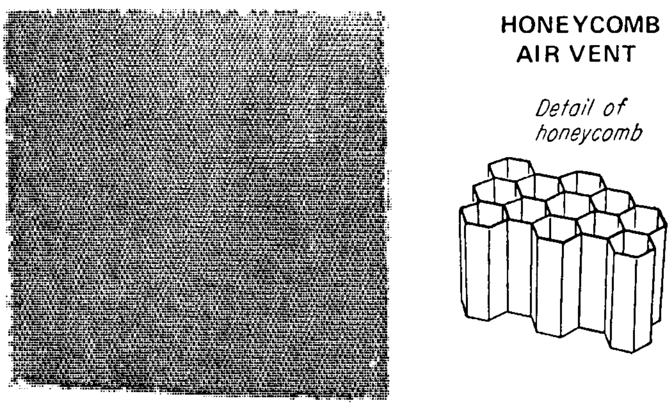


Fig. 10. Typical Air Vent for Solid-Wall Enclosures

See LMI on back cover.

OUTLINE OF SPECIFICATION FOR RF SHIELDED ENCLOSURES

The implementation of the requirements of this document is the responsibility of the supplier unless exceptions are explicitly identified.

1. SCOPE

1.1 *Scope.* This specification details the minimum requirements for a shielded enclosure.

1.2 *Classification.* Shielded enclosures of this specification encompass the following types in combination, not more than one from each column for both performance and construction. (Not all performance requirements are obtainable from all construction features.)

a. Performance (Steady-State)

Shielding Effectiveness	Frequency Range	Standing Waves
(1) 40 dB	(1) 14 kHz-400 MHz	(1) Unsuppressed Standing Waves
(2) 70 dB	(2) 14 kHz-1 GHz	(2) Suppressed
(3) 120 dB	(3) 14 kHz-10 GHZ	(3) Mode-Stirred
(4) Other	(4) Other	(4) Other

b. Construction

Type	Shielding Arrangement	Material Kind	Form
(1) Modular	(1) Single Layer	(1) Steel	(1) Plate
(2) Welded	(2) Cell-Type or Hybrid	(2) Copper	(2) Sheet
(3) Soldered	(3) Isolated Double	(3) Aluminum	(3) Screen
		(4) Bronze	

2. APPLICABLE DOCUMENTS

2.1 One of the following documents (according to type of procurement) of the issue in effect on the date of invitation for bids forms a part of this specification.

MILITARY

MIL-STD-285 — Method of Attenuation Measurements for Enclosures, Electromagnetic Shielding for Electronic Test Purposes.

non-MILITARY

IEEE Standard 299 — Recommended Practice for Measurement of Shielding Effectiveness of High Performance Shielding Enclosures.

3. REQUIREMENTS

3.1 *Performance.* The shielded enclosure to be procured shall provide a minimum of (100) dB of shielding effectiveness against low-impedance magnetic fields at 14 kHz, rising to (120) dB at 1 MHz. It shall provide a minimum of (120) dB of shielding effectiveness against plane electromagnetic waves from 1 MHz to (10) Ghz.

Standing waves shall be (suppressed by 20 dB for frequencies above 200 MHz).

3.2 *Construction.* (If performance is the only requirement, the kind of construction need not be specified. Restrictions on the kind of construction should be made only on the basis of additional considerations.)

3.2.1 *Classification.* The construction type shall be (modular) of (cell-type) shielding with (copper sheet) material.

3.2.2 *Doors.* (Many types of doors, both single and double leaf, are used in shielding enclosures. They are available with a variety of special features; those given here are simply illustrative.) (1) The door shall be of a size suitable for personnel passage and shall open outward using hinges on the (left) edge as viewed from outside the room. (2) No finger stock shall be exposed to breakage. (3) The door shall incorporate a no-latch system with pull handles to operate with a pull between 5 and 20 lbs.

3.2.3 *Filters.* Powerline filters for (single)-phase, 60-Hz, 120-volt supply shall be provided to carry powerline currents up to (100) amperes. They shall provide a minimum RF attenuation at least as great as the shielding enclosure provides over the same frequency range.

3.2.4 *Power-Factor Correction Coils.* Power-factor correction coils shall be provided to assure a power factor no worse than 0.95, unless they are unnecessary for the powerline filters used.

3.2.5 *Coaxial Feedthrough Connectors.* A feedthrough connector panel shall be provided and shall contain the following connectors:___ ________________.

3.2.6 *Air Vents.* Air vents of the waveguide-below-cutoff type shall be provided for both air intake and exhaust and shall have a maximum head loss of 0.1-inch water at 1200 ft/min air velocity. RF attenuation shall not compromise the enclosure shielding effectiveness over the operating frequency range.

3.2.7 *Floor.* (1) Floor loading shall be capable of (3000) lbs/sq ft. (2) Floor covering shall be (vinyl tile).

3.2.8 *RF Absorbers.* Interior surfaces of the enclosure, except for the floor, shall be covered with RF-absorbing material.

4. QUALITY ASSURANCE

4.1 *Test Procedures.* Test procedures shall conform to those of the applicable test standard (Section 2).

4.2 *Pre-Delivery.* A report on the RF performance of an earlier enclosure prepared by an independent testing organization shall be submitted by the manufacturer to substantiate his claims.

4.3 *Post-Delivery.* Following installation of the shielding enclosure, measurements of performance shall be made as follows:[1]

Frequency	Type of Measurement
14 kHz	Low-impedance magnetic field
1 MHz	Low-impedance magnetic field
1 MHz	Plane wave
100 MHz	Plane wave
Highest specified	Plane wave

5. PREPARATION FOR DELIVERY

(As required.)

6. NOTES

(As required.)

REFERENCE

1. P. Corona et al, "Use of a Reverberating Enclosure for Measurements of Radiated Power in the Microwave Range", IEEE Transactions on Electromagnetic Compatibility, Vo. EMC-18, No. 2, May 1976. Corrections to this paper appear in Vol. EMC-18, No. 4, November 1976.

[1]Low-frequency electric-field measurements have been omitted because they are normally satisfactory when the specified measurements are satisfactory.

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