ARCHITECTURAL SHIELDING: UPGRADING THE NATURAL SHIELDING EFFECTIVENESS OF REINFORCED BUILDINGS

The natural EM shielding potential of a reinforced facility can be augmented with effective shielding techniques.

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INTRODUCTION

Because of the growing problem of extraneous electromagnetic interference, the need for electromagnetically shielded facilities which are used to house susceptible electronics and equipment has increased. An all-metal box, known as a Faraday cage, forms the basis of a RF shield. However, designs similar to the all-metal Faraday cage can also function quite successfully as RF shields. These similar designs are capable of:

- Reflecting and absorbing incidental EMI, and
- Reflecting and dispersing current induced upon external cables and leads, thereby preventing interference from penetrating into a protected enclosure.

The required shielding effectiveness (SE) of a facility is determined by the susceptibility of equipment to be protected and by the EM threat (e.g., lightning, NEMP, radio/radar/EW transmitters). If shielding is required, then it can be provided as part of the facility, by upgrading the equipment shielding, or by a combination of both. The decision will be based on a tradeoff between the known or estimated shielding requirement and the relative cost of providing this shielding.

Tests have been conducted on the shielding properties of seven building types, including reinforced concrete structures.[1] Both electric and magnetic field attenuators were measured in the frequency range of 20 kHz to 500 MHz. The graphs of the electric field attenuation are noteworthy. Although the surveyed buildings were not designed to attenuate radiated EMI, attenuation ranges, including H-field, were from 0 to 30 dB. The reason for the poor shielding effectiveness was probably the EMI penetration through building openings, cables, and metallic services.

This article discusses relatively simple shielding techniques by which the natural EMI shielding potential of a reinforced facility can be preserved and upgraded during construction through the use of grid net screens for wide openings (e.g. doors and windows), cable and metallic service entries, duct penetrations, and shielding effectiveness verification. Although this article aims to provide technical guidelines for upgrading the shielding effectiveness of a facility during the construction phase, these guidelines can also be useful for improving the EMI control of existing buildings.

SHIELDING TECHNIQUES FOR SPECIFIC FACILITIES

EMP- and TEMPEST-protected facilities require shielding on the order of 70 to 100 dB. This protection can be accomplished by using a specially-designed, all-metal box. However, there are facility designations where the required shielding effectiveness would typically range from 10 to 50 dB. For these facilities, one would rather harness, if possible, the natural shielding effectiveness of a building and thereby save considerable expense. A typical example would be a plant for hot assembly of ordnance, such as fitting electro-explosive devices (EED) into fuzes, rockets, and munitions. Ordnance is particularly susceptible to the hazards of electromagnetic radiation during hot assembly; hence, the assembly plant should be shielded against EMR threats. The amount of screening needed for this hazard would typically range between 20 and 60 dB.

The EMC shielding industry offers shielded enclosures with outstanding shielding effectiveness of 100 dB and more. The standard design of such an enclosure is that of a sandwich consisting of three metals — copper, aluminum, and steel. It is essentially an all-metal box with special provisions for openings, penetrating cables, transient protectors, and EMI filters. Unfortunately an EMC enclosure is rather costly. Thus, one must consider whether, for the defined needs of a plant, an EMC enclosure would be "overkill". If the shielding effectiveness requirement is, for example, 20 to 50 dB, then a girdered (reinforced) building incorporating several other technical measures may suffice.

ESTABLISH THE SHIELDING REQUIREMENTS

The shielding effectiveness (SE) requirement for a facility is expressed as: SE = $20\text{Log}(E_{in}/E_o)$ (dB) vs frequency. E_{in} represents the most severe EM environment. E_o denotes the EM field intensity that equipment located at the plant can withstand without degradation of performance. Usually, a safety factor (6 to 20 dB) is added, resulting in a conservative shielding effectiveness (SE) requirement. There are several ways to determine the values of E_{in} and E_o:

- An EM environmental survey is conducted at the facility location (E_{in}).

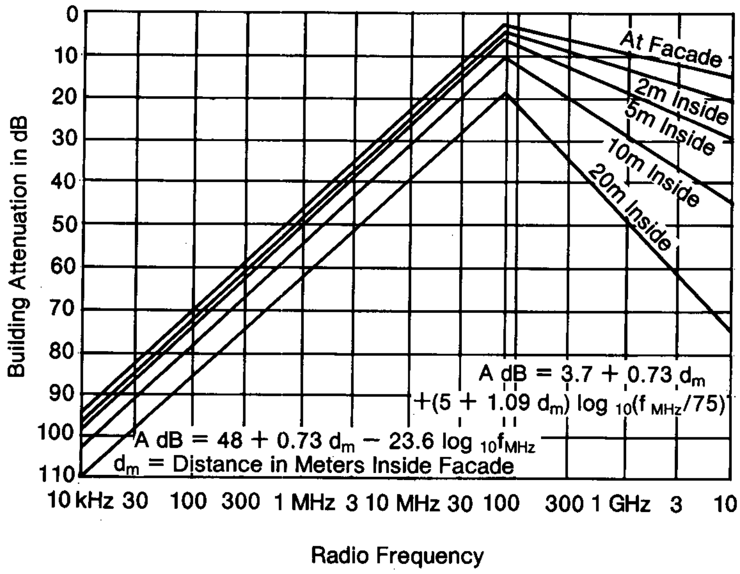

Figure 1. Building Shielding Effectiveness to Outside Radiated Emissions Versus Frequency, per Distance Inside Facade.

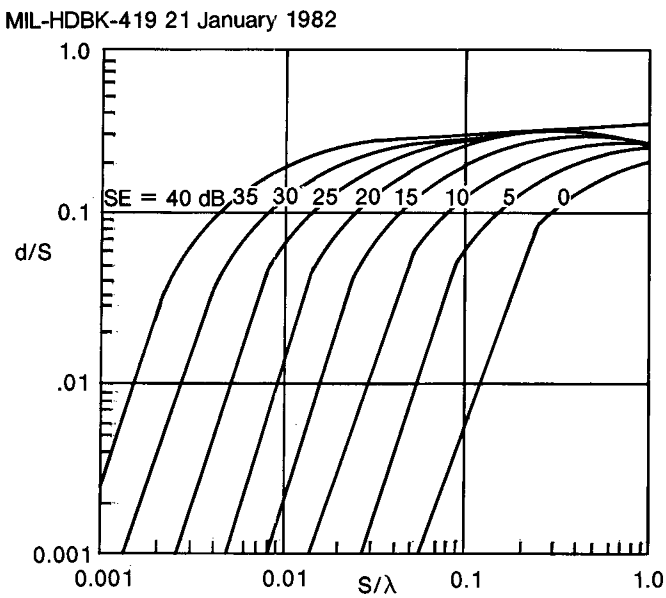

Figure 2. Shielding Effectiveness of a Grid as a Function of Wire Diameter, d.[4]

- A known specification for an EM environment envelope is referenced (as for NEMP) and then modified to suit the specific facility (E_{in}).
- The susceptibility of equipment performance at other sites with a comparable EM environment is examined (E_o).
- The measured EMI characteristics of the equipment are considered or an EMI test is conducted to obtain these characteristics (E_o).

Additional shielding is required if the natural SE of the facility falls below that of the required SE. If these estimates indicate a need for shielding, the shielding is incorporated into the design of the structure and its installation is scheduled at a time during construction when it can be done most economically. Before deciding what type or how much supplemental shielding material is necessary, the inherent shielding provided by building materials and techniques should be estimated (Figures 1 and 2).

NATURAL EM SHIELDING OF REINFORCED BUILDINGS

Common girdered buildings with facades of concrete, stone, brick or glass can provide SE of about 50 dB.[2] Only the reinforcement steel bars embedded into the structure significantly contribute to EMR reflection loss. At high frequencies, concrete elements can add 6 dB more absorption loss.[2] Nevertheless, openings in the building, including doors, windows, air-conditioning ducts, and penetrations for cables and metallic services (utilities) might severely degrade the SE of the entire facility.

Figure 1 depicts natural building shielding versus frequency and distance inside a facade.[3] The values given in Figure 1 may refer to specific building types. Regardless of the exact building type, they depict the essential nature of SE versus frequency in reinforced buildings. Steel bars or metal netting embedded in a structure create loops. The low SE depicted in part of the spectrum is due to center-to-center half-wavelength separation of the loops.

Figure 2 depicts the shielding effectiveness of a grid as a function of wire spacing (S), and wavelength (λ),[4,5] can be used to determine the relative attenuation of wire mesh or grid to electric fields and plane waves at a given frequency.

DESIGN GUIDELINES FOR UPGRADING THE SHIELDING EFFECTIVENESS OF REINFORCEMENT

The following procedures can improve the shielding effectiveness of a building's reinforcement:

- Reinforcement bars in walls, floors, and ceilings should be interconnected electrically. The reinforced concrete foundation of the building should be used as the major grounding network.
- Steel bar intersections should be welded. Welding is preferable to lashing, which results in rust and penetration of concrete film inside the bar joints.
- Extra care should be taken to achieve bonding of reinforcement components at corners and around openings where high current intensities are expected. It is strongly recommended that rein-

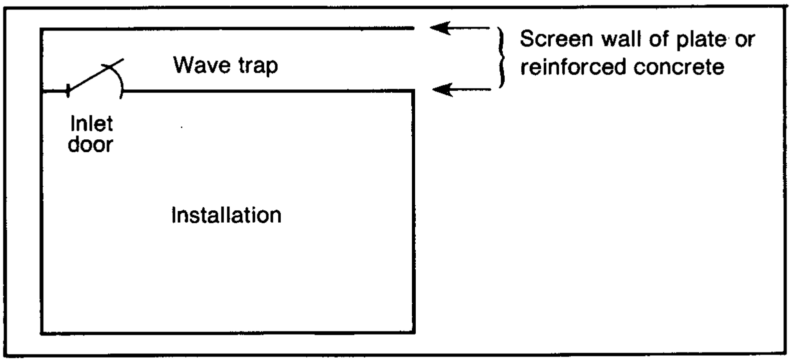

Figure 3. Wave Trap.

forcement should not be used as down-leads for lightning. Instead exterior down-leads should be utilized.

- The reinforcement should be made accessible from the outside and inside of the facade and near all the openings and entries of leads and other metallic services.
- The mesh size in the reinforcement should be as small as practicable. Recommended maximum center-to-center separation is 0.2 meters (the least shielding effectiveness at 750 MHz).
- The number and dimensions of openings should be minimized. Provisions should be made for screening windows, doors, ventilation ports, and walls. Windows should be avoided; if windows are necessary, well-bonded screen wire should be used, e.g., galvanized chicken wire, 15- x 15-mm mesh. Metal doors should be used and wave trap and honeycomb ducts over ventilation ports are effective (Figures 3 and 6).

Table 1 presents dimensions for some wave traps for frequencies up to approximately 50 MHz and attenuation on the order of 50 dB. The model used for calculating these dimensions is of a waveguide-below-cutoff.

- In buildings with a designed exterior and/or interior plastered facade, metal netting can be installed under the facade's plaster. The mesh size should be as small as practicable. The metal netting and the reinforcement should be bonded electrically. When the netting is used as an additional shield, it can be lashed to the reinforcement.
- When a significantly threatening signal emanates from one direction, the use of partial screening should be considered. One method is to cover only one wall (or ceiling or floor), with an all-metal shield. Appropriate practices for installation of metal foils on the building's facade must be followed.[6]
- The most sensitive and critical equipment should be located as close to the core of the structure as operational requirements permit.
- Substituting polymer concrete containing conductive fillers for the commonly-used Portland cement will achieve additional shielding.[7] This innovative measure is still under development; and presumably, it will take some time to become commercially available at reasonable prices — perhaps $1.00 per pound.

The shielding techniques described are tremendously important but definitely cannot stand alone and must be implemented along with other equally important measures. These include terminating to shield penetrating cables and metallic services; shielding windows, doors and other openings; grounding, and filtering.

CABLE AND METALLIC SERVICES ENTRY

It is extremely important that cable and metallic services entry be properly designed. Long cables and conductors can act as outstanding EMR interceptors; hence, a coupled EM field induces high current which might be driven inside a shielded plant. For example, lightning, EMP or NEMP could induce peak current above 20 to 30 kA. The entry zone of those conductors should be able to disperse currents approaching the plant. The group of conductors penetrating a facility may include power line networks; telephone, communication, control, and ground wires; metal water conduits; and sewage pipes. It is strongly recommended that, whenever possible, insulated materials be used for fuel and air pipes and for other services as well. The use of non-conductive materials reduces EMI leakage into the plant via service passages.

The conductor entries should be arranged according to the following guidelines and rules:

- All the entries should be channeled through one limited area. The location of the entry area should be as far as possible from susceptible electronics equipment within the building.
- An entry plate at least 2 x 2 m should be placed at the inlet, with good circumferential bonding to the shield (i.e., the reinforcement or the net embedded in the plaster). The entry plate should be

Max. width/height/ Diameter (m)	Min. Length of Wave Trap (m) Circular	Rectangular
2.0	3.2	3.7
1.0	1.6	1.9
0.5	0.7	0.9
0.2	0.25	0.3

Note: The wave trap should never be used as an inlet for cables or other metallic conductors.

Table 1. Dimensions of Sample Wave Traps.

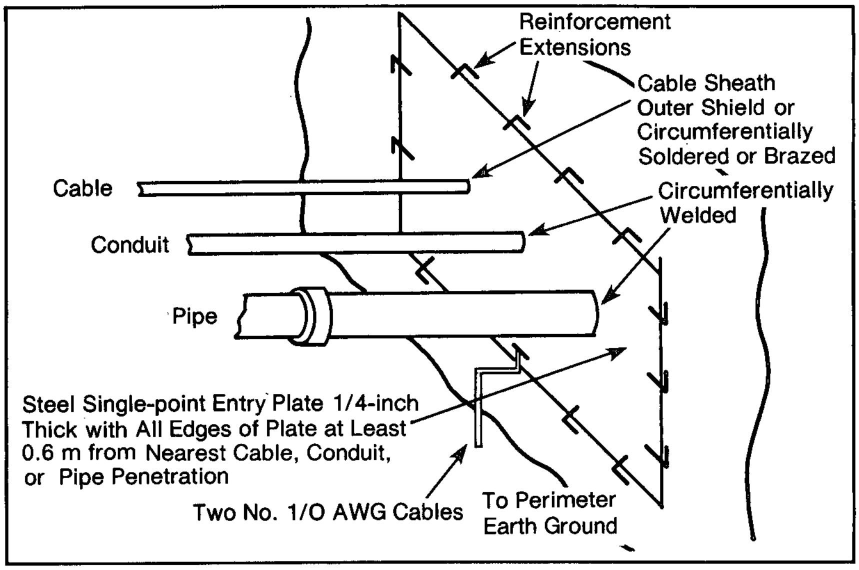

Figure 4. Single Point Entry Plate.[8]

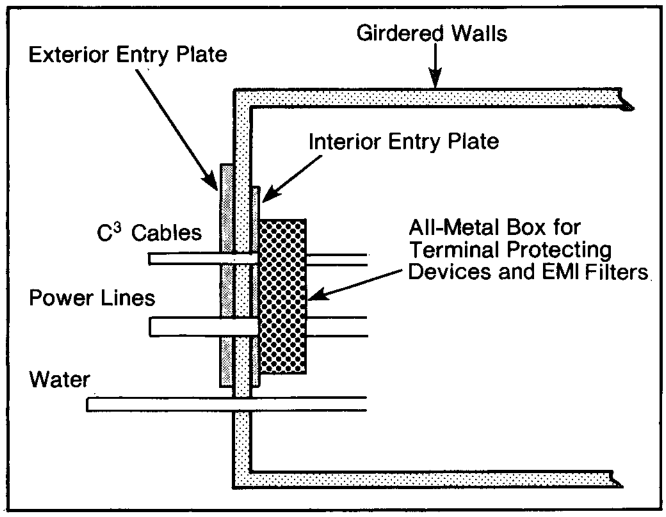

Figure 5. TPD and EMI Filters Compartment within the Facility.

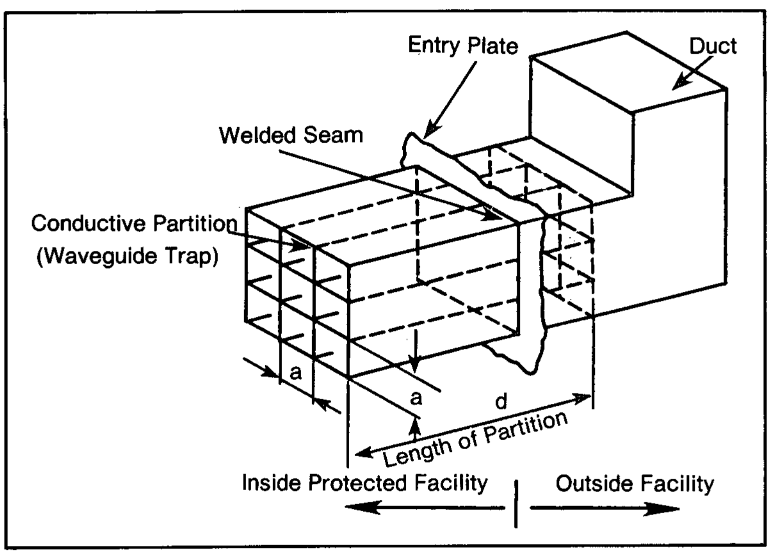

Figure 6. Duct Penetration Inside a Protected Enclosure.

welded to reinforcement extensions, preferably by MIG welding. An entry plate is illustrated in Figure 4.

- Metal conductors, power, communication, control, and ground leads, should be connected to the entry plate as shown in Figure 4.
- If possible, conductive pipes not carrying leads or wires should be replaced by non-conductive substitutes.
- Electrical cables — telecommunication, control, and power line — should be routed within feedthrough metal conduits. In addition, terminal protective devices (TPD) and EMI filters should be installed as shown in Figure 5. Note that the TPD and filter compartment is an all-metallic box bonded to the screen within the facility.
- Non-conductive services, such as plastic pipe and fiber optic cable, which do not contain conductive leads, should be routed within feedthrough metal conduits circumferentially welded to the entry plate. A metal conduit will act as a lossy waveguide for frequencies below cutoff.
- Cable passage should not be closer than 0.4 m to the edge of the entry plate. If a cable passage must be close to the building corner, the entry plate should be folded over the corner to provide the 0.4 m distance from edge.
- Ventilation and air-conditioning ducts made of conductive materials should be welded to the entry plate. If the largest dimension is greater than 0.2 m, a waveguide filter (wave trap) should be placed inside the duct as shown in Figure 5. The dimensions of the duct partitions should be noted: A <0.1 m and length (d) >0.5 m. If the length of the duct outside the facility is greater than 10 m, then it is preferable to use non-conductive material or to replace the entry part of the duct by a 5-meter non-conductive duct.

Ventilation openings that are not linked to ducts on the outside of the entry plate or to non-conductive ducts which create openings through the screen should be provided with a waveguide filter. The largest dimen-

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sion of the mesh should not exceed 0.1 m.

EMI SHIELDING EFFICIENCY VERIFICATION

Shielding effectiveness versus frequency should be tested as part of the specification/assurance testing at the completion of construction.

Appropriate test methods and test procedures are presented in two standards: IEEE-299-1969[9] and MIL-STD-285[10]. The SE measurement relates to test points inside the protected facility; hence, test points should include working and storage areas designated to house susceptible equipment. At frequencies above 30 MHz, vertically and horizontally polarized CW radiated fields shall be applied for the shielding effectiveness verification testing.

SUMMARY

The need to protect susceptible equipment and electronics against extraneous EMI in government facilities, industrial plants, hospitals, and radio and television stations has highlighted the importance of architectural shielding. In particular, EMI-control engineers are focusing on design techniques and rules which utilize the natural SE of common reinforced buildings to meet SE requirements from 20 to 60 dB in a cost-effective manner.

The major difficulties in the construction of an adequate EMI-protected facility stem from the complexity of controlling EMI leakage through openings, penetrating cables, and feedthrough metallic services. Implementation of the design techniques and practices outlined above will yield a cost-effective EMI-protected facility. ■

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