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ELECTROMAGNETIC SHIELDING TESTS ON A ROOM SHIELDED WITH 1/1

FOIL-FACED FOAM BOARD(U) CONSTRUCTION ENGINEERING

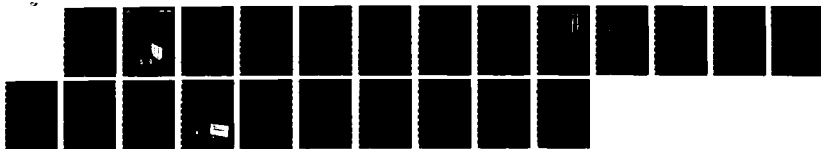
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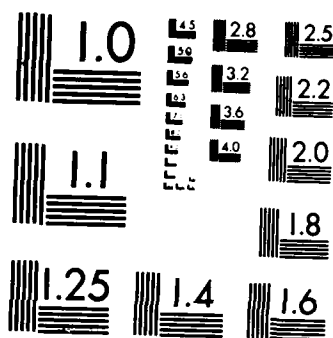
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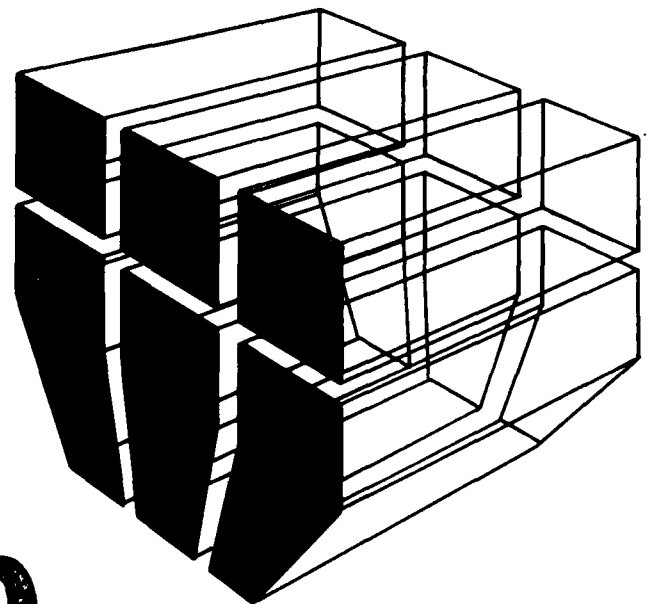
EMP/EMI Shielding Criteria and Hardness Testing

AD-A174 396

Electromagnetic Shielding Tests on a Room Shielded With Foil-Faced Foam Board

by
Paul H. Nielsen

Conventional electromagnetic shielded construction is relatively expensive. One possible approach to decreasing the cost of this type of construction would be to provide shielding through commercial construction materials and techniques with slight alterations. A readily available material that might work for this concept is foil-faced foam board. An experimental room shielded with this material was subjected to radiated electromagnetic shielding tests and Shielded Enclosure Leak Detector System (SELDS) tests. The results indicate that a low to medium-performance shielded room can be obtained when this technology is used with reasonable care.



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FOREWORD

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The work was performed by the Engineering and Materials Division (EM) of the U.S. Army Construction Engineering Research Laboratory (USA-CERL). Dr. Robert Quattrone is Chief, EM.

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COL Norman C. Hintz is Commander and Director of USA-CERL, and Dr. L. R. Shaffer is Technical Director.



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ELECTROMAGNETIC SHIELDING TESTS ON A ROOM SHIELDED WITH FOIL-FACED FOAM BOARD

1 INTRODUCTION

Background

Structures for military applications may require shielding against electromagnetic energy to: (1) protect electronic equipment from electromagnetic interference, (2) insure secure operation of electronic equipment that processes classified information, and/or (3) provide a degree of hardening against electromagnetic pulse (EMP) for electronic equipment housed inside the structure. Any shielding supplied by a structure is non-equipment-sensitive, which means that equipment can be replaced or moved within the shielded zone with little or no effect on the protection provided.

Shielding by rooms or buildings is obtained through signal reflection and/or absorption. The most convenient way to achieve shielding is usually to construct a continuous metal shell for the structure. Commercial shielded construction is produced in several forms, including: (1) all-welded steel systems for high-performance requirements, (2) modular systems consisting of metal sheets or metal-clad plywood along with supporting hardware, and (3) metal screen rooms, with copper used most often. These structures are relatively expensive; the larger the volume to be enclosed, the higher the cost. Therefore, other options for providing structural shielding are desirable—especially when the shielding requirement is less than the degree offered by conventional commercial systems.

Shielded construction that uses relatively low-cost existing materials would be an attractive solution. One such material has become readily available: the aluminum foil-coated foam insulation used for sheathing in some housing construction. This material has shielding potential and might offer a lower cost alternative to commercial systems.

Objective

The objective of this study was to determine the amount of electromagnetic shielding obtained from a small room specially constructed of foil-faced foam insulation sheathing. The results will be provided to aid in evaluating low-cost alternative shielding material on a wider scale for possible use in military construction.

Approach

A room was constructed by gluing foil-faced foam board to the exterior of a 2 ft by 4 ft wooden frame that had been covered with plywood. This room was subjected to Shielded Enclosure Leak Detector System (SELDs) tests as well as radio frequency (RF) illumination tests that were derived from Military Standard (MIL-STD) 285, Institute of Electrical and Electronic Engineers (IEEE) Practice 299, and National Security Agency (NSA) Specification 65-6.¹

Scope

Although other foil-coated building materials are available, only the foil-faced foam-backed insulation was tested. No tests were done to determine long-term shielding or aging properties of the foil-faced foam board/conductive electrical tape systems.

Mode of Technology Transfer

Information from this study will be used to recommend revisions to Technical Manual (TM) 5-855-5, *Nuclear Electromagnetic Pulse Protection* (Headquarters, Department of the Army, February 1974).

2 THE EXPERIMENTAL STRUCTURE

Materials and Construction Methods

The foil-faced foam board used for the experimental room is manufactured by Celotex and is known as Tuff R insulating sheathing. This material is an aluminum-coated, kraft paper-faced insulated sheathing (Figure 1). The sheathing consists of a layer of 1100 series and two layers of 1145 series aluminum separated by kraft paper and bonded to 0.5-in.-thick foam insulation. Series 1145 aluminum is typically used as foil for packaging and insulating and in heat exchangers. Series 1100 is used in applications requiring good

¹ Military Standard (MIL-STD) 285, *Method of Attenuation Measurements for Electromagnetic Shielding Enclosures for Electronic Test Purposes* (Headquarters, Department of the Army [HQDA], 25 June 1956); Institute of Electrical and Electronic Engineers (IEEE) Practice 299, *Trial-Use Recommended Practice for Measurement of Shielding Effectiveness of High Performance Shielding Enclosures* (IEEE, 1969); National COMSEC EMI/C Memorandum (NACSEM) 5204, *Shielded Enclosures (U)*, Appendix B, "NSA Specification for RF Shielded Enclosures for Communications Equipment," NSA 65-6 (National Security Agency, 1965).

*Metric equivalents: 1 in. = 25.4 cm; 1 ft = 0.3048 m.

formability and high resistance to corrosion when high strength is not necessary. (Additional details on the aluminum's specifications and properties are available elsewhere.²)

The material's printed face has a 0.4-mil-thick surface layer of 1145 series aluminum. This layer is separated from a 0.3-mil layer of the same aluminum (series 1145) by a layer of kraft paper. The other side of the foam insulation is faced by 0.9 mils of 1100 series aluminum. The foam material is somewhat brittle, so that the sheets must be handled with care to prevent breaking or otherwise damaging the aluminum surfaces. This material is readily available in the United States from construction supply outlets in 4 ft by 8 ft sheets of various thicknesses.

The room was a 2 ft by 4 ft wooden frame structure with the studs 16 in. on centers. The framework was covered with a 0.25-in. plywood underlay. The insulation was glued—printed side out—to the outer surface of the plywood. Shielding for the test structure was thus on the outside of the room with the framework inside.

Electrical continuity between the insulation panels is required to enable the structure to perform as an electromagnetic shield. To make the necessary seams, the aluminum foil from one face was peeled back and 0.5 in. of the foam insulation material and the opposite foil face was carefully removed from the edge of the panel. The mating sheet was prepared similarly, except that the foil was cut back from the opposite panel face. The pieces were then joined, resulting in a 0.5-in. foil overlap on each side of the joint as Figure 2 shows. The foil faces were not specially cleaned or otherwise prepared; no effort was made to clean off surface oxide or any other coating that might be present. The foil was secured with Scotch® 3M tape, Type 1267 (2 in.

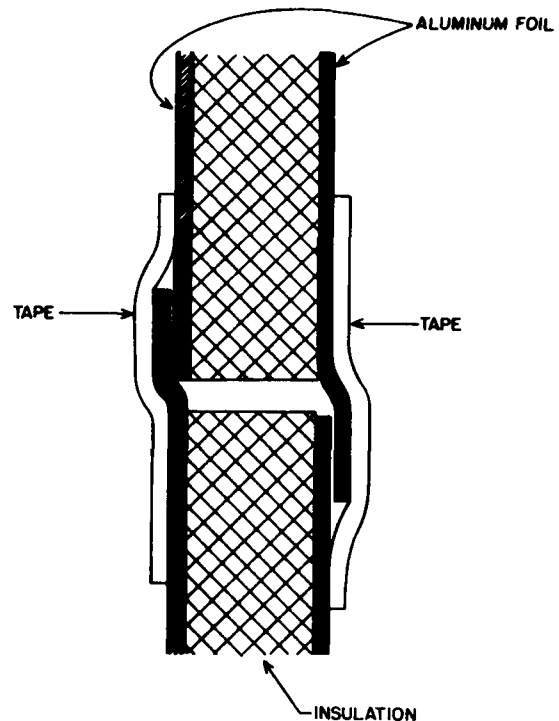


Figure 2. Seam-joining concept.

wide, nominally 4.5 mils thick). The tape is an embossed aluminum foil with acrylic pressure-sensitive, conductive adhesive and is designed for electromagnetic shielding applications. Corner seams were constructed in the same way, except that the joint was at 90 degrees.

The floor was constructed of 0.75-in. plywood placed on 4 in. by 4 in. timbers so the completed structure could be moved by forklift. The foil-faced insulation was glued to the top of this layer of plywood. An additional layer of plywood was placed over the insulation material for the floor surface and the internal framework was installed over this layer. Figure 3 shows the floor structure. The framework was attached to the bottom part of the structure with nails driven through the floor layer of foil-faced foam board. The floor foil extended beyond the framing so that the side walls could make electrical contact with the floor shielding.

The door was an experimental design built for an earlier study at the U.S. Army Construction Engineering Research Laboratory (USA-CERL).³ The

²*Metals Handbook*, 9th ed., Vol 2, "Properties and Selection: Nonferrous Alloys and Pure Metals" (American Metals Society, 1979), pp 65-67.

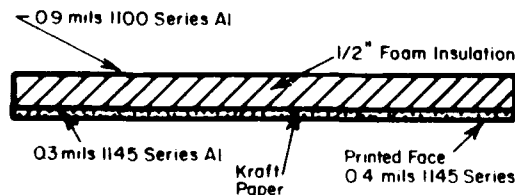


Figure 1. Foil-faced foam board composition cross section.

³B. L. Cain, *FMI/RFI Gasketing for Tactical Shielded Shelter Door Seam Application*, AFWAL-TR-83-4127 (U.S. Air Force, March 1984).

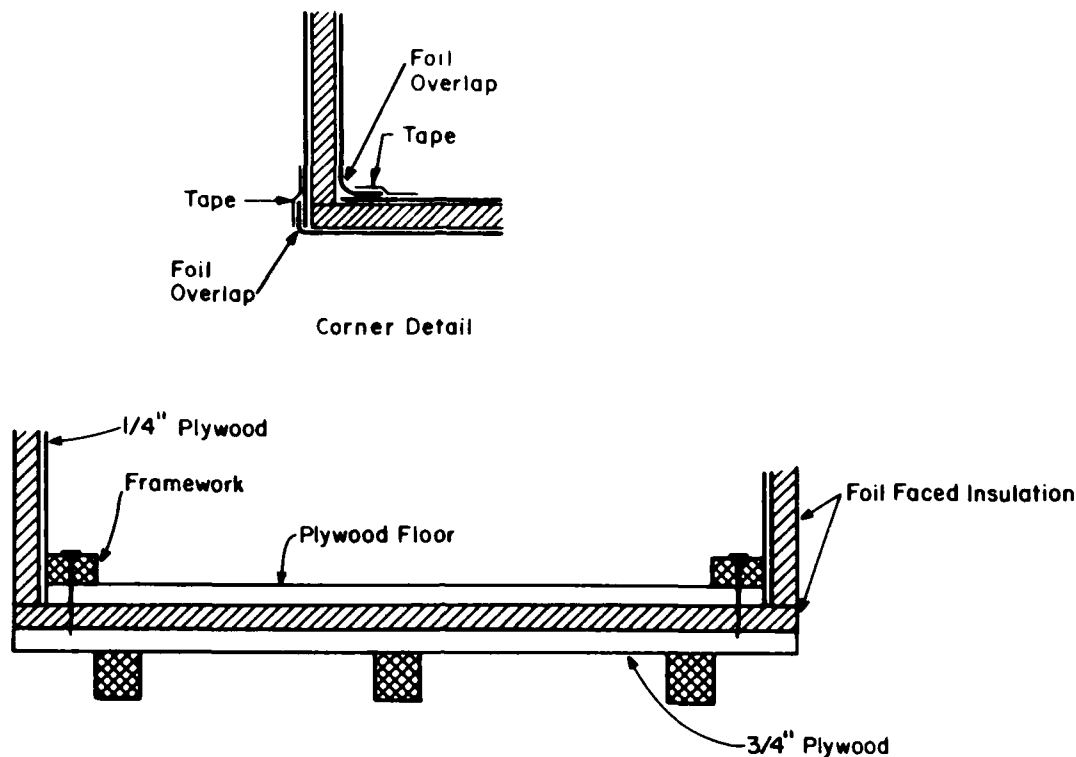


Figure 3. Floor construction details.

shielding concept included a spiral wound spring metal gasket that mated with a knife edge (Figure 4). The door was built as a test sample to fit into a "window" of a USA-CERL high-performance shielded room. The door itself was configured as a hatch with a 14 in. by 26 in. opening. In the closed position, it was held in place from the inside by four spring-loaded clamps. The door frame's external dimensions were 4 ft by 2 ft 6 in. This frame was mounted to the wooden framework by hanger bolts that passed through the foil-faced foam board. Edges of the door frame were then taped to the exterior layer of foil with the special 3M tape. The door and door frame were both constructed of 0.125-in.-thick brass.

A prefabricated 12 in. by 12 in. honeycomb air vent was installed near a lower corner of the room. The hole for the vent was cut after the walls had been installed, and the vent was mounted to the outer foil layer with wood screws that passed through the insulation material into the wooden framing. The unit was then taped to the structure's exterior with the special 3M tape.

Battery-powered receivers and lights were used inside the room during the shielding test. Thus, it was not necessary to install electrical power lines or filters on the structure.

Theoretical Shielding From Foil-Faced Foam Board

Material thickness dimensions for the foil and foam board as shown in Figure 1 were used as input for a computer program to determine the theoretical coupling between two antennas with an infinite flat plate of the material between the antennas. The computer program is based on previous work at USA-CERL.⁴ The conductivity value used for aluminum was 3.82×10^7 mho/m; the relative dielectric constant was 1 and the antenna spacing was 12 in.

⁴R. Gilbert, R. Mittra, and R. McCormack, "Coupling Between Two Arbitrarily Oriented Dipoles Through Multilayered Shields," *National Symposium on Electromagnetic Compatibility, Symposium Record*, IEEE Publication 84CH2034-4 (1984).

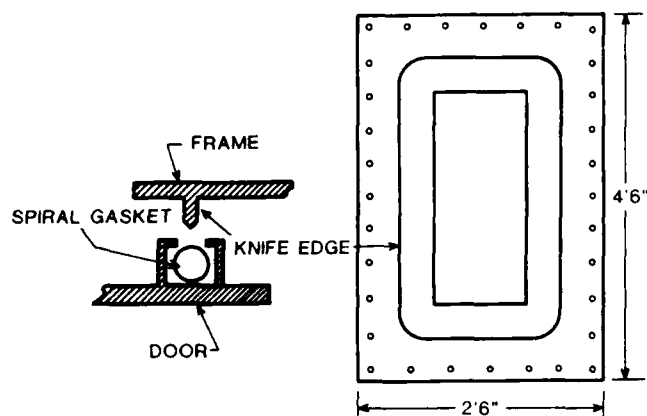


Figure 4. Door details.

Table 1 lists the results of the computer calculations. These numbers indicate that significant shielding is possible using this material. It should be noted, however, that a structure's shielding performance is generally determined by factors other than the shielding of the base material alone—including the effectiveness of seams, doors, and signal and power entry.

3 SHIELDING TESTS

The completed structure was subjected to radiated continuous wave (CW) illumination using procedures based on MIL-STD 285, NSA Specification 65-6, and IEEE Practice 299. Shielding was assessed based on low-frequency magnetic field tests (loop antennas) at 10 kHz, 100 kHz, 1 MHz, and 10 MHz; measurements at 100 MHz and 1 GHz using dipole antennas; and microwave tests at 2.4 and 10 GHz using microwave horns. In each case, the signal was radiated outside to the room and measured inside. Table 2 lists equipment used for this study.

Nine test points were chosen as representative of the total structure (Figure 5). These points included:

- One each at the door and air vent
- N and R both located at the center of horizontal seams
- O and S center of panels

Table 1
Theoretical Shielding Effectiveness of an Infinite Flat Plate of Foil-Faced Foam Board

Antenna Type	Frequency	Shielding Effectiveness (dB)
Loop ↓	10 kHz	26
	100 kHz	57
	1 MHz	97
	10 MHz	137
Dipole ↓	100 MHz	197
	1 GHz	296
	10 GHz	500+

- Q—vertical corner seam
- P—corner and horizontal seam
- T bottom corner (three-way corner).

Magnetic Field Measurements

The magnetic field measurements were made at 10 kHz, 100 kHz, 1 MHz, and 10 MHz using 12-in.-diameter loop antennas. The transmitting antenna was an electrostatically shielded switchable multiturn loop built at USA-CERL (the antenna has no matching circuitry). The receiving antenna was an Empire LP-105 loop.

A reference reading was obtained by placing the antennas 24 in. (plus the wall thickness) apart at a location away from the shielded structure with no material between the antennas. The antennas were arranged such that planes of the loops were parallel (coaxial orientation). A CW signal at the frequency of interest was radiated and the signal level indicated on the receiver (in decibels) was recorded as the reference reading. An additional reading was taken while no signal was being radiated and with the receiving antenna inside the shielded room. This reading was the receiver noise level for that frequency. The difference between these two readings is essentially the dynamic measurement range at that frequency. (The actual dynamic range is slightly larger since any reading near the noise level consists of the signal plus noise. None of the readings taken in this study were near the noise level and this correction was not applied.)

Table 2
Equipment Used for Shielding Effectiveness Testing of
Foil-Faced Foam Board Room

10 kHz and 100 kHz tests

Wavetek Signal Generator Model 147
 EMC-25 Receiver
 USA-CERL 12" loop antenna (for transmitting)
 Empire LP 105 12" loop antenna (for receiving)

1 MHz and 10 MHz tests

Hewlett-Packard Model 8601 Sweeper/Generator
 Electronic Navigation Industries Model 310 Power Amplifier
 USA-CERL 12" loop antenna (transmitting)
 Empire LP 105 12" loop antenna (receiving)
 EMC-25 Receiver

100 MHz test

Hewlett-Packard Model 8601 Sweeper/Generator
 Electronic Navigation Industries Model 310 Power Amplifier
 EMC-25 Receiver
 Empire DM-205-T1 Dipole Antennas

1 GHz test

AilTech Model 445 Power Oscillator with 187 Plug-in
 EMC-25 Receiver
 Stoddard AT-255/URM-17 Dipole Antenna (transmitting)
 Empire DM-105-T3 Dipole Antenna (receiving)

2.4 GHz and 10 GHz tests

Wiltron Model 6637 Programmable Sweep Generator
 AilTech-Stoddard NM-65T Radio Interference Analyzer/Receiver
 S Band and X Band Microwave Horn Antennas

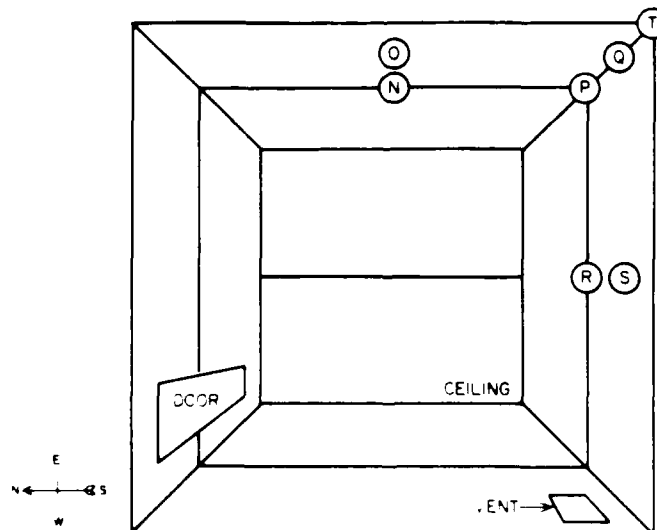


Figure 5. Test point locations for radiated CW shielding effectiveness testing (view from the inside, looking up).

The shielding was measured with the receiving antenna inside the room; the test point was at the center of the antenna at a distance of 12 in. from the wall. The transmitting antenna was located similarly outside the room opposite the test point. Figure 6 shows the test procedure. All settings on the transmitting equipment remained the same as they were for the reference reading. The only variable between the reference reading and the reading for the shielding effectiveness was the attenuator setting on the receiver. The reading was recorded and later subtracted from the reference reading. This value was the measured shielding effectiveness of that test point. All test points were measured in sequence. A second reference reading was taken after the measurements were completed to verify proper equipment operation and control settings.

Dipole Antenna Measurements

Dipole antennas were used for measurements at 100 MHz and 1 GHz as shown in Figure 7. The antennas for 100 MHz were Empire Model DM-205-T1. For the 1-GHz tests, a Stoddard Aircraft Radio Co. AT-255-URM-17 was used for transmitting and an Empire

Model DM-105-T3 was used for receiving. The antenna spacing for the reference reading was 6.8 ft (equal to 6.56 ft [2 m] outside the room, the wall thickness, and 2 in. inside the room). The reference readings were taken again with no material between the antennas. Shielding was measured by illuminating the test point with the radiation antenna outside the room at a distance of 6.56 ft. The receiving antenna was held at a distance of 2 in. from the interior wall surface and moved around to search for a maximum reading.

The wavelength at 100 MHz is 9.8 ft; therefore, at this frequency, the measurement described probably should be considered to be in the near field. The plane wave region begins 3 to 4 wavelengths from the antenna,⁵ although the geometry of the radiating wavefront is spherical and the approximation to a plane is not as close as it is at more distant points. A plane wave is defined as a traveling wave that has a free

⁵ Sy L. O'Young, Reuben Goldman, and Lars Jorgensen, "Survey of Techniques for Measuring Shielding Enclosures," *IEEE Transactions on Electromagnetic Compatibility*, Vol EMC 10, No. 1 (March 1969), p 72f.

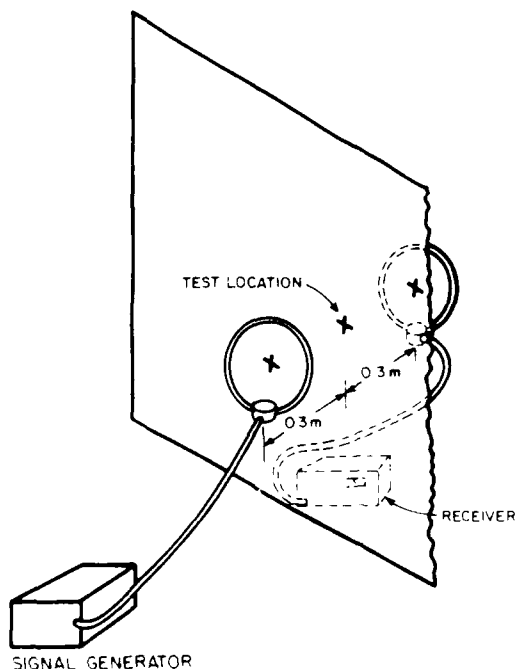


Figure 6. Magnetic field shielding effectiveness test (100 kHz and 10 MHz).

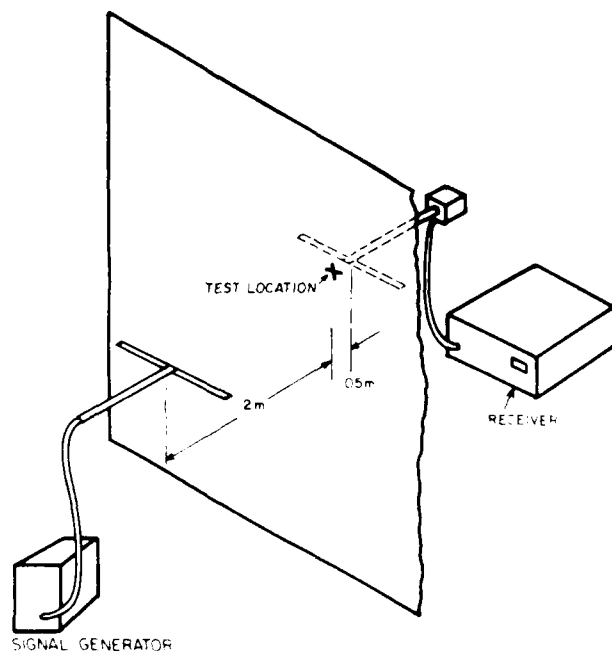


Figure 7. Shielding effectiveness test using dipole antennas (100 MHz and 1 GHz).

space wave impedance of 377 ohms; the name does not necessarily describe the shape of the advancing wavefront accurately. In general, the near field from a monopole or dipole has a wave impedance greater than 377 ohms and is termed an "electric field" whereas the near field resulting from a loop will be less than 377 ohms and is known as a "magnetic field." The value of the wave impedance is a function of the distance from the antenna up to the location where the wave impedance approximates that of free space. The 100-MHz measurement was made in the near field region since a considerable decrease in dynamic measurement range would have accompanied an antenna spacing of 30 to 40 ft (3 to 4 wavelengths). The wavelength at 1 GHz is about 1 ft. Thus, at an antenna spacing of 6.56 ft, the signal was well within the plane wave region.

Microwave Measurements

Microwave shielding effectiveness tests at 2.4 GHz and 10 GHz were conducted as shown in Figure 8. The antennas were microwave horns with a spacing of 3.5 ft (3.3 ft outside the shield, 1-in. wall thickness and 2 in. inside the room). The distances were measured from the antenna apertures. A reference reading was taken as described earlier. The interior wall near the test point was scanned with the receiving antenna to locate the maximum reading.

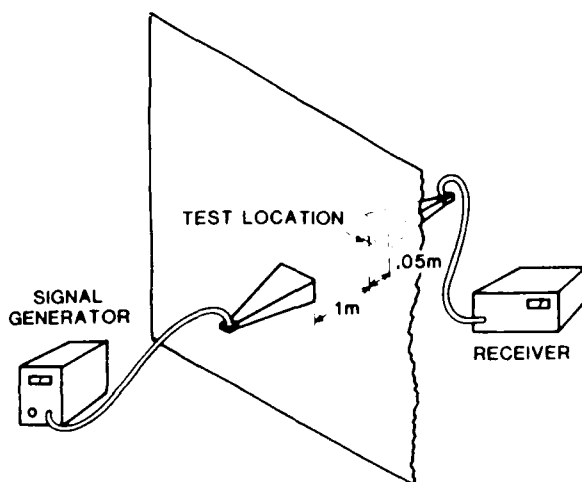


Figure 8. Microwave shielding effectiveness test (2.4 and 10 GHz).

Shielded Enclosure Leak

Detector System (SE LDS) Tests

The seams on the room were scanned using a Singer Model 500 Shielded Enclosure Leak Detection System (SE LDS also known as a "Sniffer"). This system applies a 1-amp, 100-kHz signal pulsed at a 1-kHz rate to the exterior of the room to be tested. A sensitive hand-held battery operated receiver with a ferrite probe antenna is used to scan the inside of the room. The receiver has a meter calibrated in decibels. The lower this reading, the better the room's shielding performance. The numbers obtained by this technique cannot be related in any simple way to the shielding effectiveness numbers obtained by MIL-STD 285 radiation techniques. A SELDS test does, however, give a good indication of the shielding performance expected from the room under test. If a room performs well with a SELDS test, it will probably do so in a radiated CW test. The SELDS test is especially useful in discovering leaky seams. However, it cannot reliably show unfiltered wires and some other shielding violations. (Unfiltered wires often can be located through a radiated CW test using a signal in the 100 to 500 MHz range.)

Values taken from the SELDS test are mapped in Figure 9.

4 RESULTS AND ANALYSIS

Table 3 lists the results from the radiated shielding effectiveness tests. Low-frequency magnetic shielding is provided by distortion of the magnetic flux lines, which requires a low reluctance path around the shielded volume. Low reluctance paths are best provided by a continuous material with a high magnetic permeability. Thus, limited shielding would be expected from the aluminum foil for low-frequency magnetic fields since the relative magnetic permeability of aluminum is unity the same as for air and since the material itself is relatively thin. The data show lower shielding than was observed at higher frequencies for the 10-kHz magnetic field tests at all test points. Electric field shielding results mainly from reflection losses and would be considerably higher than the magnetic field shielding at the same frequencies.

The lowest shielding was measured at the honeycomb air vent filter, probably due to the way the unit was installed. The wall consisted of the foam board glued on the outside of a layer of plywood. The air

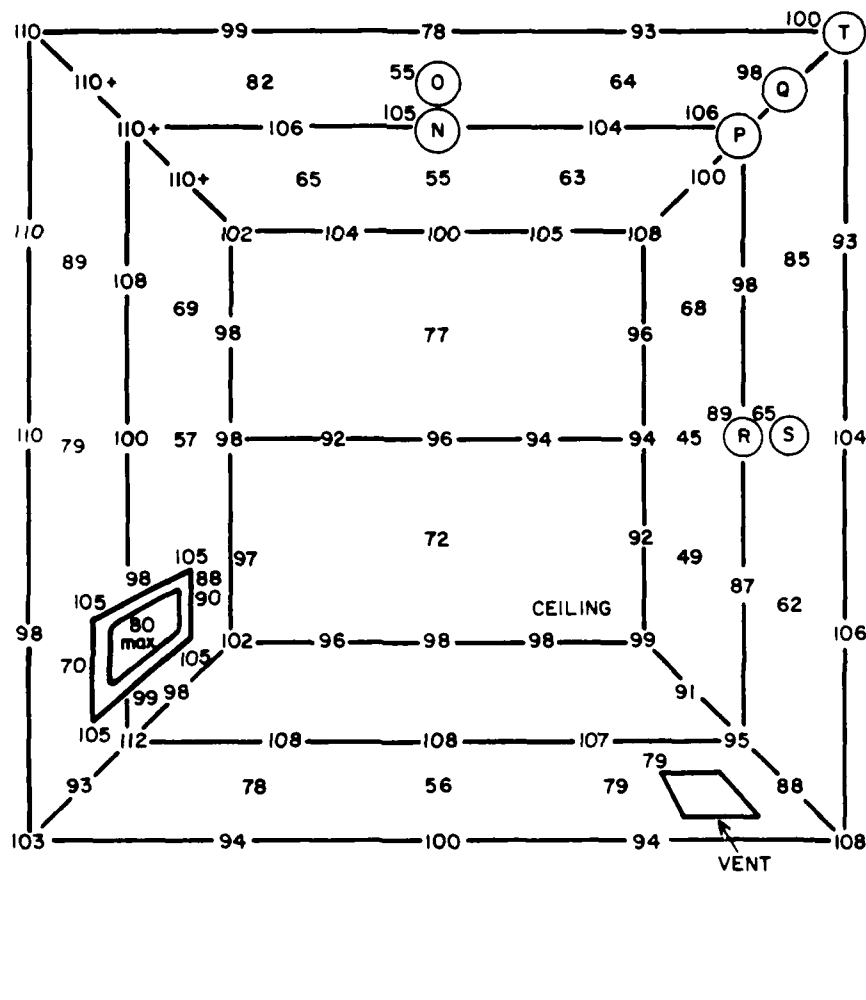
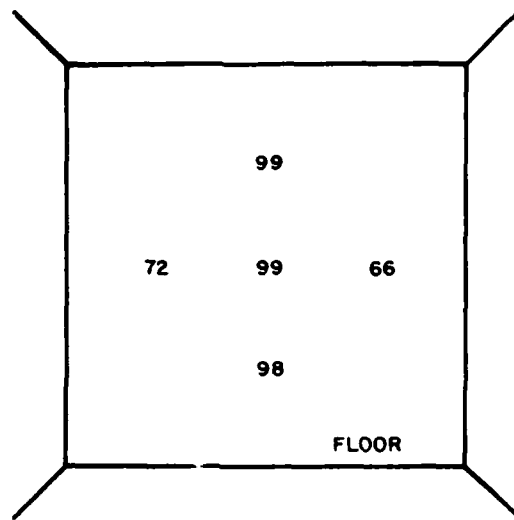


Figure 9. Readings (in decibels) taken from SELDS test.

Table 3
Electromagnetic Shielding Tests of Foil-Faced Foam Board Room

Frequency	Shielding Effectiveness (dB) at Test Location*								
	Door	Vent	N	O	P	Q	R	S	T
Magnetic field loop antennas									
10 kHz	27.5	17.5	7.5	22.5	9.5	13.5	8.0	22.5	5.0
100 kHz	42.5	40.5	23	25	22.5	18.5	25.5	46.5	24
1 MHz	60	39	48	66	44	48	45	72	41
10 MHz	73	35	61	77	49	58	67	79	45
Dipole antennas									
100 MHz	60	44	53	53	59	59	61	61	60
1 GHz	62	49	56	58	55	58	59	62	53
Microwave horn antennas									
2.4 GHz	58	59	72	71	69	64	62	63	68
10 GHz	60+	60+	60+	60+	60+	60+	60+	60+	60+
SELDS reading									
	80	102	105	55	106	98	89	65	100

*N and R = both located at the center of horizontal seams; O and S = center of panels; Q = vertical corner seam; P = corner and horizontal seam; T = bottom corner (three-way corner).

vent was installed in a hole cut in the wall by taping it to the foil on the outside of the foam board with the 3M aluminum foil tape. The foil on the glued side of the foam board was inaccessible and therefore was not taped to the air vent on that side.

The SELDS readings were high everywhere in the room due to the relatively low shielding performance of the aluminum foil at 100 kHz. Readings at the seams were measurably higher, indicating that the seams were, to a large extent, the limiting factor on the observed shielding effectiveness of this structure. Thus, it appears that any increase in shielding performance for this kind of construction will depend on improvements in seam bonding technology.

No electrical filters were used for this structure and no filter-mounting techniques were tested. In general, good electrical contact should be maintained between any entering conduit or pipe and the shield. For the aluminum foil structure, any such pipe should be aluminum to prevent galvanic corrosion. Figure 10 shows a technique that should work fairly well for filter-mounting or passing a pipe through the shield.

A threaded portion of the pipe is brought through the foil-faced foam board with an aluminum washer or plate held in place with a nut. The washer or plate is taped to the foil around its periphery. This configuration should be used on both sides of the foam board. The foam board should not be relied upon to support very much weight; thus, filters and heavy pipes would need additional support.

The results showed that the foil-faced foam board structure provides a shielding effectiveness greater than 35 to 40 dB at frequencies higher than 1 MHz. The lower shielding values at 10 kHz and 100 kHz were to be expected, given that magnetic field shielding for the aluminum foil decreases with lower frequency magnetic fields.

The shielding properties of this structure could decline with physical damage to the metal layer or deterioration of the tape adhesive over time. Physical damage can be limited by protecting the foil. Repairs with foil tape would be possible if damage occurs in the form of minor cuts. No data were gathered on the expected lifetime for the adhesive on the tape used.

and different brands may have different literatures under any given circumstances.

Shielding retrofit to existing structures was not addressed specifically in this study; however, the construction method investigated (gluing the foam board to a previously built structure and taping the seams) should be readily adaptable to retrofit construction. New construction could be designed to speed the taping of both sides of the foam-faced board, whereas this access may be more difficult for retrofit construction. In some cases, only one side may be accessible. A somewhat lower shielding effectiveness would be expected if only one side is taped, as observed with the air vent mounting in the experimental structure.

5 A FOLLOW-UP SEAM TEST

The foil-faced foam board shielded room had been designed with overlap seams because it seemed likely that this design would increase shielding effectiveness. However, the process of preparing the overlap added greatly to the time and labor necessary to apply the foam board. In addition, as discussed in Chapter 4, the seams were still a major point of leakage. Therefore, a series of tests was conducted on different seams to determine if any significant shielding increase is obtained by using the overlap seam versus one with simpler construction.

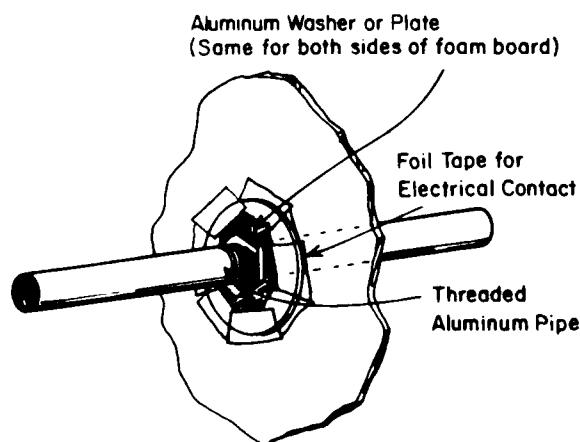


Figure 10. Conduit/pipe entry concept.

Three test samples were prepared to compare the performance of two types of foil tape and two different seam joining concepts. The samples had an approximate finished size of 2 ft 6 in. by 4 ft 6 in. This was the size necessary to fit over a test "window" in an air welded high performance shielded room at USACERL. Figure 11 shows a test sample mounted in this window. The samples were constructed with a seam across the middle of the long dimension. Sample 1 was a butt seam that had both sides taped using 3M Type 1170 aluminum foil tape with conductive acrylic pressure-sensitive adhesive. Sample 2 was a butt seam that had both sides taped with 3M Type 1267 embossed aluminum foil with acrylic pressure sensitive adhesive. Sample 3 was an overlap seam like the one used for the test structure described in this report. The foil face on one side was peeled back and approximately 0.5 in. of foam and the foil on the opposite side were trimmed off. The matching piece was prepared in the same way except that the foil from the reverse side of the panel was removed with the 0.5 in. of foam. Embossed tape (3M Type 1267) was used for this sample.

The material used for the samples was locally procured Owens-Corning Fiberglass rigid polyisocyanurate foil-faced foam board. Edges of the samples for this test were taped with 3M foil tape to reduce edge effects from the two separated surfaces, thereby more nearly simulating an infinite flat plate of material.

The samples were mounted in turn and shielding effectiveness tests were conducted. Table 4 lists the



Figure 11. Seam test sample mounted in high-performance shielded structure window.

results. No significant differences in the shielding measured are obvious from these data, i.e., the tests indicate no shielding advantage from a complex overlap seam. Also included in Table 4 for comparison are data from earlier shielding tests of a sample with no seam mounted in the window of the high-performance shielded room. The shielding values from this sample probably represent the maximum shielding that can be obtained with the material tested.

Since aluminum oxide is a nonconductor, it should be advantageous to produce seams without this layer. However, an oxide layer forms almost immediately upon exposure of aluminum to the atmosphere. None of the seams in this study were specially prepared or cleaned to remove the surface oxide layer. This area (reduction or elimination of the surface oxide for seams) is the most likely candidate for improving the shielding performance of this kind of construction.

6 COST ANALYSIS

Costs related directly to the shielding materials include the foil-faced foam board, the special tape, and the glue used to mount the foam board. Prices quoted in Central Illinois during October 1985 were:

- Foil-faced foam board, 0.5 in. thick, 4 ft by 8 ft = \$7.
- Aluminum tape, 3M Type 1170, 2 in. wide by 18 yd long = \$54.48 per roll or 12 rolls at \$51.88 each (about \$1/ft). Approximately 24 ft of tape are required for each sheet of foam board (both sides of each seam).
- Glue = less than \$1/sheet.
- Total material cost = about \$32/sheet (32 sq ft), or approximately \$1/sq ft.

Material costs may be a minor portion of total installation costs if extensive labor is required for installation. The labor cost for installing the shield materials on this structure was relatively high due to the time spent preparing the foam board for the overlap seams (removing 0.5 in. of foam from beneath the foil). Since later tests showed that the foil overlap did not appear to improve shielding performance greatly, this step could be deleted for a considerable labor cost savings. The time required to install an 8 ft by 4 ft

foam panel and tape the seams is probably 1 to 2 hr. Thus, the installation labor cost for the structure described in this report is on the order of \$1/sq ft. Adding material costs to the labor gives a total of approximately \$2/sq ft for installation of the shielding.

7 CONCLUSIONS AND RECOMMENDATIONS

A commercial foil-faced foam board has been investigated for electromagnetic shielding effectiveness. This material is a potential low-cost alternative to conventional shielding for some applications.

The data indicate that it is possible to obtain shielding effectiveness greater than 35 to 40 dB at frequencies higher than 1 MHz using the inexpensive foil-faced foam board construction with taped, overlapped seams. Lower shielding values were noted at 10 kHz and 100 kHz, but this result was expected since the maximum magnetic field shielding possible from the aluminum foil material decreases with a decrease in frequency.

The measured shielding effectiveness values for the room were considerably less than the theoretical maximum for the foil itself. Analysis of the data showed that the lower values were due mainly to the seam-joining and hardware-mounting methods (particularly that for the air vent).

No significant differences were noted in the tests comparing different tapes and seam-joining techniques. Thus, there is no apparent advantage to using overlap seams.

Although this study did not address the shielding retrofit potential for this material, the method of installation should be readily adaptable for retrofitting.

It is recommended that the Army consider foil-faced foam board construction as an option for low-performance (40 to 50 dB maximum) shielding requirements for the following reasons:

1. The foil-faced foam board is a readily available commercial product.
2. The assembly and repair of a shielded structure using this technology is simple and straightforward.

Table 4
Shielding Effectiveness of Various Foil-Faced Foam Board Test Samples

	Shielding Effectiveness by Sample (dB)*					
Frequency	1	2	3	4	N**	
Magnetic field						
-coaxial 12 in. loop antennas						
10 kHz	18	11	9	54	7.5	
150 kHz	34	30	31	56	23***	
200 kHz	36	34	30	—	—	
500 kHz	46	42	41	—	—	
800 kHz	52	52	49	—	—	
1 MHz	54	53	50	68	48	
2 MHz	64	60	60	—	—	
5 MHz	71	70	70	79	—	
10 MHz	80	76	72	—	61	
Electric field						
-vertical monopoles						
150 kHz	132	136	134	125+	—	
200 kHz	130	125	122	124	—	
500 kHz	126	125	119	—	—	
1 MHz	140	116	115	134+	—	
2 MHz	117	107	105	—	—	
5 MHz	103	98	89	—	—	
10 MHz	96	99	92	104	—	
15 MHz	118	85	101	91	—	
18 MHz	112	102	85	113	—	
20 MHz	107	91	78	110	—	
50 MHz	87	50	56	96	—	
100 MHz	92	81	72	—	53 (dipole)	
200 MHz	100	96	103	—	—	
300 MHz	106	102	106	47	—	
400 MHz	94	59	65	42	—	
500 MHz	82	90+	84	64	—	
Conic antennas						
300 MHz	—	109	104	—	—	
400 MHz	—	89	89	—	—	
500 MHz	—	105	120	—	—	
800 MHz	104+	—	106	—	—	
1000 MHz	102+	—	104	—	56 (dipole)	
Microwave						
-horn antennas						
2 GHz	55	53+	59	—	—	
2.5 GHz	83	82	87	—	72	
3 GHz	83	82	87	—	—	
4 GHz	83	81	86	—	—	
5 GHz	66	75	70	59	—	
6 GHz	64	73	78	—	—	
8 GHz	75	70	75	—	—	
10 GHz	65	62	65	60+	60+	

*Sample 1 = butt seam, 3M Type 1170 tape; 2 = butt seam, 3M Type 1267 tape; 3 = overlap seam, 3M Type 1267 tape; 4 = 4 ft 6 in. by 2 ft 6 in. sheet with no seam.

**Point N on test structure - horizontal seam.

***At 100 kHz.

3. The total cost for the installed shielding is low (about \$2/sq ft).

4. The material is already used for much construction.

It should be noted that this structure was constructed in the laboratory under fairly close supervision. As with conventional shielded construction, quality control would be a serious consideration for any field application of this technology.

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