EM Shielding Effectiveness of Low-cost Architectural Shielding Materials

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With proper construction techniques, architectural shielding can be achieved with minimal cost using common construction materials.

INTRODUCTION

Traditional shielded room construction such as the modular "sandwich" panel of steel sheet and particle board, although very effective for small and moderate-sized shielded rooms, is neither practical nor cost-effective for typical architectural shielding applications.

The modular or continuous welded type of construction typically provide over 100-dB shielding from 10 kHz to 10 GHz. The requirement for architectural shielding, on the other hand, rarely exceeds 60-dB attenuation, and the frequency is typically limited to 1 GHz. The reasons for this are obvious. First, due to the number of penetrations that are required in architectural shielding and the restrictions due to safety code requirements, such as handicapped access doors and quick release emergency doors, it is impractical and virtually impossible to achieve better than 60-dB effectiveness. Second, in most cases this level of shielding effectiveness is simply not required.

Consideration for architectural shielding should therefore be made on a case-by-case basis. The basic factor that must first be considered in determining the required shielding is the threat (i.e., the signal or signals that must be attenuated). Often, the shielding required may turn out to be much less than what is specified for shielding enclosure standards. The shielding required may be further reduced due to physical conditions or physical security zoning. In some cases the required shielding effectiveness may be achieved at very minimum cost using common low-cost shielding materials. This article presents shielding effectiveness measurements of common low-cost materials that can be used in providing required architectural shielding.

SHIELDING MATERIALS

Typical materials commonly used for shielding are copper, hot or cold rolled steel, galvanized steel, aluminum, and brass or bronze. These materials are traditionally used to construct large "boxes," or shielded rooms, but the cost for most of these materials and construction is prohibitive when applied to large facilities. Screening materials commonly used in industry for somewhat lower performance requirements are made from copper or bronze. Another alternative is stainless steel, which reduces material cost, but traditional construction practices still make it expensive to implement. The most cost-effective approach to architectural shielding is to utilize common, low-cost materials that have inherent shielding properties and can be applied as an integral part of the building construction using industry-wide construction practices.

Recent additions to the list of suitable shielding materials are conductive fabrics, copper and aluminum foils, and conductive coatings or thin films. The materials commonly used for conductive coatings are copper, nickel, aluminum, zinc, and silver. These conductive coatings are applied by spray painting, electroless plating (a chemical reduction process), or arc/flame spray techniques. The coatings can be applied in different combinations or as one material. These coatings are not self-supporting and require a host material such as plastic, wood, or fabric.

On the basis of performance, all these materials may be suitable for architectural shielding. Other criteria, however, should be taken into consideration. These include constructibility, durability, and material and construction costs. Conductive coatings, for example, will not meet most of these criteria. The materials listed below, although not inclusive, were selected for evaluation because they represent the most common materials that can be used for architectural shielding applications. Some of these materials were combined and were also tested as composites.

The following samples were tested for their shielding properties:

1. #2 square mesh wire cloth, 1/2″ x 1/2″ squares, 0.035″ diameter steel wire, 86.5% porosity (open area).
2. #4 square mesh wire cloth, 1/4″ x 1/4″ squares, 0.025″ diameter steel wire, 81.0% porosity.
3. 18 x 16 aluminum screen, 0.011″ diameter wire, 74.4% porosity.
4. 18 x 14 bright bronze screen, 0.011″ diameter wire, 87% porosity.

*See advertisement on page 246.

5. Chicken wire grid, 1″ openings, #20 gauge galvanized poultry netting.
6. Common construction rebar, 0.5″ diameter square pattern spaced on 9″ centers.
7. Standard metal stud wall frames, studs 16″ apart.
8. 5/8″ thick Sheetrock with 0.0015″ thickness aluminum foil backing.
9. Conductive fabric, Z-Cloth (manufactured by Zippertubing Company) sheer shield, 18% copper black sheer, 2 ohms/square: two pieces of fabric material sewn together.
10. Conductive fabric, Z-Cloth (manufactured by Zippertubing Company), 30% copper glossy, 0.05 ohms/square: two pieces of fabric material sewn together.
11. Conductive fabric (SAF "N" Shield, part number 8000-861): two pieces of fabric material overlapped and taped together.
12. Expanded ferrous metal, flat rib lathe, 3/16″L x 1/2″W slots spaced 3/16″, with an additional solid 1/2″ strip every 1.25″ intervals.
13. Expanded ferrous metal, diamond mesh, 1/2″ x 1/4″ openings.
14. Two #24 gauge (70″ x 30″ panels) galvanized solid steel sheets mounted over stud frame: metal pieces overlapped 6″ along vertical center of test aperture and screwed together with two rows of sheet metal screws at 6″ staggered spacing at 4″ apart.
15. Four #18 gauge (35″ x 15″ panels) galvanized solid steel sheets mounted over stud frame: four metal pieces were connected with tight-fitting steel S-clips along the vertical and horizontal center of the test aperture.
16. Samples #3 (aluminum screen) and #8 (aluminum backed Sheetrock) combined as a composite. Horizontal seam of Sheetrock along center of aperture taped over with 2″–wide nonconductive adhesive aluminum tape; vertical seam of screen overlapped 2″ and screwed to the support stud on 12″ center.

TEST SETUP AND PROCEDURES

The shielding effectiveness (SE) tests were conducted by mounting the test samples on the test aperture which is located on the side wall of a modular 100-dB shielded enclosure. The enclosure is a standard two-sided 8′ x 4′ panel constructed of two layers of 24-gauge galvanized steel with overall inside dimensions of 180″L x 146″W x 96″H. The wall opening was 6′H x 4′W while the actual test aperture (with the mounting frame installed) was 64.25″H x 40.25″W. All the test samples were cut to fit the test aperture and were mounted on the metal frame located inside the enclosure (Figure 1). Screw fasteners (1/4-20) spaced 3″ apart were used to mount the test sample onto the aperture.

In order to minimize the impedance across the mounting perimeter joints, care was taken to ensure adequate bonding to the mating surfaces between the test sample and the test chamber. Prior to installation, the mount-

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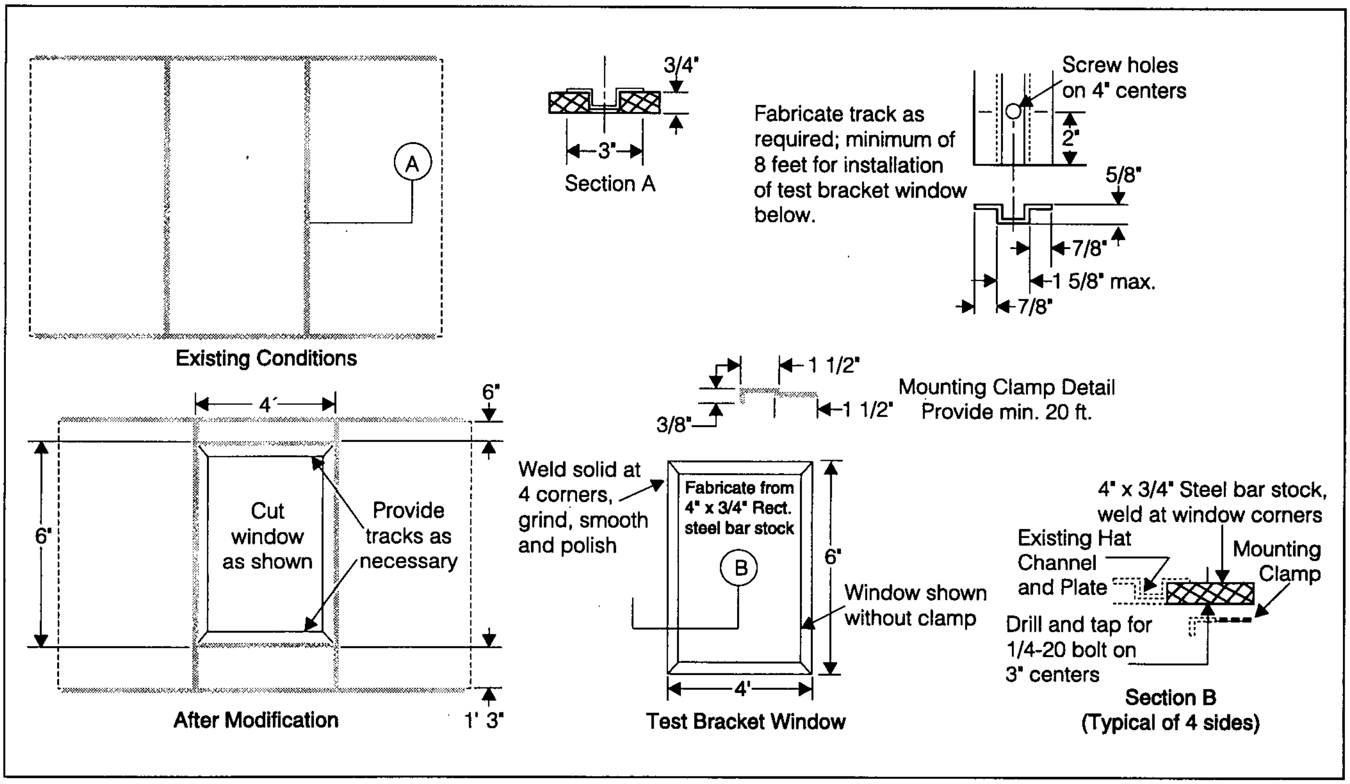

***Figure 1**. Chamber Modifications to Create Test Aperture.*

ing surfaces of the test sample and the test aperture perimeter were cleaned.

Special precautions were taken with non-uniform test samples (e.g., rebar and lathe materials) to ensure proper contact to the test chamber wall. Smooth surface materials (e.g., foils and solids) made the best joints, and rough materials such as the rebar made the worst. In each case, however, an attempt was made to accomplish the best possible contact at the perimeter joints in order to evaluate the performance of the material itself while minimizing frame perimeter joint influence.

In architectural shielding, joints or seams are major contributing factors in the shielding performance. Poor joints can cause buildings to become "leaky" due to changes in the impedance across the joints which occur regardless of the effectiveness of the shield material. In order to determine the effects of the joints or seams on the shielding performance, typical seam designs were tested on some materials.

Testing was performed by following procedures similar to those outlined in MIL-STD-285 and NSA 65-6, with some modifications as follows:

- Biconical and log-periodic antennas replaced the dipole antennas for E-field and plane wave measurements.
- The upper frequency range was limited to 1 GHz instead of the 10 GHz specified in the referenced standards.
- Swept frequency measurements were made in the frequency range of 30 to 1000 MHz in lieu of discrete frequencies specified in the referenced standards.
- The antenna-to-shield distance for the E-field and plane wave measurements was maintained at a 1-meter distance from the wall aperture for both receive and transmit antennas. For H-field measurements, the transmit and receive loop antenna distance from the wall was 12 inches.

The SE measurements were obtained by conducting reference tests and panel tests. The reference signal was measured with the transmitting antenna radiating a continuous wave (CW) signal into the receiving antenna directly across the test aperture without the test sample installed (Figure 2a). (This signal is the maximum that the receiver will register at a particular power level and specific antenna spacing.) Then, once the test sample was in place on the shielded enclosure aperture, and without changing any of the equipment settings and antenna locations (Figure 2b), the measurements were repeated. The difference between the reference signal level measured through the aperture without the test sample installed and the signal level obtained with the test sample installed is the shielding effectiveness of the material. The SE, therefore, is expressed as follows:

$$SE = S\ (\text{reference}) - S\ (\text{sample})$$

For consistency, all SE tests were performed by the same person and the test setup was verified periodically by conducting baseline measurements of the measurement system sensitivity and dynamic range.

MATERIAL SHIELDING EFFECTIVENESS

The shielding effectiveness test data for the material samples are presented in Table 1. In the Table, the (>) sign indicates readings that exceeded the dynamic range of the test equipment. This means that with the test sample mounted, there was no detectable signal at those frequencies. Therefore, the recorded level is actually the value

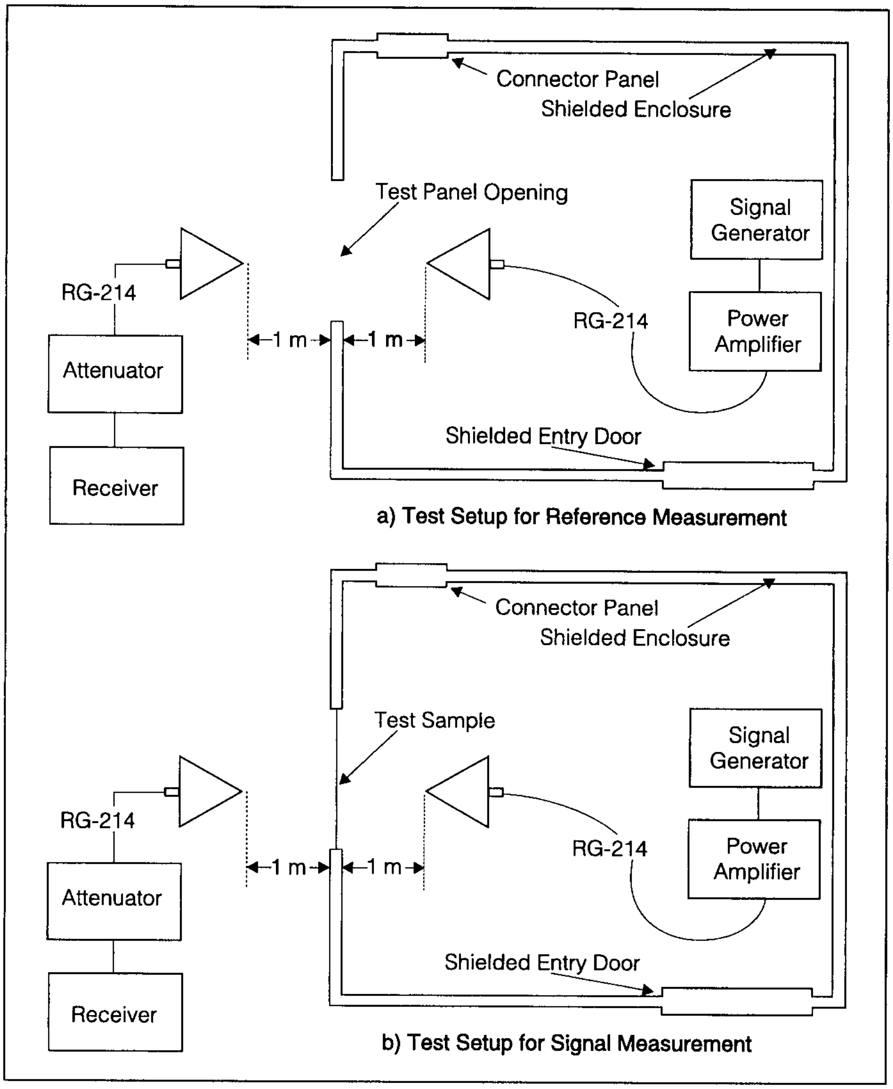

Figure 2. Test Setup: E-Field and Plane Wave.

of the ambient noise level of the receiver. These values of the dynamic range varied daily somewhat due to changes in ambient noise, receiver sensitivity, and transmitted power output levels.

In general, SE in the magnetic field region increases with bulk of material, while in the plane wave region, seams, gaps, and penetrations decrease shielding. The results in Table 1 clearly demonstrate this when comparing the solid materials (Items #14 and #15) with the screen or fabric materials. All materials showed a degradation in shielding performance typically above 400 MHz, which is attributed to either leakage through seams or penetration through material hole openings.

Materials #14 and #15, for example, are basically identical, but the construction technique varied: on #14 the seam construction consisted of 6″ overlap and was held together with screws, while on #15, approximately 2-inch wide S-clips were used to connect the metal pieces together. Clearly this case demonstrates that the construction technique for #14 is superior, but it is probably more expensive to implement.

Table 1 also depicts the shielding requirements of the NSA 73-2A[1] specification for comparison with the shielding characteristics of the materials that were tested. This is an old document that has been replaced by the new document, NSA 89-02, which eliminated the H-field requirement. This in itself has far-reaching implications, as the selection of shielding materials can be vastly expanded. For example, of the fifteen individual materials presented in Table 1, the majority of the materials would be acceptable if there were no H-field shielding requirements. Even the "chicken wire" (Item #5 in the table), which would add very little to the overall cost of a new building construction, comes close to meeting this shielding requirement.

Several of the individual materials were combined and tested as composites. Results of the composites showed a definite improvement in shielding effectiveness as expected. One of the composites was the aluminum screen sample together with the aluminum backed Sheetrock sample (see Item #16 in Table 1). Even with typical construction techniques that were implemented on this test sample (i.e., taped aluminum Sheetrock seams and overlapped aluminum screen seams) over 60-dB shielding effectiveness was achieved for E-field and plane waves up to 1 GHz.

Another material that was not evaluated here but can play a significant role in architectural shielding is common "earth." Ground soil has shielding properties that can be taken into consideration in designing shielded facilities. These shielding properties can be used to an advantage for underground enclosures, for buildings where the floors are recessed into the earth, and in combinations of earth and metal screens. The electrical properties that define soil are conductivity and dielectric constant, both of which vary with frequency. Damp, sultry soil provides the best attenuation and dry, sandy soil provides the least.

Another factor on the shielding performance of earth soil is the polarization of the E-field. Polarization is a vector quantity and refers to the relative orientation of the E-field to the earth surface: horizontal means the E-field vector is parallel and vertical means the E-field vector is perpendicular to the surface of the earth. In

Field	Frequency	NSA 73-2A[1]	Shielding Effectiveness of Test Samples (dB)															
		SE (dB)	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12	#13	#14	#15	#16
H	1 kHz	10	4	1	0	4	1	3	2	1	0	0	0	7	4	20	33	4
H	10 kHz	20	13	13	8	17	6	6	3	12	0	1	1	18	13	53	49	18
H	100 kHz	30	16	25	23	38	11	8	4	22	2	10	1	27	22	63	60	34
H	1 MHz	40	20	39	35	51	18	9	5	51	28	29	8	37	32	79	78	53
E	10 kHz	50	>41	>41	>47	>51	>44	15	14	>50	>51	>50	>50	>52	>50	>50	>50	>50
E	100 kHz	50	53	58	>54	58	48	15	15	>80	64	66	58	72	52	>80	78	>80
E	1 MHz	50	59	67	80	78	44	16	15	>80	68	>80	63	58	60	>80	78	>80
E	10 MHz	50	41	50	77	70	35	16	14	>90	52	77	45	70	52	>90	>90	>90
P	40 MHz	50	40	47	60	65	33	15	20	84	50	62	42	50	40	80	82	79
P	100 MHz	50	41	50	66	64	29	14	22	98	60	80	55	50	42	88	40	90
P	400 MHz	44	28	39	55	52	25	2	6	90	57	78	53	38	30	86	80	85
P	1 GHz	40	17	26	41	41	11	0	0	80	57	74	46	28	16	57	40	61

KEY:

#1 #2 Steel Mesh
#2 #4 Steel Mesh
#3 18x16 Aluminum Screen
#4 18x14 Bronze Screen
#5 Chicken Wire
#6 Rebar
#7 Metal Stud
#8 Aluminum Sheetrock
#9 Z-Cloth (18%)
#10 Z-Cloth (30%)
#11 SAF "N" SHIELD
#12 Expanded Metal
#13 Expanded Metal Diamond Mesh
#14 24 AWG Galvanized Steel Metal
#15 18 AWG Galvanized Steel Sheet
#16 Composite Aluminum Screen and Foil

***Table 1**. Shielding Effectiveness of Common Shielding Materials.*

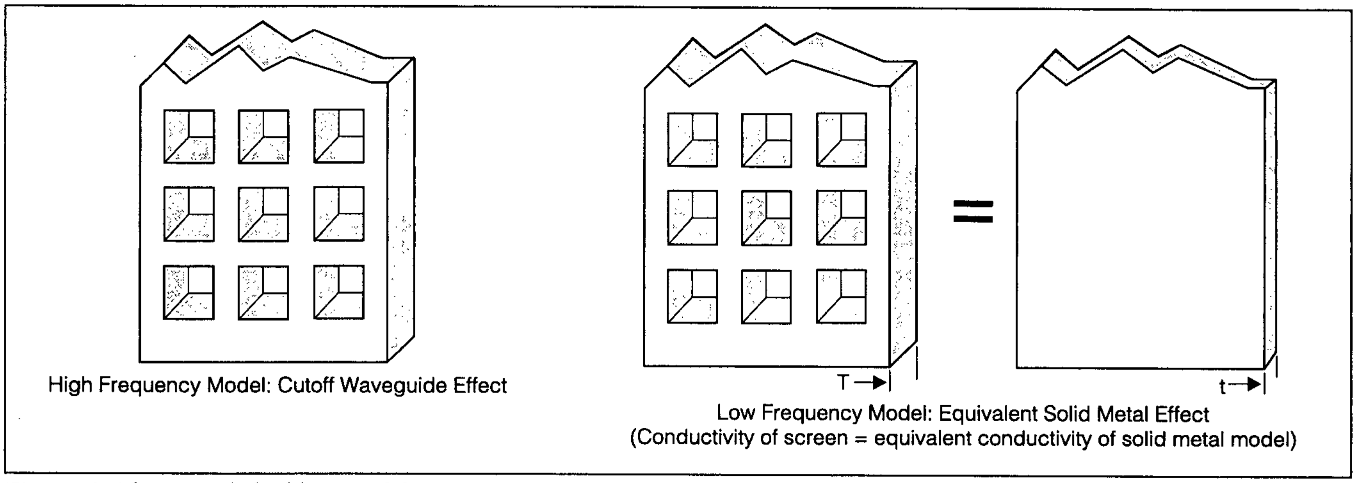

***Figure 3**. Theoretical Shielding Models.*

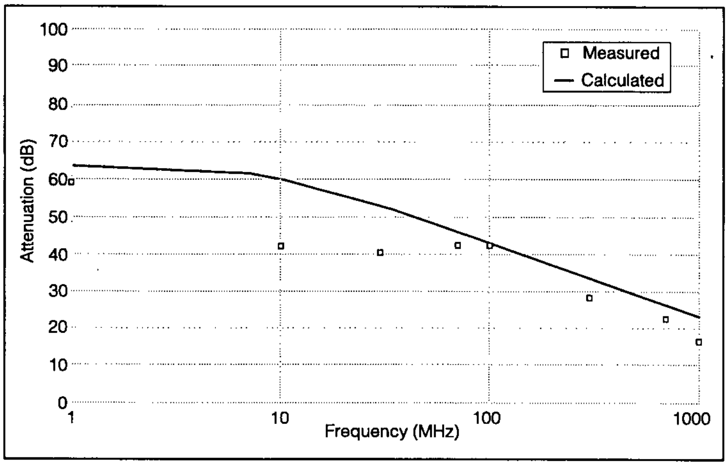

***Figure 4**. Shielding Effectiveness: #2 Steel Mesh.*

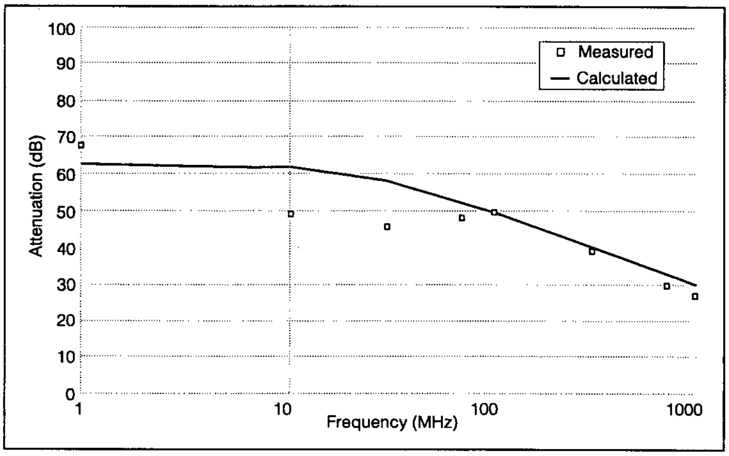

***Figure 5**. Shielding Effectiveness: #4 Steel Mesh.*

general, earth provides significant shielding at higher frequencies, but the shielding diminishes at lower frequencies.[2]

Combining earth with another low-cost shielding material (e.g., chicken wire), however, could enhance the shielding performance of a facility over a broad frequency range.

COMPARISON WITH THEORY

For comparison, theoretical calculations were conducted for some materials (i.e., screen/mesh type materials) that can be easily modeled and have minimum leakage from typical construction seams. For the theoretical calculations it was assumed that the shield material was an infinitely large sheet and was not affected by the test aperture or the orientation of the antenna. In the plane wave frequency range, the shielding was based on the finite thick cutoff waveguide model, and at low frequency the shielding was based on the solid metal skin depth theory (equivalent metal volume and conductivity were derived to analyze and calculate shielding effectiveness) (Figure 3).

Shielding effectiveness calculations were performed for five screening materials studied here. The calculated and measured values were plotted and presented in Figures 4 through 8. As shown in these figures, the measured values in general compare closely with the calculated values, which demonstrates confidence in the validity of the measurements.

CONCLUSIONS

This study demonstrates that proper use of common construction materials (i.e., rebar, chicken wire, metal studs, expanded metal lathe, and foil-backed Sheetrock) enhances the shielding effectiveness of a building by 10 to 40 dB. These materials add very little or essentially no additional cost to the building construction. Of all the materials studied here, solid steel sheets overlapped and screwed in place are the most expensive to implement. The material and construction technique shown here has been used successfully on several applications (new and retrofit constructions) to achieve 60-dB shielding effective-

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