LARGE SHIELDED ANECHOIC FACILITIES

Introduction

This article presents a discussion of the factors involved in defining, designing and provisioning a major shielded anechoic test facility, as envisioned for use in evaluating complex communications/electronics systems. Emphasis is placed on the importance of integrating and coordinating every facet of such a facility during criteria development, requirement definition and design phases. Achievement of desired function and operation, cost effectively, is highly dependent on careful analysis of the complex interrelationship of shielding, anechoic properties, brick-and-mortar, utilities, logistics and support functions. An a la carte approach to facility provisioning, like Topsy, can result in functional and fiscal difficulties, unrecognized until late in the project when only symptomatic treatment rather than cure remains a viable option.

A Definition of Facility Concept and Criteria

An ideal shielded anechoic facility can be defined as a volume of space sufficiently large to house the system under test; containing electromagnetic energy absorbing material designed to prevent reflected return of any signal generated within the test area, shielded to prevent intrusion of harmful interference and to contain all electronic intelligence generated within (for security as well as prevention of interference to external receptors), Structurally designed for seismic stability, environmentally controlled to specific temperature and humidity parameters, architecturally designed for optimum flow of people, equipment and services as well as aesthetic considerations, complete with support areas, adequate and flexible electrical power, fire protection, accessibility, and all this at minimum cost.

Shielding

For purposes of discussion, "high-performance" shielding will be assumed essential to the facility and arbitrarily defined as 100 dB attenuation from 10 KHz to 20 GHz. This would probably be minimum for a flexible and sophisticated facility located in the midst of multiple adjacent electronic operations.

Electromagnetic shielding for high performance is normally constructed either as bolt-up panels or seam-welded steel sheets. For a large facility, the welded approach offers advantages over bolted construction. Although initial cost might be higher, the shielding effectiveness will be maintained over long periods of time without degradation. Once installed and tested, welded shielding may be covered with microwave absorber or other finishes without concern for needing to periodically rework or tighten joints and seams. Also, attenuation levels greater than 100 db at frequencies higher than 1 GHz are very difficult if not impossible to obtain using bolt-up construction.

In either construction method, the penetrations must be given microscopic design scrutiny. Penetrations include all openings in the basic shielding, which permit access for personnel. C/E system equipment, electrical power, mission-related electronic signals, control wiring, air, water, fire-protection sensors and suppressors, antenna ports and so forth.

Shielding has two basic functions relating to any C/E installation; containment of electromagnetic energy and exclusion of external E/M energy.

Containment is needed either to prevent interference with other spectrum users or to satisfy security requirements or both. The maximum energy levels to be generated within the facility must be established as a function of frequency spectrum. Then the maximum tolerable energy levels outside the facility must be determined, also as a function of frequency. The difference between the two represents the minimum shielding effectiveness required for each portion of the frequency spectrum.

Similarly, exclusion requirements are determined by a reverse process of estimating the maximum tolerable internal energy levels and comparing those to the energy actually present or expected external to the facility. A spectrum measurement of ambient E/M energy is usually worthwhile to record early in the program.

The shielding effectiveness (attenuation) must exceed the greater of these comparisons for all frequency bands. As a matter of practical application, only the low and high extremes of the frequency spectrum need normally be considered, since shielding effectiveness declines at low frequencies for magnetic fields and at high frequencies for plane waves.

Further, low frequency magnetic field attenuation is primarily related to mass or thickness of the shield, whereas high frequency attenuation is determined by discontinuities in the shield, eg., joints, seams, accesses and penetrations.

Finally, a most important consideration in the design process is the test procedure to validate the shielding effectiveness. There is no way to assure a given attenuation without testing of the completed shielded structure, since installation technique is all-important and since most "leaks" are not visually apparent.

The difficulty with test procedures is that no comprehensive standard exists and, therefore, the user must write his own. MIL-STD-285, for example, was written more than 20 years ago and is applicable to small, modular shielded enclosures over a frequency range effectively limited to 150 KHz-400 MHz. Test procedures must be tailored individually to every major shielding project, especially where extended performance and frequency range is required. A series of trade-offs must be analyzed involving the number of test positions and number of frequencies within the specified spectrum versus the high cost of testing. For a large shielded structure, the cost of thoroughly testing every square foot of shielding is prohibitive. Thus, a judicious selection of test locations must be established. For example, a recent project, including a 50′ x 65′ x 50′ chamber and six adjacent shielded laboratories, totaling more than 25,000 square feet of high-performance shielding surface, required three weeks of test time. Forty positions for radiated testing were carefully selected to probe the areas most likely to fail the test, and ten frequencies were agreed upon between 10 KHz and 18 GHz. Emphasis was placed on those frequencies most critical to the project. Prior to radiated testing, every welded seam (and there were perhaps 2 miles of welds) was 100% probed with a "sniffer." This device, operating at about 100 KHz, generates small currents within the shielding. A highly sensitive probe detects anamolies present due to weld occlusions, poor binding, cracks, etc. When all detectable signals had been eliminated by repair, the radiated test was conducted. With this procedure, and by carefully specifying that multiple antenna orientations would be explored at each test location, the test engineer established a high probability that the shielding performance requirements were met, even though every square foot was not checked by radiated test. It should be obvious that the test engineer must be experienced in electromagnetic testing and able to interpret and analyze results.

Anechoic Material and Properties

Like the shielding design, the selection and placement of microwave absorber (anechoic material) is interrelated with the C/E system requirements, chamber configuration and geometry, frequency range, and electrical, mechanical and structural interfaces. The first determination to be made is maximum signal reflection levels. Simply put, for a given spectrum radiation from the C/E system, how much energy can be tolerated returning to the system with altered phase, polarization and direction characteristics? The ratio between initial and reflected energy, expressed in decibels, is the figure of merit, or performance, of the chamber.

The C/E system project designers must determine the levels at which reflected energy becomes significant to the system error budget.

The anechoic material design then must consider such diverse factors as frequency range, size and directivity of C/E system antennas, types of system measurements, contemplated, power levels, available space and available funds. Somewhere along the design path, a geometrical analysis must be made. From each and every transmitting antenna to each and every receiving antenna, there exist "x" paths involving one or more reflections from the anechoic material. The total anechoic surface area against which transmitted energy may be returned to a receiver by a single reflection is designated the specular region. All other surface areas require multiple reflections to return energy. The specular region, therefore, requires the highest performance absorber. Further, the angle at which the incident energy reaches the absorber must be calculated, since absorber performance is best at normal incidence. Figure 1 shows absorber reflection attenuation for varying angles of incidence as a function of thickness in terms of wavelength. The numbers are representative of pyramidal solid-foam material.

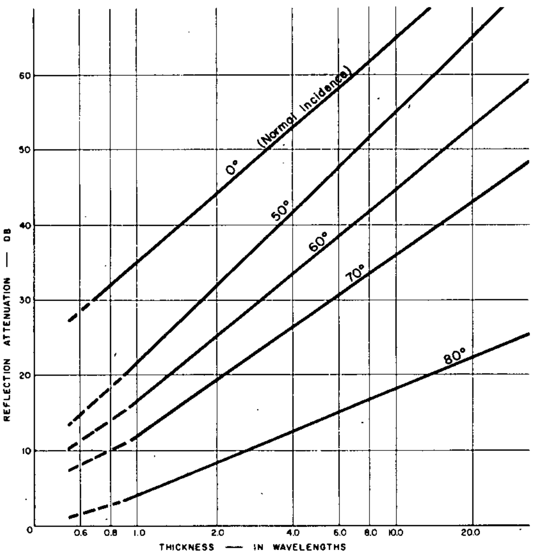

Figure 1
Reflection Attenuation vs. Absorber Thickness in Wavelengths and Angle off Normal

Similar curves are available from anechoic material suppliers for other types of absorber.

The approximate thickness of absorber material required and the total specular region surface area may thus be determined from analysis of frequency, geometry, antenna directivity, incident angles and maximum acceptable return energy levels. The remainder of the surface area (non-specular) may be covered with lesser performance material (thinner, different type, or both). Absorber manufacturers are normally happy to assist in this analysis and they are specialists at design optimization.

Other design considerations of significance to the C/E system user are polarization integrity and axial ratio. Polarization integrity refers to the ratio, in dB, of the co-polarized reflected signal to the cross-polarized reflected signal, in relation to the incident signal. This ratio should be greater than 20 dB for high performance absorber. Axial ratio refers to the ratio, in dB, of the reflected signal level using co-polarized antennas to the signal level as both antennas are synchronously rotated through 360 degrees. This ratio should be near unity, say less than 0.5 dB for high performance absorber.

Close coordination in the design process is necessary with the mechanical, electrical and structural designers. If temperature and humidity control is required, and it usually is, air must enter and exit the chamber without compromising the absorption characteristics, that is, air vents must be "hidden" from radiated energy. This also applies to all fire protection and electrical devices in the chamber, such as light fixtures, switches and controls, which obviously should be minimized.

Finally, and most importantly, the procedure for verifying chamber performance must be developed early in the design process, since different test procedures often yield different results. The "free-space VSWR" method is most commonly employed but with several significant variables. The probe antennas may be physically translated through the chamber to measure VSWR or swept-frequency equipment may be used with fixed antenna locations. The directivity of the test antennas should correspond to that of the C/E system antennas. The extent of test frequencies, antenna locations or traverses, and the number of different test antenna aximuths must be carefully evaluated, since test time is expensive. Some compromise is essential since one could spend months setting up, recording and analyzing test data from all conceivable angles, locations, and frequencies.

Brick and Mortar and Utilities

The term "brick and mortar" here refers to all building structure permanently in place, including floors, walls, ceilings, roof(s), stairways, elevator shafts, doorways, foundations, system support hardware and so forth. Utilities include equipment and material for provisioning of air, water, environmental controls, electrical power and lighting, signal and control equipment and wiring, communications (other than C/E system), restroom facilities and the like.

The key concept here is *integrated design* for optimum system operation. Once the facility is "cast in concrete" changes become very costly and inconveniences must usually be tolerated rather than tearing apart the facility.

The facility architect must choose with care his allocation of spaces to assure adequate access, smooth equipment and people "flow" during operation, flexibility and growth allowance, all of course with a heavy hand on the budget. Books have been written on architecture and its importance, yet this aspect is frequently overlooked or given short-shrift in the planning of a major system test facility. Perhaps we engineers become too engrossed in the elegant complexities of our system, yet we all have experienced the frustrating effects of poor layout.

The structural designer must not only arrange to carry all live and dead weight, including future growth, but in a system test facility he frequently must develop specifications for rigidity and seismic motion. Problem corrections of this nature after the walls are in place are usually inadequate.

Fire Detection and Protection

The complexities of fire protection within an anechoic facility are too numerous to explore in detail here. Briefly, however, here are some of the design considerations:

- Type of detection
- Fire retardant absorber or not
- Type of suppressant system
- Code compliance requirements

The fire protection designer must coordinate early and intimately with the C/E systems personnel, fire-safety people and the facility design staff to assure an installation compatible with functional and safety requirements.

Summary

Total system testing of complex communications/electronics installations frequently requires a "free-space" operating environment, which may be simulated by a shielded anechoic facility, often more cost-effectively than placing, operating and testing the complete system within its ultimate operational environment. Successful provisioning of such a facility is vitally dependent on comprehensive integration of all functional and operational aspects throughout the design process. From concept to completion, the interrelationships of system, shielding, anechoic properties, brick and mortar, utilities, logistics and support functions must be understood and analyzed, trade-offs performed and conflicts resolved. Only then will the facility be assured of adequate and versatile capability to achieve the desired objectives.

Properly designed and constructed, the shielded anechoic facility offers cost effective operation, energy conservation and pollution reduction as well as enhanced system reliability during critical operational environments. The operational reliability of complex C/E systems is not only related to major economic consequences, but most importantly, may involve human lives.

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