LARGE SHIELDED ANECHOIC FACILITIES

As communications/electronics (C/E) installations become increasingly sophisticated and complex, the need to operationally and functionally test the total system within its ultimate operating environment becomes paramount to system performance and reliability. Although components, racks, drawers and assemblies are meticulously tested and controlled by rigorous quality control procedures, the performance of the "whole" does not always equal the sum of its parts. Performance failure, impairment or alteration may be expected when the system is installed in its airborne, land-based, underwater, or ship-at-sea operational conditions.

The difficulty and cost of complete system testing under *actual* operating conditions, with the multitudinous variables involved, dictate the need for a more practical and cost effective method. The shielded anechoic facility provides this capability by simulating the "free space" conditions of a realistic electromagnetic environment, permitting convenient and variable control of all desired parameters, while maintaining the efficient logistics of a laboratory.

A thorough approach to the concept and design of the facility is needed to assure compliance with the C/E system user's needs and objectives.

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.

This concept encompasses a complete functional facility; a controlled environment ready to accommodate the test instrumentation as well as the system to be tested.

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 re-work 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.

Shielding has two basic functions relating to any C/E installation; containment of electromagnetic energy and exclusion of external E/M energy. The shielding performance requirements, to be realistic, i.e., cost-effective, must be determined from the *extent* to which the above functions are imperative for satisfactory C/E system operation. The approach to shielding requirement definition, therefore, involves investigation and analysis of both containment and exclusion functions.

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 150KHz - 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 positons 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 10KHz and 18GHz. 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 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.

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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.

The importance of this type of analysis is felt most significantly in the pocketbook. The cost of absorber is high, ranging from perhaps $8/sq. ft. for 1 foot thick pyramidal solid-foam absorber to roughly $20/sq. ft. for 4' thick material. Four-foot thick absorber is about 2½ times as heavy as 1' material, a significant cost factor in the structural design of the chamber.

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 20db 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.

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.

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.

The mechanical engineering function is more well known and he too must be involved early in the design process or (and this happens all too often) he ends up attempting to work a four-foot air duct into a two-foot space, or using closets for air handling equipment because no one realized that it takes 50 tons of air conditioning to remove that big heat load and maintain specified temperature control.

The electrical designer must achieve cost effective distribution of all electrical power and controls, also allowing for future growth. Experience has shown that system engineers often underestimate power requirements. Power quality, lighting design, electrical filters, power factor correction and D.C. power distribution requirements must all be identified and integrated into the facility design. A grounding scheme, suitable for power, signal, safety and electronic purposes must be designed and incorporated into the facility.

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