Building a semi-anechoic chamber: An overview

A number of factors influence the electromagnetic performance and the usability of a semi-anechoic chamber.

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As EMC considerations have become increasingly important in the product development cycle, a large number of engineering departments are starting to look into building a test facility of their own. The measurement of radiated emissions from a product is the most demanding as far as test location and instrumentation are concerned. Radiated emissions measurements require an open area test site (OATS) or a semi-anechoic chamber (SAC). For most other types of EMC measurements, a test bench in a shielded room suffices, while for radiated immunity measurements, a fully anechoic chamber is used.

This article focuses on test site design issues for radiated emissions measurement facilities. The OATS is the most prevalent emissions test site but, due to increasing electromagnetic "pollution" and the dependence of the OATS on weather, the SAC has become an economically viable alternative. This article is an introduction to the technical aspects of designing and building a SAC for radiated emissions measurements per commercial EMC test standards.

SHIELDED ROOM

A SAC consists of a shielded room lined with absorber materials. The shielded room isolates the interior volume from the outside electromagnetic environment. The electromagnetic spectrum in the surrounding area contains signals from TV and radio broadcasting stations, personal communication devices, noise originating from a manufacturing environment and so on. The function of the shielded room is to reduce disturbances to levels considerably below the fields an EUT would produce inside the chamber.

Two basic construction methods are used for building a shielded room for SAC applications: modular and welded. A modular enclosure is built out of panels and a framework that clamps the panels together. The panels are large plywood boards laminated on both sides with thin zinc-plated or galvanized steel sheets. A clamping system mounts these panels together and ensures electrical continuity between the panels. Gaskets and high-frequency absorber materials are sometimes used to enhance the shielding performance. Even though most manufacturers use the same shielding system concept, the individual differences in implementation results in mutual incompatibilities between the systems on the market.

Welded shielding systems consist of large sheets of steel or copper welded together to form a tight RF seal. It is a very labor-intensive technique. The advantages of a welded enclosure are durability and higher shielding performance due to the elimination of leakage at the seams. A common disadvantage is the higher cost of installation.

The ground plane is an essential part in the electromagnetic operation of a SAC. During emissions measurements, some EUT emissions are reflected by the ground plane and measured by the scanning receive antenna, emulating the situation that exists in an office. To emulate a perfect ground plane, the panels in the floor need to be assembled with electrical continuity and with as little surface height variation as possible. This is most easily achieved by building a raised floor, which is essentially a false floor made out of the same panels as the walls and the ceiling. The measurement and control cables, the power lines and the turntable hardware are located underneath the raised floor. Raised floors are typically 30 cm (1 ft) to 60 cm (2 ft) high, depending on the turntable hardware. To achieve the desired electrical continuity over the entire ground plane, the conducting top of the turntable needs to be continuous with the surrounding ground plane. A ground ring with equidistantly-spaced contacts is usually employed.

For operational purposes, penetrations into the shielded room are required. These penetrations need to be carefully selected and installed to maintain shielding integrity. For a typical SAC, several types of penetrations can be found. These are described here.

ACCESS DOOR
At least one door is required. The most common types feature a recessed contact mechanism (RCM), in which a knife edge on the door rests in a pocket on the frame lined with fingerstock to maintain electrical continuity, or a compression seal, in which the electrical contact between the door and the frame is enforced through compression. The most popular and least expensive type is the swing door with one or two door leaves. When absorber material is mounted on one or both leaves of a swing door system, the clear space in the door opening may be reduced considerably. To eliminate this drawback, a sliding door is an option; it offers greater convenience and accessibility at a premium price.

WAVEGUIDE VENTS
For air-conditioning and cooling purposes, airflow is enabled through honeycomb vents that operate as waveguides below cut-off with very low drop in air pressure. Most waveguide vents are designed for operation up to 10 GHz. For higher frequencies, i.e., up to 40 GHz, more expensive designs are available.

POWER
Power line filters mounted on the outside of the shield are used to filter power for the turntable and antenna mast as well as the EUT and associated equipment inside the shielded room. Filters are available for high amperage and up to very high voltages (400 V) for both DC and AC. Applicable standards are MIL-STD-220A for electrical performance verification and UL1283 for operational safety.

LIGHTS
Incandescent lights can be mounted inside a chamber, but usually high-hat light fixtures mounted in the ceiling are used for higher yield and reduced interference with the absorber treatment.

CONNECTOR PANEL
This panel contains the RF connectors for emission measurements, EUT signal connectors and filters, fire suppression control cables and a fiber optic feed-through, which is a waveguide below cut-off. Fiber optic control cables are used in modern turntable, antenna mast and CCTV systems. Other types of penetrations include feed-through pipes for liquid cooling purposes and air intake and exhaust systems for engines.

SHIELDING EFFECTIVENESS
The performance of a shielded room is specified as shielding effectiveness (SE). This is equivalent to the attenuation imposed on a signal by the presence of the shielding. A widely-used standard in specifying SE is NSA 65-6 (Table 1). The attenuation levels specified in this standard are sufficient for almost all applications and exceed the requirements for commercial EMC testing. For EMC applications, SE is typically specified at just one or a few frequencies. At 1 GHz, the frequency specified most often, modular shielded rooms typically exhibit 100 dB of shielding effectiveness, whereas welded shielded rooms can achieve as high as 120 dB.

Prior to absorber installation, a test is performed to verify that the completed shielded room meets the specified shielding levels. Next to NSA 65-6, the two most

Frequency	Shielding Effectiveness	Type of Field
1 kHz	23 dB	Magnetic
	70 dB	Electric
10 kHz	56 dB	Magnetic
	100 dB	Electric
100 kHz	90 dB	Magnetic
	100 dB	Electric
1 MHz	100 dB	Magnetic
	100 dB	Electric
10 MHz	100 dB	Electric
100 MHz	100 dB	Plane wave
400 MHz	100 dB	Plane wave
1 GHz	100 dB	Plane wave
10 GHz	100 dB	Microwave

Table 1. NSA 65-6 SE performance requirements.

widely-used standards describing shield test methods are MIL-STD-285 and IEEE 299-1997. The IEEE 299-1997 can be regarded as a technically more elaborate and extensive successor to MIL-STD-285, which was written in 1956. Both address the need for a test plan and describe critical test locations (panel seams, doors, and all other penetrations). SE is most difficult to achieve around the penetrations, so extra care should be taken to ensure the integrity of the shield around these points.

ELECTROMAGNETIC ABSORBERS

Electromagnetic absorbers are mounted on the walls and the ceiling of the shielded room to reduce electromagnetic reflections from these surfaces. An absorber absorbs electromagnetic radiation from all incident angles and converts a portion of the electromagnetic energy to heat. The remainder is reflected back into the chamber, potentially interfering with the measurement.

There are two widely used types of broadband electromagnetic absorbers for SAC applications, distinguished by the operational mechanism employed: ferrite, which is a magnetic absorber, and carbon-loaded foam, which is an electric absorber. Hybrid absorbers combine both types. There are some more exotic absorber designs but these are not widely used. Table 2 shows a number of typical absorber designs and their attributes. Foam-only absorbers are mostly pyramidal in shape, whereas the foam portion of a hybrid often exhibits a wedge shape. Ferrite tiles are commonly mounted on a dielectric layer (often plywood) which enhances the tile performance at the high-frequency end.

The design of a broadband EMC absorber is a very involved process. Trade-offs need to be made between low-frequency performance, high-frequency performance, sizing and manufacturing cost. Usually, manufacturers resort to a cut-and-try process in which absorbers are designed, built and tested in an iterative process to produce a working design. To speed up the design process and make it more cost-effective, some manufacturers have implemented a computer-aided numerical design process. When using computer-aided design, the building and measuring of the absorber prototypes is not done until after an extensive design stage in which computers are used to optimize a design. If accurate models are used, and the bulk material parameters of the absorber materials are well characterized, a numerical design process can produce superior absorbers either through the increased number of design iterations or through computer-aided mathematical optimization.

Most manufacturers specify absorber performance for normal incidence only. This is typically an optimum number, and reflects the attenuation of the absorber for waves that are directly perpendicular to the surface of the shield. Most absorber materials are designed for best performance at normal incidence. However, in a SAC the off-angle performance is more important than the normal-incidence performance. Absorber performance degrades considerably with increased angle of incidence, which is an important consideration in designing a chamber.

In a SAC, absorber performance is not only determined by the properties of the basic absorber design. The quality of the absorber installation plays a major role. Especially ferrites, whether used in a hybrid absorber design or not, are subject to performance degradation due to installation. As a result of the limited size of the individual tiles, small air gaps exist in between two adjacent tiles. These gaps act as magnetic resistors, reducing the continuity of the flux between the tiles, and hence, reducing absorption effectiveness. After careful installation, the individual gaps should be less than a few tenths of a millimeter wide. Large air gaps result in a substantial reduction of attenuation of the incident waves, therefore allowing more reflection from that particular section of the wall. This so-called gap effect

	Pyramidal Foam	Ferrite Tile	Ferrite Grid Tile	Foam-tile Hybrid
Base size	60 cm x 60 cm	10 cm x 10 cm (or larger)	10 cm x 10 cm	60 cm x 60 cm
Depth	60 cm up to 2.5 m	5 mm up to 1 cm (up to 2 cm with dielectric layer)	1.5 cm up to 2.5 cm	40 cm up to 1.5 m
Relative off-angle performance degradation	Low to medium	High	Medium	Medium
Installation sensitivity	Low	High (tile gap)	Moderate (tile gap)	High (tile gap)
Highest operational frequency	> 40 GHz	1 GHz	3 GHz	> 40 GHz

Table 2. Widely used broadband EMC absorbers.*

**Less common configurations like multi-layer ferrite tiles, hollow foam absorbers, surface impedance absorbers, grid tile hybrids, etc., have not been included. All numbers are typical values and will vary from manufacturer to manufacturer.*

should be taken into consideration during the absorber and chamber design process, since a small gap is always encountered in a practical installation. Even a small gap reduces the theoretical performance of a ferrite tile or grid tile to a substantially lower level than the theoretical value.

Measurement of the absorbers is important to verify their performance. Since low frequency performance is critical in a SAC, absorber performance should be verified down to 30 MHz. In a coaxial waveguide, frequencies from 150 MHz down to 30 MHz and lower can be measured. For higher frequencies, other types of waveguides (100 MHz and up) and free-space measurement setups (higher than 800 MHz) are used.

CHAMBER DESIGN TECHNIQUES

In order to build a SAC that complies with the site attenuation requirements, the variation of the measured normalized site attenuation should be less than 4 dB from the theoretical value of a perfect OATS (ANSI C63.4-1992). This requirement can be challenging to meet, especially at the low end of the frequency range where the size of the absorber is electrically small and the electromagnetic performance is worse. Numerical simulations are required to verify and optimize a chamber design before it is built. A manufacturer can opt to use a cut-and-try method instead, but that will result in a time-consuming and costly process. Numerical simulation, combined with correlation of simulated data with the measured performance of chambers that have already been built, is the most important design tool available to chamber designers today.

At the mid- and high-end of the operational frequency range, the electromagnetic energy incident on the absorbers can be thought of as plane waves. In these cases, a ray-tracing approach to the modeling of the chamber performance will produce a reliable prediction of the chamber performance. For low frequencies, however, the assumption of plane waves incident on the absorber is no longer valid.

Two types of methods are used for simulating the performance of a SAC in the low-frequency range: a modified version of the high-frequency ray-tracing technique and solution of Maxwell's equations in 3D for the shielded room lined with absorbers.

In the case of the ray-tracing model, multiple reflections need to be taken into account because of the size of the chamber and the low-frequency absorber performance. Since measured data of absorber performance at low frequencies is difficult to obtain at angles other than normal incidence, numerically simulated data is often used. Care must be taken that this simulated absorber performance data is closely correlated to the measured data at normal incidence to avoid systematic errors in the chamber simulation model. In the multiple-order ray-tracing model, the chamber simulations correlate better with measured chamber performance data for 10-m chamber designs than for 3 m, due to the larger electrical dimensions of the room and better low-frequency performance of the larger absorbers used in 10-m chambers.

Solving Maxwell's equations in 3D is a computationally intensive task. Usually, a finite element or finite difference technique is used. These methods divide the solution space into discrete elements for which Maxwell's equations are solved. For low frequencies, a low-frequency layered approximation of the absorber can be used to minimize the computational effort. However, the accuracy of these techniques depends highly on the implementation of the absorber model used and measured absorber performance and bulk parameter data. In theory, this approach will be more accurate than ray-tracing and produce more reliable results. However, absorber installation and chamber qualification measurement issues introduce an uncertainty in the implementation which limits the de-facto design accuracy to that of the multiple-order ray-tracing technique.

The multiple-order reflection ray-tracing method has the advantage that it is very efficient computationally. Application of this technique allows the designer to evaluate a large number of design alternatives and to choose the optimum design. An experienced design engineer can interpret the results such that chamber performance can be guaranteed regardless of the inherent limitations of the simulation technique (Figure 1).

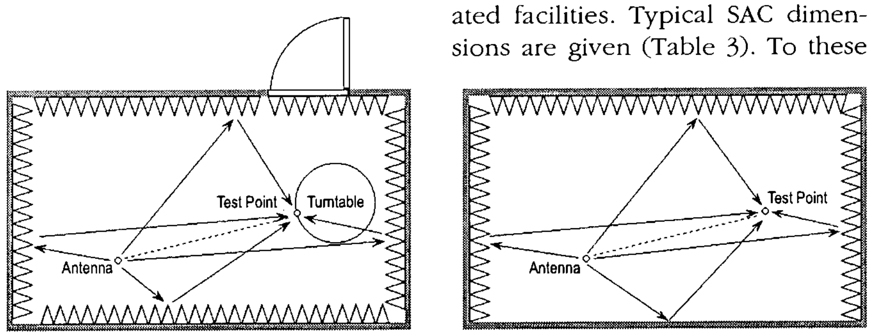

Figure 1. First-order ray tracing.

BUILDING A FACILITY

In previous sections, an overview has been given of the major issues involved in designing a SAC: shielding, absorber materials and chamber modeling. This section focuses on integrating these aspects.

When building an EMC test facility, a substantial amount of space is required in the parent building to house the chamber and the associated facilities. Typical SAC dimensions are given (Table 3). To these numbers, space needs to be added for fire protection, raised floor and structural steel for reinforcement of the shielding to carry the weight of the absorber materials and provide structural integrity.

After completion of the SAC and the associated facilities, performance verification validates the chamber as a viable alternative to an ideal OATS. In commercial EMC applications, the performance of the SAC is tested per the alternative site method described in ANSI C63.4-1992, CISPR 22 or similar standards. These test procedures verify the chamber performance by comparing the site attenuation of the chamber with that of an ideal OATS. The site attenuation is measured for a quiet zone centered over the turntable, encompassing the EUT per the volumetric method described in the standard for alternative sites. This procedure establishes a measurement range for radiated emissions EUT measurements. After the initial qualification and acceptance, the operation of the SAC should be verified on an annual basis.

The electromagnetic performance of a SAC depends on a number of factors. Absorber installation is one of those factors. The ferrite tile gap effect can be particularly noticeable around a door or other penetration in the shield, where the absorber treatment is not continuous. Care must be taken to locate doors, penetration panels, lights and vents in locations where the discontinuity in the absorber treatment will not cause absorber performance problems or where the presence of untreated reflective materials will not cause spurious reflections of EUT emissions. Furthermore, the ground plane needs to be very flat and electrically continuous around the turntable. Finally, antenna factors play a critical role when qualifying a chamber. Absorber drooping, which may occur in some deep foam absorbers over time, has little influence on performance, but definitely has a negative cosmetic effect.

A very important issue when selecting an absorber/chamber manufacturer is quality control. Since absorber performance is the most important factor in the electromagnetic performance of a SAC, care should be taken that the manufacturer can guarantee the consistency in absorber performance for each batch of absorbers produced in the factory. A quality control program, in which absorbers in every batch are checked for electromagnetic performance in the critical low frequency range is highly recommended. And since chamber performance depends on the quality of the absorber installation, experience in quality control during installation is mandatory.

As a rule, an EMC test facility embodies more than just a SAC. Depending on the budget and the test requirements, shielded control and test rooms can be added, as can a pre-compliance debugging SAC or an immunity-only fully anechoic chamber. As a minimum, space is required for measurement test setup and test personnel.

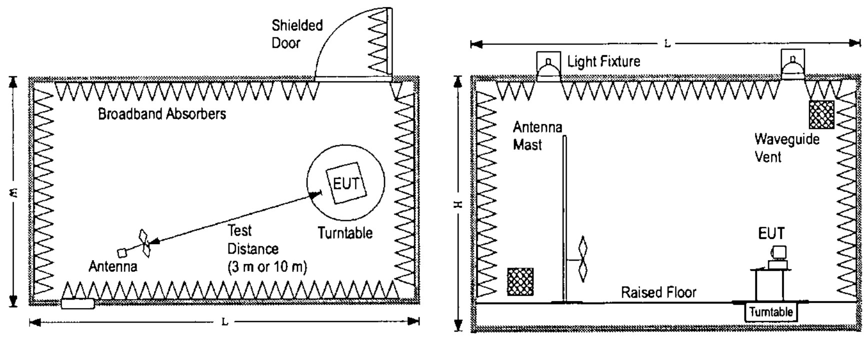

Figure 2. Typical chamber layout.

	Pre-compliance	3-meter Test Distance	10-meter Test Distance
Height	3 m (10 ft)	5.5 m (18 ft)	8.5 m (28 ft)
Width	3 m (10 ft)	6 m (20 ft)*	12 m (39 ft)*
Length	6.7 m (23 ft)	9 m (30 ft)*	19 m (62 ft)*
Absorber treatment	Ferrite tile, grid tile, foam (± 60 cm deep)	Hybrid (± 40 cm deep), grid tile, foam (± 1 m deep)	Hybrid (± 1 m deep), foam (± 2 m deep)
Typical performance	± 6 dB from theoretical normalized site attenuation (TNSA), pre-compliant	± 4 dB from TNSA regular, ± 3 dB for a high-performance chamber	± 4 dB from TNSA regular, ± 3 dB for a high-performance chamber
Cost	Around US $100 K	US $350 K - US $500 K	US $850 K - US $1.5 M

Table 3. Typical semi-anechoic chamber dimensions.

**Sizes depend on quiet zone diameter, interior shield room from ground plane up. For approximate exterior dimensions, a raised floor, structural steel and fire protection system must be added. Absorber depths are subtracted for interior working space. All numbers are typical values and will vary from manufacturer to manufacturer.*

SUMMARY

This article is a selective overview of what is involved in building a SAC. It does not try to be a complete how-to nor does it address all issues involved in building a functional SAC. Several important building code issues like fire safety and structural integrity have not been thoroughly examined. Building a semi-anechoic chamber is not an easy task. A number of factors influence the electromagnetic performance and the usability of a SAC. Especially with fully compliant chambers, with 3-m and/or 10-m test distance, issues like quality control, design capabilities and a proven track record play an important role in selecting a chamber manufacturer. Also, successful operation of an EMC facility depends on the test accessories (turntable, antenna mast, antennas, cables) and the measurement equipment used, as well as the experience of the test personnel performing the measurements.

RECOMMENDED READING

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