REVERBERATION CHAMBER FOR EMI TESTING

INTRODUCTION

EMI Testing

1. Whether a product is intended for military, industrial, commercial or residential use, it must perform its intended function in the electromagnetic environment. Its operation must not degrade the performance of other systems. In other words, it must have Electromagnetic Compatibility with the EM environment. Electromagnetic Compatibility (EMC) testing requires appropriate electrical and structural design, equipment installation, wiring installation, and equipment qualification.

2. Electromagnetic Interference (EMI) testing is performed to ensure that a product will perform properly when subjected to the electromagnetic environment in which it is expected to operate. Each system must be compatible with itself, other systems, and the external environment to ensure required performance and to prevent costly redesigns for the resolution of problems. External to the system are electromagnetic effects such as lightning, electromagnetic pulse (EMP), electrostatic discharge and man-made RF transmissions. Internal to the system are electromagnetic effects such as electronic noise emissions, self-generated RF transmissions from antennas, and cross coupling of electrical currents.

Anechoic Chamber

3. An Anechoic chamber is designed to attenuate sound or electromagnetic energy, to provide echo suppression features, to provide isolation from the noise present in the external environment, range from small compartments to ones as large as aircraft hangars, and the size of the chamber depends on the size of the objects to be tested and the frequency range of the signals used. The Anechoic chamber, in addition to its capacity for evaluating reflection characteristics of various materials, can be used for audition of sound-field simulation (sound-field prediction system after completion) results for concert halls and studios.

Reverberated Chamber

4. In a reverberated chamber the aim is to create standing waves that are used to generate the high field strengths. There are no absorbers in a Reverberated chamber. A reverberation chamber has hard surfaces which reflect sound. The sound from a machine or other noise source is reflected many times to produce a non-directional or ‘diffuse’ sound field within the chamber. The sound power emitted from a machine can then be determined from the sound level in the chamber and from the characteristics of the room such as its volume, surface area and reverberation time. Unlike the sound pressure level produced by a machine or piece of equipment, the sound power level is a property of the machine and is independent of the test environment.

5. A reverberation chamber is also used to measure the sound absorption of acoustic materials, soft panels or screens, and items of furniture for example theatre seats, office desks and chairs, etc. Reverberation chamber enables us to generate high-intensity
diffuse noise fields for acoustic fatigue testing of, for example, spacecraft and aircraft components.

6. A reverberation chamber typically consists of four parts:
   (a) A shielded room.
   (b) A stirrer.
   (c) A receiving antenna.
   (d) A transmitting antenna.

**Comparison: Anechoic and Reverberation Chambers**

7. The Anechoic and Reverberation chambers are both very useful in measuring a wide range of applications in acoustics. An Anechoic chamber is a room whose purpose is to prevent any sound reflections or electromagnetic waves. Specifically, sound energy travels away from a source with no reflection back. They are used primarily for experiments in free field conditions. An example of a test that could be done in this chamber includes measuring the sound pressure level or transfer function of a loudspeaker. In the Reverberation Room, acoustic characteristics of sound-absorption materials can be evaluated and transmission loss of sound-insulation materials can be measured. A Reverberation chamber is designed to create a diffuse sound field. All of the acoustic energy that hits any surface in the room is reflected back into the room. An example of an experiment to be done in this room could be to measure the absorption coefficient of a material.

**Enclosure**

8. An electromagnetic reverberation chamber is an electrically large, highly conductive closed cavity or chamber used to perform Electromagnetic (EM) measurements (both emissions and immunity) on electronic equipment. Any facility that fits this description can be considered a reverberation chamber (also called a mode-stirred chamber).

**Stirring**

9. A rotating paddle or other means of altering the geometry of the room is almost always used in a reverberation chamber for “mode-stirring” or “mode-tuning”. Sometimes a frequency-modulated source is used to achieve “electronic mode-stirring”.

**Principles of Operation**

10. A closed cavity has many propagating modes which form 3-dimensional standing wave patterns with a large number of resonant modes. This gives rise to regions where the field is small and others where it is large. Typical variations are of the order of 40 dB, making the perceived test field very strongly dependent on the exact locations inside the cavity. At sufficiently high frequencies, the coupling between equipment and an antenna varies rapidly with position and frequency.

11. When a large number of modes are present (as in a reverberation chamber) the field pattern becomes highly detailed (although regular), but there are still large and rapid
variations in field with position and frequency. The mode stirrer or tuner alters the boundary conditions, thus moving the position of the maxima and minima of the field magnitude.

**How does it work?**

12. We can compare the effect to moving a piston up and down in water. If this is done in a quiet lake we will see the waves moving away from the plunger in rings. If we do the same thing in a bath tub, the waves will be reflected and patterned more chaotically with wave crests appearing in different places. However, if we look more closely, we will see that the crest comes and goes regularly in the same spot and if we place a diagonal plate called a stirrer into the water, the image will change and the crests appear will appear in different spots. Thus, if we place the plate in enough diagonal positions we will end up with wave crests all over the tub.

13. There are two ways of ensuring a high field strength in the entire volume which are as follows:

(a) The stirrer is typically a zigzag bent plate, placed on an axis which is rotated by a motor. There are two ways of ensuring that the field strength has been high in all places: 1. Place the stirrer in one position and switch on the generator in order to generate the field. Then switch off the generator and place the stirrer in a new position before turning on the generator again. Repeat the procedure with the stirrer in a sufficient number of different positions. This method is called “tuned mode” because you tune the chamber with the stirrer.

(b) Rotate the stirrer continuously with a generator that is switched on. This method is called “stirred mode” and is not used as often as it can be difficult to achieve repeatable results.

**Building a Reverberation Chamber**

14. **Dimensions** - Room sized reverberation chambers (e.g., volumes of between 75 to 100 m$^3$) are typically operated above 200 MHz. Operations below 200 MHz require chambers that are larger than the typical shielded room. Operation above 1 GHz allows for smaller chambers (cavities) to be used.

15. The shape of a reverberation chamber is by and large unimportant, very different shapes have shown to perform equally well. Instead, the volume of the chamber is the key factor for satisfactory performance. When choosing a rectangular room as a basis for building a reverberation chamber, ideally the dimensions should not be simple multiples or rational fractions of each other, this gives the largest number of modes with different resonance frequencies and in principle improves the room performance, particularly at lower frequencies.
16. The above table gives the approximate values of lowest useable frequency (LUF) against volume for a range of chamber sizes. The frequency of the first resonance ($f_{110}$) is also given.

**Measurement Equipment**

17. Since a reverberation chamber may be used to perform EMC measurements over a large frequency range (typically 200 MHz to 18 GHz), the equipment required depends greatly on our measurement requirements. The aim is to indicate the similarities and differences in equipment requirement compared with other EMC test systems.

**Signal Generators and Amplifiers**

18. The signal generators and power amplifiers used for immunity testing in (semi) anechoic chambers are likely to be more than adequate for use in a reverberation chamber if they extend to the required frequency range. However high reflections are often present in reverberation chamber tests and an amplifier with output stage protection is likely to be required.

19. The exact fields that can be achieved in a reverberation chamber depend on both the amplifier power and Quality ($Q$)-factor of the room when fully loaded with the test object and any other equipment. The average electric field strength is known by a comparison of an amplifier of 10W, in a typical anechoic chamber which can generate a field of 10V/m at 3m using a suitable antenna above 100 MHz (100W for 10m). Greater power is often required below 100 MHz depending on the antenna used.
Receiving Equipment

20. The receiving equipment used for open area test-site and/or (semi-) anechoic chamber measurements is likely to be suitable for use in a reverberation chamber if it extends to the required frequency range.

Antennas and Field Probes

21. The antennas used for other EMC test purposes are likely to be suitable for use in a reverberation chamber which can cover the desired frequency range. Horn antennas are typically used at higher frequencies though antenna gain and pattern are not important in a reverberation chamber.

Modes

22. The resonant frequencies (modal resonance frequencies) of a rectangular cavity (in hertz) are given by:

\[ f_{\hat{y}k} = \frac{c_0}{2} \sqrt{\left(\frac{\pi}{a}\right)^2 + \left(\frac{\pi}{b}\right)^2 + \left(\frac{\pi}{c}\right)^2} \]

where a, b, and c are the dimensions of the enclosure (in meters); m, n, and p are integers, only one of which may be zero and \( c_0 \) is the propagation velocity of waves in the cavity (m/s in free-space).

Mode tuned operation

23. In mode tuned operation the field or power is measured at different discrete frequencies for discrete positions of the tuner. The tuner is moved to the next position and the measurement is repeated. The set of measurements are then averaged over all stirrer positions for each measurement frequency.

Mode stirred operation

24. In mode-stirred operation the stirrer rotates continuously, at constant speed and a set of measurements are taken and averaged at each frequency before moving on to a new frequency.

Q Factor

25. Quality factor is used to describe the ability of a chamber or cavity to store energy. The ability of a chamber to store energy is determined by the losses present in the chamber. The dominant loss in an empty chamber is due to the chamber walls. Additional losses due to items such as antennas, apertures, support structures and the Equipment Under Test (EUT) also can affect the overall Q of the chamber. The Q-factor described here is often referred to as a composite or average Q-factor as it considers the composite (average) effect of a large number of modes.
26. The Q-factor can be measured if the input power to the room and average field are measured:

\[
Q = \frac{16\pi^2 V}{\frac{\lambda^3}{n_{tx} n_{rx}}} \left( \frac{P_{aveRec}}{P_{input}} \right) \]

where \( V \) is the chamber volume, \( \lambda \) is the wavelength, \( \langle P_{aveRec} / P_{input} \rangle \) is the ratio of the average received power to the input power over one complete tuner/stirrer sequence, and \( n_{tx} \) and \( n_{rx} \) are the antenna efficiency factors for the Transmit (Tx) and Receive (Rx) antennas, respectively. The Q-factor determines the field strength in the chamber for a given level of radiated power. This determines:

(a) The sensitivity of the chamber for emissions measurements;
(b) The maximum field strength that can be achieved for a given amplifier in immunity tests.

The time constant, of the chamber at sufficiently high frequencies is, on average:

\[
\tau = \frac{Q}{2\pi f} 
\]

27. Although the Q-factor of a chamber can be calculated theoretically, measured Q values are usually around an order of magnitude lower (around 1/50 at low frequencies to about 1/5 at high frequencies). This is partly due to the imperfections in the construction of the room. If the Q factor is reduced too far by the presence of loss in the chamber then the field uniformity may be adversely affected.

**Benefits Of Reverberation Chambers**

28. **Measurements above 1 GHz.** Whilst a range of EMC measurement techniques exist for use in the frequency range up to 1GHz, new measurement techniques are required above 1GHz. The reverberation chamber is one such technique. A reverberation chamber can be used below 1GHz too.

29. At low frequencies, when an equipment under test (EUT) is small compared with the wavelength, it tends to radiate power in a broad, dipole pattern. It is relatively easy to find the direction of maximum radiation (emissions measurement). As frequency increases and the equipment under test become comparable in size with the wavelength, the radiation pattern becomes more irregular. By rotating the object and scanning the antenna height, it is feasible to find the maximum radiation with an OATS or anechoic chamber measurement.

30. When the object is several wavelengths in extent, its radiation pattern can be very irregular then determining the direction and magnitude of the maximum radiation becomes very difficult using open-area test-site (OATS) or anechoic chamber measurements. A reverberation chamber measures the total radiated power regardless of the radiation pattern.

31. In the case of immunity measurements a similar argument can be made, on account of reciprocity. An EUT with a complex radiation pattern will have a similarly complex pattern in reception. In order to find the most sensitive direction, it would have to be rotated to a large number of positions about two axes. A reverberation chamber provides illumination from all directions and so must find the most sensitive direction without the need to rotate the EUT.
Versatility

32. The reverberation chamber is very versatile and it can be used for:

(a) Radiated emissions.
(b) Radiated Immunity.
(c) Enclosure Shielding.
(d) Cable shielding.
(e) Absorber characterization.

ADVANTAGES VS DISADVANTAGES

Advantages

33. There are following advantages of a Reverberated Chamber:

(a) A screened environment - no ambient signals.
(b) Wide frequency range.
(c) Measures total radiated power (emissions).
(d) Illuminates with all directions and polarizations (immunity).
(e) Large working volume in chamber.

Disadvantages

34. Disadvantages of a Reverberated Chamber are given as under:

(a) Needs measurement averaged over many stirrer positions.
(b) Not in many current standards.
(c) No simple method to compare emissions/immunity measurements with other techniques.