The overview of measuring the shielding effectiveness of the materials in complex electromagnetic environment

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Abstract. The wide-spreading use of innovative lightweight materials like advanced composites and metal coated plastics in several fields of applications has pushed toward an increasing interest in the characterization of the shielding performances of test materials. In the paper, we revisit the conventional methods of measuring shielding effectiveness of materials, and introduce the nested reverberation chamber methods (two reverberation chambers). The deficiencies in the existing approaches were illustrated. We advised the new approach should account for aperture, cavity size, and chamber loading effects, for which some current reverberation chamber approaches do not correctly account. This work is useful in estimating the shielding ability of the materials in complex electromagnetic environment.

1. Introduction
Materials used for the shielding of electromagnetic fields range from very simple metallic wire meshes to more sophisticated advanced composite materials (ACMs). ACMs are typically made by pressing and binding together several matrix-reinforced laminates with different fiber orientations. ACMs are becoming a very popular material because the main advantages of these materials with respect to metals are superior mechanical and chemical properties, such as lower weight, higher stiffness and strength, lower corrosion, lower tooling costs, and greater ease of fabrication. ACMs have been used for some time within the spacecraft and aircraft structure industry. In recent years, composite materials have begun to spill over into other applications, such as cases and housings used in electronics, computer and business equipment, and in naval and industrial environments, to mention only a few applications [1-3].

Shielding effectiveness (SE) is typically used to assess the shielding property of a material [4, 5], and is defined as the ratio of the transmitted power through the material to the incident power [6-10]. The SE can be obtained through numerical modelling or through measurements.

2. Shielding effectiveness test methods

2.1. Conventional methods of measuring shielding
The coaxial fixture is a commonly used measurement technique for determining far-field equivalent SE [11]. Dual TEM cells have been used to measure near-field SE [12]. However, those approaches determine SE for only a very limited set of incident wave conditions. Figure 1 illustrates such

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conditions. But in most applications, ACMs are exposed to complex electromagnetic environments where fields are incident on the material with various polarizations and angles of incidence [13, 14]. This is illustrated in figure 2, where the materials are incident on multiple-incidence.

![Figure 1. Conventional methods of measuring the SE of the materials.](image1)

![Figure 2. The materials of exposure in the realistic electromagnetic environment.](image2)

The electromagnetic field and the electromagnetic radiation exists in lots of instruments such as inside the boxes for avionics and electronic equipment, aircraft cavity, and instrument enclosures, the electromagnetic field coupling from exterior and the electromagnetic radiation of the interior electronic device, which will reflect and refract for times with inner surface, so the electromagnetic environment is very intricate. In those applications, the materials are exposed to complex electromagnetic environments where fields are incident on the material with various polarizations and angles of incidence [15-17]. A reverberation chamber SE test which differs from traditional SE measurement technique offers such an environment [18, 19].

2.2. Nested reverberation chamber method
A reverberation chamber is an electrically large, highly conductive enclosed cavity or chamber used to perform electromagnetic measurements (both emissions and immunity) on electronic equipment. When the chamber is excited with RF energy, the resulting multi-mode electromagnetic environment can be “stirred” by the mechanical tuner/stirrer. The resulting environment is statistically uniform and statistically isotropic (i.e., the energy was arrived from all aspect angles and at all polarizations) when the field is averaged over a sufficient number of positions of the mechanical tuner/stirrer [20].

There are many test techniques which are available to evaluate the shielding performance of gaskets, window materials, and other system configurations designed to provide shielding. Typically, a SE measurement compares the electromagnetic environment with and without the shielding material in place. SE test techniques are described in many sources [6-10]. Unfortunately, many SE measurements are noted for their lack of repeatability and facility-to-facility comparability. Some of these discrepancies can be attributed to the test technique while the test article itself causes others. Many factors such as the condition of mating surfaces and torquing of fasteners can markedly affect the repeatability of SE measurements.

For many shielding designs (e.g., gaskets, windows, etc.), reverberation testing uses a “nested chamber” approach (e.g., a reverberation chamber within a reverberation chamber). A receiving antenna and paddle wheel tuner are installed in a test fixture to detect any RF energy that "leaks" into the fixture. Figure 3 illustrates such an experimental setup.

Nested reverberation chambers have been used in the past to determine the SE of materials [21, 22]. However, after we revisited the methods, we found that all the existing standards for the SE measurements leave some open questions.

Firstly, the SE definition gives incorrect results.
The SE is commonly defined as:
\[ SE = -10 \log_{10} \left( \frac{P_{ic,s}}{P_{oc,s}} \right) \]  \hspace{1cm} (1)

Where \( P_{ic,s} \) is the power received inside the inner chamber with a sample, and \( P_{oc,s} \) is the power received in the outer chamber with a sample in the aperture and source in the outer chamber. Throughout this paper, received powers and power densities are actually ensemble averages that are obtained from a large number of stirrer (tuner) positions, where stirrers are located in both the inner and outer chamber. Theoretically, if no sample is in the aperture, the SE should go to zero [18]. The problem with this approach is that it does not accurately account for the amount of power that can actually couple into the inner chamber’s aperture; as a result, the measurement SE based on equation (1) will not in general go to zero with no sample in the aperture for all possible chamber and aperture sizes. This is illustrated in figure 4, where the SE is plotted as a function of frequency.

![Figure 3. Typical test fixture installation for material testing.](image)

![Figure 4. SE obtained with no sample in the aperture.](image)

These measurements were performed in a nested chamber with no sample in the aperture. The outer chamber has dimensions of 2.8 m × 3.2 m × 4 m, and the inner chamber has dimensions of 1.6 m × 1.2 m × 1.2 m, with an aperture size of 0.25 m × 0.25 m. Ridged horn antennas were used as the receiving and transmitting antennas and the inner chamber was placed on the center of the floor of the outer chamber. This figure shows that SE does not yield zero in the no-sample case.

Secondly, when the inner chamber is placed into the outer chamber, there is the possibility that the small chamber will “load” the chamber. If the small chamber loads the big chamber, the energy absorbed by the inner chamber is no longer available to generate the desired environment, and the EM environment may not be a statistically uniform environment [23]. For this reason, the inner chamber is always small with linear dimensions less than 2 m. The difficulty here is that in practice, tested chambers are usually too small to have a complex mechanical stirring system and a receiving antenna. On the other hand, it is still problematic even if the tested enclosure is large enough to be installed with a mechanical stirrer since this adds internal structure to the enclosure in an uncontrolled way.

The principle of nested reverberation chamber is the creation of a statistically uniform field distribution in the inner chamber. To achieve a statistically uniform and statistically isotropic environment, means other than mechanical tuners may be acceptable. Frequency stirring is an alternative way to mechanical stirring to achieve statistical field uniformity in an over-moded chamber or enclosure, and has the potential to be used in the shielding effectiveness measurements (SE) of materials [24]. Holloway et al. have validated the frequency stirring approach by comparing it with the results obtained from mechanical stirring [25, 26], and the testing approach was illustrated in figure 5.

Finally, the use of reverberation chambers for the SE measurement of materials should fulfill the following requirements: to be account for aperture, cavity size, and chamber loading effects, to be easy to be implemented by technical personnel, to be not too expensive in terms of testing time and equipment, to be reliable and meaningful of the shielding performance of the materials in case of real electromagnetic environment.
3. Conclusions
In this paper, we have overviewed some techniques for measuring the SE of materials, and also made comparisons to existing reverberation techniques. The nested reverberation chamber approach can provide the realistic environment, but there are some open questions, such as loading effects, normative aperture and cavity size, shielding effectiveness definition, the correlation with conventional method results. In these comparisons, deficiencies in the existing approaches were illustrated.

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