Comparison of SE Measurements Between MIL-STD-285 and the ASTM Standard E1851

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Abstract: The American Society for Testing and Materials (ASTM) published a standard test method (E1851) for electromagnetic shielding effectiveness (SE) of a room-size transportable shielded enclosure [1]. A baseline set of data has been collected to compare both SE measurement results and the length of testing time for the modified MIL-STD-285 and the recently published ASTM Standard E1851.

BACKGROUND

Members of the Department of Defense triservice organization called Joint Committee on Tactical Shelters (JOCOTAS), including the U.S. Army Natick Research and Development Center at Natick, MA, have been plagued by MIL-STD-285 [2], an outdated military standard published in June 1956. I should point out, for the sake of the people who dedicated their precious time and effort to produce the standard, that techniques used in MIL-STD-285 are essentially adequate, but some portions of the standard can be interpreted differently, depending on the user. Because of this problem, test results typically vary by 10 to 20 dB, depending on many factors, but the major contributing factors are test point assignment, placement of an antenna at a given test point, and qualification of test personnel. In addition, the highest measurement frequency, 400 MHz, for MIL-STD-285 is not high enough for today's environment.

For many years, because no other standard was available for shelter testing, JOCOTAS had tried to revise the MIL-STD-285. To resolve this logjam, the U.S. Army Communications and Electronics Command (CECOM), which controls MIL-STD-285, requested that the Institute of Electrical and Electronics Engineers (IEEE) publish its proposed standard 299, in 1969 [3]. Later, IEEE took over an Electromagnetic Compatibility Analysis Center (ECAC) project to revise MIL-STD-285 and published IEEE Std 299-1991 [4] in 1991 [5]. Careful review of IEEE Std 299-1991 revealed that the standard developers tailored the standard for a shielded enclosure installed in a building or large facility and that the standard is not well suited for a transportable shielded enclosure. Therefore, JOCOTAS requested ASTM to publish a standard specifically intended for a transportable enclosure or shelter. As a result, ASTM Standard E1851 was published in February 1997 [1] and complements the IEEE Std 299-1991.

The primary objective of ASTM standard E1851 was providing uniform test techniques. Other objectives were developing a test method to produce a high repeatability and excellent reliability and minimizing uncertainty in the measurements. Every effort was made to meet the objectives, such as clearly defining test points and explaining proper orientation and alignment of antennas. However, the ASTM subcommittee that developed the standard could not reach a consensus on a few important issues such as specifying equipment and qualification of test personnel. Thus, these issues were not addressed in the standard.

BRIEF DESCRIPTION OF ASTM STANDARD E1851

Scope

The standard is targeted for a room-size transportable shielded enclosure that does not have any equipment or equipment racks. The main text of the standard is written for a first-article testing to assess the adequacy of an enclosure's design and may require a few days to complete. An appendix is provided to verify the construction quality in about one-half day of a shielded enclosure coming off an assembly line. This standard requires the use of five specific frequencies for testing, two frequencies in magnetic fields and three frequencies in plane wave fields, within the given specific frequency ranges. The frequency range specified in the standard is from 140 kHz to 10 GHz, but the range may be extended without changing test methods specified in the standard. The standard allows testing at a manufacturing site and requires preliminary procedures to be conducted to detect weak areas or poor workmanship prior to actual measurement to save time.

Source fields

For testing, the standard requires one to assess a shielded enclosure using a low-impedance magnetic field and plane wave field (377 ohms). Use of high impedance electric fields is not required because of the difficulties in making measurements and in detecting leaks.

Preparation of apparatus

The standard contains a table of test apparatus for necessary equipment characteristics, and its footnotes provide restrictions imposed on the characteristics. Choose test equipment that provides a dynamic range of at least 10 dB above the SE requirement at a test frequency.

The following restrictions are included on apparatus used for testing. Power amplifier output is matched to an unbalanced to
balanced (balun) transformer; the balanced output is matched to a balanced dipole. A circular-loop antenna that is 1 ft in diameter shall be used. The shielded circular receiving antenna can have multiple turns, but the total length of the wire forming the loop shall be less than 1/6 wavelength. For plane wave testing, any antenna that radiates at the prescribed frequencies may be used. However, antennas that require a large clear space in the direction of propagation shall not be used if clear space is limited for testing. Examples of such antennas are linearly polarized log periodic dipole and circularly polarized conical spiral antennas. If a dipole antenna is used as a receiving antenna, its length shall be less than 1/6 wavelength. The receiving antenna is connected to a balun then to an attenuator.

**Calibration procedures**

**Magnetic field calibration.** Calibrate each frequency to be tested by placing the transmitting and receiving antennas in coplanar orientation so the distance between them is 3 ft plus the thickness of the enclosure. If an attenuator is used as the basis for the desired measurements, calibrate the attenuator at each frequency also and include its results in the report.

During calibration, do not allow any other equipment or any electromagnetic reflectors except the ground closer than three times the antenna separation. Place the antennas at least 3 ft above the ground during the calibration. Also, the standard requires continuous wave (cw) measurements to be conducted at each frequency to be tested to avoid any interferences and equipment coupling problems.

**Plane wave calibration.** Conduct calibration for reference measurement at each plane wave test frequency and antenna polarization. Position dipole antennas in a coplanar, with their elements parallel. Position aperture antennas so their apertures are parallel. Separation distance for either antenna shall be as large as possible but at least 8.2 ft. Receiving equipment can be placed inside the shielded enclosure. During the calibration, vary the receiving antenna from its original position to measure the local maximum signal without varying the antenna polarization or alignment.

During calibration, do not allow any other equipment or any electromagnetic reflectors except the ground closer than three times the antenna separation. Measure the maximum test area by moving the receiving antenna horizontally from left to right, and measure the distance between -3 dB points. Repeat the same measurement now vertically to measure the distance between -3 dB points. Make the above measurements without changing antenna polarization. Also, the standard requires that cw measurements be conducted at each frequency to be tested to avoid any interferences and equipment coupling problems.

**SE measurement procedures**

**Magnetic field SE measurement.** Conduct magnetic field SE measurements by placing the transmitting antenna outside the shielded enclosure and centering it on a test point as shown in figure 1. Place the antenna’s plane perpendicular to the surface of the shield. The distance from the transmitting antenna to the test point shall be 2 ft. Place the receiving antenna inside the shielded enclosure, without changing the polarization. Sweep the receiving antenna along the seams or edges within the test area keeping the receiving antenna 1 ft from the shield surface until a maximum signal is received. Cross polarization measurements are not required.

Figure 2 shows antenna orientations for door, seam, and edge measurements for a magnetic field. Test edges by uniformly assigning test points along the edges into equal segments not to exceed 2 ft. Place the transmitting and receiving antennas in coplanar orientation with the coplane perpendicular to a seam or edge being tested. Both horizontal and vertical polarization measurements are required at each section test point. To test a door, assign one test point for each corner. In addition, assign two vertical test points on each vertical seam by dividing them equally in distance. The horizontal test points are located at the center of each horizontal door seam. Assign additional test points for openings such as ventilation openings and signal entry panels if test points are not overlapped with other test points. Use the same equipment, antennas, cables, generator output levels, and equipment settings that were used in the calibration settings except the attenuator settings. To test corners, assign three test points 1 ft away from the interior corner along the three edges.

Obtain magnetic field SE measurements at 150 kHz and 14 MHz; however, these frequencies may be adjusted. Additional frequencies may be used if required by the customer. Use the highest signal and the corresponding polarization to calculate the SE values at each test point and frequency.

**Plane wave SE measurement.** Place the transmitting antenna outside the enclosure and the receiving antenna inside so their propagation axes are collinear and perpendicular to the surface of the enclosure at a test point as shown in figure 3. With the receiving antenna inside the enclosure, slowly (not to exceed receiver response time) scan the entire test point area to cover all seams and openings with its antenna plane parallel to the plane of the transmitting antenna. Perform the scan 2 in. from the enclosure surface. At the point of the highest signal, move...
the antenna about 1/2 wavelength to measure the local maximum signal. During the measurement, rotate the antenna to explore both the horizontal and vertical polarizations for each transmitting antenna polarization. Change the transmitting antenna polarization and repeat the above measurement.

Assign corner test points 1 ft away from the interior corner along the three edges. Edge test points are assigned along the edges between the corner test points by equally dividing them, not exceeding X m, where X is the distance between the -3 dB points (choose X as the shorter distance between horizontal and vertical -3 dB points) measured during the calibration procedure as shown in figure 4. Assign seam test points by uniformly dividing each seam, not exceeding X m just like edge test points. Assign door and section test points by dividing them equally, not exceeding X m by X m as determined during the calibration. Assign additional test points for openings such as ventilation openings and signal entry panels if test points are not overlapped with other test points. Use the same equipment, antennas, cables, generator output levels, and equipment settings that were used in the calibration settings except the attenuator settings.

Obtain plane wave SE measurements at 400 MHz, 1 GHz, and 10 GHz; however, these frequencies may be adjusted. Additional frequencies may be used if required by the customer. Use the highest signal and the corresponding polarization to calculate the SE values at each test point and frequency. Figure 5 shows antenna orientations for door, seam, and edge measurements for a plane wave.

Nonlinearity effects and enclosure resonances

Because of an increase in use of magnetically operated doors, the standard provides guidance on nonlinear effects. The nonlinear effects are made by measuring SE as a function of source strength.

The SE test procedures are to measure attenuation of electromagnetic energy, but resonant cavity mode affects test data considerably. Therefore, avoid the frequency range 0.8 to 3.0 $f_r$, where $f_r$ is the lowest cavity resonance.

Report

The standard requires a comprehensive technical report that will describe the enclosure’s performance and contain enough detail on measurements to assure the validity of the approach and accuracy of instrumentation. The report shall include a preparer of
TESTS TO COMPARE SE BETWEEN TWO DIFFERENT METHODS

Overview

Comparing ASTM Standard E1851 with the MIL-STD-285 is not considered appropriate because of the outdated equipment and the highest frequency (400 MHz) specified for testing in the MIL-STD-285. Consequently, I decided to compare E1851 with a modified version of MIL-STD-285. Fortunately, I found a group of engineers at Keesler AFB, MS, who volunteered to conduct the testing.

The team of volunteers conducted SE tests on a military shelter to compare differences between ASTM standard E1851 and a modified MIL-STD-285. The leader of the team developed a test procedure for his department called S-285, by modifying MIL-STD-285 to supplement outdated portions and to produce repeatable test results. Thus, the team and I compared the ASTM standard test results with that of S-285.

Summary of modified MIL-STD-285

Measurement techniques specified in the S-285 are essentially the same as that of MIL-STD-285 except for the following changes. To accommodate test requirements in high frequencies and dynamic range, S-285 specifies the use of modern equipment and high-quality cables. It also assigns test areas along the seams, edges, and other penetration areas, dividing the surfaces to be tested into small measurement areas. The S-285 requires scanning a test area with a receiving antenna and recording the highest signal. Prior to each series of measurements, it requires one to measure ambient noise level in the test area using a receiver system. Also the S-285 specifies dynamic range of at least 10 dB in excess of a required shielding level. For each test area, it requires two measurements using horizontal and vertical polarizations and two cross coupling measurements. For magnetic field measurements, the S-285 specifies one to position the transmitting antenna 2 ft away from the exterior wall, and it also requires one to maintain the receiving antenna 2 in. from the shield. For 400 MHz testing, S-285 specifies a circularly polarized antenna as a transmitting antenna and a broadband dipole antenna as a receiving antenna. It requires one to use standard gain horn antennas for measurements at 10 GHz [6].

Comparison of test results

The team conducted SE tests after establishing test points as required by the ASTM Standard E1851, and only three frequencies were used instead of the required five because of limited time. Figures 6 and 7 show test points assigned on an end wall and a side wall. Table 1 shows SE data taken on a door, penetration, and panel test points. Even though the data are presented side by side, test points do not always coincide, but they are close enough to make meaningful comparisons [6]. Apparently,

Summary of improvements of ASTM Standard E1851 compared to IEEE Std 299-1991

ASTM Standard E1851 requires very strict test point assignments to improve repeatability and reliability. Conducting plane wave measurements is much easier and less cumbersome. ASTM Standard E1851 virtually eliminated variations in measurements caused by differences in antenna types. Especially for plane wave measurements, ASTM Standard E1851 requires a test area be assigned within 3-dB falloff points, measured during the calibration procedures. IEEE Std 299 is a highly technical and well-documented standard, but it usually takes a long time to complete an entire SE testing. ASTM standard E1851 may even take longer for verification of a design, but thereafter, each SE test for a given type of shelter will take only about four hours to complete with the use of reduced test requirements delineated in an appendix. Generally, the test method is similar to that of IEEE Std 299-1991, except in test point assignments and antenna positioning. Contrary to the IEEE standard, ASTM standard E1851 considers all walls and ceilings accessible for testing with emphasis on testing seams and joints, and its guidance on antenna positioning is more specific.
The ASTM test method required more test points than the S-285 method obviated by blanks in the tables, and test points that were not close to each other are not included in Table 1.

The ASTM test method required about 50 percent more time to complete compared to the S-285 test method, but as I pointed out earlier, subsequent qualification testing can be completed in about four hours, a tremendous savings in time and money. The SE tests readily showed that results of the two test methods agree fairly well, considering the differences in test points and antenna positioning. However, the greatest variance in the two methods was seen at the 10-GHz level. Eight test points measured more than 5 dB apart, a definite indication of problems, but the team did not have time to go back and repeat the measurements.

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REFERENCES


