Designation: E1851 – 21

Standard Test Method for Electromagnetic Shielding Effectiveness of Durable Rigid Wall Relocatable Structures[1]

This standard is issued under the fixed designation E1851; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the U.S. Department of Defense.

1. Scope

1.1 This test method covers the determination of the electromagnetic shielding effectiveness of durable relocatable shielded enclosures.

1.1.1 The intended application of this test method is for virgin shielded enclosures that do not have any equipment or equipment racks. It is recommended that tests be conducted before the interior finish work begins. However, the shield assembly including all enclosure penetrations shall be completed and required penetration protection devices shall be installed in accordance with the design specification. The test method can also be used on existing shielded enclosures after repair work is done to verify workmanship, but it may be necessary to remove equipment or equipment racks to gain access to a test area.

1.1.2 The test procedures delineated in this document are comprehensive and may require several days to complete for a room-size shielded enclosure. A user can apply this test method for a first article test that requires proof of concept and validation of design and fabrication technique. Appendix X2 provides guidance on choosing test points so shielding effectiveness tests on a room-size shielded enclosure may be completed in about one-half day for which it applies to shielded enclosures coming off an assembly line.

1.2 This test method is for use in the following frequency ranges: 140 kHz to 160 kHz, 14 MHz to 16 MHz, 300 MHz to 500 MHz, 900 MHz to 1000 MHz, and 8.5 GHz to 10.5 GHz. Specific test frequencies within these ranges are required (see 11.1.1 and 11.2.1). Additional measurements in the range of 10 kHz to 10.5 GHz may be performed. For specific applications, the frequency range may be extended from 50 Hz to 40 GHz. Appendix X1 provides guidance on selecting measurement frequencies.

1.3 This test method is not applicable to individual components such as separate walls, floors, ceilings, or shielded racks.

1.4 This standard may involve hazardous materials, operations, equipment, or any combination.

1.5 The values stated in SI units are to be regarded as standard. The values given in parentheses after SI units are provided for information only and are not considered standard.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.7 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

E631 Terminology of Building Constructions

E1749 Terminology Relating to Rigid Wall Relocatable Shelters

2.2 *IEEE Standards:*[3]

IEEE Std 299-1997 IEEE Standard Method for Measuring the Effectiveness of Electromagnetic Shielding Enclosures

[1] This test method is under the jurisdiction of ASTM Committee E06 on Performance of Buildings and is the direct responsibility of Subcommittee E06.53 on Materials and Processes for Durable Rigidwall Relocatable Structures.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from Institute of Electrical and Electronics Engineers, Inc. (IEEE), 445 Hoes Ln., Piscataway, NJ 08854-4141, http://www.ieee.org.

TABLE 1 Test Frequencies and Test Configurations

Nominal Test Frequency	Corresponding Test Configuration
150 kHz and 14 MHz	Fig. 1
400 MHz, 1000 MHz, and 10 GHz	Fig. 2

IEEE Std C95.1-1991 IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz

2.3 *Military Standard:*[4]

MIL-STD-188-125 High Altitude Electromagnetic Pulse (HEMP) Protection for Ground Based C[4]I Facilities Performing Critical, Time-Urgent Missions

2.4 *OSHA Standard:*[5]

OSHA Regulation, 29 CFR 1910, Department of Labor, July 1992

3. Terminology

3.1 *Definitions:*

3.1.1 For definitions of general terms related to building construction used in this test method, refer to Terminology E631, and for general terms related to rigid wall relocatable shelters, refer to Terminology E1749.

4. Summary of Test Method

4.1 *Test Configuration*—A transmitting antenna is connected to an electromagnetic source set to a specific frequency and amplitude. A receiving antenna is placed a specified distance from the transmitting antenna, and the received electromagnetic field level is recorded as a reference or calibration measurement. The transmitting antenna and electromagnetic source are placed outside the shielded enclosure. The receiving antenna and associated test equipment are placed inside the shielded enclosure. The transmitting and receiving antenna's separation, frequency, and amplitude are the reference measurements. The transmitting and receiving antennas are at the same height for a given test point. The received electromagnetic field level is recorded as the test measurement. The ratio of the test measurement to the reference measurement is the electromagnetic shielding effectiveness of the shielded structure at the measurement location and frequency. The logarithm of this ratio is typically used in expressing the shielding effectiveness in decibels.

4.2 *Test Frequencies*—A summary of nominal test frequencies and corresponding test configurations is shown in Table 1.

5. Significance and Use

5.1 This standard provides measurement procedures for determining the electromagnetic shielding effectiveness of durable rigid wall relocatable shielded enclosures. This standard specifies a method for comparing the shielded enclosure performance of structures provided by different suppliers. In addition, this standard is written to minimize variations in measured shielding effectiveness at a given frequency and test point regardless of test personnel, equipment, and test site. Therefore, the shielding effectiveness of a durable rigid wall relocatable shielded enclosure of any size from any supplier can be determined. This standard specifies a minimum set of measurements at a given frequency and a minimum set of frequencies to determine shielding effectiveness.

5.2 *Source Fields*—Performance of a shielded enclosure is to be assessed for two source fields: magnetic and plane wave.

5.2.1 *Magnetic Field Measurements*—The attenuation provided by a shielded enclosure is assessed by using a local source to generate the near field. The magnetic field measurements are specified for two narrow frequency bands: 140 kHz to 160 kHz and 14 MHz to 16 MHz.

5.2.2 *Plane Wave Measurements*—The attenuation provided by a shielded enclosure is assessed by using a locally generated distant source or plane wave field. The plane wave measurements are specified for three narrow frequency bands: 300 MHz to 500 MHz, 900 MHz to 1000 MHz, and 8.5 GHz to 10.5 GHz.

6. Interferences

6.1 *Interference with Electronic Equipment*—Care shall be taken to avoid interference with other electronic equipment operating in the vicinity.

6.2 *Operational Impact Analysis and Risk*—The electromagnetic barrier must remain intact during the shielding effectiveness measurement sequence, and use of electrically noisy equipment must be restricted. Therefore, construction activity or unusual operations (facility modification or maintenance) may be affected. Radiated signal levels should present no hazard to equipment, but frequency adjustments may be required to avoid self interference or interference with nearby facilities. Record the actual test frequencies. Normal electrical safety precautions apply.

7. Apparatus

7.1 The required apparatus is identified in Table 2. Choose test equipment that provides a dynamic range of at least 10 dB (20 dB is preferable [see Note 1]) in excess of the shielding effectiveness requirement at the test frequency.

NOTE 1—20 dB of dynamic range makes the test easier to perform by less experienced personnel. The standard uses a minimum of 10 dB because it offers a lower cost solution to testing durable rigid wall relocatable structures. If the existing test equipment has 20 dB of dynamic range then 20 dB of dynamic range should be used. It makes the hot spots stand out more clearly from the background noise on the LCD displays on spectrum analyzers.

8. Hazards

8.1 For human exposure to electromagnetic energy in controlled environments, the maximum permissible exposure to electric and magnetic field strengths shall be minimized to the maximum extent possible. Acceptable levels can be found in IEEE Std C95.1-1991 and OSHA Regulation, 29, CFR.

9. Preparation of Apparatus

9.1 *New and Existing Durable Relocatable Enclosure Testing*—Testing of new durable rigid wall relocatable shielded

[4] Available from DLA Document Services, Building 4/D, 700 Robbins Ave., Philadelphia, PA 19111-5094, http://quicksearch.dla.mil.

[5] Available from Occupational Safety and Health Administration (OSHA), 200 Constitution Ave., NW, Washington, DC 20210, http://www.osha.gov.

TABLE 2 Test Apparatus

Equipment	Characteristics
Oscillator(s)	140 kHz to 160 kHz, 14 MHz to 16 MHz, 300 MHz to 500 MHz, 900 MHz to 1000 MHz, 8.5 GHz to 10.5 GHz
Power Amplifier(s)	140 kHz to 160 kHz, 14 MHz to 16 MHz, 300 MHz to 500 MHz,[A] 900 MHz to 1000 MHz,[A] 8.5 GHz to 10.5 GHz, amplification and noise figures as required for dynamic range
Preamplifier(s)	140 kHz to 160 kHz, 14 MHz to 16 MHz, 300 MHz to 500 MHz, 900 MHz to 1000 MHz, 8.5 GHz to 10.5 GHz, amplification and noise figures as required for dynamic range
Receiver(s)/Spectrum Analyzer(s)	140 kHz to 160 kHz, 14 MHz to 16 MHz, 300 MHz to 500 MHz, 900 MHz to 1000 MHz, 8.5 GHz to 10.5 GHz
Antenna Kit	140 kHz to 160 kHz,[B] 14 MHz to 16 MHz,[B] 300 MHz to 500 MHz,[C] 900 MHZ to 1000 MHz,[C] 8.5 GHz to 10.5 GHz[D]
Miscellaneous Cables and Attenuators as Required[E]	

[A] The power amplifier output is usually matched to an unbalanced to balanced (balun) transformer; the balanced output is matched to a balanced dipole.
[B] Circular loop antenna whose diameter is 30 cm (1 ft) shall be used. The shielded circular receiving antenna can have multiple turns, but the total length of wire forming the loop shall be less than ⅛ wavelength.
[C] Any antenna that radiates at the prescribed frequencies may be used. However, antennas that require a large clear space in the direction of wave propagation shall not be used where clear space is limited for testing. Examples of such antennas are linearly polarized log periodic dipole and circularly polarized conical spiral antennas. Procedures are written assuming use of dipole antennas for plane wave measurements. If a dipole antenna is used as a receiving antenna, its length shall be less than ⅛ of wavelength. The receiving antenna is usually connected to a balun then to an attenuator.
[D] Any antenna that radiates at the prescribed frequencies may be used except a linearly polarized log periodic dipole antenna or circularly polarized conical spiral antenna. Procedures are written assuming use of aperture antennas for high frequency plane wave measurements. An isolator is usually used between the source and its antenna to minimize variation of power between reference and test measurements.
[E] Well shielded coaxial cable such as flexible semi-rigid coaxial cable, RG-214 or RG-223, shall be used.

enclosures can be conducted at the manufacturing site. Manufacturing site testing can locate structural defects or weaknesses or both and corrections may be easily implemented. For existing structures, weaknesses can be determined and corrected during maintenance or periodic retesting.

9.2 *Movable Equipment*—Moveable equipment containing metal, not normally housed in the enclosure or attached outside the enclosure, shall be removed from the enclosure prior to making measurements.

9.3 *Preliminary Procedures*—Perform the following preliminary test on all accessible shielding faces to detect weak points and to permit remedy of shielding defects caused by faulty assembly and poor workmanship prior to actual measurement.

9.3.1 With the transmitting antenna turned off, perform a continuous wave (cw) measurement at each frequency to be used for testing to ensure that no emitters are nearby that may cause interference. Frequency adjustments may be necessary to avoid interference. Setup for this measurement is the reference measurement (see Section 10 and Fig. 1a and Fig. 2a).

9.3.2 Additionally, perform a receiving equipment coupling measurement. The setup for this measurement is the reference measurement (Section 10) with the following exceptions. Disconnect the receiving antenna from the nearest cable and replace the receiving antenna with a dummy load (resistive load matched to the characteristic impedance of the receiving system) as shown in Fig. 3. Measured levels shall be negligible so the required dynamic ranges are maintained. If the measured levels are larger than expected, determine the penetration points and correct the identified leakage points. Repeat the receiving equipment coupling measurements until negligible levels are maintained.

9.3.3 Perform a noise measurement with the following equipment setup. Place the receiving antenna and equipment inside the enclosure and turn off the transmitting antenna placed outside the enclosure (see Fig. 4). The receiving antenna can be placed outside the enclosure. When this is done an attenuator shall be inserted between the receiving antenna and receiving equipment, and it shall be set to a shielding effectiveness level of the enclosure being tested. Measure the noise level at each frequency to be used for testing.

9.3.4 After noise levels have been found negligible (or the test equipment has been modified to make the penetration negligible), position the transmitting and receiving antennas in accordance with the procedures detailed in Section 11. For each location, use the receiving antenna as a probe to locate areas of maximum penetration. Alternatively, a commercial leak detector may be used. Check all penetrations such as doors, power line filters, air vents, seams, and coaxial cable fittings. If the performance of the enclosure appears to be inadequate for its design, remedial measures are suggested prior to complete testing. Identify regions of significantly greater field penetration for later measurements.

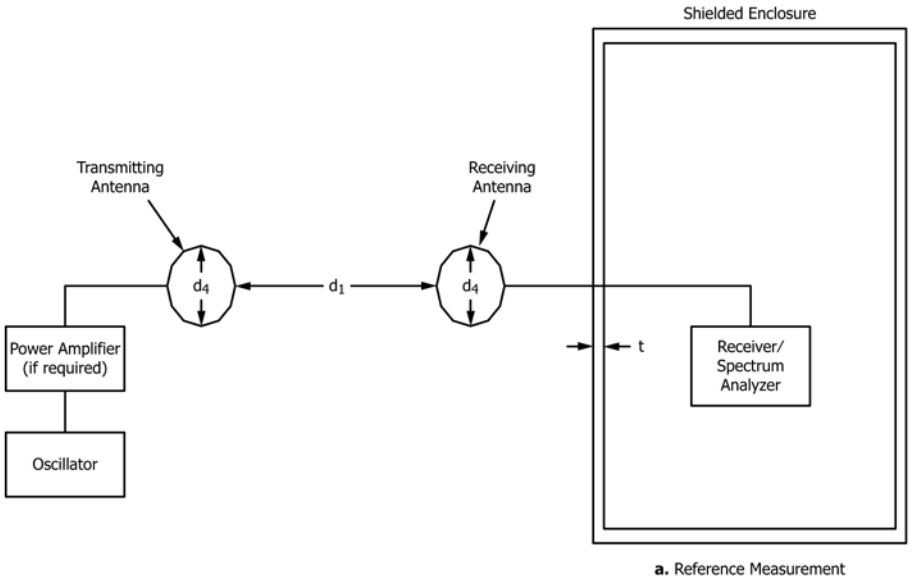
10. Calibration Procedures

10.1 *Magnetic Field Calibration Procedure*—Conduct the calibration for magnetic field measurements for each magnetic field test frequency as shown in Fig. 1a. Choose test equipment that provides a dynamic range of at least 10 dB (20 dB is preferable (see Note 1)) in excess of the shielding effectiveness requirement at the test frequency. Place the loops of the transmitting and receiving antennas in a coplanar configuration. Place the transmitting and receiving antennas so the distance between them is 90 cm (3 ft) plus the thickness of the enclosure (see Fig. 1a). If an attenuator is used as the basis for the desired measurement, the attenuator shall be calibrated and the results shall be documented. The attenuator impedance shall match the system transmission line impedance. Place the receiving system, but not the receiving antenna, inside the enclosure.

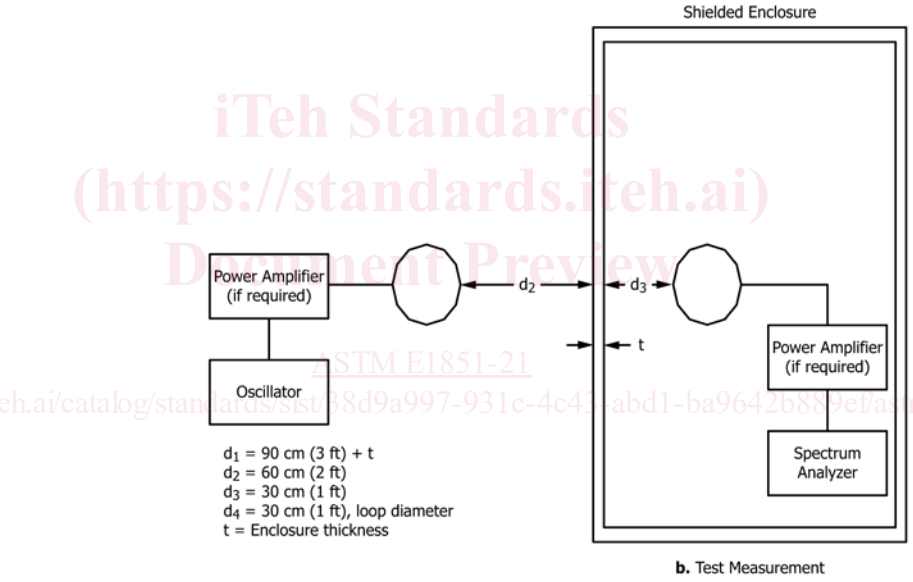
10.1.1 During calibration no other equipment or electromagnetic reflectors (except ground) shall be closer than three times the antenna separation. The antennas shall be at least 1 m (3.3 ft) above the ground.

10.1.2 Record the received signal strength for each frequency and transmitting antenna polarization as the calibration signal (V_c) for that configuration. Record all equipment settings, including generator loop current or transmit power.

10.2 *Plane Wave Calibration Procedure*—Conduct the calibration for plane wave measurements for each plane wave test frequency and antenna polarization as shown in Fig. 2a.



a. Reference Measurement



b. Test Measurement

FIG. 1 Magnetic Field Test Procedures

Choose test equipment that provides a dynamic range of at least 10 dB (20 dB is preferable (see Note 1)) in excess of the shielding effectiveness requirement at the test frequency. For dipole antennas, place the transmitting and receiving antennas so both antennas lie in the same plane (coplanar) and their elements are parallel. For aperture antennas, place the transmitting and receiving antennas so their apertures are parallel. Separation distance between the antennas shall be as large as possible within dynamic range constraints, but at least 2.5 m (8.2 ft) plus enclosure thickness. Place the receiving system, but not the receiving antenna, inside the enclosure. Vary the receiving antenna position ±0.3 m (1 ft) from its nominal location toward and away from the transmitting antenna to measure the local maximum, but do not vary the antenna alignment or polarization.

10.2.1 During calibration, no other equipment or electromagnetic reflectors (except ground) shall be closer than three times the antenna separation. The antennas shall be at least 1 m (3.3 ft) above the ground.

10.2.2 Record the highest received signal strength for each frequency and both antenna polarizations as the calibration signal (V_c) for that configuration. Record all equipment settings, including generator output.

10.3 *Antenna Coverage*—Measure the maximum test area during the calibration. Place the vertically polarized transmitting antenna at least 2.5 m (8.2 ft) away from the vertically polarized receiving antenna, move the receiving antenna horizontally from left to right from its center, and measure the distance X (m) between the −3 dB points (below the peak

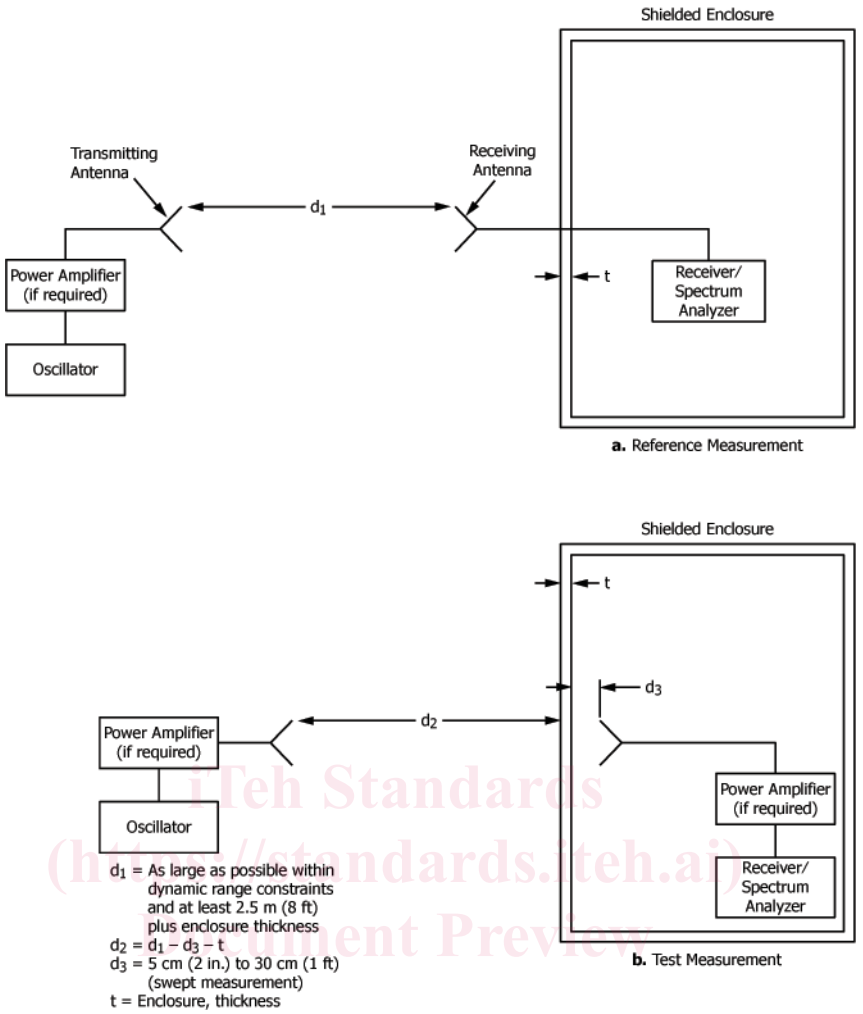


FIG. 2 Plane Wave Field Test Procedures

amplitude). Repeat the above procedure by moving the receiving antenna up and down from its center position without changing either antenna polarizations and measure the distance Y (m) between the −3 dB points.

11. Test Measurement Procedures

11.1 *Magnetic Field Test Measurement Procedure*—Conduct the magnetic field test measurement as shown in Fig. 1b. Use the same equipment, antennas, cables, loop current or transmit power, and equipment settings (except attenuator settings) that were used in the calibration sequences.

11.1.1 *General Test Procedures:*

11.1.1.1 Place the transmitting antenna outside the test structure and center it on the test point. Place the antennas in coplanar orientation with the coplanar normal to the surface of the shield surface. The distance from the transmitting antenna to the test point shall be 0.6 m (2 ft) (see Fig. 1).

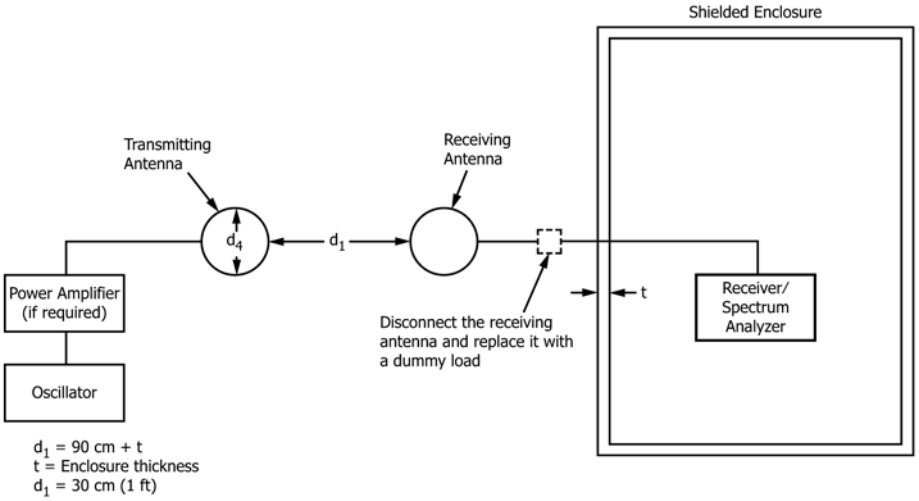
11.1.1.2 Place the receiving antenna inside the test structure maintaining the same polarization. Sweep the receiving antenna along the seams or edges within the test point area keeping the receiving antenna 0.3 m (1 ft) from the test point surface until a maximum signal is received. Both horizontal and vertical coplanar measurements shall be performed at each section test point (see 11.1.4) and other openings (see 11.1.6). Cross-polarization measurements are not required. Record only the maximum received signal strength as the swept measured signal (V_m) for that test point, frequency, and transmitting antenna polarization.

11.1.1.3 After completion of a series of test measurements, not to exceed 4 h, repeat the reference level calibration determined in Section 10 to ensure there has been no deviation greater than 1 dB or 2 dB for the duration of the measurement period. If only a small deviation is found (1 dB or 2 dB), do not adjust the data in determining the shielding effectiveness. If a greater deviation is found, investigate the transmitter and receiver hardware, cables, connectors, and other test equipment. When the source of the deviation is located, repair or replace the faulty hardware and retest the affected test points.

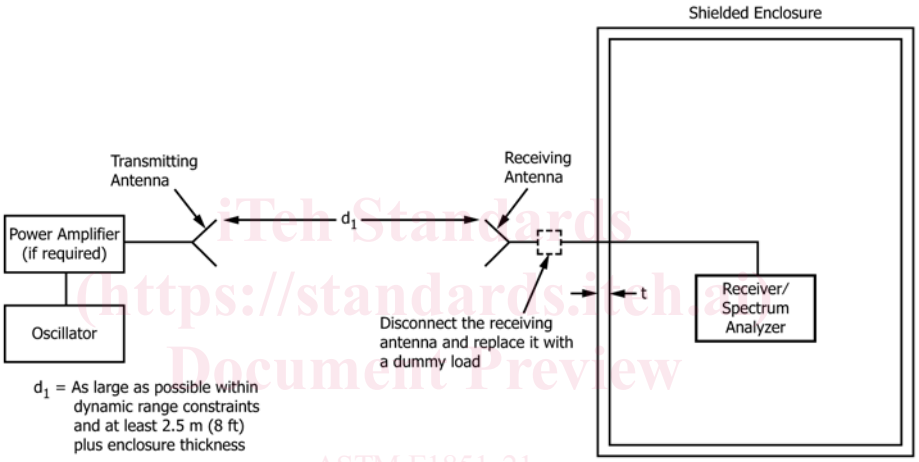
11.1.2 *Test Frequencies*—Obtain the magnetic field loop measurements at 150 kHz and 14 MHz. These test frequencies may be adjusted if the interference conditions described in 6.2 occur. Additional measurements may be performed within 10 kHz to 20 MHz if specified by the procuring agency.

11.1.3 *Corners and Edges:*

11.1.3.1 *Test Point Assignment*—For rectangular enclosures, a corner is formed where three panels meet. Assign three test



a. Magnetic Field Equipment Coupling



b. Plane Wave Equipment Coupling

FIG. 3 Equipment Coupling Measurement

points to each corner. Locate these three corner test points at a distance of 0.3 m (1 ft) from the interior corner along the three edges where three panels meet as shown in Fig. 5.

(a) An edge is formed where two non-planar panels meet. Determine the length of an edge by measuring the distance along the edge between the corner test points. The edge length determination applies to curvilinear surfaces as well. Assign edge test points that are uniformly spaced along the edge by dividing the edge length into equal segments not to exceed 0.6 m (2 ft) as shown in Fig. 6. Assign an additional test point if any test point interval exceeds 0.6 m (2 ft).

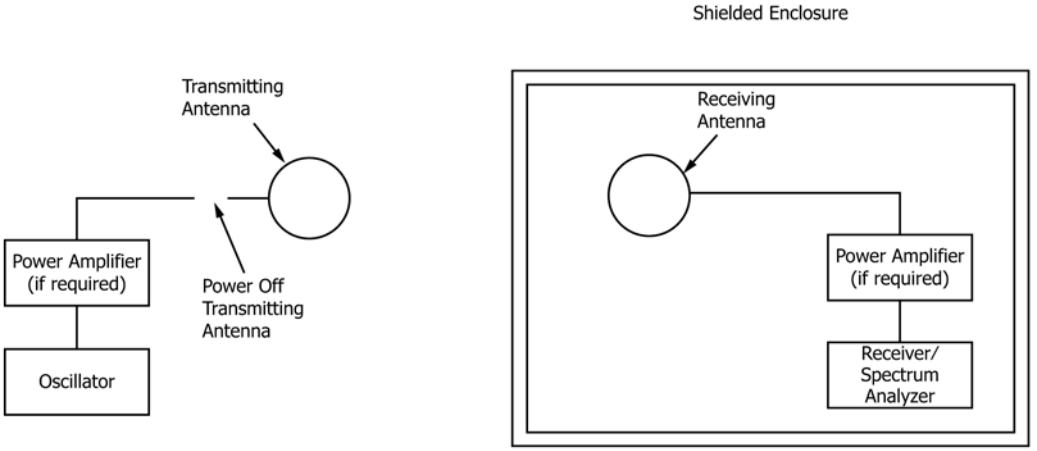
11.1.3.2 *Antenna Orientation*—For fully accessible corners, place the transmitting and receiving antennas in a coplanar orientation with the line between the center of antennas angled at 45° to the interior shielding surfaces at each test point (see Fig. 7e). For partially accessible corners, orient the transmitting and receiving antennas as shown in Fig. 7d. Position the antennas for edge test points as shown in Fig. 7e. Obtain one test measurement for each corner test point and each edge test point.

11.1.4 *Sections and Seams:*

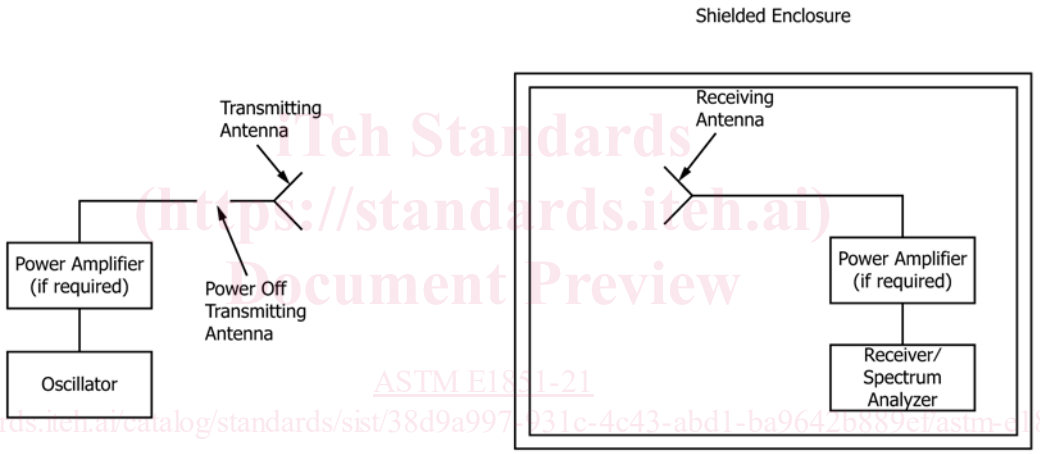
11.1.4.1 *Test Point Assignment*—A shielded enclosure is usually comprised of one or more integrally fabricated sections such as a roof panel or a formed knee-wall panel. These sections are attached together directly or to a common supporting frame. Seams are formed as a result of connecting sections together.

(a) Sections made of metallic panels do not require testing except where seams are formed. Floor sections do not require testing even if they have seams, unless otherwise specified by a procuring agency. Assign seam test points that are spaced uniformly along each seam at a spacing not to exceed 0.6 m (2 ft) as shown in Fig. 6. The seam test point spacing applies to curvilinear surfaces as well. For seams less than 0.6 m (2 ft) long, assign a single test point at the seam midpoint. Assign an additional test point if any interval exceeds 0.6 m (2 ft). Any test points that overlap with each other can be eliminated.

11.1.4.2 *Antenna Orientation*—Place the transmitting and receiving antennas in coplanar orientation as indicated in 11.1 with the coplane of antennas perpendicular to the seam line at



a. Magnetic Field Noise Measurement



b. Plane Wave Noise Measurement

FIG. 4 Noise Measurement Procedures

each seam test point. Obtain one measurement for each seam test point with the coplane of the antennas perpendicular to the seam line.

11.1.5 *Doors:*

11.1.5.1 *Test Point Assignment*—Assign one test point for each door corner. In addition, the vertical seam test points consist of two test points at one-third the distance from the top of the door and one-third the distance from the bottom of the door. The horizontal seam test points are the center of each horizontal door seam. See Fig. 7a and Fig. 7b.

11.1.5.2 *Antenna Orientation*—Place the transmitting and receiving antennas in coplanar orientation as indicated in 11.1 with the coplane of antennas perpendicular to the door seam at each test point (see Fig. 7a). Door corner test points require two measurements, first with the transmitting antenna vertically polarized and then horizontally polarized.

(a) Obtain one measurement for each door seam test point and obtain two measurements for each door corner test point (see Fig. 7). Record the highest signal and the corresponding antenna polarization.

11.1.6 *Other Openings*—This section describes test procedures for openings such as hatches, power/signal entry panels, ventilation/environmental control unit openings, and so forth.

11.1.6.1 *Test Point Assignment*—Assign one test point at the geometric center of the opening. For each opening larger than 0.6 m (2 ft) by 0.6 m (2 ft) assign additional test points to cover the entire opening. Any test points that overlap with each other can be eliminated.