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Electromagnetic Immunity—Off-Vehicle Source (Reverberation Chamber Method)—Part 16—Immunity to Radiated Electromagnetic Fields

1. *Scope*

1.1 Vehicle electrical/electronic systems may be affected when immersed in an electromagnetic field generated by sources such as radio and TV broadcast stations, radar and communication sites, mobile transmitters, cellular phones, etc. This part of SAE J551 specifies off-vehicle radiated source test methods and procedures for testing passenger cars and commercial vehicles within a Reverberation Chamber. The method is used to evaluate the immunity of vehicle mounted electronic devices in the frequency range of 80 MHz to 2 GHz, with possible extensions 20 MHz to 10 GHz, depending upon chamber size and construction. Three methods for calibrating and applying electromagnetic fields are described in the document: 1) Mode Tuned Reverberation Chamber method, 2) Mode Stir (Standard) Reverberation Chamber method and 3) Mode Stir (Hybrid) Reverberation Chamber method. Optional pulse modulation testing at HIRF (High Intensity Radiated Fields) test levels, based upon currently known environmental threats, has been included in this revision of the standard. Each method has its advantages and disadvantages which are discussed in each individual test section. All methods have been proven to be effective at finding potential field issues at the vehicle level. SAE J551-1 specifies general definitions, practical use, and basic principles of the test procedure. Specific chamber characterization procedures, formulas and calibration procedures for the Mode Tuned and Mode Stir (Standard) methods can be found in SAE J1113-28 and J1113-27 respectively. Chamber characterization procedures for the Mode Stir (Hybrid) method are described in 6.3 of this document.

1.2 This document provides vehicle manufacturers with a test procedure and performance requirements necessary to evaluate the immunity of vehicles early in the design stage as well as pilot and production stages. This method is an alternative to testing in an absorber lined chamber.

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1.3 Rationale and Application

Vehicle electrical/electronic systems may be affected when immersed in an electromagnetic field generated by sources such as radio and TV broadcast stations, radar and communication sites, mobile transmitters, cellular phones, etc. This part of SAE J551 specifies off-vehicle radiated source test methods and procedures for testing passenger cars and commercial vehicles within a Reverberation Chamber. The method is used to evaluate the immunity of vehicle mounted electronic devices in the frequency range of 80 MHz to 2 GHz, with possible extensions 20 MHz to 10 GHz, depending upon chamber size and construction. Three methods for calibrating and applying electromagnetic fields are described in the document: 1) Mode Tuned Reverberation Chamber method, 2) Mode Stir (Standard) Reverberation Chamber method and 3) Mode Stir (Hybrid) Reverberation Chamber method. Optional pulse modulation testing at HIRF (High Intensity Radiated Fields) test levels, based upon currently known environmental threats, has been included in this revision of the standard. Each method has its advantages and disadvantages which are discussed in each individual test section. All methods have been proven to be effective at finding potential field issues at the vehicle level. SAE J551-1 specifies general definitions, practical use, and basic principles of the test procedure. Specific chamber characterization procedures, formulas and calibration procedures for the Mode Tuned and Mode Stir (Standard) methods can be found in SAE J1113-28 and J1113-27 respectively. Chamber characterization procedures for the Mode Stir (Hybrid) method are described in 6.3 of this document.

This document provides vehicle manufacturers with a test procedure and performance requirements necessary to evaluate the immunity of vehicles early in the design stage as well as pilot and production stages. This method is an alternative to testing in an absorber lined chamber.

2. References

2.1 Applicable Publications

The following publications form a part of this specification to the extent specified herein. The latest issue of SAE publications shall apply.

General information regarding this test, including general definitions, and safety considerations are found in SAE J551-1.

2.1.1 SAE Publications

Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

SAE J551-1—Performance Levels and Methods of Measurement of Electromagnetic Compatibility of Vehicles and Devices (60 Hz to 18 GHz)
SAE J1812—Function Performance Status Classification for EMC Testing of Automotive Electronic and Electrical Devices
SAE J1113-27—Electromagnetic Compatibility Measurements Procedure for Vehicle Components—Part 27—Immunity to Radiated Electromagnetic Fields—Mode Stir Reverberation Method
SAE J1113-28—Electromagnetic Compatibility Measurements Procedure for Vehicle Components—Part 28—Immunity to Radiated Electromagnetic Fields—Mode Tuned Reverberation Method

2.2 Related Publications

The following publications are provided for information purposes only and are not a required part of this document.

NBS Information Report 81-1638—Evaluation of a Reverberation Chamber Facility for Performing EM Radiated Fields Susceptibility Measurements. Available from NIST, U.S. Department of Commerce, Gaithersburg, MD 20899.
Phillips Laboratory Report PL-TR-91-1036—Frequency Stirring: An Alternate Approach to Mechanical Mode-Stirring for the Conduct of EM Susceptibility Testing
Commission Directive 2004/104/EC
IEC 61000-4-3—Electromagnetic Compatibility (EMC)—Part 4-3: Testing and Measurement Techniques—Radiated, Radio-Frequency, Electromagnetic Field Immunity Test
IEC 61000-4-21—Electromagnetic Compatibility (EMC) —Part 4-21: Testing Measurement Techniques—Reverberation Chamber Test Method
GMW3097 (General Motors), “General Specification for Electrical / Electronic Components and Subsystems; Electromagnetic Compatibility (EMC)”
ES-XW7T-1A278-AC (Ford Motor Company), “Component and Subsystem Electromagnetic Compatibility, Worldwide Requirements and Test Procedures”
NBS Technical Note 1092, “Design, Evaluation, and Use of a Reverberating Chamber for Performing Electromagnetic Susceptibility / Vulnerability Measurements”
NIST Technical Note 1506, “Electromagnetic Theory of Reverberation Chambers”
NIST Technical Note 1508, “Evaluation of the NASA Langley Research Center Mode-Stirred Chamber Facility”

3. Definitions

Definitions specific to this test method are included.

3.1 Reverberation Chamber

A high Q shielded room (cavity) whose boundary conditions are changed via a rotating tuner (either stepped or continuous). This results in a time-averaged uniform electromagnetic field. The chamber size and construction determines the type of tests to be performed, the size of the vehicle to be tested, and the usable frequency range. See Appendix A for additional information.

3.2 Tuner

A large metallic reflector capable of changing the electromagnetic boundary conditions in a reverberation chamber as it rotates or moves. As the tuner moves, the nulls (Emin) and maximums (Emax) of the field change location, ensuring the vehicle is exposed to a time-averaged uniform field. Several examples of tuner designs are shown in Appendix B.

3.3 Mode Tuned Reverberation Chamber Method

During Mode Tuned Reverberation testing, the tuner is operated in a step/stop/step/stop fashion (instead of a continuous rotation). The field generating antenna is pointed into a corner of the chamber to eliminate direct coupling to the vehicle. A constant field can be applied to the vehicle for a specified dwell time at each tuner position, frequency, and modulation tested. Multiple test positions about the vehicle are no longer required since the entire vehicle is immersed in the applied field. This method requires characterization of the chamber (per IEC 61000-4-21 also described in SAE J1113-28) with and without the vehicle.

3.4 Mode Stir (Standard) Reverberation Chamber Method

During Mode Stir (Standard) Reverberation testing, the tuner is operated in a continuous rotating manner (Typically 10-20 seconds/revolution). The field generating antenna is pointed into a corner of the chamber to eliminate direct coupling to the vehicle. The dwell time at each frequency and modulation tested is typically the time it takes for one full rotation of the tuner. Multiple test positions about the vehicle are no longer required since the entire vehicle is immersed in the applied field. Characterization of the chamber, with and without the vehicle (per SAE J1113-27), is required for this method.

3.5 Mode Stirred (Hybrid) Reverberation Chamber Method

During Mode Stir (Hybrid) Reverberation testing, the tuner is operated in a continuous rotating fashion (Typically 10-20 seconds/revolution). Unlike the methods described in 3.3 and 3.4, a combination of direct illumination of the vehicle by the RF generating antenna and mode stirring are utilized. This method is typically used to evaluate larger vehicles (ie. Class 8 trucks, Agriculture Equipment, Earth Moving Equipment, etc.) in large chambers where the other indirect illumination methods are not practical. Multiple test positions about the vehicle should be utilized, since direct illumination of the vehicle is being utilized. The dwell time at each frequency tested is typically the time it takes for one full rotation of the tuner. Field uniformity characterization of the chamber without the vehicle, using methods and requirements derived from IEC-61000-4-3 is required to show the useful frequency range and the performance of the chamber.

3.6 Emax

The peak level (maximum) RF field being generated and moved about the chamber.

3.7 Emin

The minimum level (null) RF field being generated and moved about the chamber.

4. Test Conditions

The following test conditions should be condidered during the testing. See SAE J551-1 Section 6 for additional guidance on test conditions.

4.1 Test Temperature and Supply Voltage

(See SAE J551-1) In addition, heat is generated in the test facility when the vehicle is operated during the performance of the test. Sufficient cooling must be provided to ensure that the engine does not overheat. The ambient temperature in the test facility shall be recorded if it is outside the 23 °C ± 5 °C range. The electrical charging system shall be functional for tests that require the vehicle engine to be running. For tests where the vehicle engine is not required to be running, the battery voltage shall be maintained above 12.2 V and 24.4 V for 12 V and 24 V systems, respectively.

4.2 Frequency Range

(See SAE J551-1) In addition, to test automotive electronic systems, the applicable frequency range of this test method is 20 MHz to 10 GHz. Testing over the full frequency range is not required and should be done at the engineering judgment of the vehicle manufacturer. At a minimum, the testing should be performed over the frequency range of 80 MHz to 2 GHz. Different field-generating devices may be required for testing over the full frequency range. This does not imply that testing of overlapping frequency ranges is required. Ultimately, the frequency range will be limited to the chamber performance and the method being utilized.

4.3 Modulation

(See SAE J551-1) In addition, the characteristics of the systems of the vehicle determine the type and frequency of modulation. If no values are agreed upon between the users of this document, the following shall be used: a) No modulation (CW), b) 1 kHz sine wave amplitude modulation (AM) 80% and c) Pulse Modulation should also be considered at frequencies above 800 MHz (See Table C2 of Appendix C for suggested Pulse Modulations, test severity levels and Function Performance Status Classification associated with those pulse modulations).

4.4 Dwell Time

(See SAE J551-1) In addition, at each frequency the vehicle shall be exposed to the test level for the minimum response time needed to control the subsystems of the vehicle. The dwell time will also be dependent upon the method being utilized. The minimum dwell times are discussed in more detail in the test procedure for each method (See 6.1, 6.2 or 6.3).

4.5 Frequency Steps

(See SAE J551-1) In addition, the tests will be conducted with the maximum frequency step sizes shown in Table 1. Alternatively, logarithmic frequency steps (shown in Table 2), with the same minimum number of frequency steps in each frequency band, can be used. The values, as agreed upon by the users of this document, shall be documented in the test report.

NOTE—If it appears that the susceptibility thresholds of the vehicle are very near the chosen test level, these frequency step sizes should be reduced in the concerned frequency range in order to find the minimum susceptibility thresholds. (Refer to SAE J551-1.)

TABLE 1—LINEAR FREQUENCY STEPS

Frequency Band	Maximum Frequency Step Size
20 MHz to 200 MHz	2 MHz
200 MHz to 1 GHz	5 MHz
1 GHz to 2.0 GHz	10 MHz
2.0 GHz to 10 GHz	50 MHz

TABLE 2—LOGARITHMIC TEST FREQUENCY CALCULATION

$$f_{test} = f_0 * 2^{\left(\frac{k}{n}\right)}$$

where:

f_0 is base frequency

k is Frequency index number (1,2,3,…)

n is Number of steps per octave

Frequency Range (MHz)	fo (MHz)	n
1…<30	1	7
30…<400	30	25
400…<1000	400	25
1000…<10 000	1000	50

4.6 Test Signal Quality

(See SAE J551-1).

4.7 Threshold of Response

(See SAE J551-1) In addition, for continuously stirred test methods; as a responding frequency is being thresholded, the amplitude shall slowly be increased to allow time for tuner rotation so that the unit is allowed to be subjected to the high point of the field. The peak field point shall be recorded as the threshold amplitude level. During mode tuned testing, if deviations are observed, the field shall be reduced until the vehicle functions normally. The field shall then be increased in 1 dB increments and the tuner rotated to all positions for a full rotation. This process would be repeated until the deviation occurs. This level shall be reported as deviation threshold.

4.8 Test Severity Levels

(See SAE J551-1) In addition, the vehicle manufacturer shall specify the test severity level(s) over the frequency bands to be tested. Suggested test severity levels are included in Appendix C of this document. A full description and discussion of the Function Performance Status Classification including Test Severity Levels are given in SAE J1113-1 Appendix A. Please review it prior to using the suggested Function Performance Status Classification objectives presented in Appendix C. These test severity levels are expressed in terms of equivalent root-mean-square (RMS) value of an unmodulated wave. Peak conservation shall be used during amplitude and pulse modulated tests.

5. Test Instrument Description and Specification

5.1 Test Plan

Prior to performing the tests, a test plan shall be generated which shall include, vehicle mode of operation, vehicle acceptance criteria, vehicle test positions (if applicable) and any other special instructions and/or changes from the standard test. Every vehicle shall be verified under the most significant situations, e.g., at least in stand-by and in a mode where all the actuators can be excited.

5.2 Reverberation Radiated Immunity System

Reverberation Radiated Immunity is a method of carrying out immunity tests by applying disturbance signals onto the vehicle by means of a radiated RF electric field. An appropriate RF field generating device is used in conjunction with an RF amplifier and signal source. Depending upon the method being utilized, the RF electric field intensity level is established from either a previous chamber characterization or a closed loop leveling system. If the mode stirred method is being utilized, a field monitoring antenna in conjunction with a spectrum analyzer, should be used to measure the generated RF field. If electric field probes are used for mode stirred tests, they should be capable of making measurements at a rate of 50Hz or greater. The immunity tests are then carried out by varying the test severity level and frequency of the disturbance. The radiated electric field shall be applied to the entire vehicle either simultaneously or at multiple test positions, depending upon the method being utilized.

5.3 Test Setup and Instrumentation

A sample set-up for each test method is shown in Appendix A. All equipment used, shall be capable of operating over the test frequency range required. The field generating device (antenna) shall be capable of withstanding a continuous input power over the test frequency range regardless of the system loading. The RF measurement equipment shall be capable of operating over the test frequency range. Prior to testing, the RF measurement devices shall be characterized per manufacturers instructions. During testing, the RF measurement devices shall be operated in the same manner as during pretest characterization. Any variations shall be documented and noted in the test report.

5.4 Vehicle Set-Up

The vehicle should be tested as built and no additional grounding connections are allowed between the vehicle and the chamber. Tests should be performed inside a shielded room. The distance between vehicle and all other conductive structures, such as walls of a shielded room (with the exception of the ground plane underneath the vehicle), shall be a minimum of 0.5 m.

5.5 Vehicle Monitoring Equipment

Steps shall be taken to prevent RF energy from coupling into control and monitoring equipment to prevent erroneous readings. This may require RF hardening of the simulator and the control/monitoring equipment. The monitoring equipment shall be placed outside the room. Either filtering or fiber optic cables may be required. If filters are used, care should be taken to ensure that the filters do not present additional loading or affect the immunity of the vehicle.

5.6 Measurement Approach (Tuned vs Stirred)

The mode tuned approach (described in detail in SAE J1113-28 and IEC 61000-4-21) steps the tuner at selected, uniform increments, permitting measurements of the forward and reflected input power, received power, field measuring probe response, and the DUT response at each tuner position. This allows for corrections and normalization of the received power, field measurements, and DUT response due to variations in the net transmit power. The mode tuned approach also allows the operator to select long test field exposure times as needed to accommodate long DUT response times. The number of tuner steps per revolution that should be used is a function of frequency, chamber Q, and desired uncertainties. Typically, at least 20 steps are required to provide sufficient sampling to reasonably determine the statistical parameters of the test field and DUT response (maximum and average amplitudes). Additional steps (samples) will reduce the uncertainty in the measurements. If the sample size is too small, the accuracy of the measurements suffers and true maximum, minimum, etc. are not recorded. Refer to IEC 61000-4-21.

Mode stirred approach (described in detail in SAE J1113-27) rotates the tuner continuously for a complete revolution while sampling the received power, field probe response, and DUT response at rates much faster than the tuner revolution rate. The mode stirred approach allows large data sets (400 samples or more is recommended) for a single tuner revolution. Tuner revolution rates and test instrumentation sampling rates are adjusted to meet DUT response time and output monitor response time requirements. The optimum settings result in a nearly identical number of samples for the DUT and test instrumentation (see A.5.4). Revolution periods can range from 2 seconds - 10 minutes, with typical values of 10 - 20 seconds. A larger sample set can improve the accuracy in determining the statistics of the measured parameters. However, this technique may have increased uncertainty due to failure to correct for transmit power variations, unknown DUT response times, or the interactions between the DUT and the continuously changing fields in the chamber.

6. Test Methods and Procedures

CAUTION—The high RF field level generated inside the test chamber during this test may be hazardous to human health. Safety precautions shall be taken to prevent human exposure to high RF field levels.

6.1 Mode Tuned Reverberation Chamber Method

6.1.1 GENERAL

During Mode Tuned Reverberation testing, the tuner is operated in a step/stop/step/ stop fashion (instead of continuous rotation). The number of tuner steps is dependant upon the uncertainty requirements. Field uncertainty can be increased or decreased dependant upon the number of tuner steps. The tuner is stopped at each position for the dwell time required and one complete tuner rotation is required for each frequency and modulation tested.

The main beam of the field-generating antenna and field-monitoring antenna (usually in the horizontal polarization and pointed upwards at a 20 degree angle) are aimed into a corner of the chamber or at the tuner to eliminate direct coupling to the vehicle. A constant field, with the modulation required, can be applied to the vehicle for the dwell time required. Multiple test positions about the vehicle are no longer required since the entire vehicle is immersed in the applied field. Multiple antenna polarizations (horizontal and vertical) are no longer required due to loss of field polarity. During reverberation chamber immunity testing, the RF field is simultaneously bombarding the vehicle from all directions, reducing the chance of missing a response area of the vehicle due to antenna positioning.

The tuner positioning device must be a computer controlled stepper motor which can step the tuner position in fine increments (2 degrees). Specialized software used in conjunction with a computer and the RF test equipment should be utilized to characterize the chamber performance prior to any testing. The software should store the characterization information for use during testing. The computer and software will then be used to control the RF test equipment and tuner positioning during the testing. The software shall be capable of performing the tests as described in 6.1.3 of this document.

The chamber size, and the fact that indirect illumination is being utilized, will dictate the lowest usable frequency of the chamber for this method. Characterization of the chamber with and without the vehicle is required and will verify the usable frequency range of the chamber. See IEC 61000-4-21 and SAE J1113-28 for additional information in regards to chamber design, chamber characterization, and test performance.

6.1.2 Chamber Characterization

Prior to test, the empty and vehicle loaded test chamber shall be characterized using the methods described IEC 61000-4-21 (also described in SAE J1113-28). The frequency ranges discussed in the IEC 61000-4-21 and SAE J1113-28 standards can be expanded as discussed in this standard, since vehicle chambers are typically larger than the component test chambers. The usable frequency range of the chamber will be determined during the chamber characterization process.

6.1.3 Test Procedure

The vehicle shall be operated in the mode(s) that are delineated in the EMC test plan. The test shall be carried out per SAE J1113-28 with the following exceptions:

a. Setup the vehicle in the chamber as shown in Figure A-1 of Appendix A. The instrumentation setup is shown in SAE J1113-28.
b. Prior to collecting data, the Characterization and vehicle Loading Check procedures discussed in 6.1.2 shall be performed.
c. The field generating antenna and field monitoring antenna shall be in the same location as used for characterization.
d. Step the test frequencies across the desired frequency range according to Table 1 using the modulations specified in 4.3. (or as otherwise specified in the test plan).
e. The vehicle shall be exposed to the field level at each frequency for one full rotation of the tuner.
f. The dwell time at each tuner position, frequency and modulation tested shall be at least 2 s.
g. Electric field probes can be used during the test, however, shall not be used for field leveling.
h. If deviations are observed, the field shall be reduced until the vehicle functions normally. Then the field shall be increased in 1 dB increments and the tuner rotated to all positions for a full rotation. This process is repeated until the deviation occurs. This level shall be reported as deviation threshold.

6.2 Mode Stir (Standard) Reverberation Chamber Method

6.2.1 GENERAL

During Mode Stir (Standard) Reverberation testing, the tuner is operated in a continuous rotating manner (typically 10 – 20 s). The field being applied to the vehicle will be fluctuating from Emax to Emin at a rate much faster than the tuner rotation rate. At each frequency, the DUT shall be exposed to the test level for at least one rotation of the tuner. If multiple tuners are used, the dwell time shall be at least one rotation of the slowest tuner. Regardless of the number of tuners used, the rotation rate of the tuner or tuners should be slow enough to ensure that the field remains relatively constant for the duration of the dwell time. It is assumed that, during any measurement, the DUT is exposed to a constant field for the duration of the dwell time. Since, in a mode-stirred measurement, the tuner is constantly turning, it is not possible to hold the fields perfectly constant. Therefore, care must be taken to ensure that the tuner is turned slowly enough that the fields remain approximately constant for the duration of the dwell time. This may require a tuner rotation period that is several hundred times longer than the dwell time, and will be a function of frequency.

The rotation rate used at each frequency, as well as the method used to determine the rotation rate, must be documented in the test report.

The main beam of the field-generating antenna and field-monitoring antenna (usually in the horizontal polarization and pointed upwards at a 20 degree angle) are aimed into a corner of the chamber or at the tuner to eliminate direct coupling to the vehicle. Multiple test positions about the vehicle are no longer required since the entire vehicle is immersed in the applied field. Multiple antenna polarizations (horizontal and vertical) are no longer required due to loss of field polarity. During reverberation chamber immunity testing, the RF field is simultaneously bombarding the vehicle from all directions, reducing the chance of missing a response area of the vehicle due to antenna positioning.

Although a computer controlled stepper motor (similar to Mode Tuning) is preferred for the tuner positioning device a low speed motor can be used instead. Specialized software used in conjunction with a computer and the RF test equipment should be utilized to characterize the chamber performance prior to any testing. The software should store the characterization information for use during testing. The computer and software will then be used to control the RF test equipment and tuner rotation (optional) during the testing. The software shall be capable of performing the tests as described in 6.2.3 and 6.2.4 of this document.

The chamber size, and the fact that indirect illumination is being utilized, will dictate the lowest usable frequency of the chamber and this method. Characterization of the chamber with and without the vehicle is required and will verify the usable frequency range of the chamber. See SAE J1113-27 for additional information in regards to chamber design, chamber characterization, and test performance.

6.2.2 CHAMBER CHARACTERIZATION

Prior to test, the empty and vehicle loaded test chamber shall be characterized using the methods described in SAE J1113-27. The frequency ranges discussed in the SAE J1113-27 standard can be expanded as discussed in this standard since vehicle chambers are typically larger than the component test chambers. The usable frequency range of the chamber will be determined during the chamber characterization process.

6.2.3 TEST PROCEDURE (PREFERRED)

The vehicle shall be operated in the mode(s) that are delineated in the EMC test plan. The test shall be carried out per SAE J1113-27 with the following exceptions:

a. Setup the vehicle in the chamber as shown in Figure A-1 of Appendix A. The instrumentation setup is shown in SAE J1113-27.
b. Prior to collecting data, the Characterization and vehicle Loading Check procedures shall be performed.
c. The field generating antenna and field monitoring antenna shall be in the same location as used for characterization.
d. Step the test frequencies across the desired frequency range according to Table 1 using the modulations specified in 4.3. (or as otherwise specified in the test plan).
e. The dwell time at each frequency and modulation tested shall be at least one tuner rotation. If multiple tuners are utilized, the minimum dwell time at each frequency should be the time it takes for the slowest tuner to make one rotation. Regardless of the number of tuners used, the rotation rate of the tuner or tuners should be slow enough to ensure that the field remains relatively constant for the duration of the dwell time. Care must be taken to ensure that the tuner is turned slowly enough that the fields remain approximately constant for the duration of the dwell time. This may require a tuner rotation period that is several hundred times longer than the dwell time, and will be a function of frequency. The rotation rate used at each frequency, as well as the method used to determine the rotation rate, must be documented in the test report.
f. Electric field probes can be used during the test, however, shall not be used for field leveling.
g. If deviations are observed, the field shall be reduced until the vehicle functions normally. Then the field should be slowly increased in 1 dB increments per tuner rotation until the deviation occurs. This level shall be reported as deviation threshold.

6.2.4 TEST PROCEDURE (ALTERNATE)

A closed loop leveling test may be utilized as an alternate method. Prior to test, the empty test chamber shall be characterized using the methods described in SAE J1113-27. The characterization of the chamber with the vehicle will verify the usable frequency range of the chamber.

Multiple (two or more) electric field probes or a field monitoring antenna in conjunction with a spectrum analyzer can be used to measure the field at the vehicle location(s) being tested. If electric field probes are used for mode stirred tests, they should be capable of making measurements at a rate of 50Hz or greater. As the RF field is stirred the electric field displayed will vary from Emax to Emin. The RF field intensity applied to the vehicle is leveled from the Emax meter reading. Care should be taken that adequate stirring (Δ Emax and Emin > 20 dB) is occurring at the frequencies being tested. Users should understand that much higher levels of uncertainty can occur if adequate field stirring is not achieved and special considerations are required in these instances. If multiple electric field probes are used, the highest Emax meter reading of all the electric field probes will be used to determine compliance.

a. Setup the vehicle in the chamber as shown in Figure A-1 of Appendix A. The instrumentation setup is shown in SAE J1113-27 with the exception that the RF field monitoring equipment (antenna and spectrum analyzer) or multiple electric field probes will be used to control the field leveling. The field monitoring antenna may be located at the center point or the perimeter of the vehicle. The highest Emax meter reading displayed will be used to determine compliance.

b. Step the test frequencies across the desired frequency range according to Table 1 using the modulations specified in 4.3. (or as otherwise specified in the test plan)
c. The dwell time at each frequency and modulation tested shall be at least one tuner rotation. If multiple tuners are utilized, the minimum dwell time at each frequency should be the time it takes for the slowest tuner to make one rotation. Care must be taken to ensure that the tuner is turned slowly enough that the fields remain approximately constant for the duration of the dwell time. This may require a tuner rotation period that is several hundred times longer than the dwell time, and will be a function of frequency. The rotation rate used at each frequency, as well as the method used to determine the rotation rate, must be documented in the test report.
d. If deviations are observed, the field shall be reduced until the vehicle functions normally. Then the field should be slowly increased in 1 dB increments per tuner rotation until the deviation occurs. This Emax field level shall be reported as deviation threshold.

6.3 Mode Stir (Hybrid) Reverberation Chamber Method

6.3.1 General

This method is typically used in very large chambers where large vehicles (ie. Class 8 trucks, Agriculture Equipment, Earth Moving Equipment, etc.) are being tested and the other indirect illumination methods are not practical.

During Mode Stir (Hybrid) Reverberation testing, the tuner is operated in a continuous rotating manner typically 10 – 20 s. The field being applied to the vehicle will be fluctuating from Emax to Emin at the rate of the tuner rotation. At each frequency, the DUT shall be exposed to the test level for at least one rotation of the tuner. If multiple tuners are used, the dwell time shall be at least one rotation of the slowest tuner. Regardless of the number of tuners used, the rotation rate of the tuner or tuners should be slow enough to ensure that the field remains relatively constant for the duration of the dwell time. It is assumed that, during any measurement, the DUT is exposed to a constant field for the duration of the dwell time. Since, in a mode-stirred measurement, the tuner is constantly turning, it is not possible to hold the fields perfectly constant. Therefore, care must be taken to ensure that the tuner is turned slowly enough that the fields remain approximately constant for the duration of the dwell time. This may require a tuner rotation period that is several hundred times longer than the dwell time, and will be a function of frequency.

The rotation rate used at each frequency, as well as the method used to determine the rotation rate, must be documented in the test report.

Unlike the methods described in 6.1 and 6.2, a combination of direct illumination of the vehicle by the RF generating antenna and mode stirring is utilized. This is a closed loop type of test where the RF field being applied to the vehicle is monitored and leveled. Tests should be performed with the field generating antenna placed at multiple test positions about the vehicle perimeter, since direct illumination of the vehicle is being utilized. Multiple field generating antenna polarizations (horizontal and vertical) are optional if field uniformity for both field monitoring antenna polarizations can be shown with the field generating antenna in a single polarization (see 6.3.2). During reverberation chamber immunity testing, the RF field is simultaneously bombarding the vehicle from all directions, reducing the chance of missing a response area of the vehicle due to antenna positioning.

The continuous stirred chamber only requires a low speed motor for the tuner positioning device instead of a computer controlled stepper motor which is required for Mode Tuning.

The chamber size will dictate the lowest usable frequency of the chamber. Utilization of the chamber at lower frequencies may be possible since direct illumination is being utilized. A field uniformity characterization of the chamber without the vehicle, as described in 6.3.2, is required to show the useful frequency range and the performance of the chamber.

Multiple (two or more) electric field probes or a field monitoring antenna in conjunction with a spectrum analyzer can be used to measure the field at the vehicle location(s) being tested. If electric field probes are used for mode stirred tests, they should be capable of reading three orthogonal axes and making measurements at a rate of 50Hz or greater. As the RF field is stirred, the electric field displayed will vary from Emax to Emin. The RF field intensity applied to the vehicle is leveled from the Emax meter reading. Care should be taken that adequate stirring (Δ Emax and Emin > 20 dB) is occurring at the frequencies being tested. Users should understand that much higher levels of uncertainty can occur if adequate field stirring is not achieved and special considerations are required in these instances. If multiple electric field probes are used, the highest Emax meter reading of all the electric field probes will be used to determine compliance.

The following should be considered when utilizing this test method:

- The reverberation chamber shall be sized large enough to test a vehicle within the chamber's working volume.
- The mechanical tuner should be as large as possible with respect to overall chamber size (at least two-thirds of the smallest chamber dimension) and working volume considerations. Each tuner should be shaped such that a non-repetitive field pattern is obtained over one revolution of the tuner.
- The electric field probes should be capable of reading and reporting three orthogonal axes and should be capable of making measurements at a rate of 50Hz or greater.
- The RF signal generator shall be capable of covering the frequency bands and modulations specified.
- The transmit antenna shall be linearly polarized and capable of satisfying the frequency coverage requirements.
- The power amplifiers shall be capable of amplifying the RF signal to produce the required field strengths.

6.3.2 CHAMBER CHARACTERIZATION

Prior to testing, the field uniformity of the empty chamber shall be characterized using the methods described below. The field uniformity characterization of the chamber without the vehicle, using methods and requirements derived from IEC-61000-4-3 is required to show the useful frequency range and the performance of the chamber. The usable frequency range of the chamber will be determined during the chamber characterization process.

6.3.2.1 Field Uniformity Characterization

1. The field generating antenna shall be placed in a location typically used during testing, at a predetermined height (1.75 m suggested), and shall not be moved during the characterization process.
2. A 1.5 m x 1.5m planer grid consisting of sixteen (16) equally spaced points (0.5 m separation) shall be established where the vehicle perimeter will be typically located. The grid shall be parallel with the face of the field generating antenna and perpendicular with the chamber floor. The lowest four (4) grid points should be 1 meter above the chamber floor. The center point of the field monitoring antenna, with the same antenna polarization as the field generating antenna, will be placed at the first point in the grid.

3. With the tuner(s) continuously rotating and at the first frequency of test, a pre-determined reference field strength (eg Emax Level = 10V/m) shall be established. The forward power (in dBm) required to generate the reference field shall be recorded. The Emax and Emin meter readings at this frequency shall also be recorded. This process shall be repeated at all frequencies of test.
4. The field monitoring antenna shall be moved to the second point on the grid. At each frequency, the reference field strength shall be re-established. The forward power (in dBm) required to generate the reference field shall be recorded. The field intensity measured (Emax and Emin), at the reference field strength, shall be recorded.
5. Step (4) shall be repeated at the remaining grid points.
6. After the data is obtained at all sixteen (16) points of the grid, it shall be processed to determine if the empty chamber field uniformity and chamber performance in that frequency range is acceptable. As a minimum, 75% (12 of 16 points) of the power levels recorded at the 16 points for each frequency shall have a difference of less than or equal to 6 dB. In addition, adequate stirring (Δ Emax and Emin > 20 dB) shall be occurring at the frequencies being tested. If the 75% minimum field uniformity requirements of 12 points/frequency are met, go to Step (7). If the field uniformity requirements are not met, analyze the data to determine the usable frequency range of the chamber. If corrections can be made to the chamber configuration to improve performance, make the changes and perform the chamber characterization again.
7. Rotate the field monitoring antenna 90 degrees while keeping the field generating antenna in the original polarization. Perform Steps (3) through (5). Process the data of all 32 points per Step (6). As a minimum, 75% (24 of 32 points) of the power levels recorded at the 32 points for each frequency shall have a difference of less than or equal to 6 dB. If the 75% minimum field uniformity requirements of 24 points/frequency are met, then adequate loss of polarity is occurring. Testing of the vehicle can performed with a single field generating antenna polarization. If the 75% field uniformity requirements of the 24 points/frequency do not meet the requirements, then go to step (8).
8. Rotate the field generating antenna so that it is in the same polarization as the field monitoring antenna. Perform Steps (3) through (5). After the data is obtained at all sixteen (16) points of the grid, it shall be processed to determine if the empty chamber field uniformity and chamber performance in that frequency range is acceptable. As a minimum, 75% (12 of 16 points) of the power levels recorded at the 16 points for each frequency shall have a difference of less than or equal to 6 dB. In addition, adequate stirring (Δ Emax and Emin > 20 dB) shall be occurring at the frequencies being tested. If the 75% minimum field uniformity requirements of 12 points/frequency are met, then testing on the vehicle must be done with the transmitting antenna in two polarizations. If the field uniformity requirements are not met, analyze the data to determine the usable frequency range of the chamber. If corrections can be made to the chamber configuration to improve performance, make the changes and perform the chamber characterization again.

6.3.3 TEST PROCEDURE

A closed loop leveling test is utilized for this method. Multiple (two or more) electric field probes or a field monitoring antenna in conjunction with a spectrum analyzer can be used to measure the field at the vehicle location(s) being tested. If electric field probes are used for mode stirred tests, they should be capable of making measurements at a rate of 50Hz or greater. As the RF field is stirred the electric field displayed will vary from Emax to Emin. The RF field intensity applied to the vehicle is leveled from the Emax meter reading. Care should be taken that adequate stirring (Δ Emax and Emin > 20 dB) is occurring at the frequencies being tested. Users should understand that much higher levels of uncertainty can occur if adequate field stirring is not achieved and special considerations are required in these instances. If multiple electric field probes are used, the highest Emax meter reading of all the electric field probes will be used to determine compliance.

a. Setup the vehicle in the chamber as shown in Figure A-2 of Appendix A. The instrumentation setup is shown in SAE J1113-27 with the exception that the field monitoring equipment will be used to control the field leveling.
b. Based upon the vehicle system(s) being tested and their locations, determine the positions where the field generating antenna will be located during the testing. The test positions should be selected to best illuminate areas where electronic modules and their interconnecting cables are located.
c. If the field is monitored with an antenna and spectrum analyzer, the field monitoring antenna shall be placed at the location of the vehicle being tested. It shall be positioned so that it can accurately measure the field being generated during the test without effecting the area being tested. The field monitoring antenna may also be placed in the area(s) about the vehicle where the system(s) of concern are located. If electric field probes are used., at least two electric field probes should be used to level the applied RF electric field during the test. The probes should be capable of reading three orthogonal axes and making measurements at a rate of 50Hz or greater. One probe should be located at the perimeter of the vehicle where the transmitting antenna is directed. The other probe(s) shall be located in the area(s) about the vehicle where the system(s) of concern are located.
d. Step the test frequencies across the desired frequency range according to Table 1 using the modulations specified in 3.3. (or as otherwise specified in the test plan).
e. The dwell time at each frequency and modulation tested shall be at least one tuner rotation. If multiple tuners are utilized, the minimum dwell time at each frequency should be the time it takes for the slowest tuner to make one rotation. Regardless of the number of tuners used, the rotation rate of the tuner or tuners should be slow enough to ensure that the field remains relatively constant for the duration of the dwell time. Care must be taken to ensure that the tuner is turned slowly enough that the fields remain approximately constant for the duration of the dwell time. This may require a tuner rotation period that is several hundred times longer than the dwell time, and will be a function of frequency. The rotation rate used at each frequency, as well as the method used to determine the rotation rate, must be documented in the test report.
f. If deviations are observed, the field shall be reduced until the vehicle functions normally. Then the field should be slowly increased in 1 dB increments per tuner rotation until the deviation occurs. This Emax field level shall be reported as deviation threshold.

7. Test Report

When required in the test plan, a test report should be submitted detailing information regarding The test equipment, test site, systems tested, frequencies, power levels, system interactions, and any other relevant information regarding the test. The following information shall be included in the test report.

- Part Number and/or the Description of the Vehicle
- Vehicle Operating Conditions (i.e., test plan)
- Description of the Deviations Monitored
- Date of Test
- Facility Name
- Modulation Status
- Maximum Field vehicle Exposed to at Each Frequency
- Equipment Limits, if reached Requesting Engineer
- Requesting Company
- Data Summary Sheet for Each Deviation
- Indicate frequencies where L has increased by more than 6 dB and/or receive power max/min ratio is less than 20 dB.

PREPARED BY THE SAE EMI STANDARDS COMMITTEE

APPENDIX A
(INFORMATIVE)
TEST SETUP DRAWINGS FOR VEHICLE REVERBERATION TESTING

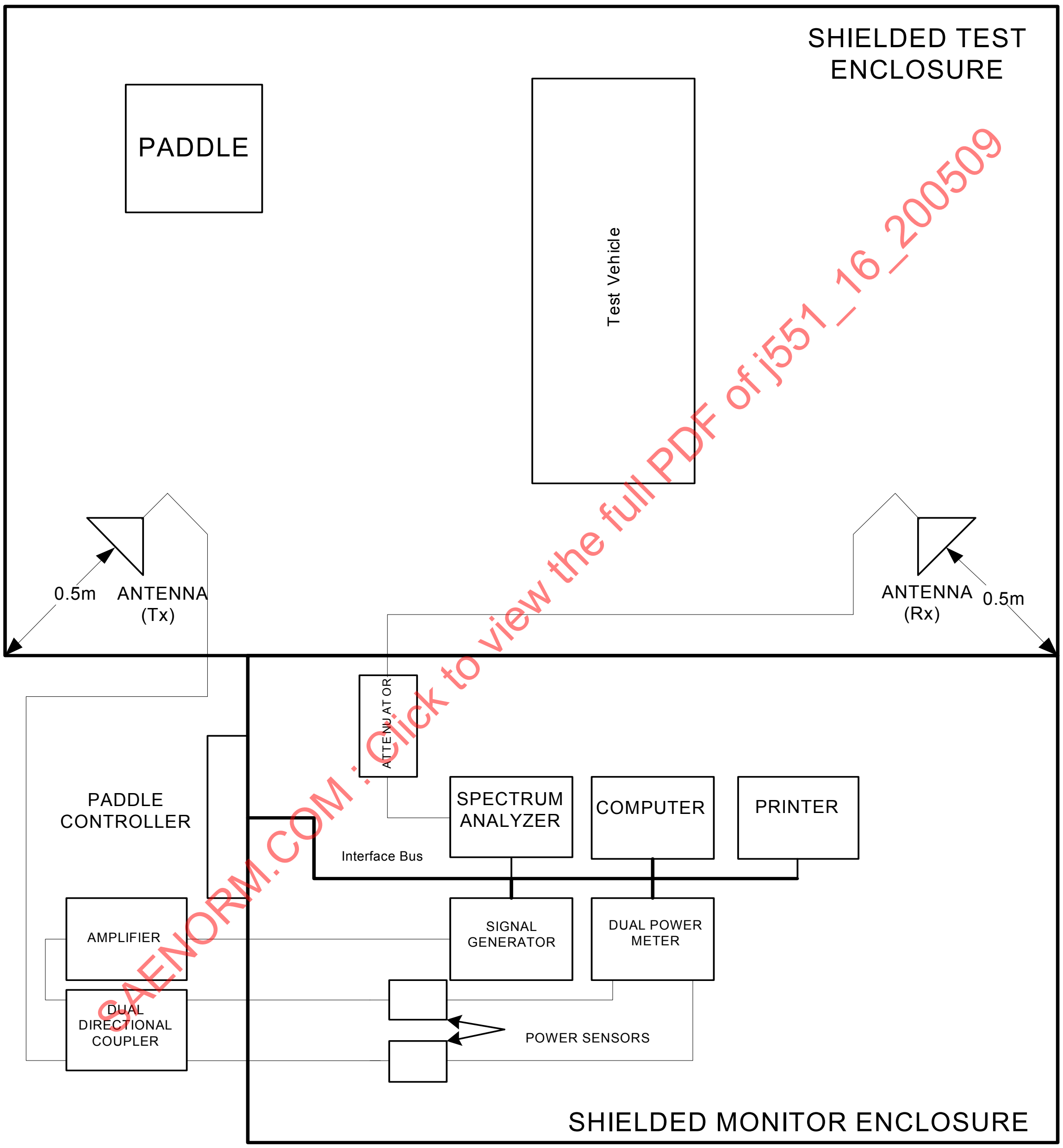

FIGURE 1—TYPICAL REVERBERATION CHAMBER LAYOUT
(MODE TUNED AND MODE STIR STANDARD)

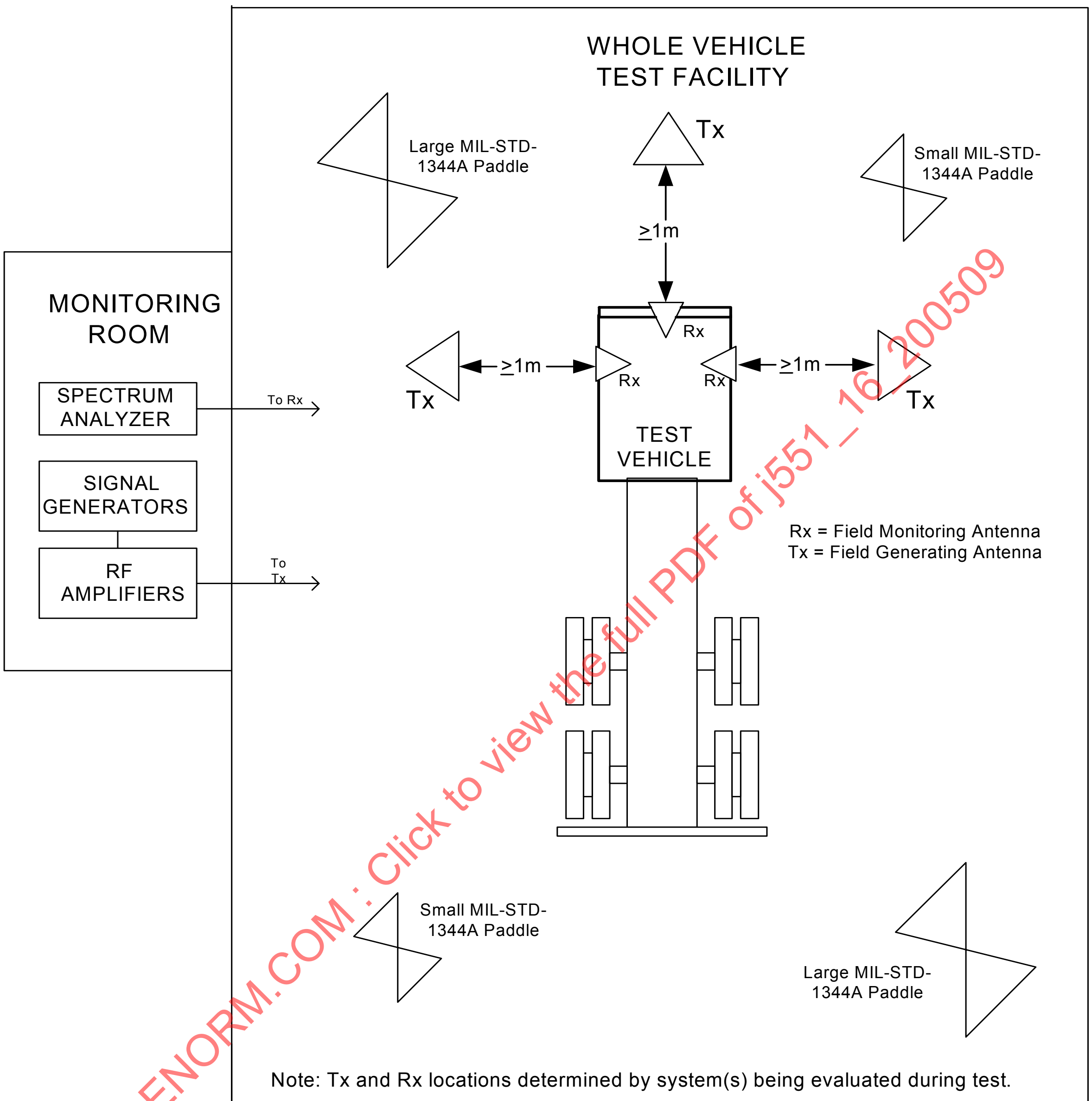

FIGURE 2—TYPICAL REVERBERATION CHAMBER LAYOUT(MODE STIR HYBRID)