

SURFACE VEHICLE STANDARD

SAE J551

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(R) PERFORMANCE LEVELS AND METHODS OF MEASUREMENT OF ELECTROMAGNETIC RADIATION FROM VEHICLES AND DEVICES (30 to 1000 MHz)

FOREWORD

International activity to control electromagnetic radiation from ignition systems of vehicles began in Paris, France in 1934. The fifty plus years following have led to the development of C.I.S.P.R.¹ Publication² 12, Third Edition.

C.I.S.P.R. limits are incorporated in the laws of European countries and are used in most of the world, except North America where the SAE J551 method is used as a basis for control of broadband electromagnetic radiation. The latter is conceptually identical, but more rigorous. It is the policy of the Electromagnetic Radiation (EMR) Technical Committee to work toward a common worldwide standard. In the past ten years the U.S. has undertaken a concerted effort to arrive at a common document by changing SAE J551 and proposing changes to Publication 12. At this time, the two documents are about 95% harmonized.

This document adopts the vast majority of the wording of the third edition of C.I.S.P.R. Publication 12. The performance limits are identical to those of Publication 12. The changes that have been made broaden the applicability of the document, enhance its applicability to automated test methods, and increase the stringency of the test by requiring scanning over the entire frequency range.

Commencing with Section 3 changed or added paragraphs are indicated by bold print; otherwise the text and numbering of paragraphs is identical to Publication 12.

¹International Special Committee on Radio Interference.

²Publication refers to C.I.S.P.R. documents.

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1. SCOPE:

This SAE Standard covers the measurement of broadband electromagnetic radiation over the frequency range of 30 to 1000 MHz from a vehicle or other device powered by an internal combustion engine or electric motor. Operation of all engines (main and auxiliary) of a vehicle or device is included. All equipment normally operating when the engine is running is also included except operator-controlled equipment, which is excluded.

The recommended level applies only to complete vehicles or devices in their final manufactured form. Vehicle mounted rectifiers used for battery charging in electric vehicles are included in this document when operated in their charging mode.

1.1 Purpose:

This document provides test procedures and recommended levels to assist engineers in the measurement of broadband electromagnetic radiation and the control of radio interference resulting from the use of equipment covered by this document.

Adherence to the recommended levels will minimize the degradation effects of large populations of potential interference sources on broadcast or communication receivers or equipment susceptible to electromagnetic radiation. Procedures are included to measure the radiation from a single vehicle or device. From these measurements, predictions may be made of the radiation levels of individual vehicles or devices in a production run.

2. REFERENCES:

2.1 Statistics:

1. Albert H. Bowker and Gerald J. Lieberman, "Engineering Statistics." Second Edition, Englewood Cliffs, NJ: Prentice-Hall Inc, 1972.
2. D. B. Owen, "Factors for One-Sided Tolerance Limits and for Variables Sampling Plans." Sandia Corporation Monograph, SCR-607 (March 1963).
3. D. B. Owen, "A Survey of Properties and Applications of the Non-Central t-Distribution." Technometrics, Vol. 10 (1968), pp. 445-478.
4. Edwin L. Crow, Francis A. Davis, Margaret W. Maxfield, "Statistics Manual." U.S. Naval Ordinance Test Station, China Lake, CA, (1955).
5. George J. Resnikoff and Gerald J. Liebermann, "Tables of the Non-Central t-Distribution." Stanford, CA: Stanford University Press, 1957.
6. Mary Gibbons Natrella, "Experimental Statistics." National Bureau of Standards Handbook 91, Issued August 1, 1963, Reprinted October 1966 with corrections.
7. Roy H. Wampler, "One-Sided Tolerance Limits for the Normal Distribution, $P=.80$, $\gamma=.80$." Journal of Research of the National Bureau of Standards Section B, Vol. 80B, No. 3, (July-September, 1976).

2.1 (Continued):

8. N. L. Johnson and F. C. Leone, "Statistics and Experimental Design I." New York: John Wiley & Sons, 1964, pp. 298-348.
9. H. J. Larson, "Introduction to Probability Theory and Statistical Inference." New York: John Wiley & Sons, 1969.
10. "The Statistical Consideration in the Determination of Limits of Radio Interference." International Electrotechnical Commission (International Special Committee on Radio Interference - C.I.S.P.R.) Report No. 48 (Document CISPR (Secretariat) 952E, September 1973 as approved at West Long Branch meeting 1973).

2.2 Antennas, Electronics, and Fields:

1. Henry Jasik and Richard C. Johnson, "Antenna Engineering Handbook." Second Edition, New York: McGraw-Hill Book Co., Inc. 1983.
2. Frederick Emmons Terman, "Electronic and Radio Engineering." Fourth Edition, New York: McGraw-Hill Book Co., Inc., 1951.
3. Frederick Emmons Terman and Joseph Mayo Pettit, "Electronic Measurements," Second Edition, New York: McGraw-Hill Book Co., Inc., 1952.
4. Simon Ramo, John R. Whinnery, and Theodore Van Duzer, "Fields and Waves in Communication Electronics." New York: John Wiley & Sons, Inc., 1965.
5. Ezra B. Larsen, "Calibration of Radio Receivers to Measure Broadband Interference." NBSIR 73-335, Final Report, Phase I (September 1973).
6. SAE ARP958, "Broadband Electromagnetic Interference Measurement Antennas; Standard Calibration Requirements and Methods." SAE, Inc., Warrendale, PA.
7. SAE ARP1267, "Electromagnetic Interference Measurement Impulse Generators; Standard Calibration Requirements and Techniques." SAE, Inc., Warrendale, PA.
8. ANSI C63.2, "Electromagnetic Noise and Field Strength Instrumentation, 10 kHz to 1 GHz." ANSI, New York.

2.3 Other:

Available from American National Standards Institute, 1430 Broadway, New York, NY 10018.

1. International Electrotechnical Commission (IEC) Publication, International Electrotechnical Vocabulary (IEV), Chapter 161 Bureau Central of IEC, Geneva, Switzerland.
2. C.I.S.P.R. Publication 12 [1990-01], "Limits and Methods of Measurements of Radio Interference Characteristics of Vehicles, Motorboats and Spark-Ignited Engine-Driven Devices." Bureau Central of IEC, Geneva, Switzerland.

2.3 (Continued):

3. C.I.S.P.R. Publication 16, "Specification for Radio Interference Measuring Apparatus and Measurement Methods." Bureau Central of IEC, Geneva, Switzerland.

3. DEFINITIONS:

For the purpose of this document, the definitions contained in IEC Publications 50 (161) and 50 (902) are applicable. For additional definitions, refer to ANSI/IEEE Standard 100.

The following definitions are specific for this document:

- 3.1 IMPULSIVE VEHICULAR NOISE: The unwanted emission of electromagnetic energy, predominately impulsive in content, arising from sources within a vehicle or device.
- 3.2 IMPULSIVE IGNITION NOISE: The unwanted emission of electromagnetic energy, predominantly impulsive in content, arising from the ignition system within a vehicle or device.
- 3.3 IGNITION NOISE SUPPRESSOR: That portion of a high voltage ignition circuit intended to limit the emission of impulsive ignition noise.
- 3.4 NOISE SUPPRESSION IGNITION CABLE: High voltage ignition cable, which has a high impedance at radio frequencies.
- 3.5 NOISE SUPPRESSION IGNITION CABLE HARNESS: A set of suppression ignition cables designed specifically for a given type of engine.
- 3.6 DISTRIBUTED IGNITION NOISE SUPPRESSORS: An ignition cable having its suppressive element (resistive or reactive) distributed throughout its length.
- 3.7 LUMPED IGNITION NOISE SUPPRESSOR: An ignition noise suppressor containing only discrete elements.
- 3.8 SPARK PLUG IGNITION NOISE SUPPRESSOR: A lumped suppression component designed for direct connection to a spark plug.
- 3.9 SLEEVE TYPE IGNITION NOISE SUPPRESSOR: A lumped suppression component designed for insertion in series in a high voltage ignition cable.
- 3.10 DISTRIBUTOR IGNITION NOISE SUPPRESSOR: A lumped suppression component designed for direct connection to the high voltage terminals of a distributor cap.
- 3.11 NOISE SUPPRESSION SPARK PLUG: A spark plug with a built-in noise suppressive element.
- 3.12 NOISE SUPPRESSION DISTRIBUTOR ROTOR: A rotor of an ignition distributor with a built-in suppressive element.

- 3.13 RESISTIVE DISTRIBUTOR BRUSH: A resistive pickup brush in an ignition distributor cap.
- 3.14 DEVICE: A machine equipped with an internal combustion engine but not self-propelled. Devices include, but are not limited to, chain saws, irrigation pumps, and air compressors.
- 3.15 IMPULSE: An impulse is a noise transient having a frequency spectrum that is instantaneously uniform over a specified frequency band.
- 3.16 IMPULSE BANDWIDTH: The maximum value of the output response envelope divided by the spectrum amplitude of an applied impulse.
- 3.17 IMPULSE ELECTRIC FIELD STRENGTH: The root-mean-square value of the sinusoidally varying radiated electric field producing the same peak response in a bandpass system, antenna and bandpass filter, produced by the unknown impulse electric field.
- 3.18 SHALL: Used to express a command. Conformance with the specific recommendation is mandatory and deviation is not permitted. The use of shall is not qualified by the fact that compliance with the document is considered voluntary.
- 3.19 VEHICLE: A self-propelled machine (excluding aircraft and rail vehicles and boats over 10 m in length). Vehicles may be propelled by an internal combustion engine, electrical means, or both. Vehicles include, but are not limited to, automobiles, trucks, agricultural tractors, snowmobiles, mopeds, and small motorboats.
- 3.20 CHARACTERISTIC LEVEL: The maximum of the measured value shall be taken as the characteristic level at each measuring frequency.
- NOTE: A characteristic level is used for the purpose of comparison with the recommended level. The characteristic level for each band shall be the maximum measurement obtained for that band for both polarizations and for all measurement positions of the vehicle or device as specified in Section 5 and shall be compared to the level at the arithmetic mean frequency of the band. Known ambient carriers shall be ignored in determining characteristic levels.
- 3.21 TRACKING GENERATOR: A narrowband radio frequency source synchronized to the instantaneous receive frequency of a scanning receiver or spectrum analyzer.

4. LIMITS OF INTERFERENCE:

The limits for radiation are in the table and shown graphically in Figure 1. Only one of the bandwidths listed need to be chosen for testing. For more accurate determination, the table given in Figure 1 shall be used:

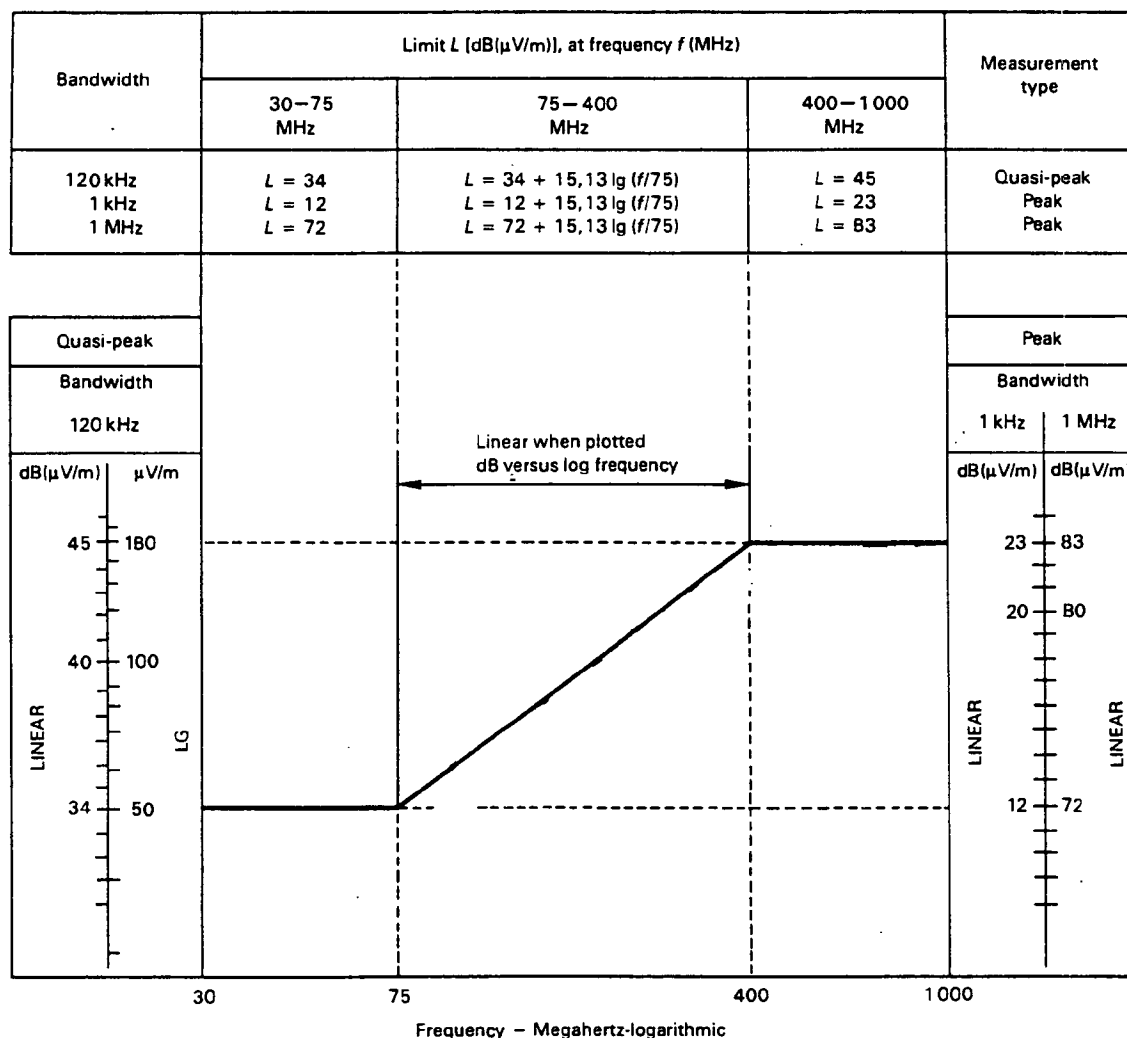


FIGURE 1 – Limits of Interference

NOTES:

- ¹Limits for vehicles equipped with electric propulsion motors are under consideration.
- ²For peak type measurements the limits given above may be related to bandwidths other than 1 KHz by adding a correction factor of $20 \log \text{bandwidth (kHz)}/1 \text{ kHz}$. For example, to relate the limit to 120 kHz bandwidth, the correction is $20 \log (120 \text{ kHz}/1 \text{ kHz}) = 42 \text{ dB}$.
- ³The correlation factor between quasi-peak and peak measurements is +20 dB at 120 kHz bandwidth.

5. METHODS OF MEASUREMENT:

5.1 Measuring Apparatus Requirements:

5.1.1 Receiver: Scanning receivers, which meet the requirements of ANSI C63.2 or C.I.S.P.R. Publication 16, are satisfactory for measurement of ignition noise. Either the peak or the quasi-peak detector may be used. Manual or automatic frequency scanning may be used.

5.1.1.1 Detector Function: The measuring instrument shall be a receiver capable of detecting the peak of the envelope of the response of a bandpass filter to an impulse type signal over the specified frequency range.

5.1.1.2 Indicating Device: The measuring instrument shall have an indicating device (meter, numerical display, graphical display, etc.) to determine the peak response as defined in Appendix G. This peak response is a function of the effective bandwidth of the measuring system (usually the impulse bandwidth of the tuned IF circuits of the measuring instrument). Hence, the effects of bandwidth shall be included in the calibration of the indicating device (see Appendix G). The indicating device readings shall be dB above 1 $\mu\text{V}/\text{kHz}$. The impulse bandwidth of the measuring instrument shall not exceed 10% of the frequency at which measurements are made.

5.1.2 Antenna Types:

5.1.2.1 Reference Antenna: The reference antenna shall be a balanced half wave resonant dipole (see C.I.S.P.R. Publication 16).

5.1.2.2 Broadband Antennas: Although linearly polarized antennas are recommended, any receiving antenna is permitted, provided that it can be normalized to the reference antenna.

A broadband antenna is required when making measurements with an automated receiving system using a scanning receiver. Such a broadband antenna is usable for measuring radiation levels (over the frequency spectrum covered by this document), provided that its output can be normalized to the output of the reference antenna in the actual test environment at the actual test site.

NOTE: When broadband antennas are used, they shall meet the requirements for complex antennas given in C.I.S.P.R. Publication 16. Examples of factors to be considered include:

- a. The effective aperture area of the antenna, including its polar response (horizontal and vertical planes).
- b. The effect of a phase center, which moves with frequency.
- c. The effect of ground reflection characteristics (including multiple ray reflections, which may arise at specific frequencies at about 500 MHz vertical polarization and 900 MHz horizontal polarization).

5.1.3 Scanning Plotters: The sine wave signal frequency response at 1.3 cm (0.5 in) peak-to-peak shall not be down by more than 3 dB at 10 Hz from the 1 Hz response.

5.1.4 Accuracy: The measuring system, excluding source, shall be able to measure impulse electric field strength over the frequency range 30 to 1000 MHz with a maximum uncertainty of ± 5 dB. The frequency uncertainty shall be less than $\pm 3\%$.

NOTE: To insure that the measurements defined in this document are within the stated tolerances, consideration should be given to all pertinent measuring equipment characteristics such as: frequency and amplitude stability, image rejection, cross-modulation, overload levels, selectivity, time constants, and signal/noise ratio as well as those affecting antenna and lead-in cable.

5.1.5 Repeatability: The repeatability of the measurement system shall be established and periodically checked to detect variability; the input/output characteristics of the measuring instrument shall be checked at shorter intervals of time.

NOTE: In view of the variations in ground conductivity and other factors that influence repeatability, it is reasonable to expect a standard deviation not to exceed 3 dB in the measurements made of an impulse electric field (see A.15) within the range of 30 to 1000 MHz.

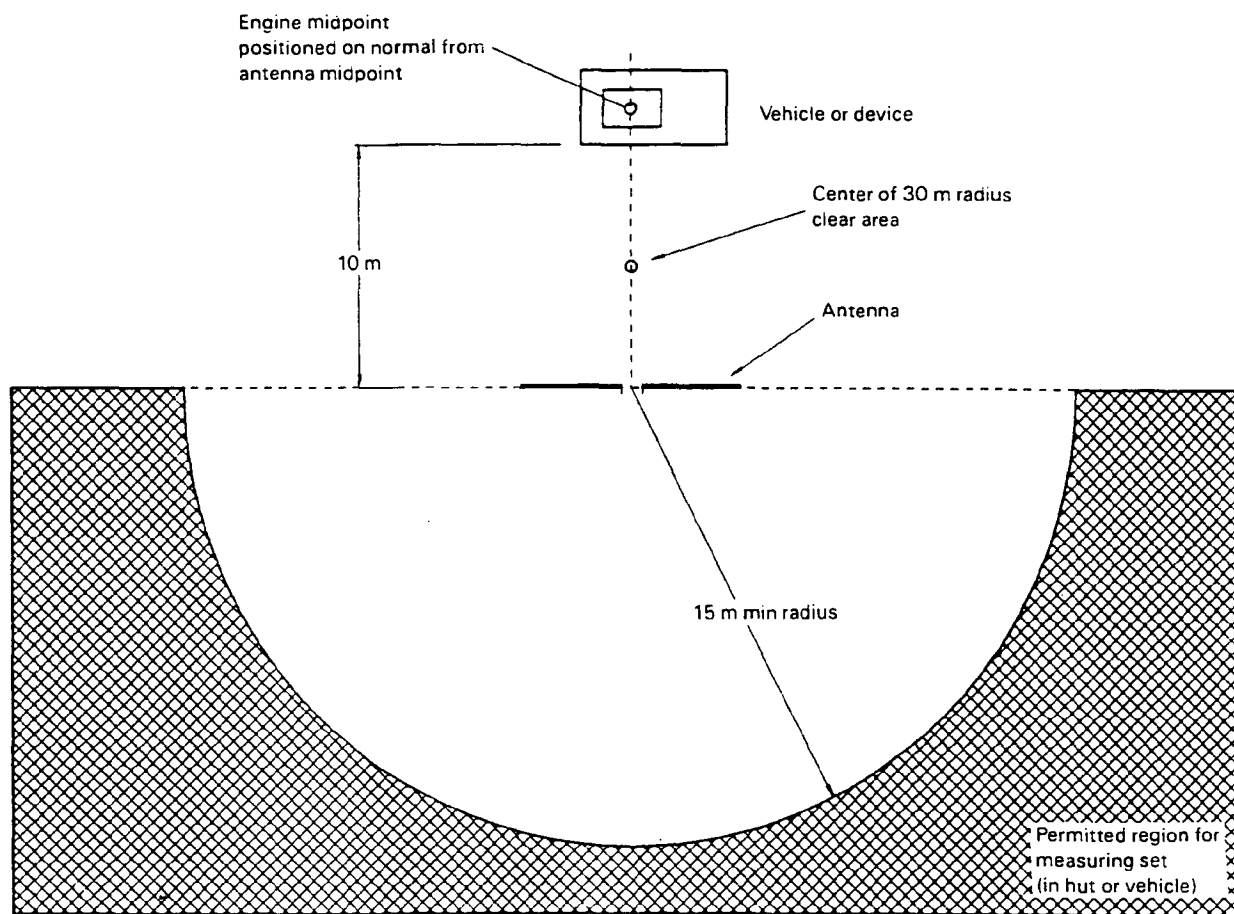
5.1.6 Calibration: See Appendix A.

5.2 Measuring Location Requirements:

5.2.1 Site Requirements:

5.2.1.1 The test site shall be a clear area free from electromagnetic reflecting surfaces within a circle of minimum radius 30 m measured from a point midway between the vehicle or device and the antenna.

5.2.1.2 The measuring set, test hut, or vehicle in which the measurement set is located may be within the test site, but only in the permitted region indicated by the crosshatched area of Figure 2.



All dimensions ± 0.2 m

FIGURE 2 - Measuring Site

NOTES:

¹The site requirements defined in 5.2.1 are the application of C.I.S.P.R. Publication 16 to large automotive objects.

²Anechoic chambers may be used provided that the results obtained can be correlated with those obtained using the outdoor sites described. Such chambers have the advantages of all weather testing, controlled environment, and improved repeatability because of stable chamber electrical characteristics.

- 5.2.2 Antenna Position Requirements: At each measuring frequency, measurements shall be taken for horizontal and vertical polarization (see Figures 3 and 4).

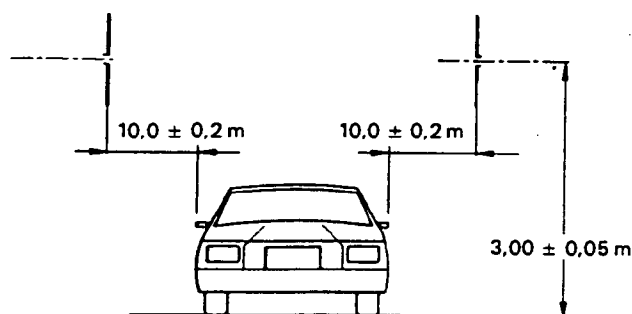


FIGURE 3 - Antenna Position to Measure Radiation: Vertical Polarization

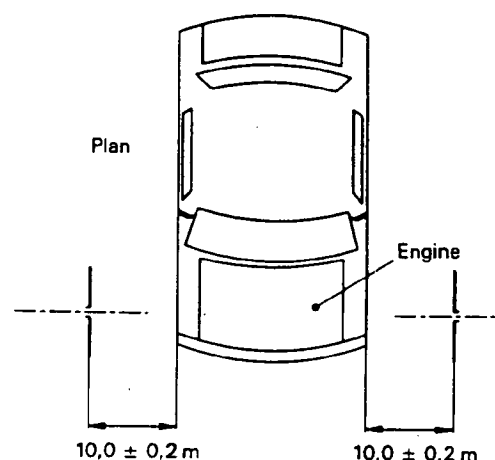


FIGURE 4 - Antenna Position to Measure Radiation: Horizontal Polarization

- 5.2.2.1 Height: The center of the antenna shall be $3.00\text{ m} \pm 0.05\text{ m}$ above the ground or water surface.
- 5.2.2.2 Distance: The horizontal distance of the antenna to the nearest metal part of the vehicle or device shall be $10.0\text{ m} \pm 0.2\text{ m}$.
- 5.2.3 Ambient Requirements: To ensure that there is no extraneous noise or signal of a magnitude sufficient to affect materially the measurement, measurements shall be taken before and after the main test, but without the engine under test running. In both of these measurements, the extraneous noise or signal shall be at least 10 dB below the limits of interference given in Section 4.
- 5.2.4 Auxiliary Antenna: For simultaneous left and right measurement in automated test systems or for reference antenna purposes, the auxiliary antenna shall be located on the other side of the vehicle or device symmetrically opposite the antenna.

To minimize possible interaction when active, the antennas shall be operated in opposite polarization modes to each other. For example, when making a simultaneous recording, one antenna would be in the horizontal mode while the other would be in the vertical mode and vice versa.

5.3 Test Object Conditions:

Measurements shall not be made while rain is falling on a vehicle or boat, nor within 10 min after the rain has stopped. For outboard engines and devices, all surfaces other than those normally in contact with water shall be dry.

NOTE: Dew or light moisture may seriously affect readings obtained on devices having plastic enclosures.

- 5.3.1 Vehicles: Measurements shall be made on the left and right sides of the vehicle (see Figures 3 and 4).

Only the ancillary electrical equipment necessary to run the engine shall be operating. The engine shall be at normal operating temperature. For vehicles equipped with an internal combustion engine, the engine shall be operated during each measurement as in Table 1:

TABLE 1 - Engine Operating Speeds

Number of cylinders	Method of measurement	
	Quasi-peak	Peak
	Engine speed	
One	2 500 rev/min	Above idling
More than one	1 500 rev/min	Above idling

NOTE: The measuring conditions for vehicles equipped with an electric propulsion motor are under consideration.

Auxiliary engines shall be operated in their normal intended manner and tested separately from the main engine, if possible.

Dependent on the location of auxiliary engines, this requirement may dictate multiple tests of the vehicle with the several engines successively positioned in front of the antenna on successive tests.

- 5.3.2 Devices: Measurements shall be made in normal operation position(s) and height(s) and without load at idle speed and in the direction of the maximum interference radiation. Where practical, the device under test shall be measured in three orthogonal planes.

As the case may be, the following conditions shall additionally be taken into account:

If the operating position and height are variable, the device to be tested shall be so positioned that the spark plug is $1.0 \text{ m} \pm 0.2 \text{ m}$ above the ground.

No operator shall be present, but, if necessary, a mechanical arrangement shall be made, using nonmetallic material as far as possible, to keep the device in normal position(s) and at the specified engine speed.

- 5.3.3 Motorboats: Inboard motorboats shall be tested in salt or fresh water as shown in Figure 5. The engine shall operate under the conditions specified in 5.3.1.

The test site shall be a clear area free from electromagnetic reflecting surfaces within a circle of minimum radius 30 m measured from a point midway between the engine under test and the antenna. The center of the antenna shall be $3.00 \text{ m} \pm 0.05 \text{ m}$ above water level.

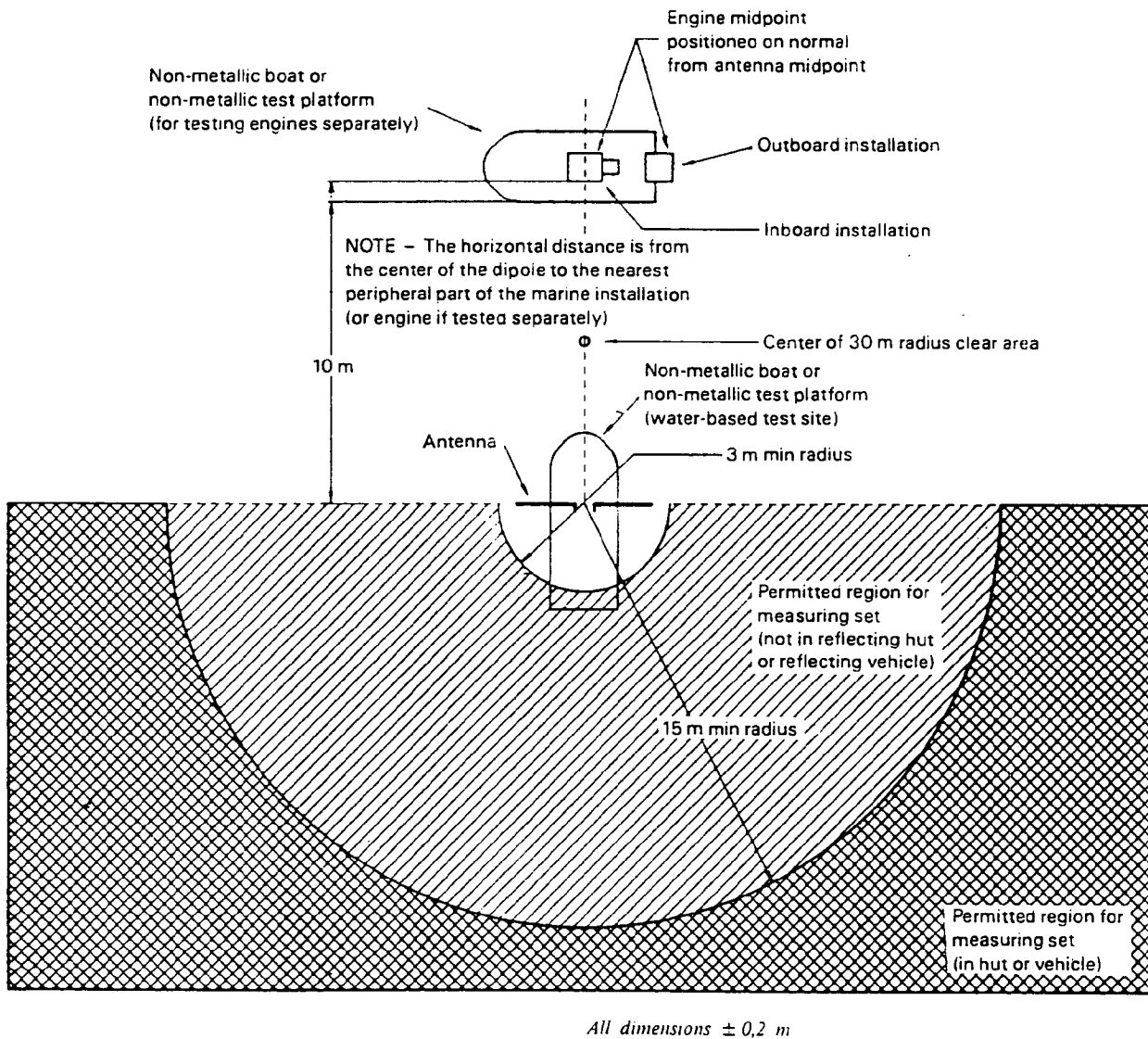


FIGURE 5 - Motorboat Measuring Site

5.3.3.1 Land-Based Testing Set: When the test equipment is on land, the test hut or vehicle in which the measuring set is located may be within the test site, but only in the permitted region indicated by the crosshatched area of Figure 5. If the measuring set is not in a hut or vehicle, it may be located within the test site in either the shaded or crosshatched area of Figure 5.

5.3.3.2 Water-Based Testing Set: The measuring set shall be installed in a nonmetallic boat or nonmetallic test fixture, which may be within the test site, but only within the permitted region indicated by the shaded area of Figure 5.

When tested separately, inboard, stern drive, and outboard engines shall be attached to a nonmetallic board or nonmetallic test fixture and tested in a similar way to that prescribed for inboard motorboats.

5.3.4 Electric Vehicles: Electric vehicles shall be tested in accordance with Appendix H.

5.3.5 Moisture: During testing, all surfaces, other than those normally in contact with water, shall be dry. Immersible devices shall be tested at their normal operating depth.

NOTE: Dew or light moisture may seriously affect readings obtained on devices incorporating plastic enclosures. Data used to determine compliance with the performance levels shall comply with the requirement of 5.3.5. Relative data may be taken on wet vehicles or devices for development or engineering purposes, but such data shall not be used to determine compliance.

5.4 Test Frequencies:

5.4.1 Frequency Range: Measurements shall be made over the frequency range of 30 to 1000 MHz. For analysis, this range shall be divided into a minimum of 14 bands with approximately three bands in each octave (2:1 ratio) of frequency. For bands that include the frequency range of 75 to 400 MHz (that is where the recommended limit is not constant), the ratio of the highest frequency to the lowest frequency in each band shall be no greater than 1.33. Each band shall be scanned to determine the maximum radiation level for that band.

Example:

30 to 34 MHz	100 to 130 MHz	400 to 525 MHz
34 to 45	130 to 170	525 to 700
45 to 60	170 to 225	700 to 850
60 to 80	225 to 300	850 to 1000
80 to 100	300 to 400	

5.4.2 Observation Time:

5.4.2.1 Peak Detected Measurements: An analog swept instrument shall scan at a rate not to exceed: ten times the instrument IF bandwidth per second. An incrementally stepped instrument shall scan at an equivalent rate, taking into account the settling time and the control time of the instrument and its control system.

5.4.2.2 Quasi-Peak Detected Measurements: The time at each frequency shall not be less than the settling time plus the control time of the instrument and its control system, or 1 s, whichever is greater.

5.5 Expression of Results:

The results of measurement shall be expressed in microvolts per meter for 120 kHz bandwidth. For statistical evaluation, the logarithmic unit dB ($\mu\text{V/m}$) shall be used. If the actual bandwidth (expressed in kilohertz) of the measuring apparatus is just outside 120 kHz for certain frequencies, the results measured shall be related to the 120 kHz bandwidth by applying the factor 120/bandwidth.

5.5.1 Characteristic Level: The maximum of the measured values shall be taken as the characteristic level at each measuring frequency.

6. METHODS OF CHECKING FOR COMPLIANCE WITH C.I.S.P.R. REQUIREMENTS:

6.1 Type Test:

6.1.1 Compliance with the requirements given in Section 4 shall be checked as follows:

6.1.1.1 Measurements may be made on a prototype vehicle or a prototype device of a later production series. The results shall be at least 2 dB below the limits specified in Section 4.

6.1.1.2 Five or more additional samples may be tested and the results combined with the first test and evaluated statistically as defined in Appendix B; the result shall be below the specified limits of Section 4.

6.1.2 Some differences in the construction of vehicles or devices are unlikely to have a significant effect on the ignition noise radiation. For road vehicles, examples of such differences are given in Appendix C.

NOTE: For vehicles with spark-ignited internal combustion engines already in service and not yet equipped with ignition noise suppressors, suppression methods as shown in Appendix D are suggested. These methods can be expected to give effective compliance with C.I.S.P.R. requirements in the majority of cases. For devices, similar suppression methods are suggested.

6.2 Surveillance of Series Production:

6.2.1 The results of the measurements on one vehicle or device may be 2 dB above the specified limits of Section 4.

6.2.2 Five or more additional samples may be tested and the results combined with the first test and evaluated statistically as defined in Appendix B; the overall result shall be below the specified limits of Section 4.