

Open Field Whole-Vehicle Radiated Susceptibility 10 kHz-18 GHz, Electrical Field - SAE J1338 JUN81

SAE Information Report
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OPEN FIELD WHOLE-VEHICLE RADIATED SUSCEPTIBILITY 10 kHz–18 GHz, ELECTRICAL FIELD—SAE J1338 JUN81

SAE Information Report

Report of the Electronic Systems Committee, approved June 1981.

1. Purpose—This report covers the open field requirements for the determination of system susceptibility in the presence of an electric field in the frequency range 10 kHz–18 GHz.

2. Measurement Philosophy—The increasing use of electronic control systems for automotive application dictates a need to ensure electromagnetic compatibility (EMC) of these systems within their intended environment. Testing techniques are needed for complete systems (whole-vehicle) since component systems, which may not be susceptible to electromagnetic interference (EMI) when tested by themselves, may be susceptible when installed as part of a larger or whole-vehicle system. Open-field testing offers an important possible test environment since it can provide both a reference and perturbation-free environment in which actual operating conditions of the equipment under test (EUT) can be simulated. Tests can be performed at discrete frequencies from 10 kHz to 18 GHz provided proper experimental licensing is first obtained from the Federal Communications Commission (FCC). Since tests must be limited to only specific FCC-approved frequencies, alternative sites, such as anechoic chambers, buried low-Q chambers, TEM cells, etc., may be more appropriate in some instances.

The scope of this report is limited to susceptibility tests of a whole vehicle as a system. Susceptibility tests on subsystems or components should be carried out as indicated in SAE J1113a (15) using laboratory facilities such as TEM cells, anechoic enclosures, parallel plate lines, or other test facilities. In such laboratory facilities, the operating parameters or variables of the device under test can be better controlled, and swept frequency testing can be performed to pin-point specific problems in the device under test.

3. Licensing—An FCC experimental license for open field radiated susceptibility tests of whole vehicles may be obtained in accordance with Part 5 of the Rules and Regulations of the FCC. The procedure and notes for this are contained in Appendix A. An FCC license *must* be obtained *before* performing open field radiated susceptibility tests.

4. Grounding and Shielding—It is recommended that a ground plane over which to perform tests be established. Such a ground plane will improve the repeatability of the tests, make establishing the test fields easier, and make the test simulate the 'worst-case' conditions in the vehicle's normal environment. The ground plane may be made of wire mesh, pierced aluminum planking, pierced steel planking, or other similar material laid on the surface, buried 1–2 in (2.5–5 cm) below the surface or cast in pavement 1–2 in (2.5–5 cm) below the surface. The ground plane must encompass the setup, including the external field generating antenna when used. It should preferably extend as far as is practicable beyond the perimeter of the vehicle under test and any test antenna used. If the extent of the ground plane around the perimeter of the vehicle under test and the test antenna is reduced to about 1 m or less, the amount of ground plane is not large enough to provide an adequate return path for displacement currents. This modifies the physical shape and extent of the electric fields and changes the coupling between the antennas and the vehicle under test in a manner which is very difficult to predict.

The test equipment must be shielded and all power and control lines to it must be shielded and filtered with sufficient effectiveness to prevent instability and false indications of susceptibility. If the test equipment is not designed to be used in high-strength fields, external shielding and filtering must be provided. The test equipment shields must be bonded to the ground plane using care not to create any ground loops or other undesired coupling paths. The test equipment operators and any other personnel involved in the tests should be provided shielding from the test fields or be located at a distance from the test setup.

An example of a ground plane layout and test facility is shown in Fig. 1 in an elevation sketch of the National Bureau of Standards (NBS) facility. Such a facility is more elaborate than is necessary, but serves as a good example of one approach to the problem.

5. Apparatus—The following listed test apparatus and equipment are needed. Typical examples of equipment and references, for example, (1), (5), etc. are listed in Section 7. The apparatus discussed in this section is recommended assuming that the highest electric field strengths to which the test vehicles are to be exposed are on the order of 200 V/m. This level was selected based on the premise that the maximum EM field exposure of the occupants of a vehicle should be 10 mW/cm². The national safety standard for nonionizing radiation gave this as the limit until late 1979.

Also, there have been studies by the Environmental Protection Agency (EPA) and others (12), (13) which would generally support this level for exposure of automobiles. If the maximum field strength to be used in the tests is much less than 200 V/m, then lower-powered generators and other apparatus may be used.

Frequency Range	Antenna Type
10 kHz – 1.6 MHz	Modified Beverage antenna (1), (5), (6), (9), parallel plate (2), (7), or 3-meter whip (transformer coupled) (3), (8)
1.6 – 10 MHz	3-Meter whip (transformer coupled) (3), (8)
10 – 25 MHz	2-Meter whip (transformer coupled or base-loaded) (3), (4), (8)
26 – 50 MHz	Mobile base-loaded or $\lambda/4$ whip
25 – 200 MHz	High-power biconical dipole
20 – 200 MHz	Log periodic array (Note 1)
148 – 174 MHz	Mobile $5\lambda/8$ or $\lambda/4$ whip
200 MHz – 1 GHz	Ridged waveguide horn or log periodic array
200 MHz – 1 GHz	Conical log spiral (Note 2)
450 – 470 MHz	Mobile colinear or $\lambda/4$ whip
800 – 915 MHz	Mobile colinear or $\lambda/4$ whip
1 – 8 GHz	Ridged waveguide horn (Note 3)
1 – 10 GHz	Conical log spiral (Note 2)
8 – 18 GHz	Rectangular waveguide horn (Note 3)

Note 1: The log periodic arrays for the frequency range of 20–200 MHz are not as effective as the high-power biconical dipoles when used near a ground plane and near the equipment under test.

Note 2: The conical log spiral antennas do not have as much gain as the ridged waveguide horns and log periodic arrays. Also, they emit a circularly polarized wave. These two factors tend to make them less desirable as susceptibility test field radiators, since more RF power is required to achieve a given linear (equivalent) field. Their VSWR also tends to be higher, making them more difficult to drive. However, since they are circularly polarized, they tend to excite all responses of the vehicle without being repositioned to provide both vertical and horizontal polarizations as is necessary with the linearly polarized antennas.

Note 3: Ridged waveguide horns could be used up to 18 GHz but most are coaxial cable fed—too lossy for frequencies above 8 GHz at the power levels necessary to achieve 200 V/m.

5.2 Generators and Transmitters—The generators and transmitters needed depend on the desired field strength and frequency for external field generation. It is assumed that tests for on-board generated fields, that is, from on-board mobile transmitters, will be performed with the maximum FCC authorized power to the antenna of 110 W for the business, public service, police, and mobile telephone radio services. The approximate generator power required to produce external fields of 200 V/m under the conditions discussed in Section 6 is given in the following table.

In the frequency range of 10 kHz–1.6 MHz, the power level is antenna height dependent. All other power level variations are versus frequency. These approximate levels are based on driving the external field generating (fixed) antennas to produce 200 V/m at the vehicle under test when set up as specified in paragraph 6.1. (These are estimates which will be refined as the technique develops.)

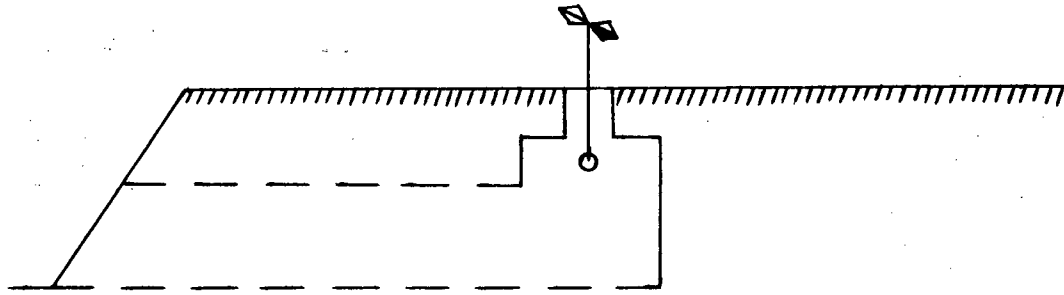


FIG. 1—NBS GROUND PLANE FACILITY

Frequency Range	Power Level
10 kHz — 1.6 MHz	0.3 — 2 kW
1.6 — 30 MHz	0.6 — 2 kW
30 — 200 MHz	2 — 0.7 kW
200 MHz — 1 GHz	0.5 kW
1 — 18 GHz	0.2 kW

5.3 Field Sensing and Calibration Equipment—The fields may be set using a standard EMI meter with calibrated dipole and rod antennas, but under some of the conditions of irradiation of the vehicle, a considerable uncertainty will exist with this method of field calibration. The magnitude of this uncertainty is generally unknown. Electrically small, isolated E-Field probes which can be used near the vehicle to sense the fields reduce the uncertainty to a known and acceptable amount provided great care is used in their placement. This is discussed more in paragraph 6.1.2. Other needed calibration equipment is listed below:

- (1) Accurate frequency meter.
- (2) Directional wattmeters 10 MHz–18 GHz.
- (3) High-impedance RF voltmeter 10 kHz–30 MHz.
- (4) Vehicle susceptibility monitoring equipment.

6. Test Setup and Procedures—This section is divided into two parts.

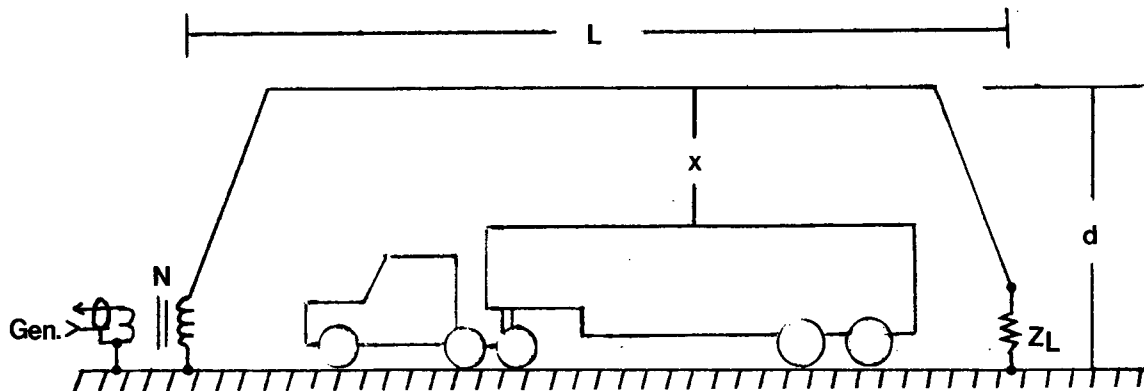
The first part, paragraph 6.1, covers the generation of fields external to the vehicle, and the second part, paragraph 6.2, covers the generation of fields from on-board transmitters.

Climatic conditions may affect the tests and should be considered. Tests must not be performed during periods of precipitation or with the surface of the vehicle under test wet. Precipitation in the air and moisture on the vehicle will cause anomalies in the electromagnetic fields and their coupling to the vehicle. Moisture collected on tents and shelters for the test site may also cause anomalous test results. The test equipment should be protected from direct sunlight and extreme temperatures, hot and cold. Temperatures that are much higher or lower than are typical for indoor laboratory environments may degrade the performance of the test equipment.

6.1 External Field Source

6.1.1 Antenna Setup

6.1.1.1 Modified Beverage or Parallel Plate Line—This antenna is set up over the ground plane so that the single-wire flat top of the modified Beverage or the upper plate of the parallel plate line is 1–2 m above the top of the vehicle. (The ground plane forms the lower plate of the parallel plate line. See References 2 and 7 on the parallel plate line for its application.) The following refers solely to the modified Beverage antenna. (See References 1 and 5.) The 50-Ω transmission line from the test signal generator must be connected to the feed end of the antenna through one or more matching transformers. The impedance transformation ratio (N^2) should be nearly equal to the ratio of the antenna impedance to 50 Ω. Fig. 2 de-



- x = space above vehicle, ideally, $x > d/2$
 - d = height of antenna above ground plane
 - L = antenna length including end sections, $L < 23$ m
 - a = radius of the wire
 - Z_a = characteristic impedance of the antenna
 - Z_L = load resistance, calculated below:
- $$P_{in} \approx \frac{E^2 d^2}{Z_L}, \quad Z_L = Z_a \approx 138 \log(2d/a)$$

FIG. 2—MODIFIED BEVERAGE ANTENNA

picts the antenna configuration. The antenna should be sufficiently long to accommodate the maximum dimension of the vehicle that is to be parallel to the antenna during the test. The flat top part of the antenna should be long enough so that the field is uniform over this dimension of the vehicle without the vehicle present. The height of the antenna and the slope of the end sections affect the uniformity of the field near the end of the flat top, so some experimentation will probably be needed to determine the necessary length.

6.1.1.2 Other Antennas—These antennas are set up near the edge of the ground plane 1 m from the vehicle under test. The height above the ground plane depends upon the type of antenna and its size. A rod or whip antenna may use the ground plane as its counterpoise, or if the antenna has its own counterpoise, it should be on or near the ground plane and electrically bonded to it. Dipole and log periodic linear antennas should be placed at a height above the ground plane as near the level of potentially susceptible circuits as possible. However, such antennas must be at least a half-length of their longest element above the ground plane where horizontally polarized and at least 0.3 m more than their longest element's half-length when vertically polarized. (This choice in vertical polarization is somewhat arbitrary, but it is accepted by the developers of MIL-STD-462 (6), (10) as minimally adequate.) The spiral antennas and the horn antennas should be placed at the level of potentially susceptible circuits, with the limit that the spiral antennas not be closer than 1 m (6), (10) to the ground plane. (The effect of the ground plane on the antenna impedance is relatively small at this and greater distances.) The position of the antenna relative to the vehicle must be changed and the test repeated as many times as necessary to assure that all critical areas of the vehicle are exposed to fields of the required strength. The area of 'uniform' exposure for the whip, dipole, and log periodic antennas is a surface of the approximate length calculated from the following equation (1) from Reference 6:

$$L = 2 \sqrt{Rd - (d/2)^2}$$

where: R is the distance between the antenna and the vehicle, and d is the thickness of the vehicle measured perpendicular to the surface directly exposed to the antenna (see Fig. 3).

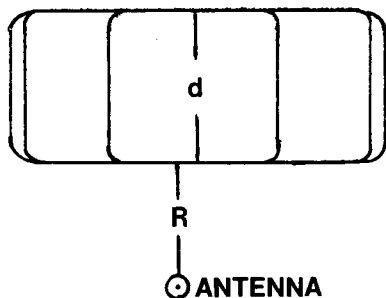


FIG. 3—PLAN VIEW OF TEST SETUP

The area of 'uniform' exposure for the horn antennas varies with the design of the horn. Refer to the manufacturer's literature to find the 3 dB beam width and apply equation (2) to find the approximate length of the area.

$$L = 2R \tan \frac{\theta}{2} \quad (2)$$

where: θ is the 3 dB beam width of the antenna and R and L are as for equation (1).

The higher frequency antennas which tend to have narrower beams of radiation may need to be mounted at elevations and angles that will maximize their radiation through windows or other openings. This may be needed for adequate tests of cluster or dash-mounted electronics. In planning the test, the effects of the vehicle body must be considered.

The whip antennas are used vertically polarized. Details on their design and construction can be found in References 3, 4, and 8. The dipole, log periodic, and horn antennas are used both vertically and horizontally polarized.

6.1.2 Field Calibration Procedure

6.1.2.1 Standard EMI Meter Method—If a standard EMI meter is used¹, place its calibrated field measuring antenna for the appropriate frequency range in the position which the vehicle is to occupy during the tests. Using the RF voltmeter below 25 MHz and the directional wattmeter above 25 MHz to monitor the RF drive to the transmitting antenna, establish the required field strength at each test frequency and record the RF voltage or the incident power to the transmitting antenna. Do not use a loop antenna to measure the field strength produced. Position the vehicle to be tested in its proper place in the test setup and re-establish the RF fields by driving the antennas with the same voltage or power at each frequency determined during calibration.

This calibration procedure is based upon the faulty premise that the field radiated by the antenna (the primary field) is unperturbed by the presence of the vehicle under test so close to the transmit antenna. This perturbation may be very large and practically unquantifiable. However, the primary field is *always* proportional to the RF voltage across the terminals of the antenna as long as the antenna is much shorter than a wavelength ($\ell \leq 0.15\lambda$). Thus, for frequencies below 25 MHz, the primary field may be reset by monitoring the RF voltage at or near (within about 30 cm at 25 MHz) the antenna terminals. Above 25 MHz, one way to counteract the interaction of the antenna and vehicle under test is to monitor both forward and reflected power and adjust the transmitter for the same net power (forward power minus reflected power) to the antenna both before and after locating the vehicle under test 1 m from it. This is not a very accurate means for maintaining the primary field, but it can be used. If a base-loaded resonant (having an electrical length of $\lambda/4$) antenna is used above 10 MHz, the directional wattmeter method will have to be used along with it. The voltmeter method can still be used with a base-loaded antenna that is electrically shorter than $\lambda/4$.

If an indication of susceptibility is observed at any test frequency, reduce the generator level to determine the threshold of susceptibility and record the RF drive voltage or power. The field strength is proportional to the drive voltage directly or the square root of the drive power.

6.1.2.2 Isolated Probe Method—If isolated probes² are used to calibrate and monitor the susceptibility test fields, arrange the transmitting antenna and the vehicle as described in paragraph 6.1.1. Place one or more isolated probes near the surface or area of the vehicle to be irradiated. Follow the probe manufacturer's instructions as to exact placement of the probes. If the probes are not properly placed, the field produced by the reflections from the vehicle under test may cause indications considerably different from those that would be produced by the primary field. For example, if the probe were placed near a discontinuity, such as a sharp bend or corner of the vehicle, or near a resonant cable or component, the reflected or scattered field could be much larger than the primary field produced by the transmit antenna. Generally, the reflections from approximately flat surfaces parallel to the direction of propagation (perpendicular to the field) will be elliptically polarized in the direction of propagation. If an electrically small probe is placed parallel to the primary field above such surfaces, the scattered field will cause only a small increase or decrease in the indication of the primary field. Again, the probe manufacturer's directions should be obtained and followed. At each test frequency, increase the generator output level until the probe (or probes) indicates the desired field strength. If more than one probe is used, the indicated field strength from each probe will probably be different, depending on its placement. The lowest indicating probe should be used as the field strength level standard for worst-case tests. Be sure that the probe polarization is appropriate for the field transmitted, that is, vertical for vertically polarized fields and horizontal³ for horizontally polarized fields. If susceptibility is found, determine and record the threshold of susceptibility.

6.1.3 Susceptibility Monitoring—Susceptibility of automotive systems and equipment must be monitored by methods appropriate to their particular characteristics. The susceptibility monitoring method must not include metallic or highly conductive wires attached to the vehicle. Such wires may perturb the test causing spurious indications of susceptibility or failure to indicate actual susceptibility. Fiber-optic links are considered

¹ Be sure that the calibrated field strength measuring antennas are rated for use in the high-strength fields that are intended to be produced.

² Battery operated optically isolated monopole E-Field probes are available from Instruments for Industry and several types of optically and high-resistance-transmission-line isolated dipole probes are available from Southwest Research Institute.

³ There is disagreement among the experts as to the accuracy of the field strength indication of unbalanced probes, e.g., monopoles when used horizontally polarized. Balanced dipole probes are preferred for horizontally polarized fields.