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SURFACE VEHICLE INFORMATION REPORT

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VEHICLE ELECTROMAGNETIC RADIATED SUSCEPTIBILITY TESTING USING A LARGE TEM CELL

***Foreword*—**This Reaffirmed Document has not changed other than to put it into the new SAE Technical Standards Board Format.

1. ***Scope*—**This information report gives the procedures for use and operation of a large transverse electromagnetic (TEM) mode cell for the determination of electromagnetic (EM) radiated susceptibility of equipment, subsystems and systems (whose dimensions are less than 3 m × 6 m × 18 m) in the frequency range 10 kHz - 20 MHz. Several large TEM cells have been designed and constructed by various organizations for EMP and high power CW testing. Two cell designs and associated instrumentation are included for example purposes in this report. Other cell configurations have also been constructed. Users should consult the literature before undertaking a project of this magnitude for other cell and instrumentation designs.

2. ***References***

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

2.1.1 N. Pollard, "A Broadband Electromagnetic Environments Simulator (EMES)," IEEE 1977 Inter. Symp. on EMC., Seattle WA, Aug 2-4, 1977.

2.1.2 W. F. Decker, M. L. Crawford, and W. A. Wilson, "Constructions of a Large Transverse Electromagnetic Cell," NBS Technical Note 1011, Feb. 1979.

2.1.3 M. L. Crawford and J. L. Workman, "Using a TEM Cell for EMC Measurements of Electronic Equipments," NBS Technical Note 1013, April 1979.

3. ***Measurement Philosophy*—**A reasonably uniform (variations $\leq \pm 2$ dB[1]) TEM field can be established over a large region using a TEM transmission cell at frequencies below approximately 20 MHz. The TEM field simulates a planar field in free space with the electric (E) and magnetic (H) fields orthogonal to each other and related by a wave impedance, nominally of 377 Ω or $n_o \cong E/H$; typically, only the electric field component is monitored.

1. Obtaining a uniform test field over a test volume as large as shown in the examples of Figures 1 and 2 at high field levels is very difficult, especially at frequencies below 20 MHz. Hence variations £ ± 2 dB are considered very reasonable.

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A typical TEM transmission cell is simply a rectangular 50-Ω transmission line constructed with transitions at each end to adapt from stripline (flat center plate) to coaxial transmission line with standard connectors.[2] Susceptibility test fields are established inside the cell by connecting an rf generator to the cell's input port and coupling rf energy through the cell to a 50-Ω termination connected to the cell's output port. Tests are performed on equipment under test (EUT) by placing the EUT inside the cell and exposing on equipment under test (EUT) by placing the EUT inside the cell and exposing it to the test field while monitoring the functional parameters of the EUT. This technique prevents disturbance to equipment not under test since the rf test field and EUT are completely self-contained within the EM enclosure.

4. ***Apparatus*—**The test apparatus consists of the following:

a. Signal Source - Any commercially available signal source and power amplifier capable of supplying up to 5000 W of modulated and unmodulated power to develop the susceptibility levels specified in the test plan may be used.[3] The harmonic and spurious outputs from the rf source should be less than –20 dB referred to the fundamental. Specific tests may require additional harmonic suppression requiring the use of appropriate low pass filters as specified in (f). The frequency accuracy shall be within ±2%, if a frequency counter is not used.
b. Rf Voltmeter - A commercially available rf voltmeter capable of measuring up to 500 V over the frequency range 10 kHz - 20 MHz.
c. Termination - One 5000-W, 50-Ω load with maximum VSWR ≤ 1.10.
d. Frequency Counter - A frequency counter capable of measuring frequencies up to 20 MHz, or an equivalent frequency determination built into the rf signal source.
e. TEM Transmission Cell - A TEM transmission cell similar to the examples shown in Figure 1 (Reference 2.1.1) or Figure 2. The cell's outer wall can be fabricated using a lining of screen wire mesh or metal sheets welded or soldered together to form a continuous electrical conductor. The small ends of the cell may be fabricated from brass, electroformed copper, or other appropriate metal material and attached to complete the cell transmission line transitions to conventional coaxial connectors. The cell's center plate or septum may also be fabricated from screen wire mesh or metal sheets welded or soldered together into the appropriate shape. All supporting members within the cell which are not a part of the effective cell conductance are constructed from material with the lowest possible dielectric constant to minimize the effects of these members on the characteristic impedance of the cell. A fabrication procedure with detailed drawings for constructing a medium-sized symmetric cell (2.8 m x 2.8 m x 5.6 m) is available (Reference 2.1.2) and may be useful in designing a full-sized cell.
f. Low-Pass Filters - As required and as appropriate with cut-off frequencies, Fc, of from 15 kHz - 30 MHz and with the signal down as required at frequencies greater than 2 Fc.
g. Signal Samplers and Monitor Tees - As required by frequency and rf voltage monitoring equipment.
h. EUT Monitors - Test equipment required to monitor the operation of the EUT.

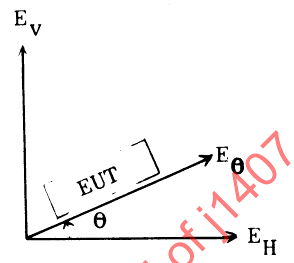
2. Other cell configurations have been developed that eliminate the need for the second output taper.
3. 5000 W of power applied to the inputs of the cells shown in Figures 1 and 2 would result in test E-field strengths of approximately 125 V/m and 83 V/m, respectively. Other rf power generation equipment may be substituted, as required, to generate higher or lower field strengths.

5. ***Test Setup and Procedure—***The TEM cell susceptibility measurement technique has been described in great detail (Reference 2.1.3). The setup and measurement procedure is summarized below.

a. The test setup is shown in Figure 3A or Figure 3B.
b. The EUT may be placed on the bottom of the cell, centered with respect to the width and length, or it can be placed on an inclined ramp as shown in Figure 2. If the EUT is not normally grounded, it should be insulated from the cell. The EUT would be placed on the inclined ramp if exposure (polarization matched proportional to sin θ to the vertical TEM field) of the long dimension of the EUT was required. The field strength, E_V, is determined by

(Eq. 1)

$E_v = V_{rf}/b$ volts/meter, or
$E_\theta = E_v \sin\theta$



where E_θ and θ are defined in the above diagram, V_{rf} is the input voltage to the cell in volts, and b is the cell bottom-to-septum separation in meters. If the test frequency is high enough (>1 MHz) that the wavelength, λ, of the test frequency is an appreciable part of the cell length, the cell input voltage may be different from the voltage potential at the center of the cell. This would result in an error proportional to the VSWR or cell mismatch impedance. A more accurate determination of the test-field amplitude at these frequencies can be made by measuring the net input power to the cell, P_{net}, and its complex admittance. The vertical E-field is then given as

$$E_V = \frac{\sqrt{P_{net}/G_C}}{b} \qquad \text{(Eq. 2)}$$

where G_c is the real part of the cell's complex characteristic admittance (≅ 0.02 mhos) referenced to the center of the cell (that is, halfway along the length of the cell transmission line). The value of E_V determined from either Equation 1 or 2 is the field approximately midway between the septum and bottom of the cell. If the EUT is placed on the bottom of the cell, the test field is approximately 3% lower for the cell of Figure 1 and 20% lower for the cell of Figure 2 as compared to the field midway between the floor and septum as determined by expression (see Equation 2). This decrease in the field amplitude is due to the E-field gradient that exists between the septum and floor.
c. The EUT should be operated as required. Connection to monitoring instrumentation may be accomplished by using fiber optics, by high resistance (carbon impregnated teflon) leads or by leads from the device to filtered feed-through connectors mounted on the bottom outer shield of the cell. The monitor leads should be oriented to obtain minimum interaction with the cell's test field. EUT/input/output leads required for operation should have similar lengths if possible as intended for normal operation, and be terminated to simulate operational conditions. Orientation of these leads in the test field established inside the TEM cell will influence the measurement results; hence, it is important to document and carefully control the leads' positioning to assure repeatability of the test results.
d. The entire frequency range, 10 kHz - 20 MHz, should be scanned. The susceptibility of any particular equipment may be extremely frequency selective which is indicative of resonance effects. Also, some EUT have components with relatively slow thermal and electrical time constants. In such cases, the sweep rate must be slow enough to allow reaction/interaction of the EUT to the test field. In addition, care must be exercised when testing the EUT at critical frequencies, such as local oscillation

frequencies, intermediate frequencies and others as specified in the test plan, to prevent irreversible damage to the EUT which would render continued testing meaningless and require costly repairs.
The susceptibility threshold levels for the EUT should be determined as a function of frequency by slowly increasing the amplitude of the test field until degradation in performance is observed or the maximum test level required is reached. The EUT susceptible frequencies and levels are then recorded.

6. Notes

a. If required in the equipment specification or approved test plan, the test signals (10 kHz - 20 MHz) can be modulated. The following guidelines are suggested:

1. EUT's with audio channels/receivers[4]

AM receivers: Modulate 30% with 100-Hz tone.
FM receivers: When monitoring signal-to-noise ratio, modulate with 1000-Hz signal using 10-kHz deviation. When monitoring receiver quieting, use no modulation.
Other Equipment: Same as for AM receivers.

2. EUT's with video channels other than receivers - Modulate 90 - 100% with pulse duration of 2/BW and repetition rate equal to BW/1000, where BW is the video bandwidth.
3. Digital equipment - Use pulse modulation with pulse duration(s) and repetition rate(s) equal to those used in the EUT.
4. Non-tuned equipment - Modulate amplitude 30% with 1000-Hz tone, or as otherwise required in the test plan.

b. This procedure also exposes the EUT to magnetic fields, and thus the cell may be calibrated for use in determining magnetic-field susceptibility.
c. Test samples of any size could be tested using a TEM cell modeled from Figures 1 or 2 to meet the criterion that the cross-sectional size of the EUT be less than $W/3 \times b/3$. (These dimensions are considered a maximum to prevent excessive impedance loading and test-field perturbation when inserting the EUT into the cell.) Thus, a small EUT could be tested at lower frequencies in large cells. If any of these dimensions are exceeded, the cell's impedance or VSWR should be measured to determine if the loaded cell VSWR (that is, with the EUT inserted) is acceptable for the particular measurement application. The procedure for testing in large cells is the same as for testing in small cells, but a larger signal source (higher power) and an appropriate high-power (50-Ω) termination are required.
d. The useful upper frequency for the cell may be reduced 20 - 30% from the cutoff/multimode frequency of the cell by the loading effect of the EUT.
e. Test samples that exceed the 1/3-linear dimension criterion could be tested in the cell (for example, up to 3 m × 6 m × 18 m in the cell of Figure 2), bearing in mind that excessive loading of the cell reduces the accuracy in determining the test field. This effect occurs because the sample tends to short out the test field in the region between the plates, increasing the vertically polarized test field. The error, however, can be reduced by measuring the field in the region above and below the EUT using small E-field probes and making an appropriate correction.

4. There are several industry standards for the performance of radio receivers that may be helpful for determining the modulation to be used on the susceptibility test signal. Two of them are IEEE 185 and EIA RS-204-A. Others may be more appropriate for certain equipment.

f. Field measurement errors may result from resonances in the EUT interacting via the cell transmission line with the rf source connected at the cell's input. These resonances can be detected at frequencies above 1 MHz by using a bidirectional coupler with rf power monitors on the calibrated ports as shown in Figure 3B. The bidirectional coupler and power monitors are used to measure both forward and reflected power at the cell's input, giving an indication of the system VSWR. The probe monitors the field level inside the cell for comparison with the predicted cell test field (based on the measured input net power to the cell, its impedance, and its plate separation). The field measurement with the probe can verify if sufficient interaction between the EUT/cell/rf source exists to destroy the absolute determination of the test-level amplitude inside the cell that stimulates the resonances in the EUT.

g. Every effort should be made to match conditions between the TEM cell and actual operating conditions. This includes, if possible, matching (1) lead lengths, (2) lead impedances, and (3) lead exposure to rf fields.

h. The wide bandwidth characteristic of a TEM cell makes it compatible with automatic testing. Several computer-controlled test instrumentation systems are commercially available.

7. Typical Test Equipment—Table 1 is provided to give typical equipment required to perform susceptibility testing using a large TEM cell. No approval or disapproval of any manufacturer is intended, either by inclusion or exclusion from this list.

TABLE 1 - Equipment List

1. Signal Source
   HP8601A Sweep Generator (100 kHz - 100 MHz)
   Wavetek Model 2001/2002 Sweep Oscillator (1 MHz - 1400 MHz)
   HP 8660A Signal Synthesizer with 86601A F Section 10 kHz - 110 MHz or
   HP 8662A Synthesized Signal Generator (10 kHz - 1280 MHz)
   AILTECH MODEL 460 Programmable Signal Generator (30 kHZ - 1300 MHz)
2. Rf Amplitifers
   Amplifier Research model 5000LA (1 - 100 MHz), 67 dBm
   Amplifier Research Model 2000L (10 kHz - 220 MHz), 63 dBm
   Instruments for Industry Model M466 (100 kHz - 100 MHz), 66 dBm
3. Frequency Counter
   HP 5305A (DC-1100 MHz)
   Fluke Model 1910/1911A/1912A (DC-125 MHz/250 MHz/520 MHz)
4. Power Meters
   HP 436A with HP8482B Sensors (100 kHz - 4.28 GHz)
5. Low Pass Filters - cut-off frequencies specified as required
   BIRD Model 5323
   Lark Engineering
   MDI Model FCL A35
6. Directional Couplers
   BIRD Model 4310 or 4311 with appropriate elements
   BIRD Model 4712 with appropriate element (2 MHz - 30 MHz)
   MDI Model 568A8 4 kW or Model 568A9, 12 kW
7. Coaxial Termination (high power)
   BIRD Model 8720 (dc-4 GHz), 4 kW
   BIRD Model 8736 (dc-1400 MHz), 10 kW
   MDI 638A (dc-1 GHz), 6 kW
8. XY Recorder
   HP 7046A Dual Channel
9. Test Monitor
   Instrument for Industries EFS-1-E-field monitor, 10 kHz - 200 MHz
   Radiation Devices Fiber Optic Model FAT-6PB (Fiberoptic analog transmitter and receiver system with optical fiber for telemetry of data). -3 dB bandwidth = 15 Hz - 30 MHz.
10. RF Voltmeter
    HP400GL (20 Hz - 4 MHz)
    HP410C (20 Hz - 700 MHz), (0.5 V-300 V), 10 MΩ with HP 455A Probe T connector
11. RF Signal Samples
    BIRD Model 4273, 5 kW (1.5 MHz - 35 MHz)

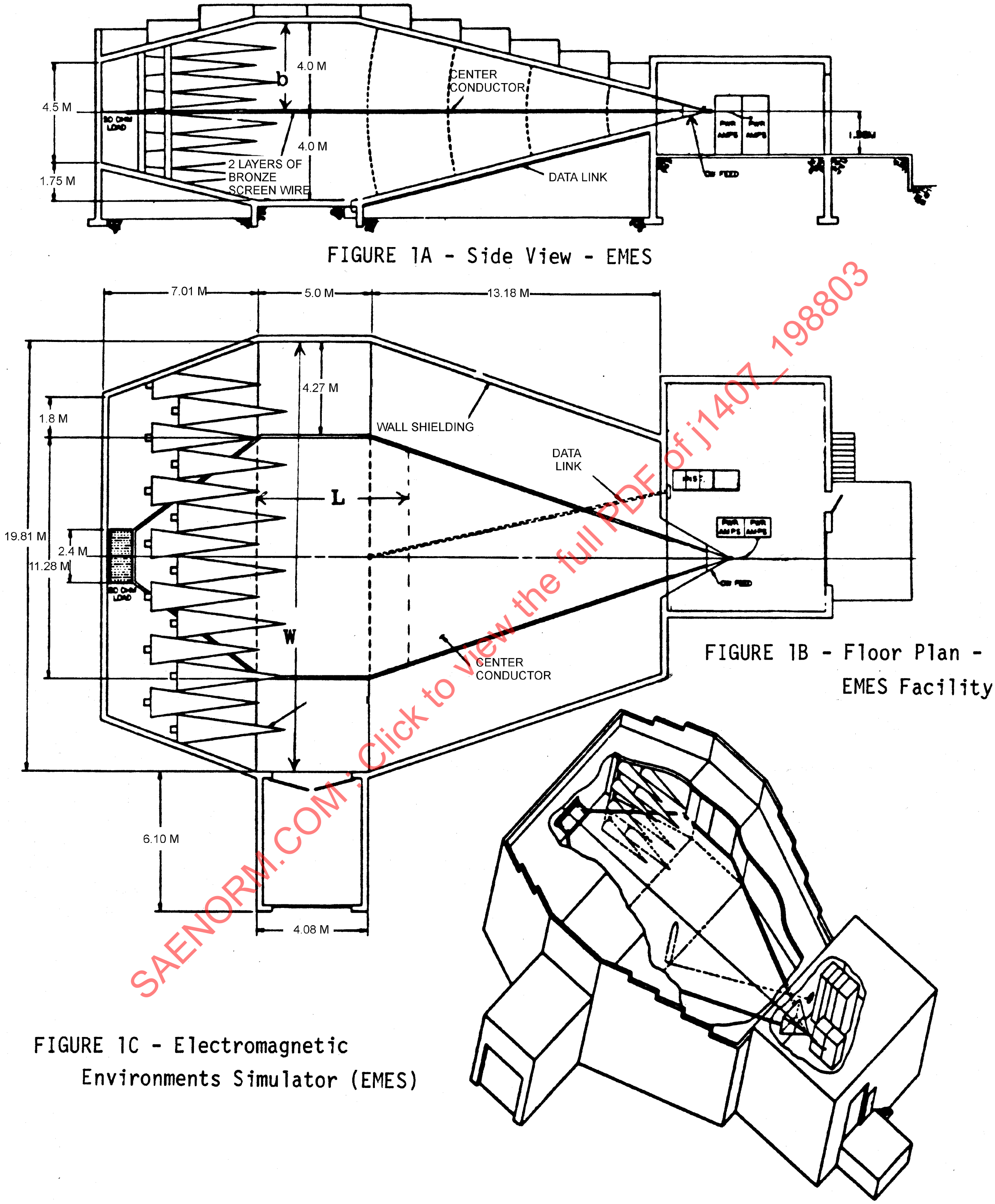


FIGURE 1A - Side View - EMES

FIGURE 1B - Floor Plan - EMES Facility

FIGURE 1C - Electromagnetic Environments Simulator (EMES)

FIGURE 1—EXAMPLE OF END LOADED TEM CELL FOR RADIATED EM SUSCEPTIBILITY MEASUREMENTS

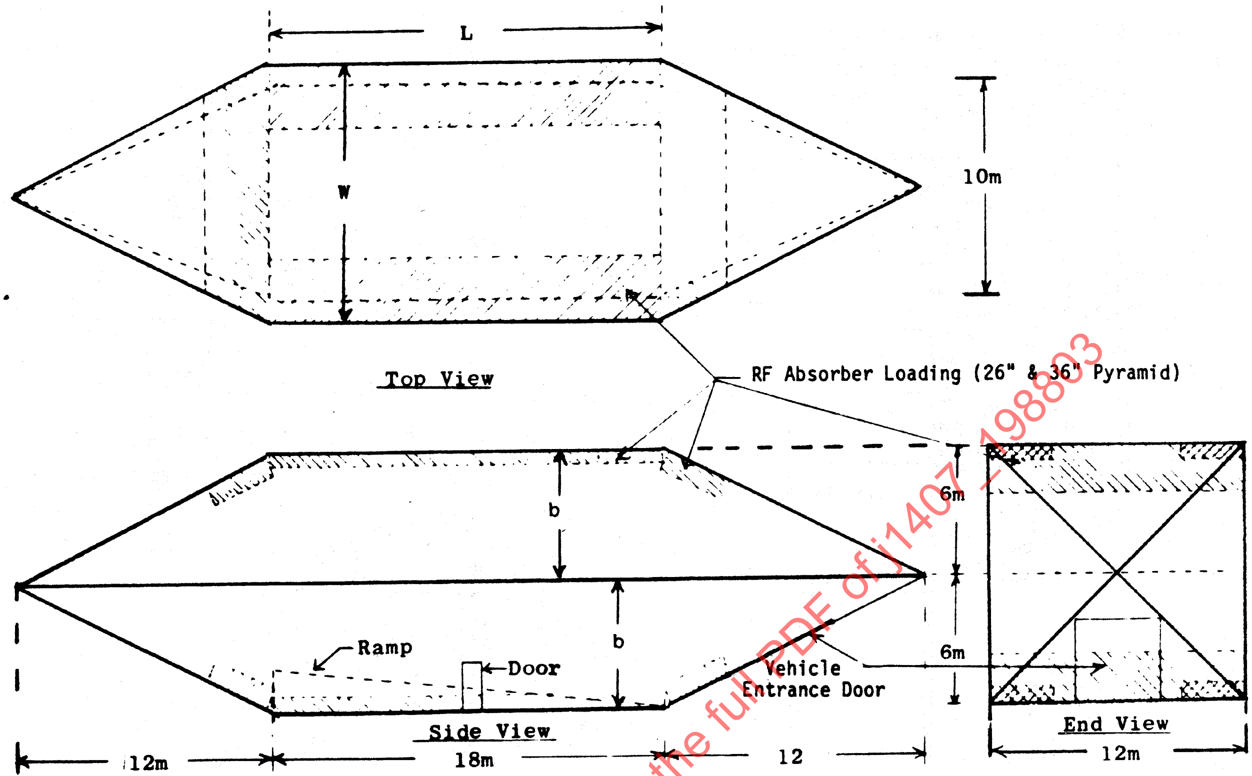


FIGURE 2—EXAMPLE OF DISTRIBUTED LOADED TEM CELL
FOR RADIATED EM SUSCEPTIBILITY MEASUREMENTS