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SURFACE VEHICLE RECOMMENDED PRACTICE

SAE J1752/3

ISSUED MAR95

Issued 1995-03

Submitted for recognition as an American National Standard

ELECTROMAGNETIC COMPATIBILITY MEASUREMENT PROCEDURES FOR INTEGRATED CIRCUITS—INTEGRATED CIRCUIT RADIATED EMISSIONS MEASUREMENT PROCEDURE 150 KHZ TO 1000 MHZ, TEM CELL

TABLE OF CONTENTS

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1. ***Scope—***This SAE Recommended Practice defines a method for measuring the electromagnetic radiation from an integrated circuit. The method uses a standardized IC test board containing the IC being evaluated mounted to a mating port cut in the top or bottom of a 1 GHz TEM cell. The standardized test board controls the geometry and orientation of the operating IC relative to the TEM cell and eliminates any connecting leads within the cell (these are on the back side of the board which is outside the cell). One of the TEM cell feeds is terminated with a 50 Ω load and the other one is connected to the input of a spectrum analyzer which measures the RF emissions over the frequency range of 150 kHz to 1000 MHz emanating from the integrated circuit and impressed onto the septum of the TEM cell (see Figure 1).

1.1 **Measurement Philosophy—**The RF voltage appearing at the input to the spectrum analyzer is related to the electromagnetic radiation potential of the IC and of the electronic module of which it would be a part. The intent is to provide a quantitative measure of the RF emissions from ICs for comparison or other purposes.

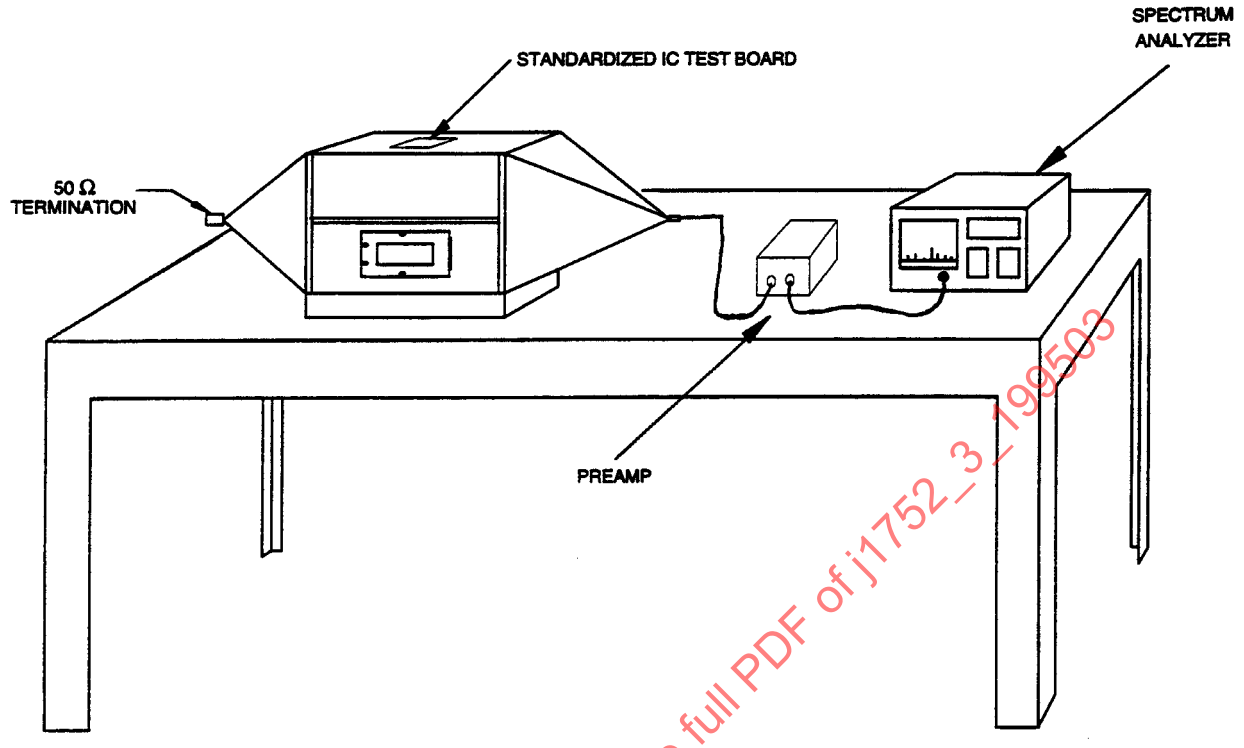

FIGURE 1—TEM CELL SETUP

2. *References*

2.1 Applicable Documents—General information relating to this document including definitions, references, and general safety considerations is available in SAE J1113/1 and SAE J1752/1.

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

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

SAE J1113/1 SEP94—Electromagnetic Compatibility Measurement Procedures and Limits for Vehicle Components

SAE J1752/1 (DRAFT)—Electromagnetic Compatibility Measurement Procedures for Integrated Circuits, General and Definitions

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

Goulette R. R., Crawhall R. J., and Xavier S. K. of Bell Northern Research, Ottawa, Ontario, Canada, "The Determination of Radiated Emissions Limits for Integrated Circuits within Telecommunications Equipment," IEICE Transactions on Communications, Vol. E75-B, No. 3, March 1992

Goulette R. R. of Bell Northern Research, Ottawa, Ontario, Canada, "The Measurement of Radiated Emissions from Integrated Circuits," 1992 IEEE International EMC Symposium Record, August 1992

Koepke, G. H. and Ma, M. T., "A New Method for Determining the Emission Characteristics of an Unknown Interference Source," Proc. 5th Intl. Zurich Symposium & Technical Exhibition on EMC, (Zurich, Switzerland), March 1983, pp. 35–40

3. Definitions—See SAE J1752/1.

4. Test Conditions

4.1 Test Temperature and Supply Voltage—The ambient temperature during the test shall be 23 °C ± 5 °C for repeatability. IC emissions may vary with temperature. For the IC being tested on the standardized test board, the supply voltage shall be as specified by the IC manufacturer. If other values are agreed to by the users of this procedure they shall be documented in the test report.

4.2 Frequency Range—The frequency range of this radiated emissions procedure is 150 kHz to 1000 MHz.

4.3 Frequency Bands—The frequency bands and spectrum analyzer settings in Table 1 are recommended.

TABLE 1—SPECTRUM ANALYZER SETTINGS

Start Frequency (MHz)	Stop Frequency (MHz)	Applications	Res. Bandwidth (kHz)
0.15	2	AM Broadcast	1
2	30	AM & SW Broadcast	10
30	200	FM & Communication	10
200	400	UHF TV	10
400	600	UHF Communication	10
600	800	UHF TV	10
800	1000	Cellular Telephone	10

5. Test Equipment

5.1 Shielding—A shielded room may be required to provide a controlled ambient for low level measurements. Double shielded or semi-rigid coaxial cable is required.

5.2 TEM Cell—The TEM cell used for this test procedure shall not exhibit higher order modes over the frequency range of 150 kHz to 1 GHz. The frequency range shall be covered using a single cell. The VSWR over this frequency range shall be less than 1.5 to 1. See Appendix A.

5.3 50 Ω Termination—A 50 Ω termination with VSWR less than 1.1 to 1 GHz, is required for one of the TEM cell feed points.

5.4 Spectrum Analyzer or Receiver—The spectrum analyzer setup is as given in Table 1 with video bandwidth greater than three times the resolution bandwidth and sweep in calibrated (coupled) mode (auto sweep). The instrument is to be set up for peak reading and max hold with measurements in dBμV [for 50 Ω system: (dBm readings) −107 = dBμV].

5.5 Preamplifier—(optional) 20 dB gain (typical) from 150 kHz to 1000 MHz. ***Information on the preamplifier and a copy of calibration data shall be included in the test report***.

5.6 System Gain—The gain (or attenuation) of the measuring equipment, without the TEM cell, shall be known with an accuracy of ±0.5 dB. The gain of the equipment shall remain within a 6 dB envelope for each frequency band.

6. Test Setup

6.1 System Setup and Calibration—All test equipment shall be calibrated on a regular basis. See Appendix A for TEM cell information. One of the TEM cell feed points is terminated with a 50 Ω load. The remaining TEM cell feed is connected to the preamplifier or spectrum analyzer as in Figure 1.

6.2 Standardized IC Test Board—Refer to Figure 2. This special square printed circuit board includes a ground plane which serves as a shield; the periphery of this shield is tinned to facilitate contact to the edge of the mating hole cut in the top or bottom of the TEM cell. The top side of this board that is inside the test cell shall be fully shielded except for the IC being evaluated and the narrow strip of vias around the IC. The access wiring and other required components (such as crystals) shall be on the other (bottom) side of this board (the side that is outside the TEM cell) or on a daughter board that is connected to the back side of the test board. Power bypass capacitors for the IC are to be chosen according to manufacturer's recommendations and located to minimize lead length. All wiring should be minimized and controlled. ***A description of the test board setup (photo or artwork, schematic, and parts list) shall be included with the test report.***

6.3 Test Board Power Supply—The DUT shall be powered from a source with low conducted RF emissions that will not interfere with or confuse the test results. A low impedance battery (i.e., alkaline, nickel-cadmium, or equivalent) is the preferred power source (carbon batteries are not acceptable). Check battery before and after test. An AC power supply may be used if it meets the low RF emissions requirement. All power supply lines into the DUT shall be adequately filtered per the IC manufacturer's recommendation.

6.4 IC Software—If a programmable integrated circuit is to be tested, software which flows in a continuous loop shall be written to assure that measurements are repeatable. ***The type of software used to exercise the IC (minimum, typical, or worst case) shall be documented with the test report.***

6.4.1 MINIMUM—Implement counter function, see Appendix B: Test Code—Counter Circuit.

6.4.2 TYPICAL—Exercise microprocessor and I/O on a "normal" basis using production code.

6.4.3 WORST CASE—Exercise all I/O, see Appendix C: Worst Case Software Description.

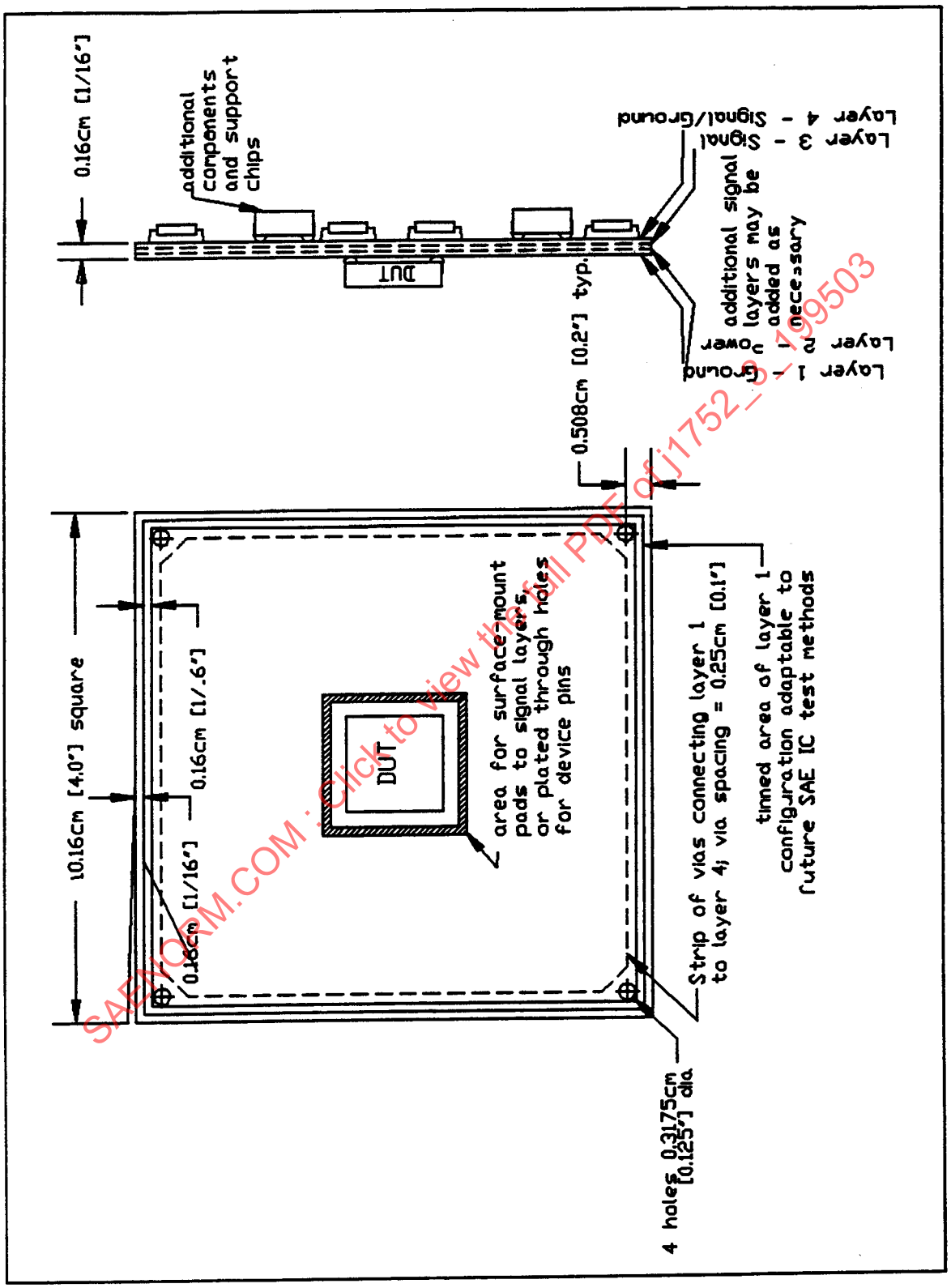

FIGURE 2—STANDARDIZED IC TEST BOARD

6.5 Multi IC Sets—ICs that operate as part of a set shall be evaluated by one of the following methods:

6.5.1 INDIVIDUALLY WITH SIMULATED LOADS—Load I/O pins on the IC to simulate in-circuit values as given in Table 2.

TABLE 2—IC PIN LOADING REQUIREMENTS

IC PIN TYPE	PIN LOADING REQUIREMENTS
POWER - DIGITAL	PER MANUFACTURER'S TYP. LOAD RECOMMENDATIONS
POWER - ANALOG	PER MANUFACTURER'S TYP. LOAD RECOMMENDATIONS
ANALOG I/O	SAME AS DIGITAL I/O
DIGITAL INPUT	GND OR 10K PULLUP TO V_{cc} IF CANNOT GND
DIGITAL OUTPUT	50 pF TO GND
DATA/ADDRESS	PER MANUFACTURER'S TYP. LOAD RECOMMENDATIONS
CONTROL INPUT	GND OR 10K PULLUP TO V_{cc} IF CANNOT GND
CONTROL OUTPUT	PER MANUFACTURER'S TYP. LOAD RECOMMENDATIONS
BIDIRECTIONAL	CONFIGURE AS OUTPUT - 50 pF TO GND

NOTE—These are recommended default values. If other values are more appropriate for a particular IC, they may be substituted for the values in Table 2 and shall be called out in the test report.

6.5.2 INDIVIDUALLY WITH SUPPORTING ICS—The IC being evaluated shall be mounted on the top side of the standardized test board with the other supporting ICs located on the underside of the board with minimal connecting lead length.

6.5.3 AS AN IC CHIP SET—A set of ICs may be evaluated together in order to characterize the emissions from the system (i.e., operating a microprocessor in expanded mode). The set being evaluated shall be grouped together on the top side of the test board in a compact configuration.

7. Test Procedure

7.1 Ambient—Measure ambient levels to ensure that any ambient signals present are at least 6 dB below the target reference level (see Section 8). This is accomplished by placing the IC mounted on the standardized test board in the measurement position on the TEM cell port with the test board not powered and measuring the detected ambient level with the spectrum analyzer. ***The ambient data shall be a part of the test report.*** If the ambient is excessive, check the integrity of the overall system, especially the interconnecting cables and connectors. If necessary, use a shielded enclosure, a lower noise preamplifier, or a narrower spectrum analyzer resolution bandwidth.

7.2 Operational Check—Energize the DUT and complete an operational check to assure proper function of the device (i.e., run IC test code, see 6.4).

7.3 Test Technique—With the test board energized and the IC under test being operated in the intended test mode, monitor the R**F emissions using the spectrum analyzer set up according to Table 1 and accumulating *3 sweeps on max hold.*** Two sets of data are to be taken, one with the standardized IC test board in the original position and also with it rotated 90 degrees. ***Both sets of data are to be reported.***

7.4 Test Report—*Measurement parameters shall be documented using the data sheet illustrated in Figure 4 to record the required information and this data sheet shall accompany the measurement data.*

8. IC Emissions Reference Levels—IC emissions acceptance levels are to be agreed upon between the manufacturers and the users of ICs and may be selected from the reference levels in Figure 3. These reference levels apply to measurements over the frequency range of 150 kHz to 1000 MHz in units of dBμV. To transform the dBμV level obtained from the spectrum analyzer into an equivalent index of the strength of the IC as an electric or magnetic field source, see Appendix D.

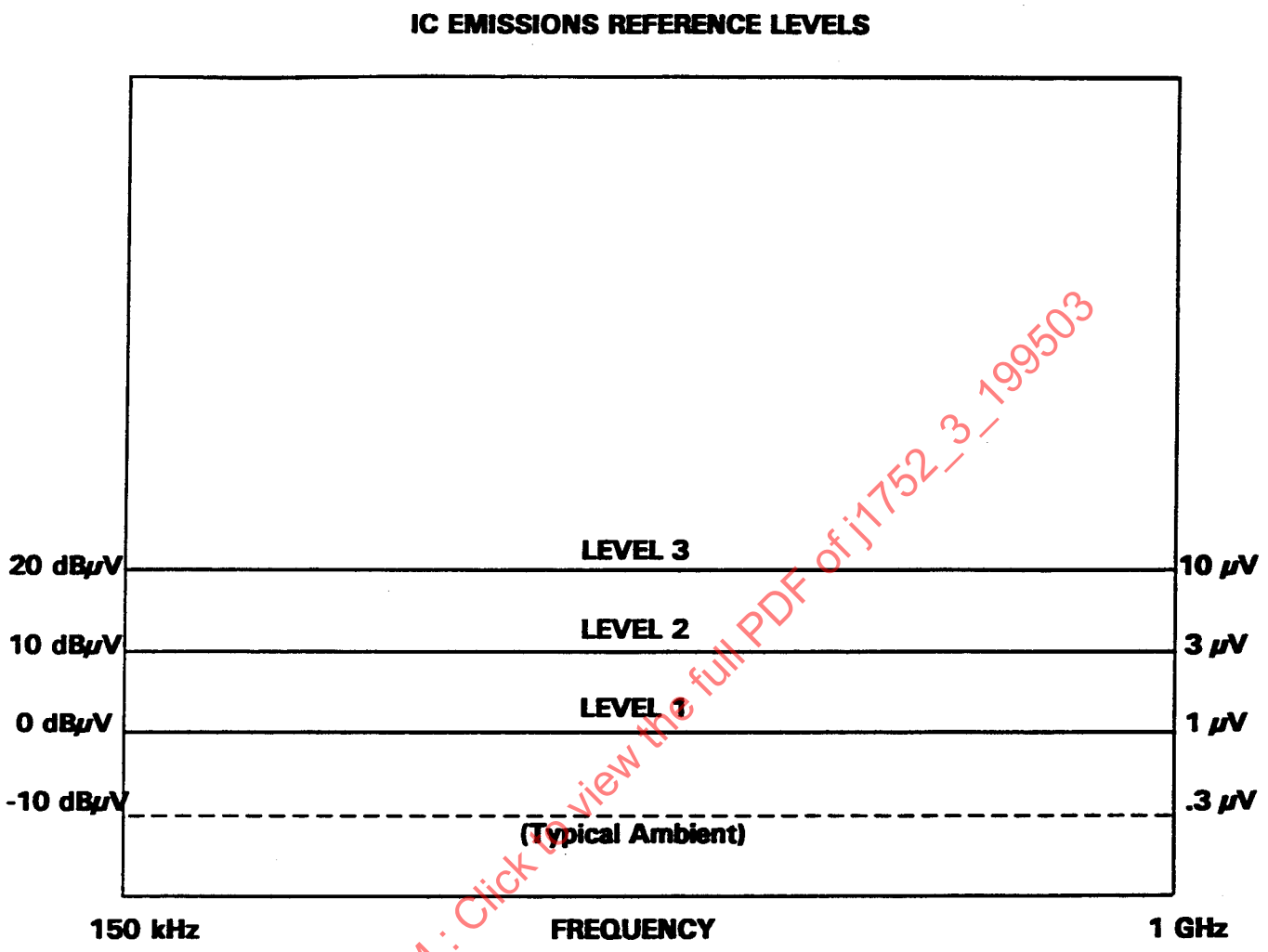

FIGURE 3—IC EMISSIONS REFERENCE LEVELS

INTEGRATED CIRCUIT RADIATED EMISSIONS MEASUREMENT PROCEDURE

150 kHz to 1 GHz, TEM CELL

SAE J1752/3 DATA SHEET	
TEM cell used:	**VSWR OK to 1 GHz:**
Spectrum analyzer used:	**Cal. OK to 1 GHz:**
RBW:	**VBW:**
Pre-amp model:	**Gain: Cal. OK to 1 GHz:**
Coax cable type and approx. length:	
50 ohm termination for TEM cell verified to 1 GHz:	
System gain check (without the TEM cell):	
Ambient noise floor level:	
Ambient temperature:	
IC supply voltage:	**Power supply or battery:**
Type of software used to exercise the IC:	
Notes:	

Description of IC test board (attach picture or copy of artwork, schematic & parts list):

FIGURE 4—EXAMPLE DATA SHEET

PREPARED BY THE SAE IC-EMC TASK FORCE OF THE SAE EMR COMMITTEE

APPENDIX A

1 GHZ TEM CELL

A.1 The TEM cell offers a broadband method of measuring either immunity of a DUT to fields generated within the cell or radiated emissions from a DUT placed within the cell. It eliminates the use of conventional antennas with their inherent measurement limitations of bandwidth, nonlinear phase, directivity, and polarization. The TEM (Transverse Electromagnetic Mode) cell is an expanded transmission line that propagates a TEM wave from an external or internal source. This wave is characterized by orthogonal electric (E) and magnetic (H) fields which are perpendicular to the direction of propagation along the length of the cell or transmission line. This field simulates a planar field generated in free space with an impedance of 377 Ω. The TEM mode has no low-frequency cutoff. This allows the cell to be used at frequencies as low as desired. The TEM mode also has linear phase and constant amplitude response as a function of frequency. This makes it possible to use the cell to generate or detect a known field intensity. The upper useful frequency for a cell is limited by distortion of the test signal caused by resonances and multi-moding that occur within the cell. These effects are a function of the physical size and shape of the cell. See Figure A1.

The 1 GHz TEM cell is of a size and shape, with impedance matching at the input and output feed points of the cell, that limits the VSWR to less than 1.5:1 up to its rated frequency. It is tapered at each end to adapt to conventional 50 Ω coaxial connectors and is equipped with an access port to accommodate the standardized IC test board. The first resonance is demonstrated by a high VSWR over a narrow frequency range. The high Q of the cell is responsible for this high VSWR. A cell verified for field generation to a maximum frequency will also be suitable for emission measurements to this frequency.

NOTE—The Crawford TEM Cell was originally developed at the National Bureau of Standards (now NIST) and one of its principal investigators was Myron Crawford.

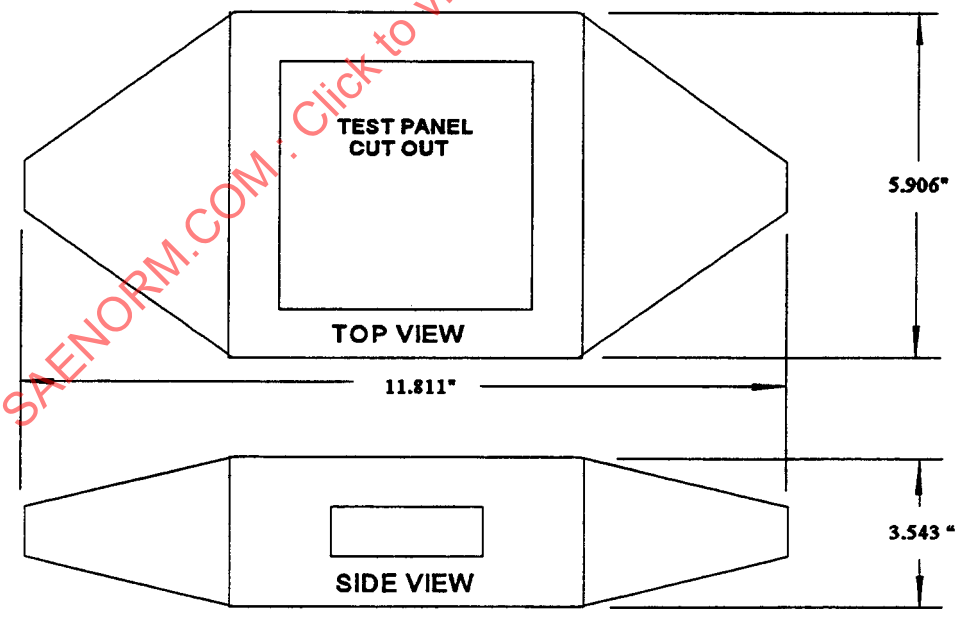

FIGURE A1—TEM CELL

APPENDIX B

TEST CODE—COUNTER CIRCUIT

B.1 This simple routine implements a counter function using a single 8 bit port. Every 100 µs, the port output is incremented or decremented. After 10 count cycles (256 ms) an LED output is complemented. This will provide a blinking light indication with a frequency of about 2 Hz. For consistency, equivalent loop times should be maintained. (Used in European IC emissions testing.)

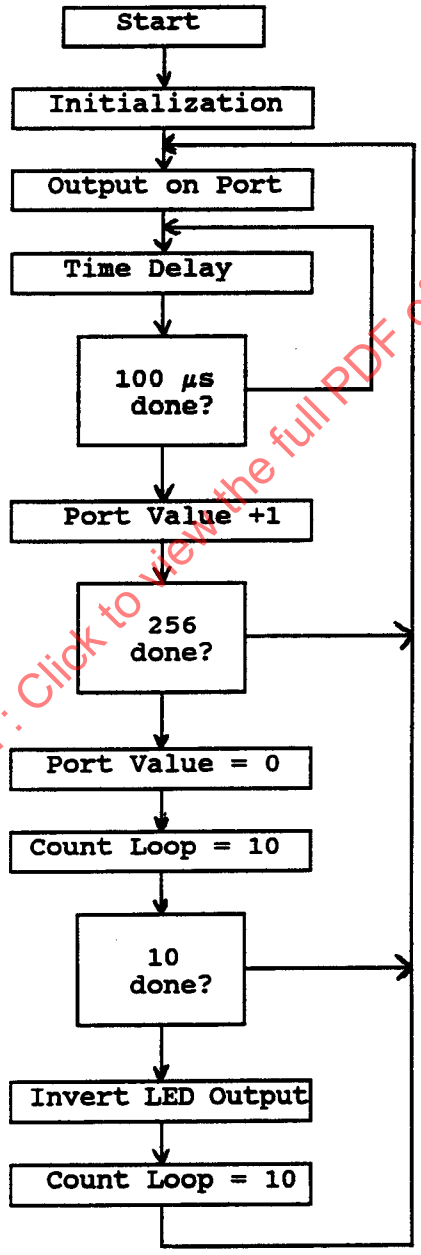

FIGURE B1—TEST CODE

APPENDIX C

WORST CASE SOFTWARE DESCRIPTION

C.1 While under test, the IC shall execute software which is representative of that which could be found in a worst case application. The software loop execution time shall be at least three orders of magnitude smaller than the spectrum analyzer sweep period (e.g., sweep = 6 s, software loop ≤ 6 ms). The following recommendations are applicable to a single IC microcontroller (MCU). They are intended as guidelines for the software writer; however, it is recognized that not all of the points are necessarily appropriate for all MCU devices:

a. The CPU should maximally exercise the internal address and data buses. Attention should be given to the bus implementation (precharged or static).
b. The test software should provide some means of indicating correct execution to the user (e.g., toggling port pin).
c. The test software should enable and exercise all onboard IC peripherals where practical. In particular, peripherals that can generate fast periodic signals (serial peripherals, some timers) should be configured and exercised to generate these periodic signals. However, if these peripherals significantly contribute to the total radiated emission figure, then the test may be performed, and results reported, with the peripheral enabled and disabled.
d. The test software should enable all internally generated clock sources that appear on any I/O pin. However, if these clocks significantly contribute to the total radiated emission figure, then the test may be performed and results reported with the clocks enabled and disabled.

When it is impractical to execute test software (e.g., when the device has no programmable memory and cannot bootstrap code into internal RAM), then the test should be performed with the device held in reset. However, this test condition shall be reported with the test results.