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(R) Measurement of Radiated Emissions from Integrated Circuits— TEM/Wideband TEM (GTEM) Cell Method; TEM Cell (150 kHz to 1 GHz), Wideband TEM Cell (150 kHz to 8 GHz)

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1. Scope—This measurement procedure defines a method for measuring the electromagnetic radiation from an integrated circuit (IC). The IC being evaluated is mounted on an IC test printed circuit board (PCB) that is clamped to a mating port (referred to as a wall port) cut in the top or bottom of a TEM or wideband TEM (GTEM) cell. **The test board is not in the cell as in the conventional usage but becomes a part of the cell wall.** This method is applicable to any TEM or GTEM cell modified to incorporate the wall port; however, the measured RF voltage is affected by the septum to test board (wall) spacing. This procedure was developed using a 1 GHz TEM cell with a septum to wall spacing of 45 mm and a GTEM cell with average septum to wall spacing of 45 mm over the port area. Other cells may not produce identical spectral output but may be used for comparative measurements, subject to their frequency and sensitivity limitations. A conversion factor may allow comparisons between data measured on TEM or GTEM cells with different septum to wall spacing. The IC test board controls the geometry and orientation of the operating IC relative to the cell and eliminates any connecting leads within the cell (these are on the backside of the board, which is outside the cell). For the TEM cell, one of the 50 Ω ports is terminated with a 50 Ω load. The other 50 Ω port for a TEM cell, or the single 50 Ω port for a GTEM cell, is connected to the input of a spectrum analyzer or receiver that measures the RF emissions emanating from the IC and coupled 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.

2. References—General information supporting this document is in SAE J1752-1, Integrated Circuit EMC Measurement Procedures, General and Definitions.

2.1 Applicable Publication—The following publication forms a part of this specification to the extent specified herein. Unless otherwise indicated, the latest version of SAE publications shall apply.

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

SAE J1752-1—Electromagnetic Compatibility Measurement Procedures for Integrated Circuits—Integrated Circuit EMC Measurement Procedures—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.

2.2.1 IEC PUBLICATION—Available from International Electrotechnical Commission, 3, rue de Verambe, P.O. Box 131, 1211 Geneva 20, Switzerland.

IEC 61967—Measurement of RF Emissions from Integrated Circuits

2.2.2 IEEE PUBLICATIONS—Available from IEEE, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331.

Characterization of the RF Emissions from a Family of Microprocessors Using a 1 GHz TEM Cell, J. P. Muccioli, T. M. North, K. P. Slattery, 1997 IEEE International Symposium on Electromagnetic Compatibility, August 1997.
Model of IC Emissions into a TEM Cell, A. Engel, 1997 IEEE International Symposium on Electromagnetic Compatibility, August 1997.
Investigation of the Theoretical Basis for Using a 1 GHz TEM Cell to Evaluate the Radiated Emissions from Integrated Circuits, J. P. Muccioli, T. M. North, K. P. Slattery, 1996 IEEE International Symposium on Electromagnetic Compatibility, August 1996.
The Measurement of Radiated Emissions from Integrated Circuits, R. R. Goulette of Bell Northern Research, Ottawa, Ontario, Canada, 1992 IEEE International Symposium on Electromagnetic Compatibility, August 1992.

2.2.3 OTHER PUBLICATION

A New Method for Determining the Emission Characteristics of an Unknown Interference Source, G. H. Koepke, and M. T. Ma, 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 Supply Voltage—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 usable frequency range of this radiated emissions procedure is determined by the test cell used. For a 1 GHz TEM cell, the range is 150 kHz to 1 GHz. For a wideband TEM cell (GTEM), the range is 150 kHz to 8 GHz, or as limited by the GTEM and test PCB characteristics. This is to be verified using the appropriate procedure in 5.4 or 5.5.

5. Test Equipment

5.1 Shielding—The use of double shielded or semi-rigid coaxial cable is required. Depending on the local ambient conditions, operation in a shielded enclosure may be required.

5.2 RF Measuring Instrument—The spectrum analyzer or receiver resolution bandwidth shall be 9 or 10 kHz and the video bandwidth shall not be less than three times the resolution bandwidth. Spectrum analyzer sweep is to be in calibrated or coupled mode (auto sweep). The instrument shall be set for peak reading and max hold with measurements in dBµV [for 50 Ω system: (dBm readings) –107 = dBµV].

5.3 Preamplifier—Typically, a 20 to 30 dB gain, low noise preamplifier is required.

5.4 TEM cell—The TEM cell used for this test procedure shall be fitted with a wall port sized to mate with the IC test board. The TEM cell shall not exhibit higher order modes over the frequency range being measured. For this procedure, the recommended TEM cell frequency range is 150 kHz to 1 GHz. The frequency range being evaluated shall be covered using a single cell. The VSWR over the frequency range being measured shall be less than 1.5 to 1. See Appendix A.

5.5 Wideband TEM/GTEM Cell—The wideband TEM (GTEM) cell used for this test procedure shall be fitted with a wall port sized to mate with the IC test board. The GTEM cell shall not exhibit higher order modes over the frequency range being measured. For this procedure, the recommended GTEM cell frequency range is 150 kHz to 8 GHz. The frequency range being evaluated shall be covered using a single cell. The VSWR over the frequency range being measured shall be less than 1.5 to 1. For information on TEM and wideband TEM cells, refer to Appendix B.

5.6 50-Ohm Termination—A 50 Ω termination with a VSWR less than 1.1 to 1 from 150 kHz to 1 GHz is required for one of the TEM cell 50 Ω ports.

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

6. Test Set-up

6.1 System Set-up and Calibration—All test equipment shall be calibrated on a regular basis. See Figure 1 for TEM cell with PCB in place. One of the TEM cell 50 Ω ports is terminated with a 50 Ω load. The remaining TEM cell or GTEM 50 Ω port is connected to the preamplifier or spectrum analyzer.

6.2 IC Test Printed Circuit Board (PCB)—Refer to Figure 2. This PCB includes a ground plane layer that completes the TEM or GTEM cell wall over the port opening. The periphery of this ground plane layer is tinned to facilitate contact to the edge of the wall port cut in the top or bottom of the test cell. The IC side of this PCB (the side that faces in to the test cell) shall be common with the cell wall ground plane layer except for the IC being evaluated and the narrow strip of vias around the IC. Any other conductors on this surface may act as additional radiators. The access wiring and other required components (such as crystals) shall be on or connected to the support side of this PCB (the side that faces out from the TEM or GTEM cell). Power bypass capacitors for the IC are to be chosen according to manufacturers' recommendations and located to minimize lead length (refer to Table 1). All wiring should be as short as possible and have controlled orientation relative to the PCB. The PCB material shall be compatible with the frequency range being evaluated. In theory, any size or shape of PCB may be used that will mate with the wall port on the test cell used. However, the development of this procedure was with a nominal 101 mm square PCB and a mating square wall port (refer to Figures 1 and 2). A description of the test board set-up (photo or artwork, schematic, and parts list) shall be included with the test report.

Pins that do not fall into any of the listed categories shall be loaded as functionally required and stated in the test report.

The values in Table 1 are recommended default values; if other values are more appropriate for a particular IC, they may be substituted for the values in Table 1 and shall be stated in the test report.

7. Test Procedure

7.1 Ambient—Measure ambient levels to assure that any ambient signals present are at least 6 dB below the target reference level (see Appendix D). This is accomplished by placing the IC mounted on the IC test PCB in the measurement position on the TEM or GTEM cell wall port with the test board not powered but with all other instrumentation and support equipment active 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).

TABLE 1—PIN LOADING RECOMMENDATIONS (FROM SAE J1752-1)

IC Pin Type	Pin Loading
Analog	Analog
- Supply	as stated by the manufacturer (or as required)(1)
- Input	10 kΩ to ground (Vss) unless the IC is internally terminated
- Output Signal	10 kΩ to ground (Vss) unless the IC is internally terminated
- Output Power	Nominal loading as stated by the manufacturer
Digital	Digital
- Supply	as stated by the manufacturer (or as required)(1)
- Input	ground (Vss) or 10 kΩ to supply (Vdd) if cannot ground, unless the IC is internally terminated
- Output	47 pF to ground (Vss)
Control	Control
- Input	ground (Vss) or 10 kΩ to supply (Vdd) if cannot ground, unless the IC is internally terminated
- Output	as stated by the manufacturer
- Bi-directional	47 pF to ground (Vss)
- Analog	as stated by the manufacturer (or as required)(1)

1. Shall be stated in the individual test report.

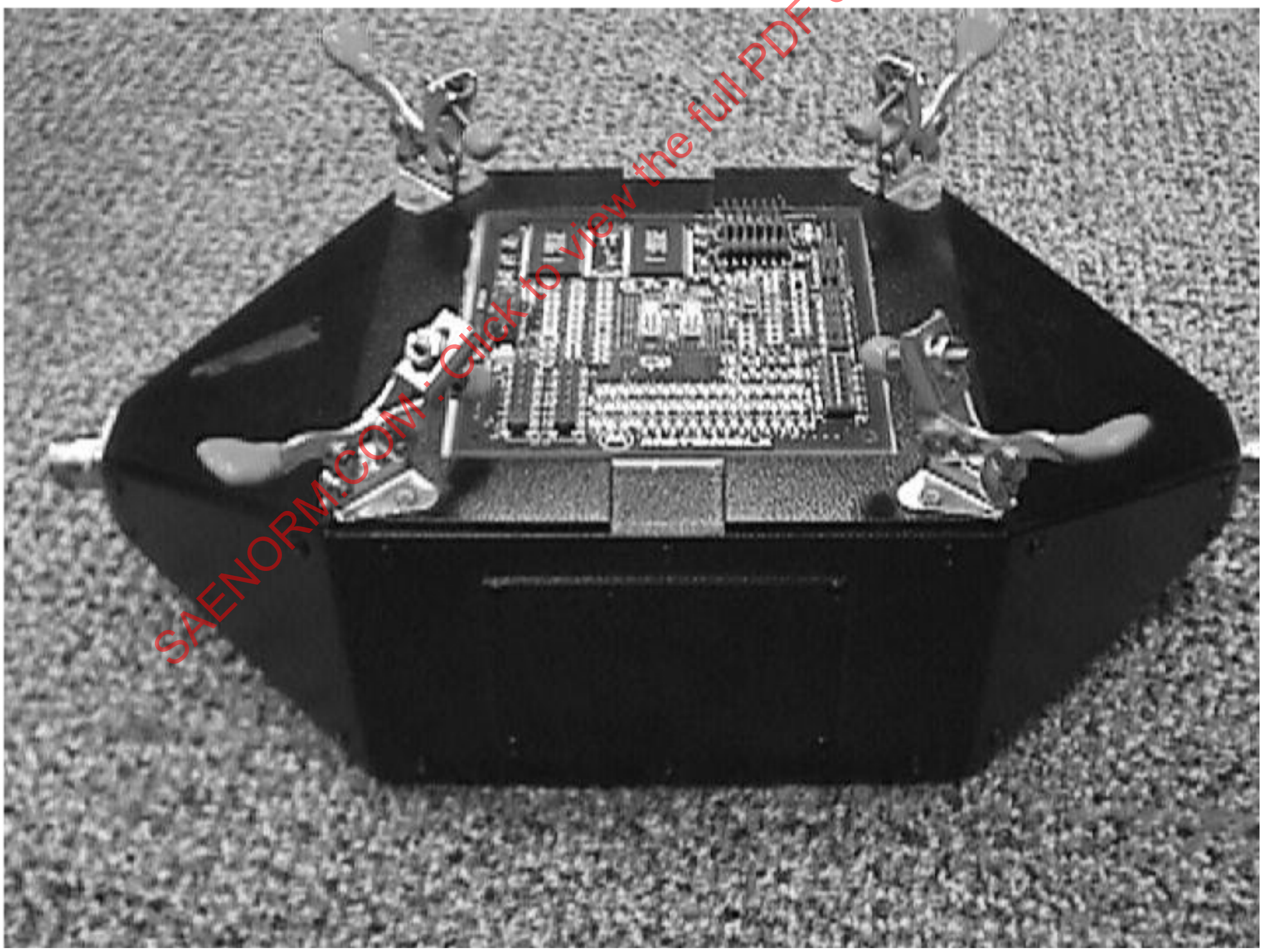

FIGURE 1—1 GHZ TEM CELL WITH TEST PCB

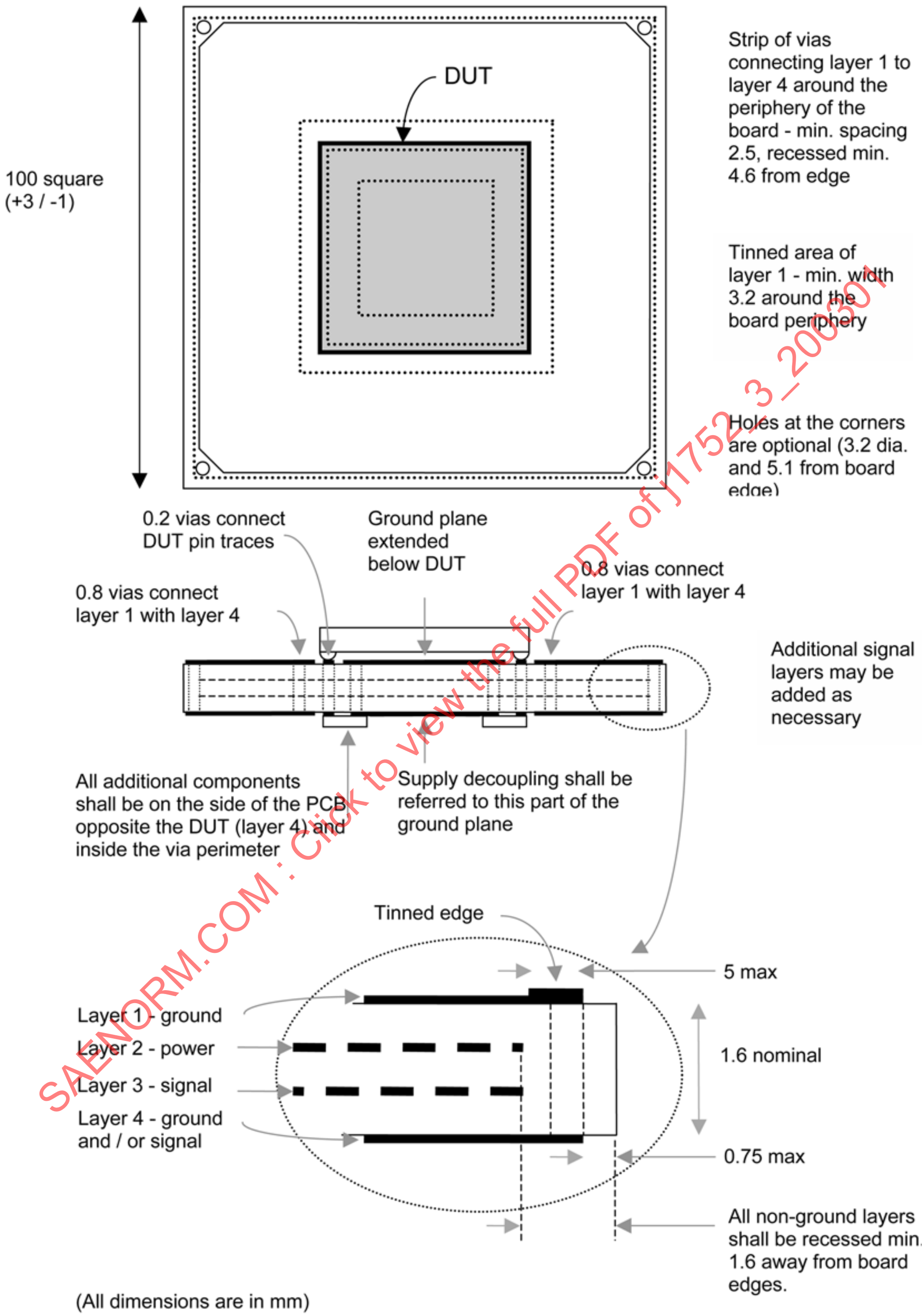

FIGURE 2—IC TEST PRINTED CIRCUIT BOARD

7.3 Test Technique—With the IC test PCB energized and the IC under test being operated in the intended test mode, monitor the RF emissions with the spectrum analyzer accumulating 3 sweeps on max hold. Two sets of data are to be taken; one with the IC test PCB in the initial position and with it rotated 90 degrees. Both sets of data are to be reported.

8. Data Presentation—Data shall be presented as a matrix of frequency and corresponding measured amplitude and/or as a plot of this matrix in an electronic spreadsheet readable format unless otherwise specified.

8.1 Documentation—Measurement parameters shall be documented using a calibration and set up verification sheet similar to the one illustrated in Appendix A to record the required information and this calibration and set up verification sheet shall accompany the measurement data.

8.2 Data Analysis—Data processing, including moving average filtering, may be useful to reduce the spectral clutter and facilitate analysis and comparison of spectral data. A description of any data processing used shall be a part of the test report.

9. 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 using the reference level scheme in Appendix D. These reference levels apply to measurements over the frequency range of 150 kHz to 1 or 8 GHz, depending on the test cell being used, 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 C.

10. Notes

10.1 Marginal indicia—The change bar (l) located in the left margin is for the convenience of the user in locating areas where technical revisions have been made to the previous issue of the report. An (R) symbol to the left of the document title indicates a complete revision of the report.

PREPARED BY THE SAE INTEGRATED CIRCUIT/EMC TASK FORCE OF THE SAE ELECTROMAGNETIC RADIATION STANDARD COMMITTEE

APPENDIX A

EXAMPLE CALIBRATION AND SET UP VERIFICATION SHEET

A.1 See Figure A1.

INTEGRATED CIRCUIT RADIATED EMISSIONS MEASUREMENT PROCEDURE CALIBRATION & SETUP VERIFICATION for 150 kHz to 1 / 8 GHz, TEM / GTEM CELL	
TEM / GTEM cell used:	**VSWR OK to 1 / 8 GHz:**
Spectrum analyzer used:	**Cal. OK to 1 / 8 GHz:**
RBW:	**VBW:**
Preamplifier model:	**Gain: Cal. OK to 1 / 8 GHz:**
Coax cable type and approx. length:	
50 Ω termination for TEM cell verified to 1 GHz:	
System gain check (without the TEM cell):	
Is ambient noise floor level at least 6 dB below target level? (attach plot):	
IC supply voltage(s):	**Type of power supply:**
Type of software used to exercise the IC: **Data processing used:**	
Notes: **Description of IC test PCB (attach picture or copy of artwork, schematic & parts list)**	

FIGURE A1—EXAMPLE CALIBRATION AND SET UP VERIFICATION SHEET

APPENDIX B

1 GHZ TEM CELL AND WIDEBAND TEM CELL

B.1 ***1 GHz TEM Cell***—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, non-linear 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 transverse 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 cut-off. 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 a known field intensity or capture an RF field produced by a DUT within the cell. The upper useful frequency for a Crawford TEM 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.

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. The cell is tapered at each end to adapt to 50 Ω coaxial connectors/terminations and is equipped with an access port to accommodate the 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.

B.2 ***Wideband TEM Cell***—The wideband TEM cell is a expanded transmission line that does not transition back to a 50 Ω feed as in a conventional (Crawford) TEM cell but continuously expands and is terminated with a septum load and RF absorber material. This cell avoids the moding limitations of conventional TEM cells so that its usable upper frequency is limited not by its dimensions, but by the characteristics of the RF absorber and septum termination. A wideband TEM cell may be almost any practical size with a usable frequency range extending above 8 GHz, determined by the cell absorber and termination characteristics.

APPENDIX C

CALCULATION OF DIPOLE MOMENT FROM MEASURED DATA

C.1 It may be desirable 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. In this way, the electromagnetic emission performance of different ICs may be compared, and noise-coupling predictions are facilitated. The magnetic dipole moment serves as a useful index. The rationale and utility of this approach is discussed further in the referenced papers.

To obtain an estimate of the dipole moment of the IC under test, a calculation is performed which is based upon the response of the TEM or GTEM cell to either magnetic or electric dipoles. In the case of a simple 50 Ω terminated TEM cell, information concerning the magnetic or electric nature of the equivalent source dipoles is lost, however, calculations of magnetic dipole moment and electric dipole moment are made independently by assuming that the source is either a magnetic or electric dipole respectively. The resulting data is plotted on graphs, which show limit lines corresponding to equivalent levels of far field emission of the IC under test for either the magnetic or electric dipole source assumption. For our purposes, we need only plot the worst case device emissions expressed as an equivalent dipole moment. The word “equivalent” in this context means capable of producing the same far field emissions. The calculations are as follows.

C.1.1 Magnetic Dipole Assumption

$$m = E_p * D * 377 * 2 / [\mu_0 * \omega * 50] \qquad \text{(Eq. C1)}$$

where

m is the magnetic dipole moment in Ampere-meters squared
E_p is the measured TEM cell output voltage into a 50 Ω load
D is the TEM cell plate spacing in the test region in meters
μ_0 is the permeability of free space ($4\pi x10^{-7}$ H/m)
ω is the angular frequency in radians/second ($\omega = 2\pi f$, f is frequency in Hz)

or, in more convenient dB units of measurement:

$$m(dB\mu A - m^2) = E_p(dB\mu V) + 20Log[D] - 20Log[f] + 125.6 \qquad \text{(Eq. C2)}$$

C.1.2 Electric Dipole Assumption

$$p = 2 * E_p * D / 50 \qquad \text{(Eq. C3)}$$

where

E_p and D are as previously stated and
p is the electric dipole moment in Ampere-meters

or in dB units,

$$p(dB\mu A - m) = E_p(dB\mu V) + 20Log[D] - 28.0 \qquad \text{(Eq. C4)}$$

Both m and p, as previously determined, can be separately plotted on graphs for magnetic dipole moment and electric dipole moment. Normally, as already explained, we use only magnetic dipole moment since this is sufficient to give far field emissions and this simple TEM cell method cannot distinguish between magnetic and electric field sources.

These calculations assume that the TEM cell calibration is ideal in the region where the DUT is mounted; that is, if a voltage V were impressed between the central plate or septum of the cell and its surrounding walls, then the field existing at the DUT location would be V/D Volts/meter (where D, in meters, is the TEM cell plate spacing in the test region). Cell calibration data may be used to adjust readings, if necessary.

APPENDIX D

SPECIFICATION OF EMISSION LEVELS

D.1 ***Scope*****—**This appendix provides a method of specifying the emission level profiles of ICs.

D.2 ***General*****—**This appendix is not meant to be a product specification. However, using the concept described in this document and by careful application and agreement between manufacturer and user, it is possible to develop a description of the RF emissions behavior for a specific IC.

D.3 ***Specification of Emission Levels*****—**The diagram in Figure D1 represents a scheme that facilitates classification of emission levels for ICs. With the given flexibility of this scheme, all application dependent parameters can be considered for the definition of the maximum emission level.

The scheme follows the theory of an trapezoidal pulse response and offers 3 different slopes of emission amplitudes with a 6 dB separation:

0 dB/decade	from theory: constant amplitude line till the first corner frequency $1/(\pi\tau)$
–20 dB/decade	from theory: decrease of amplitude until second corner frequency $1/(\pi\tau_r)$
–40 dB/decade	from theory: decrease of amplitude at frequencies > $1/(\pi\tau_r)$

The corner frequencies are dependent on the rise/fall times and the duration of the pulse. With this emission level diagram, several emission specification levels can be defined which reflect those system and module related ambient parameters, that are dominating the final application.

The emission level diagram, Figure D1, enables selection of different slopes for different frequency ranges; for example, two slopes or only one slope over the full frequency range.

Various combinations are possible reflecting the actual requirements of the application more closely (e.g., adapted to the switching frequency of the ports of a microcontroller).

D.4 ***Presentation of Results*****—**The typical description of the maximum emission level consists of two letters and one number always following the same sequence. If one of the three slopes is not needed, the corresponding letter or number will be omitted.

The **capital letter** is **first** and represents the position of the horizontal line with zero dB/decade slope. **Second** is the **number**, which defines the position of the –20 dB/decade slope. The **third** and **small letter** defines the position of the –40 dB/decade slope.

The point of intersection of the slopes represents the first and second corner frequency. Such defined maximum emission levels with the described notation offer a standardized way to communicate maximum emission levels unambiguously.