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Electromagnetic Compatibility Measurement Procedures for Integrated Circuits - Integrated Circuit EMC Measurement Procedures - General and Definitions

RATIONALE

This technical report is being stabilized because it covers technology, products, or processes which are mature and not likely to change in the foreseeable future.

STABILIZED NOTICE

This document has been declared "Stabilized" by the SAE Electromagnetic Compatibility (EMC) Standards Committee and will no longer be subjected to periodic reviews for currency. Users are responsible for verifying references and continued suitability of technical requirements. Newer technology may exist.

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1. SCOPE

This SAE Recommended Practice provides supporting information for the emission and immunity measurement procedures defined in the SAE J1752 series of documents.

1.1 Measurement Philosophy

The near field magnetic or electromagnetic radiation from an integrated circuit can be measured in a controlled manner that yields repeatable results. These emissions are related to the far field electromagnetic radiation potential of the IC and of the electronic module of which it is a part. The intent is to provide a quantitative measure of the RF emissions from ICs for comparison or other purposes. Similar quantitative measures of the immunity of an IC to RF fields and transients are being investigated.

2. REFERENCES

2.1 Applicable Documents

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

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or 724-776-4970 (outside USA), www.sae.org.

SAE J1113-1 Electromagnetic Compatibility Measurement Procedures and Limits for Vehicle Components

SAE J1752-2 Integrated Circuit Radiated Emissions Measurement Procedure, Surface Scan Method (Loop Probe Method) 10 MHz to 3 GHz)

SAE J1752-3 Integrated Circuit Radiated Emissions Measurement Standard, TEM/Wideband TEM (GTEM) Cell Method TEM Cell (150 kHz to 1 GHz), Wideband TEM Cell (150 kHz to 8 GHz)

2.1.2 IEEE Publication

Available from the IEEE, 445 Hoes Lane, Piscataway, NJ 08854-1331, Tel: 732-981-0060, www.ieee.org.

IEEE Standard Dictionary, STD100

2.2 Related Publications

The following publications are provided for information purposes only and are not a required part of this SAE Technical Report.

2.2.1 The following publications are referenced for ANSI EMC Definitions.

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 and Technical Exhibition on EMC, (Zurich, Switzerland), March 1983, pp. 35-40

3. DEFINITIONS

Refer to the IEEE Standard Dictionary of Electrical and Electronic Terms (IEEE Std 100-1992) for additional definitions.

3.1 ASSOCIATED EQUIPMENT

Transducers (e.g., probes, networks and antennas) connected to a measuring receiver or test generator; also transducers (e.g., probes, networks, and antennas) which are used in the signal or disturbance transmission path between an EUT and measuring equipment or a (test-) signal generator.

3.2 AUTO SWEEP

The fastest calibrated sweep which a spectrum analyzer will automatically select based on start frequency, stop frequency, resolution bandwidth, and video bandwidth.

3.3 CONDUCTED EMISSIONS

Conducted emissions are transients and/or other disturbances observed on the external terminals of a device during its normal operation.

3.4 DEVICE UNDER TEST (DUT)

The device, equipment or system being evaluated; as used in this standard, it refers to a semiconductor device being tested.

3.5 DIE SHRINK

The amount of shrink of the mask used to produce the IC expressed as a percentage of the original artwork layout (drawn size).

3.6 ELECTROMAGNETIC EMISSION

The phenomenon by which electromagnetic energy emanates from a source.

3.7 ELECTROMAGNETIC RADIATION

a. The phenomena by which energy in the form of electromagnetic waves emanates from a source into space.

b. Energy transferred through space in the form of electromagnetic waves.

3.8 GROUND (REFERENCE) PLANE

Flat conductive surface used as a common potential reference.

3.9 LEAD FRAME

The supporting structure for the silicon die that interfaces the external pins to the die.

3.10 LOOP PROBE

A single turn (E-field shielded) magnetic field probe as described in SAE J1752-2.

3.11 MCM

Multichip module, an integrated circuit whose elements are formed on or within two or more semiconductor chips that are mounted in a single package.

3.12 MCU

Microcontroller unit.

3.13 MULTI IC SETS

A set of ICs that function as a unit, in a higher level of integration the set could be a single IC.

3.14 1 GHZ TEM CELL

A transverse electromagnetic mode (TEM) cell with a VSWR of 1.5:1 or less and an absence of multi-moding up to an operating frequency of 1 GHz.

3.15 PREAMPLIFIER NOISE FLOOR

The inherent thermal noise generated by the first stage amplifier that limits the signal resolution of the measurement system.

3.16 REFERENCE POINT

The specific port or point on the test set-up where the measurement of the sampled parameter is made.

3.17 REPETITION RATE

The number of surges, spikes, or pulses per unit time.

3.18 RF AMBIENT (ELECTROMAGNETIC ENVIRONMENT)

The totality of electromagnetic phenomena existing at a given location.

3.19 SHIELDED ENCLOSURE

Mesh or sheet metallic housing designed expressly for the purpose of separating electromagnetically the internal and external environment.

3.20 SIGNIFICANT IC CHANGES

All changes that may influence the electromagnetic emissions of an IC. Examples are: new device, new manufacturer or process line, die shrink, new package type, significant process change, internal/external clock changes, I/O drive capability changes, etc.

3.21 SYSTEM GAIN

The gain (or attenuation) of the measurement path between the reference point and the input of the RF measuring instrument.

3.22 TEST PLAN

The test plan is a document provided by the test requester to define the tests to be done, the object of the testing, the DUT operating status, the conditions for the test and performance objectives. It completely guides the implementation of the test, by reference to the standard test procedure, or by detailing revisions or additions for the specific DUT.

3.23 WIDEBAND TEM CELL (SOMETIMES REFERRED TO AS A GTEM CELL)

A cell developed as a continuously expanding section of 50 Ω transmission line where the center conductor is transformed into an off center septum. Because of its construction, the wideband TEM (transverse electromagnetic mode) cell does not suffer from the size versus frequency constraints of a conventional TEM cell and provides more test volume at high frequencies.

4. TEST CONDITIONS

4.1 General

These default test conditions are intended to assure a consistent test environment. If other values are agreed to by the users of these procedures, they shall be documented in the test report.

4.2 Ambient Temperature

The ambient temperature during the test shall be 23 ± 5 degrees C. IC emissions may vary with temperature.

4.3 Ambient RF Field Strength

The ambient RF noise level shall be at least 6 dB below the lowest emission level(s) to be measured. This shall be verified before measurements of the IC are made. The DUT shall be installed in the test set-up for the ambient measurement. The DUT shall not be activated (e.g., power supply voltage disconnected). A scan shall be made to measure the residual noise. A description of the ambient shall be a part of the test report.

4.4 Other Ambient Conditions

All other ambient conditions that may affect the result shall be stated in the individual test report.

4.5 IC Stability Over Time

The functional behavior of the IC shall be stable over time such that two measurements, separated by an interval of time, shall yield the same results within the expected variation of the measurement technique.

5. TEST EQUIPMENT

5.1 General

The equipment described in this section is common to all the test procedures described in this series of documents. Specific equipment shall be called out in the individual test procedures.

5.2 Shielding

The necessary shielding depends upon the specific test method and the ambient noise level. A shielded room may be required to provide a controlled ambient for emission measurements. A non-shielded set-up may be used if ambient levels are at least 6 dB below the lowest level to be measured.

5.3 RF Measuring Instrument

Either EMI receivers or spectrum analyzers may be used. The EMI receiver, if used, shall meet the requirements as stated in CISPR 16-1-1.

5.3.1 RF Receiver

Table 1 - EMI receiver bands and RBW (resolution bandwidth) default settings

Frequency Range	150 kHz – 30 MHz	30 MHz - 8 GHz
EMI Receiver RBW at 6 dB	9 kHz	120 kHz

5.3.2 Spectrum Analyzer

Table 2 - Spectrum analyzer bands and RBW default settings

Frequency Range	150 kHz - 30 MHz	30 MHz - 8 GHz
SA RBW at 6 dB	10 kHz	100 kHz

5.3.3 Other RBW for Narrowband Emissions

Where the RF emissions can be verified to be narrowband, and the measurement technique requires a lower noise floor for resolution of the measured signals from the ambient, a reduced RBW may be used.

5.3.4 Emissions Type, Detector Type and Sweep Speed

Examples of narrowband sources are digital ICs operated by a synchronous clock. They will typically produce a continuous emission spectrum dominated by clock harmonics and fractions. Because the individual spectral components are narrower in bandwidth than the receiver or spectrum analyzer bandwidth the detector chosen will not influence the readings. The peak detector is preferred for narrowband sources. When narrowband sources and broadband sources are mixed, an average detector may be used to filter out the broadband spectrum and measure the narrowband content.

Examples of possible broadband sources are ICs producing a non-continuous spectrum like converters and non-synchronous logic. For broadband sources, the spectral content received is proportional to the receiver or spectrum analyzer bandwidth. These devices shall be measured, preferably using the peak detector with the sweep speed set to reflect the modulation rate, according to the following formula:

$$Vs \leq 2/3 * RBW * fm \quad \text{(Eq. 1)}$$

where:

Vs is the sweep speed in MHz per s
RBW is the resolution bandwidth in MHz
fm is the modulation frequency in Hz, defined as the lowest repetition rate of a software routine or other IC operating parameter that may affect the measured RF emissions

The sweep speed used shall be selected such that a slower sweep speed will not result in a significant change in the measured emissions.

5.3.5 Video Bandwidth (for spectrum analyzers)

The video bandwidth shall be a minimum of 3 times the resolution bandwidth except when video filtering is being used to effect average detection.

5.3.6 Verification of Calibration for the RF Measuring Instrument

The calibration of the RF measuring instrument shall be verified by comparison with an independent calibrated instrument, traceable to a recognized standard body, if absolute levels are to be reported.

5.4 Frequency Range

The default frequency range is 150 kHz to 1 GHz, but this may be extended if the specific procedure is usable over an extended frequency range. The range of interest may be smaller when, by function, the IC produces emissions only in that reduced range.

5.5 Preamplifier or Attenuator

If necessary a preamp or attenuator, either internal or external, may be used. The noise figure of the pre-amplifier or attenuator shall be less than 10 dB. The minimum resolution for calibration of the preamplifier is 10 points per decade. If a preamp is used, assure that the preamp is not being overloaded by the DUT signal voltage. This can be accomplished by switching in 10 dB of additional input attenuation and verifying that the output signal is attenuated by 10 dB.

5.6 System Gain

The gain (or attenuation) between the reference point and the input of the RF measuring instrument shall be verified to an accuracy of ± 0.5 dB.

5.7 Other Components

Cables, connectors and terminators that are in the measurement path between the reference point and the input of the RF measuring instrument and any others that may also affect the measurement result shall be verified for loss characteristics over the intended frequency range.

6. GENERAL BASIC TEST BOARD SPECIFICATION

The purpose is to describe a universal test board. Such a board is necessary to compare the EMC performance of various ICs from different manufacturers. Constraints are given for those parameters influencing the EMC aspects.

6.1 Board Description - Mechanical

For surface scanning, any board that the scan setup will accommodate may be used. The standard board size for TEM and wideband TEM cell use is 101.6 ± 1 mm (4.0 in) square, refer to Figure 1. Other board sizes may be used, such as 152.4 mm (6.0 in) square to accommodate larger IC or chip sets, but a mating adapter on the TEM or GTEM to be used must be available. Holes may be added at the corners of the board, as shown in the drawing. All edges of the board at least shall be tinned for 5 mm, or made conducting in order to make proper contact with the TEM cell, if used. As an alternative, edges may be gold-plated. The vias at the outer edge of the board shall be at least 5 mm away from that edge.

6.2 Board Description - Electrical

The drawing in the figure shall be taken as a guide. A double layer board is proposed as a minimum requirement. However if functionally needed, layers 2 and 3 or others may be added in-between such that a multi-layer board appears.

Layer 1 shall always be used as the ground plane. Layer 4 allows other signals, but shall be left as much intact as possible, to be a ground plane as well. At least the area in layer 1, underneath the IC, shall be left as a ground plane.

The PCB shall be made such that only the IC package remains on one side (layer 1) and all other components and trace patterns remain on the opposite layer (layer 4).

6.3 Ground Planes

The ground planes (layers 1 and 4) shall be inter-connected by means of vias. These vias shall be placed at the following positions over the board:

Table 3 - Test board ground plane interconnect via positions

Via Position	Location
1	All around, at the edges of the board
2	Just outside the DUT area
3	Just inside, underneath the IC area

The ground plane at layer 4 shall be continued in-between vias at position 2. As such the ground plane at layer 4 is continued over the whole board.

If possible the same shall be done for layer 1, but the possibility to do so depends on the IC package and the space available.

6.4 Pins

All functionally necessary components, other than the IC, shall be mounted on layer 4. It is therefore necessary to feed I/O and other required pins from layer 1 to layer 4.

6.4.1 DIL Packages

These packages do not require vias, as plated through hole pins are considered present, or established by the pins themselves.

6.4.2 SOP, PLCC Packages

These packages require the use of vias. The vias shall be centered in the pads used for soldering the ICs. Preferably these vias shall be placed at position 3 to minimize the loop-area involved in which the IC currents will flow.

6.5 Via Type

All vias at position1 shall have hole diameter of 0.8 mm; All other vias shall have a diameter of ≥ 0.2 mm. The spot diameter within the pad will be 0.5 mm, which is small enough for 50 mil (1.27 mm) pitched ICs.

6.6 Via Distance

A maximum distance between vias is required for measurements up to 1 GHz.

The maximum separation between the vias connecting layer 1 with layer 4 shall be 10 mm.

Vias accompanying signal traces shall be as close as possible to those vias connecting layers 1-4, to create small return signal loops.

6.7 Additional Components

All additional components shall be mounted at layer 4. They shall be placed such that they do not interfere with the constraints as set for layer 1 and 4 and vias in-between.

6.7.1 Supply Decoupling

Supply decoupling shall be in accordance with the manufacturers' recommendations. All parts necessary shall be mounted such that they meet all other requirements as set for additional components and layers.

6.7.2 I/O Load

Additional components necessary to load or activate the IC shall be mounted on layer 4, preferably directly underneath the IC package area.

7. TEST SETUP

7.1 General

Tests shall take place according to a test plan, which shall be included in the test report. Connection to auxiliary equipment shall not influence the test results. Other specific requirements are described in the individual test procedures.

7.2 Specific Test Circuit Board

The test PCB to be used depends on the specific measurement method but shall follow the guidelines given in section 6. The test PCB that applies for the individual test methods shall be described in the individual standards of this family of standards. Any deviation from this description shall be stated in the individual test report. All test boards shall use good layout practice including an adequate ground plane.

7.3 IC Pin Loading

If no other loads are required by a specific test method, the pins of the DUT shall be loaded according to Table 4 with exceptions as noted:

Table 4 - IC pin loading recommendations

IC Pin Type	Pin Loading
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	
– 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) or maximum allowed by the manufacturer, whichever is less
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) or maximum allowed by the manufacturer, whichever is less
– Analog	as stated by the manufacturer (or as required) (1)

1. Shall be stated in the individual 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. These are recommended default values; if other values are more appropriate for a particular IC, they may be substituted for the values in Table 4 and shall be stated in the test report.

7.4 Power Supply Requirements

Test Board Power Supply – The DUT shall be powered from a source with low conducted RF emissions that conform to the RF ambient requirement. If a battery is used, it shall meet the IC requirements and the voltage level shall be checked periodically to maintain a consistent operating environment. An AC power supply may be used if it meets the low RF emissions requirement; a linear power supply is recommended. All power supply lines to the DUT shall be adequately filtered per the IC manufacturer's recommendation.

7.5 IC Specific Considerations

7.5.1 IC Supply Voltage

The supply voltage(s) shall be as specified by the IC manufacturer with a tolerance of ± 5%.

7.5.2 IC Decoupling

The value and layout position of power supply decoupling capacitors shall be stated in the individual test report .The decoupling of each supply pin of the DUT may be as advised by the manufacturer, or otherwise, as long as stated in the test report

7.5.3 Activity of IC

Attempts should be made to fully exercise all available functions that significantly contribute to the emission of the IC.

7.5.4 Guidelines by IC Function

The intent is to describe the parameters to be controlled in order to assure test repeatability for the particular IC function or type as agreed to between the manufacturer and user.

7.5.5 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. The IC shall be exercised using one of the following software levels:

a. Minimum - Implement Counter Function

   Used for basic test and comparisons, see Appendix B: Counter Test Code Flow Chart.

b. Typical – Normal Operating or Production Code

   Used for representative testing, exercise microprocessor and I/O on a “normal” basis using production code.

c. Worst Case - Exercise all I/O

   Used for diagnostic purposes, see Appendix C: Worst Case Software Description.

8. TEST PROCEDURE

8.1 Ambient Check

For emissions testing, measure ambient levels to assure that any signals present are at least 6 dB below the target reference level. The ambient data shall be a part of the test report.

NOTE: 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. If the area ambient is not well known with possible sporadic local RF sources, it is recommended to check the ambient with the unpowered test board in place and with the spectrum analyzer running on max hold for one hour or as required to achieve confidence in the environment.

8.2 Operational Check

Energize the DUT and complete an operational check to assure proper function of the device (i.e., Run IC test code, see 6.5.5).

8.3 Specific Procedures

Follow the test technique described in the particular emission measurement procedure.

9. TEST REPORT

9.1 General

The test report shall include sufficient information to allow duplication of the measurements by another facility. Refer to Appendix D for sample data sheet. All variations from the default parameters shall be included in the test report.

9.2 Ambient

A plot or description of the ambient level of the measurement system with the DUT unpowered shall be included in the test report.

9.3 Description of Device

A description of the device (IC) being evaluated and any pertinent information that may influence the emissions performance of the device shall be included in the test report (e.g., IC type number, production code and date, short functional description of device as from data sheet). The operating frequency(s) shall be indicated, if applicable.

9.4 Description of Set-up

A description of the test set-up shall be included with any variations from the standard set-up clearly indicated.

a. A circuit diagram of the application (supply decoupling, bus load, peripheral ICs, etc.)

b. A description of the PCB on which the IC is applied (lay-out)

c. Actual operating conditions of the IC (supply voltage, output signals etc.)

9.5 Description of Software

The type of software used to exercise the IC, if applicable, shall be indicated. If production code is used, the revision level shall be indicated.

10. DATA PRESENTATION

Data shall be adjusted for any input gain or attenuation to represent the actual values appearing at the reference point in dBμv for voltage measurements.

10.1 Graphical Presentation

A graph of the measured data shall be available. The data shall also be provided in csv format to facilitate alternative presentations.

10.2 Software for Data Capture

An ASCII file of the measured data shall be available.

10.3 Data Processing

The smoothing or averaging of raw data may provide a more readable format. A description of any data processing used shall be included in the test report.

10.4 RF Emission Limits

As this standard describes measurement methods, no RF emission limits are given. Limits in general depend upon the application, area and country. Functional requirements and local or mandated emission requirements will define the limits.

11. INTERPRETATION OF RESULTS

11.1 Comparison Between IC(s) Using the Same Test Method

Results may be directly compared as long as measurements have been carried out under the same conditions. If comparisons are intended, the devices should be running the same code (for example, the counter test code, Appendix B) and the test environment should be as consistent as possible. The same test board should be used.

11.2 Comparisons Between Different Test Methods

At this time, general correlation between the specific test methods has not been established. Correlation has been demonstrated in specific cases only. Refer to Appendix A.

11.3 Correlation to Module Test Methods

Where sufficient data exists to establish a correlation between the measured values and the expected emissions from the IC for a given application, this shall be indicated in the specific test method (e.g., component or system level tests of the product). A number of factors are involved in the translation from IC level emissions to the module or product level. In general, this IC to module correlation is limited to specific cases where the variables involved are controlled.

12. NOTES

12.1 Marginal Indicia

A change bar (l) located in the left margin is for the convenience of the user in locating areas where technical revisions, not editorial changes, have been made to the previous issue of this document. An (R) symbol to the left of the document title indicates a complete revision of the document, including technical revisions. Change bars and (R) are not used in original publications, nor in documents that contain editorial changes only.

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