



Electromagnetic Compatibility Specification For Electrical/Electronic Components and Subsystems

Foreword

This engineering specification addresses Electromagnetic Compatibility (EMC) requirements for electrical/electronic (E/E) components and subsystems for Ford Motor Company (FMC). This specification is the direct link from ARL-09-0466. These requirements have been developed to assure compliance with present and anticipated regulations in addition to customer satisfaction regarding the EMC of vehicle E/E systems. This specification replaces ES-XW7T-1A278-AC.

EMC-CS-2009 is applicable for all E/E components/subsystems slated for use on 2013 Ford vehicle programs in addition to E/E component/subsystems whose commercial agreements are signed after October 1, 2009.

EMC-CS-2009 is available for download from the Ford [EKB](#) in addition to www.fordemc.com. Corrections and/or editorial updates to this specification will be made as required and without prior notification to the user. It is recommended that the user verify they have the latest version of the specification prior to application to their E/E component/subsystem.

Information regarding differences between these specifications may be found at <http://www.fordemc.com>

Date	Version	Revision
9/30/2009	0	Initial Release of Specification
2/11/2010	1	Annex I updated to correct errors in measurement procedure RE 310 flow chart corrections CE 410 trigger setting correction CI 280 requirements for metallic connectors Corrections in tolerance requirements for certain tests Numerous editorial corrections. Corrected errors in Tables 16-1 and F-1 to align requirements. Updates to Figures G-1 and G-3 in Annex G. Requirement revisions for Artificial Networks



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1.0 Scope

This engineering specification defines the Electromagnetic Compatibility (EMC) requirements, test methods and test procedures for electrical/electronic (E/E) components and subsystems used by Ford Motor Company (FMC) including associated vehicle brands.

1.1 Purpose of the Specification

The purpose of this engineering specification is to ensure vehicle Electromagnetic Compatibility. This specification presents EMC requirements and test methods that have been developed for E/E components and subsystems independent of the vehicle. The purpose of component and subsystem testing is the pre-qualification of EMC at a time when representative vehicles are not yet available.

1.2 Vehicle Level Requirements

In addition to meeting the requirements specified herein, E/E components and subsystems, when installed in the vehicle, shall also comply with all relevant vehicle level EMC requirements including those listed in Table 1-1.

Table 1-1: Vehicle Level EMC Requirements

ARL 09-0409	ARL 09-0410	ARL 09-0411
ARL 09-0414	ARL 09-0419	ARL 09-0422
ARL 09-0425	ARL 09-0426	ARL 09-0433
ARL 09-0464	ARL 09-0467	ARL 09-0481
ARL 09-0484		

The supplier may contact the FMC EMC department for details concerning these requirements (*these requirements are not publically available*). Verification testing to these requirements is performed by FMC. Additional component, subsystem, and vehicle level EMC requirements may be imposed by individual vehicle brands reflecting special conditions in their target markets. The component or subsystem supplier should verify that any additional requirements, or modifications to the requirements delineated herein shall be included in the supplier's statement of work and the component/subsystem's engineering specification.

1.3 Use of this Specification

The requirements and test methods in this engineering specification are based on international standards wherever possible. If international standards do not exist, military, and internal corporate standards are used. Under some circumstances, unique requirements and test methods are presented that experience has shown to better represent the vehicle electromagnetic environment. Refer to the definitions in Section 3.0 for clarification of terms. Should a conflict exist between this specification and any of the referenced documents, the requirements of this specification shall prevail. These requirements do not supersede any applicable regulatory requirements. Where such requirements exist, separate validation testing may be required.

This specification applies to all components and subsystems that reference EMC in their engineering specification. Components may be referred to in this specification as a component, device, module, motor, product or DUT (device under test). The following steps shall be taken by the FMC Design and Release (D&R) group and their supplier for assuring EMC compliance of their component or subsystem:

1. Provide the supplemental information needed to classify the E/E component/subsystem functional importance classification (see section 5.1).
2. Identify which tests are applicable (refer to section 6).
3. Identify operating modes and acceptance criteria specific to the component or subsystem.
4. Develop an EMC test plan (see section 5.2 in **EMC-P-2009**).



5. Perform testing at a FMC recognized test facility.
6. Submit the test results to the FMC EMC department. *See section 5.7 for reporting requirements.*
7. EMC department reviews and assesses the test results.

It's important to emphasize that the FMC D&R group and their supplier (not the FMC EMC department) are responsible for determining the operating modes and acceptance criteria for their component or subsystem (step 3). The FMC D&R group is also responsible for verifying that the requirements delineated in this specification are met. The supplier is responsible for performing the verification testing in accordance with the requirements of this specification.

The FMC EMC department reserves the right to perform audit testing or witness supplier design verification (DV) on sample parts in order to verify compliance with this specification. **Compliance to these EMC requirements shall be determined by the FMC EMC department after review of the test results submitted by the test laboratory. The supplier may not self certify compliance to these specifications.** See section 5.7 for additional detail concerning this requirement.

1.4 Additional Information

E/E component or subsystem testing to the requirements of this specification represents an empirical risk analysis of component/subsystem performance versus derived approximations to known environmental threats and customer satisfaction requirements. The development of this specification is based on extensive experience in achieving correlation to expected vehicle performance with a high level of predictability. However, EMC testing, by its nature, is subject to similar variation as mechanical testing. Because of coupling variability and measurement uncertainty, correlation between component/subsystem level performance and final performance in the complete vehicle cannot be exact. In order to maintain a competitive and quality product, vehicle EMC testing will be performed to evaluate overall integrated system performance. However, vehicle level analysis and testing is not a substitute for component/subsystem conformance to this specification.

This specification does not include any information regarding component/subsystem design required to meet the requirements presented herein. Information on this subject may be found in ES-3U5T-1B257-AA "EMC Design Guide for Printed Circuit Boards", which is available for download from <http://www.fordemc.com>. Additional information may be found from a number of technical journals and textbooks.

Requirements contained herein that pertain to conducted emissions or immunity are limited to low voltage DC applications (e.g. 12 VDC). Conducted requirements pertaining to high voltage systems (e.g. HEV, PHEV, EV) are not covered in this specification. However high voltage systems must comply with other EMC requirements (e.g. RF emissions/immunity, ESD requirements) as delineated herein. See Table 6-1 for specific applicability.

Although every attempt has been made to assure the information contained herein is accurate, editorial updates and/or technical clarifications to requirement/test methods are made when noted. This information may be found at <http://www.fordemc.com>. The user (i.e. suppliers, test laboratories) shall review this information prior to preparation of component EMC test plans and/or execution of testing.

2.0 References

2.1 International Documents

Only the latest approved standards are applicable unless otherwise specified.

72/245/EEC. European Community, Electromagnetic Compatibility of Vehicle

CISPR 16-1-1 Specification for radio disturbance and immunity measuring apparatus and methods - Part 1: Radio disturbance and immunity measuring apparatus.

CISPR 25 3rd Ed Limits and methods of measurement of radio disturbance characteristics for the protection of receivers used on board vehicles.

IEC 61000-4-21 Electromagnetic Compatibility (EMC) - Part 4-21: Testing and measurement techniques - Reverberation chamber test methods

ISO 10605 -2001 Road vehicles - Test methods for electrical disturbances from electrostatic discharge

ISO 7637-1-2002 Road vehicles, Electrical disturbance by conduction and coupling Part 1 – Definitions and general considerations.



ISO 7637-2-2004 Road vehicles, Electrical disturbance by conduction and coupling Part 2 - Vehicles with nominal 12 V or 24 V supply voltage - Electrical transient transmission by capacitive and inductive coupling via supply lines

ISO 11452-1- 2005 Road vehicles – Component test methods for electrical disturbances from narrowband radiated electromagnetic energy – Part 1: General and definitions

ISO 11452-2-2004 Road vehicles, Electrical disturbances by narrowband radiated electromagnetic energy - Component test methods Part 2 - Absorber-lined shielded enclosure

ISO 11452-4-2005 Road vehicles – Component test methods for electrical disturbances from narrowband radiated electromagnetic energy – Part 4: Bulk current injection (BCI)

2.2 Military Standards

MIL-STD-461E United States Department of Defense Interface Standard, Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment

2.3 Other Documents

ES3U5T-1B257-AA EMC Design Guide for Printed Circuit Boards. Available at <http://www.fordemc.com/>

ES1W7T-F407K00-AA E/E Functional Importance Classifications (contact Ford D&R activity for details)

EMC-P-2009 EMC Processes

3.0 Abbreviations, Acronyms, Definitions, & Symbols

Acceptance Criteria. Defines the limits of variance in function performance of the device during exposure to an electromagnetic disturbance.

Active Electronic Module. Electronic modules that function via use of digital or analog circuitry including microprocessors, operational amplifiers, and memory devices.

AEMCLRP. Automotive EMC Laboratory Recognition Program.

ALSE. Absorber-lined shielded enclosure. Also used in this document together with ISO or SAE to designate the test itself with reference to the method described in ISO 11452-1 or SAE J1113-21.

Annex. Supplementary material attached to the end of a specification, often used to supply additional information that may be normative or informative in nature.

Artificial Network (AN). A device used to present a known impedance to the powerline of the DUT.

Average Detection (AVG). A detection method that produces an output voltage of which is the average value of the envelope of an applied signal. The average value must be taken over a specified time interval.

BCI. Bulk Current Injection. Method for coupling common mode RF current into a harness

Carry Over. References a production level component designed to a current or previous EMC specification

CBCI. Common Mode BCI.

CE. Conducted Emissions

CI. Conducted Immunity

CISPR. An acronym for “Comité International Spécial des Perturbations Radioélectriques” (Special International Committee on Radio Interference).

CLD. Centralized Load Dump

Component. Reference for active electronic modules, electric motors, passive and inductive devices

Control Circuits. I/O circuits that are connected to the vehicle battery via switches, relays or resistive/inductive loads, where that load is fed by a direct or switched battery connection.

Component, subsystem Engineering Specification. Engineering specification for the component or subsystem documenting all performance requirements (mechanical, thermal, EMC, etc)

D&R. Design and Release

dBpT. dB picotesla (160 dBpT = 1Gauss)



Disturbance. Any electrical transient or electromagnetic phenomenon that may affect the proper operation of an electrical or electronic device (see stimulus).

DBCI. Differential Mode Bulk Current Injection.

DUT. Device(s) Under Test. Any electrical or electronic component, module, motor, filter, etc being tested.

DV. Design Verification (components not constructed from production tooling).

E/E. Electrical and/or Electronic.

EMC. Electromagnetic Compatibility

EMI. Electromagnetic Interference

Effect. A detectable change in DUT performance due to an applied stimulus.

EM. Electronically Controlled Motor.

ESA. Electronic Sub-Assembly

ESD. Electrostatic discharge.

ESD - Air Discharge. Test method whereby the electrode of the test generator is brought near the DUT and discharge is accomplished through an arc to the DUT.

ESD - Contact Discharge. Test method whereby the electrode of the test generator is brought into contact with the DUT and the discharge is triggered by the discharge switch located on the generator.

Fail-Safe Mode. A predictable operating mode intended to minimize adverse effects by restricting or shutting down operation when a significant stimulus has made operation unreliable. Operation shall recover after the stimulus is removed without permanent loss of function or corruption of stored data or diagnostic information.

FMC. Ford Motor Company including all affiliate brands

FMC D&R Group. The FMC engineering activity responsible for design or the component or subsystem

FMC EMC Department. The Ford Motor Company EMC department associated with a specific brand.

FPDS. Ford Product Development System

Function. The intended operation of an electrical or electronic module for a specific purpose. The module can provide many different functions, which are, defined (functional group and acceptable performance) by the module specification.

Functional Importance Classifications: Defines the importance of E/E component/subsystem functions with respect to safe vehicle operation.

- **Class A:** Any function that provides a convenience.
- **Class B:** Any function that enhances, but is not essential to the operation and/or control of the vehicle.
- **Class C:** Any function that controls or affects the essential operation of the vehicle or could confuse the driver or other road users.

Function Performance Status. The performance of DUT functions, when subjected to a disturbance, is described by three performance status levels:

- **Status I:** The function shall operate as designed (or meet specified limits) during and after exposure to a disturbance.
- **Status II:** The function may deviate from designed performance, to a specified level, during exposure to a disturbance but shall not affect safe operation of the vehicle, safety of its occupants and does not adversely affect customer satisfaction. The function may revert to a fail-safe mode of operation, but shall return to normal operation following removal of the disturbance either automatically or in line with the function's fail-safe recovery strategy. No effect on permanent or temporary memory is allowed. Status II performance, where applicable, is only permissible if the deviation in performance does not affect other related functions requiring Status I performance.
- **Status III:** The function may deviate from designed performance during exposure to a disturbance but shall not affect safe operation of the vehicle or safety of its occupants. Operator action may be required to return the function to normal after the disturbance is removed (e.g. cycle ignition key, replace fuse). No effect on permanent type memory is allowed. Status III performance, where applicable, is only permissible if the deviation in performance does not affect other related functions requiring Status I performance.
- **Status IV:** The device shall not sustain damage, changes in I/O parametric values (resistance, capacitance, leakage current etc.) or a permanent reduction in functionality.



Inductive Device. An electromechanical device that stores energy in a magnetic field. Examples include, but not limited to solenoids, relays, buzzers, and electromechanical horns.

Informative. Additional (not normative) information intended to assist the understanding or use of the specification.

I/O. Input and output. Also used in this document to designate the transient pulse testing on I/O-lines.

MBW. Measurement System Bandwidth

Memory (temporary or permanent). Computer memory used for, but not limited to storage of software code, engine calibration data, drive personalization, radio presets. Hardware for this includes ROM, RAM and FLASH memory devices.

N/A. Not Applicable

Normal Operation: In the context of functional performance status) A predictable and safe operating mode where the operator has full control.

Normative. Provisions that are necessary (not informative) to meet requirements.

OBDII. On-Board Diagnostics II

PCB. Printed Circuit Board.

Peak Detection (PK). A detection method that produces an output voltage of which is the peak value of an applied signal.

PRR. Pulse Repetition Rate

PV. Production Verification (component constructed from production tooling)

PWM. Pulse Width Modulated or Modulation.

Quasi-Peak Detection (QP). A detection method having specified electrical time constants which, when regularly repeated identical pulses are applied, produces an output voltage which is a fraction of the peak value of the pulses, the fraction increasing towards unity as the pulse repetition rate is increased.

RE. Radiated Emission

RI. Radiated Immunity

Recognized Laboratory. An EMC laboratory that meets the requirements for acceptance by Ford Motor Company through in part, accreditation via AEMCLRP requirements. Refer to <http://www.fordemc.com> for more details on this program.

Regulated Power Supply. A voltage regulated supply typically lower in magnitude than the vehicle's battery voltage (e.g., 5VDC, 3VDC). Regulated power is derived using active electronic devices including linear and switch-mode power supplies. Regulated power supplies are typically used to provide power to sensors.

RF Boundary. An element of an EMC test setup that determines what part of the harness and/or peripherals is included in the RF environment and what is excluded. It may consist of, for example, ANs, filter feed-through pins, fiber optics, RF absorber coated wire and/or RF shielding. The RF boundary directly affects the resonant characteristics of the DUT cable harness during radiated immunity and emissions testing.

Shall. Denotes a requirement.

Single Shot. Refers to the capture mode of a digitizing oscilloscope. A single shot represents a single capture of the voltage or current waveform over a defined sweep time setting.

Should. Denotes a recommendation.

Substitution Method. The substitution method is a technique for mapping out the power required to produce a target RF field, magnetic field, or current in absence of the DUT at a designated reference position. When the test object is introduced into the test chamber, this previously determined reference power is then used to produce the exposure field.

Switched Power Circuits. Any circuit that is connected to the vehicle battery through a switch or relay.

4.0 Common Test Requirements

- Attention shall be directed to control of the RF boundary in both emission and immunity tests to reduce undesired interaction between the DUT, the Load Simulator and the electromagnetic environment.
- The test equipment, test setups and test procedures shall be documented as part of the test laboratory's procedures. FMC reserves the right to inspect the lab procedures.
- Although testing generally involves only one physical component, subsystem testing involving multiple components (e.g. distributed audio components) is permissible.
- All DV and PV testing requires an EMC test plan in accordance with the requirements of **EMC-P-2009**. See section 5.2 for additional details.

4.1 Load Simulator

DUT operation shall be facilitated by use of a Load Simulator that is constructed to simulate the vehicle system. The Load Simulator, is a shielded enclosure that contains all external electrical interfaces (sensors, loads, etc.) normally seen by the DUT. The Load Simulator also serves as an RF boundary for the DUT cable harness in addition to serving as an interface to support and monitoring equipment required during testing. Detailed requirements for the Load Simulator are found in Annex G.

4.2 Artificial Networks

Several tests in this specification require the use of Artificial Networks. Unless otherwise stated in this specification, the use and connection of Artificial Networks shall be in accordance to the Setup shown in Annex G. Artificial Network design and performance characteristics shall conform to CISPR 25, Edition 3 or ISO 7637-2 where applicable. For tests that do not specify the use of Artificial networks, the power supply shall be connected directly to the ground plane, Load simulator and DUT.

4.3 Interconnections

The electrical interconnections between the DUT and Load Simulator shall be facilitated using a standard test harness. The length of this harness shall be 1700 mm +300/- 0 mm unless otherwise stated within this specification. The harness shall contain wiring types (e.g. twisted wire pairs) that are used in the actual vehicle installation. Selected tests (e.g. CE420) require shorter power/power return wiring between the DUT and measurement system. To avoid fabrication of multiple test harnesses, it is recommended that a single test harness be fabricated to facilitate removal of these selected circuits and to provide a method to reduce their physical length (e.g. in-line connector).

4.4 Bonding of DUT, Load Simulator and Artificial Network to Ground Plane

The Load Simulator and Artificial Networks shall be directly bonded to the ground plane used in the test setup. Bonding shall be facilitated via screws directly into the ground plane. The bond impedance shall be verified to be less than 2.5 m Ω . The same requirements apply to DUTs with metal cases that are to be directly bonded to the ground plane (specified in the EMC test plan). Use of conductive tapes for bonding is prohibited unless permitted by the FMC EMC department. *Approval requires specific process steps by laboratory to demonstrate bonding impedance remains stable over the duration of testing.*

4.5 Test Conditions

4.5.1 Dimensions

All dimensions in this document are in millimeters unless otherwise specified.



4.5.2 Tolerances.

Unless indicated otherwise, the tolerances specified in Table 4.1 are permissible.

Table 4-1: Permissible Tolerances

Time interval, length*	± 10 %
Resistance, capacitance, inductance, impedance	± 10 %
Test parameters for RF field strength, Electrical or magnetic field strength, injected current, power, energy, transient voltage amplitude *	+10% - 0%

** Higher tolerance ratings shall be considered during the design phase of the component or subsystem*

Tolerances listed do not pertain to acceptance criteria for the DUT during testing.

4.5.3 Environmental Test Conditions

Unless indicated otherwise, the climatic test conditions are defined in Table 4-2.

Table 4-2: Environmental Test Conditions

Temperature	23 ± 5.0 degrees C
Humidity	20 to 80% relative humidity (RH)

4.5.4 Power Supply

The power supply voltage shall be between 13 (+ 0.5/-1.0) volts unless otherwise stated within this specification. For regulated power sources (e.g. 5VDC) the supply voltage shall be maintained within ± 5 % of the nominal voltage level. A number of tests methods require the use of an automotive battery. When used, the battery voltage shall not fall below 12 volts during testing. The battery may be charged during testing, but for test methods RE 310, CE 420 and CE 421, only a linear power supply may be used for this purpose. If the power supply is located outside of the shielded enclosure, a bulkhead RF filter may be used to prevent stray RF signals from entering or leaving the shielded enclosure.

5.0 Additional Requirements

5.1 Functional Importance Classification/ Performance Requirements

This specification requires that all component and subsystem functions are classified according to their criticality in the overall operation of the vehicle (i.e. Functional Importance Classification). In many cases, common functions have been previously classified (see ES-1W7T-F407K00-AA). If new functions are introduced, the FMC D&R group shall work with the FMC EMC department to develop and agree to the appropriate classifications.

Once functional classifications are established, the associated performance requirements shall be developed and documented in the component or subsystem’s engineering specification. These performance requirements serve as the basis for the component/subsystem acceptance criteria used during EMC testing. The FMC D&R group and their supplier(s) shall be responsible for developing these performance requirements.

5.2 EMC test plans

An EMC test plan shall be prepared and submitted to the FMC EMC department at least 20 days prior to commencement of EMC testing. The purpose of this test plan is to develop and document well thought out procedures to verify that the component is robust to the anticipated electromagnetic environment that it must operate within. The EMC test plan also provides a mechanism for ongoing enhancements and improvement to the test setup, which better correlates with vehicle level testing.



The EMC test plan shall be prepared in accordance with the outline shown in EMC-P-2009. FMC reserves the right to review and challenge specific detail of the EMC test plan including specific acceptance criteria for immunity testing. When the test plan is accepted by FMC, a unique test plan number will be assigned. This test plan number will serve as reference for subsequent test results. **Failure to obtain this test plan number prior to commencement of testing will invalidate the test results.** See **EMC-P-2009** for additional detail. Acceptance of the EMC test plan by FMC does not relinquish the supplier from responsibility if latter review shows deficiencies in the test setup and/or the acceptance criteria. The supplier shall work with the FMC EMC department to correct any deficiency and repeat testing if required by FMC.

5.3 Sample Size

A minimum of two samples shall be tested. All applicable tests are performed on each of the samples unless approved by the FMC EMC department.

5.4 Sequence of Testing

ESD tests, both unpowered and powered (see Section 21) shall be performed prior to any other testing. All other tests may be performed in any order. Extra test samples are recommended in the event of damage due to ESD. However, retesting will be required as the result of any corrective design actions required to mitigate any ESD issues found.

5.5 Revalidation

To assure that EMC requirements are continually met, additional EMC testing may be required if there are any circuit or PCB design changes (e.g. die shrinks, new PCB layout) in addition to any software changes. The process presented in **EMC-P-2009** shall be used to determine what additional testing will be required. The FMC EMC department and the FMC D&R group shall be notified if any of the design changes outlined in **EMC-P-2009** are planned.

5.6 Test Laboratory Requirements

All testing shall be performed in a recognized EMC test facility. A list of recognized test facilities may be found at <http://www.fordemc.com>. Laboratories seeking recognition by FMC shall do so via the Automotive EMC Laboratory Recognition Program (AEMCLRP). Details on this program and steps for laboratory recognition may be found at <http://www.fordemc.com>.

FMC reserves the right to arrange for follow-up correlation tests and/or on site visits to evaluate the test methods presented herein. A laboratory which refuses such follow-up activities, or for which significant discrepancies are found is subject to having its recognition withdrawn.

5.7 Data Reporting & Data Review

Data reporting requirements, including processes for test report generation and submittal to the FMC EMC department are found in **EMC-P-2009**. **All test data shall be reviewed by the FMC EMC department to verify compliance to the requirements herein. Component/Subsystem compliance shall be determined by the FMC department.**

6.0 Requirement Applicability

Table 6-1 lists all of the EMC requirements delineated in this specification along with their applicability to E/E components. In some cases components may fall into multiple categories (e.g. active magnetic sensors powered from a regulator power supply). Under those conditions all applicable categories shall be considered.



Table 6-1: Requirement Selection Matrix

	Requirement Type	Req. ID	Component Category									
			Passive Modules	Inductive Devices	Electric Motors		Active Electronic Modules					
			P	R	BM	EM	A	AS	AM	AX	AY	AW
Requirement Applies (✓)	RF Emissions	RE 310				✓	✓	✓	✓	✓	✓	✓
		CE 420 ⁽¹⁾			✓	✓	✓	✓	✓	✓	✓	
	Conducted AF	CE 421 ⁽¹⁾				✓	✓	✓	✓	✓	✓	
	Conducted Transients	CE 410 ⁽¹⁾		✓	✓	✓				✓	✓	
	RF Immunity	RI 112				✓	✓	✓	✓	✓	✓	
		RI 114				✓	✓	✓	✓	✓	✓	✓
		RI 115				✓	✓	✓	✓	✓	✓	✓
	Magnetic Field Immunity	RI 140							✓			
	Coupled Disturbances	RI 130				✓	✓	✓	✓	✓	✓	
		RI 150				✓	✓	✓	✓	✓	✓	
	Continuous Disturbances	CI 210 ⁽¹⁾				✓	✓		✓	✓	✓	
	Transients	CI 220 ⁽¹⁾	✓			✓	✓		✓	✓	✓	
	Power Cycle	CI 230 ⁽¹⁾				✓	✓		✓	✓	✓	
	Ground Offset	CI 250 ⁽¹⁾				✓	✓		✓	✓	✓	
	Voltage Dropout	CI 260 ⁽¹⁾				✓	✓	✓	✓	✓	✓	
	Voltage Overstress	CI 270 ⁽¹⁾	✓	✓	✓	✓	✓	✓	✓	✓	✓	
ESD	CI 280	✓			✓	✓	✓	✓	✓	✓	✓	

(1) Requirements not applicable to high voltage systems (See section 1.4)

Passive Modules:

P: A passive electrical module consisting of only passive components including resistor, capacitor, inductor, blocking or clamping diode, Light Emitting Diode (LED), thermistor. *Requirement applicability may be waived all or in part if analysis, approved by FMC EMC demonstrates device robustness.*

Inductive Devices:

R: Relays, solenoids and horns.

Electric Motors:

BM: A brush commutated dc electric motor. **EM:** An electronically controlled electric motor.

Active Electronic Modules:

A: An electronic module that contains active electronic devices. Examples include analog op amp circuits, switching power supplies, microprocessor based controllers and displays.

AS: A module operated from a regulated power supply located in another module. This is usually a sensor providing input to a controller.

AM: A module that contains magnetically sensitive elements or is connected to an external magnetically sensitive element.

AX: A module that contains an electric or electronically controlled motor within its package or controls an external inductive device including electric or electronically controlled motor(s).

AY: A module that contains a magnetically controlled relay within its package.

AW: A module with no external wiring (e.g. RKE key).



7.0 Radiated RF Emissions: RE 310

The requirements, delineated in Tables 7-1 and 7-2 are applicable to the following component categories:

Electronic Modules: A, AS, AM, AX, AY, AW, EM

7.1 Requirement

Radiated emissions requirements cover the frequency range from 0.15 to 1583 MHz. Requirements are linked directly to specific RF service bands, which are segregated into Level 1 and Level 2 requirements.

Level 1 requirements are based on latest version of European directive 72/245/EEC .

- Limit A is based on use of Average detection.
- Limit B is based on use of Quasi Peak Detection.

Level 2 requirements are based on specific customer requirements.

- Limit A is based on use of Peak and Average detection. With the exception of Bands EU1, G1 and G8, the component is only required to demonstrate compliance to either the Peak or Average limit (*Bands EU1, G1, G8 are based only on Average detection*). Average limits are applicable only for components that operate with continuous duration. Components that operate with intermittent duration are only required to meet the Peak limits.
- Limit B is based on Quasi Peak Detection.

Table 7-1: RE 310 Level 1 Requirements

Band #	Frequency Range (MHz)	Limits (dBµV/m)	
		Limit A AVG ^(1,2)	Limit B QP ⁽¹⁾
M1	30 - 75	52- 25.13*Log(f/30)	62 - 25.13*Log(f/30)
M2	75 – 400	42 + 15.13*Log(f/75)	52 + 15.13*Log(f/75)
M3	400 - 1000	53	63

1 f = Measurement Frequency (MHz)

2 Limit A is based on use of a 120 kHz MBW with Average Detection.



Table 7-2: RE 310 Level 2 Requirements

Band #	Region	RF Service (User Band in MHz)	Requirement Frequency Range (MHz)	Limits (dBµV/m)		
				Limit A		Limit B
				PK ^(2,3)	AVG ^(2,3,4)	QP ^(2,3)
EU1	Europe	Long Wave	0.15 - 0.28		35	53
G1	Global	Medium Wave (AM)	0.53 - 1.7		12	30
NA1	North America	DOT 1 (45.68 - 47.34)	45 - 48 ⁽¹⁾	12	6	24
G2	Global	4 Meter (66 - 87.2)	65 - 88 ⁽¹⁾	18	12	24
JA1	Japan	FM 1 (76 - 90)	75 - 91 ⁽¹⁾	18	12	24
G3	Global	FM 2 (87.5 - 108)	86 - 109 ⁽¹⁾	18	12	24
G4	Global	2 Meter (142 - 175)	140 - 176 ⁽¹⁾	18	12	24
EU2	Europe	DAB 1 (174.1 - 240)	172 - 242 ⁽¹⁾	18	12	24
G5	Global	RKE, TPMS 1	310 - 320	20	14	30
EU3	Europe	Tetra	380 - 422	25	19	30
G6	Global	RKE, TPMS 2	429 - 439	25	19	30
EU4	Europe	Police	440 - 470	25	19	30
EU 5	Europe	RKE	868 - 870	30	24	
EU6	Europe	RKE	902 - 904	30	24	
EU7	Europe	DAB L-Band	1447 - 1494	36	30	
G8	Global	GPS	1567 - 1574		$50 - 20664 * \log(f/1567)$ ⁽⁵⁾	
			1574 - 1576		10	
			1576 - 1583		$10 + 20782 * \log(f/1576)$ ⁽⁵⁾	

- 1 User band with ~1% guard band. Applicable only for bands NA1, G2, JA1, G3, G4, EU2
- 2 Limits based on detection method. AVG= Average detection, PK= Peak detection, QP = Quasi-Peak detection
- 3 Limit A, PK and AVG values are based on use of a 9/10 kHz MBW (all bands except EU1, G1). Limit B, QP values (EU1, G1) are based on a 9 kHz MBW. Limit B, QP values (all bands except EU1, G1) are based on a 120 kHz MBW.
- 4 Average Detection limits may not be used for components that operate with intermittent duration.
- 5 f = Measurement Frequency (MHz)

7.2 Test Verification and Test Setup

The requirements of CISPR 25 Edition 3, ALSE method, shall be used for verification of the DUT performance except where noted in this specification. Component operation during testing shall be documented in an EMC test plan prepared by the component/subsystem supplier and EMC test laboratory (see section 5.2).

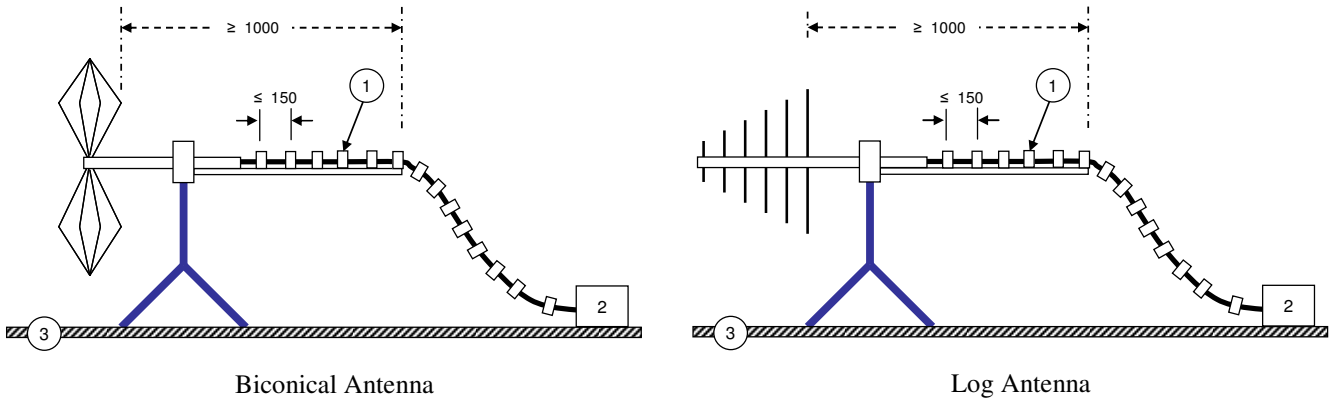
- Co-location of multiple receiving antennas in the same test chamber to support automated testing for reduced test times is not permitted.
- When performing testing using either the biconical or log antenna, the coaxial cable shall be routed directly behind the antenna as illustrated in Figure 7-1. The cable shall remain parallel to the test chamber floor for a minimum of 1000 mm behind the rear most element of the antenna (see Figure 7-1). The cable shall include ferrite beads (Fair-Rite Type 43 or equivalent) with a maximum spacing of 150 mm. Ferrite beads are not required for sections of the antenna cable lying on the test chamber floor. *The purpose for this modification is to minimize cable affects on the antenna's published antenna correction factors.*
- If a pre-amplifier is used to meet the ambient requirements (see section 7.3) , the device should be located where the antenna cable meets the test chamber floor (see Figure 7-1). Location of the pre-amplifier at the antenna connector is not recommended due to possible interactions between the antenna elements and the power supply wiring to the preamplifier. The preamplifier may be located outside of the test chamber as long as the measurement system ambient requirements are met. *See section 7.2.2 for additional requirements when using preamplifiers.*
- When tests are performed above 1000 MHz, the receiving antenna shall be relocated such that its center is aligned with the center of the DUT as illustrated in Figure 15 of CISPR 25. Height of the antenna relative to the ground plane bench shall remain unchanged.
- The DUT and any electronic hardware in the Load Simulator shall be powered from an automotive battery (see paragraph 4.5.4 for requirements). The battery negative terminal shall be connected to the ground plane bench. The battery may be located on, or under the test bench. The standard test setup shown in Annex G shall be used for the Load Simulator, battery and Artificial Networks.
- The total harness length shall be 1700 mm (+300 /-0 mm). The harness shall lie on an insulated support 50 mm above the ground plane.
- The DUT shall be placed on an insulated support 50 mm above the ground plane. However, if the outer case of the DUT is metal and, when installed in the vehicle is electrically connected to the vehicle's sheet metal, the DUT shall be mounted and electrically connected to the ground plane during the test in a manner representative of the vehicle application. *This configuration is only permitted if documented in the product engineering specification and is representative of the vehicle application.* The DUT grounding configuration shall be documented in the EMC test plan and test report.
- For some DUT's, deviations from the standard test setup may be necessary to facilitate testing. These deviations must be reviewed and approved by the FMC EMC department prior to commencement of testing. Test setup deviations shall be documented in the EMC test plan and test report.

7.2.1 Test Setup for Engine Control Circuits (Bands EU1, G1 only)

When testing engine control electronics that are packaged in the engine compartment, the test setup illustrated in Figure 7-2 may be used. This test setup shall not be used for any other module or subsystem.

The ignition and injector wires shall be removed from the main wire harness and located directly on the ground plane 100 mm behind the main wire harness. RF shielding, as illustrated in Figure 7-2 shall be placed over the selected wiring. The RF shielding shall be electrically connected to the ground plane via direct connection (e.g. screws) or copper tape with conductive adhesive. Use of this test setup shall be documented in the EMC test plan and approved by the FMC EMC department prior to commencement of testing. Photos of the test setup shall be included in the test report.

Figure 7-1: RE 310 Test Antenna Cable Configuration (excludes Rod antenna)

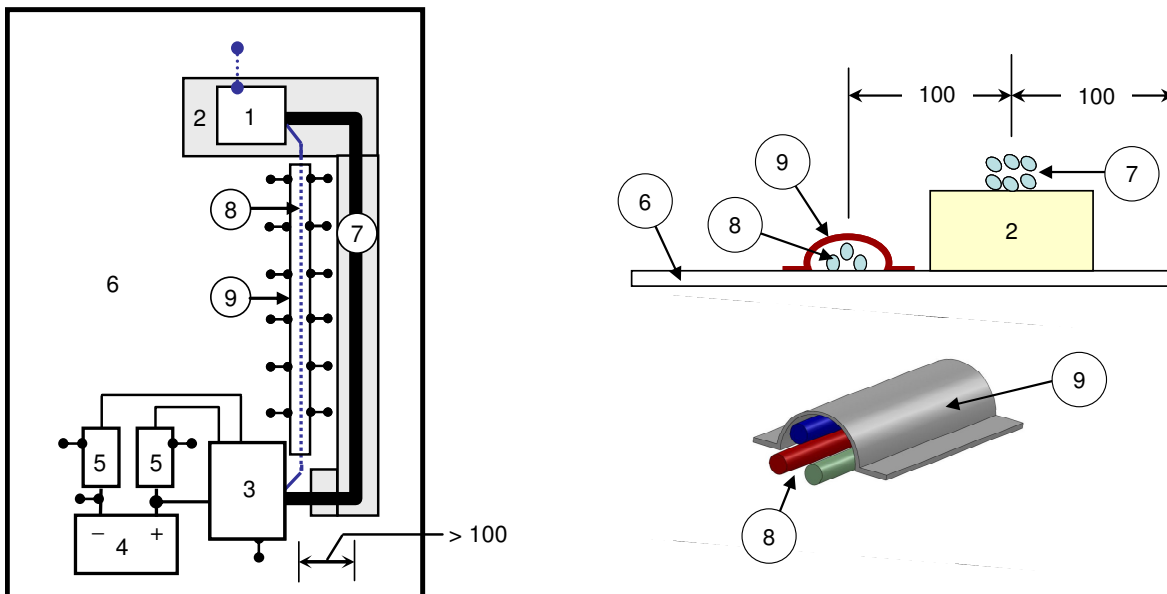


Scale: millimeters

Key:

- 1. Ferrite Cable Bead (Fair-Rite Type 43 or equivalent)
- 2. Preamplifier (if required)
- 3. Floor of ALSE

Figure 7-2: RE 310 Test Setup (EU1, G1) DUTs with Selected Wiring in Engine Compartment



Key

- 1. DUT
- 2. Insulated Support ($\epsilon_r \leq 1.4$)
- 3. Load Simulator
- 4. Automotive Battery
- 5. Artificial Network
- 6. Ground Plane Bench
- 7. Cable Harness (1700 -0/+300 mm)
- 8. Selected Wiring Removed from Cable Harness
- 9. RF Shield placed over Selected Wiring Removed from Cable Harness (may use aluminum foil)



Rod Antenna Not Shown. Physical Dimensions conform to CISPR 25 3rd Edition Except where noted. Dimensions shown are in millimeters.

7.2.2 Measurement System Requirements

The measurement receiver (spectrum analyzer or stepped receiver) shall be compliant to CISPR 16-1-1 as specified in section 4.4 of CISPR 25 3rd edition. Measurement receivers using Fast Fourier Transform (FFT) techniques may be used with prior approval from the FMC EMC department (*approval will be linked to laboratory recognition*). A list of approved measurement systems may be found at: www.fordemc.com.

Tables 7-3, 7-4 and 7-5 list the measurement system requirements when using either a swept (i.e. spectrum analyzer) or stepped EMI receiver.

- For all bands except, M1, M2, M3, Limit A is based on use of a 9/10 kHz measurement bandwidth combined with either Peak or Average detection. Limit B is based on use of 120 kHz measurement bandwidth combined with Quasi-Peak detection.
- For bands EU1 and G1, Limit A is based on use of a 0.2 – 1 kHz measurement bandwidth combined with Average detection. Limit B is based on use of 9 kHz measurement bandwidth combined with Quasi Peak detection.
- For bands M1, M2 and M3, Limit A is based on use Average detection with 120 kHz measurement bandwidth. Limit B is based on use Quasi Peak detection with 120 kHz measurement bandwidth.
- Measurement dwell times listed in Tables 7-3, 7-4 and 7-5 may be increased if the DUT operates with intermittent duration, however specific rationale must be documented in the EMC test plan to justify the increase.

Above 30 MHz, a low noise preamplifier is often required to meet the measurement system ambient requirements. However, use of a preamplifier will increase the potential of overload usually from out of band signals. To minimize this potential, it is recommended that the net gain of the pre-amplifier be selected to just meet the ambient requirements specified in section 7.3, step a). The laboratory shall also establish a procedure to avoid overload of the preamplifier, such as using a step attenuator.

Table 7-3: RE 310 Measurement System Setup Requirements (Bands EU1, G1)

	Swept Receivers		Stepped Receivers	
	Limit A	Limit B	Limit A	Limit B
Detection Method	Average	Quasi-Peak	Average	Quasi-Peak
Measurement Bandwidth {MBW} (kHz)	$0.2 \leq MBW \leq 1$	9/10 ⁽¹⁾	$0.2 \leq MBW \leq 1$	9
Video Bandwidth (kHz)	$\geq 3*MBW$	n/a		
Frequency sweep rate (sec/kHz) ⁽²⁾	$\geq 0.03/MBW$	≥ 0.2		
Frequency Step Size (kHz) ⁽²⁾			$0.5*MBW$	4.5
Measurement Time per Frequency Step (sec) ⁽³⁾			0.02	1

1. Any bandwidth in this range may be used.
2. Sweep rate calculated from MBW given in kHz.
3. Sweep rate and measurement time may be increased for low repetition rate signals. See section 7.2.2 for details



Table 7-4: RE 310 Measurement System Setup Requirements (All Bands except M1, M2, M3, EU1, G1)

	Swept Receivers		Stepped Receivers	
	Limit A	Limit B	Limit A	Limit B
Detection Method	Peak or Average	Quasi-Peak	Peak or Average	Quasi-Peak
Measurement Bandwidth {MBW} (kHz)	9/10 ⁽²⁾	120	9/10 ⁽²⁾	120
Video bandwidth (kHz)	≥ 3*MBW	n/a		
Frequency sweep rate (sec/kHz)	≥ 0.003	≥ 0.001		
Frequency Step Size (kHz)			0.5*MBW	60
Measurement Time per Frequency Step (sec) ⁽²⁾			0.005	1

1. To allow the use of various receiver types, either bandwidth may be used
2. Sweep rate and measurement time may be increased for low repetition rate signals. See section 7.2.2 for details

Table 7-5: RE 310 Measurement System Setup Requirements (Bands M1, M2, M3)

	Swept Receivers		Stepped Receivers	
	Limit A	Limit B	Limit A	Limit B
Detection Method	Average	Quasi-Peak	Average	Quasi-Peak
Measurement Bandwidth {MBW}⁽¹⁾ (kHz)	120	120	120	120
Video bandwidth (kHz)	≥ 500	n/a		
Frequency sweep rate (sec/kHz)	≥ 0.003	≥ 0.001		
Frequency Step Size (kHz)			60	60
Measurement Time per Frequency Step (sec) ⁽¹⁾			0.005	1

1. Sweep rate and measurement time may be increased for low repetition rate signals. See section 7.2.2 for details



7.3 Test Procedure

- a) Prior to measurement of DUT radiated emissions, test setup ambient levels (i.e. all equipment energized except DUT) shall be verified to be 6 db or more below the specified requirements listed in Table 7-2. If this requirement is not met, testing shall not proceed until the associated test setup issues are resolved. Plots of the test setup ambient shall be included in the test report. Test setup ambient measurements shall be performed using a 9/10 kHz MBW with peak detection except for bands EU1, G1, and G8, which require use of average detection. All test setup ambient measurements shall be performed using only vertical polarization of the measurement antenna.
- b) Measurement of DUT radiated emissions shall be performed over all frequency bands listed in Tables 7-1 and 7-2. At measurement frequencies ≥ 30 MHz, measurements shall be performed in both vertical and horizontal antenna polarizations.
- c) When assessing DUT performance per Level 1 and Level 2 above 30 MHz (except band G8), measurements may be initially performed using 120 kHz MBW with peak detection along with the measurement system requirements delineated in Table 7-5 (Limit A). This approach facilitates reduction in the overall measurement time. If the resulting DUT emission levels are below Limit A (Level 1 and Level 2(Peak)), the test data may be submitted as the final result.
When using 120 kHz MBW with PK detection to assess DUT emissions per Level 2, Limit A (Peak), measurement system ambient requirements as delineated in step a) may be waived.
If DUT emission levels, measured in step c), are above any of the individual band requirements, additional measurements shall be performed using the measurement system requirements listed in Tables 7-4 and 7-5. This process is illustrated in Figures 7-3 and 7-4. Contact the FMC EMC department regarding questions and/or clarifications with respect to this process.
 - When assessing compliance to Level 2, Limit A, Peak or Average measurements shall be performed over the entire frequency band(s), where the emissions from step c) exceeded the limit. *Separate measurements to demonstrate compliance to both PK and AVG limits is not required.*
 - When assessing compliance to Level 2, Limit B, measurements are limited to individual frequencies where the emissions from step c) exceeded the limit.
- d) Tests shall be repeated for all DUT operating modes delineated in the component EMC test plan.

Figure 7-3: Recommended Process for Assessing DUT Emissions per RE 310 Level 1 Requirements

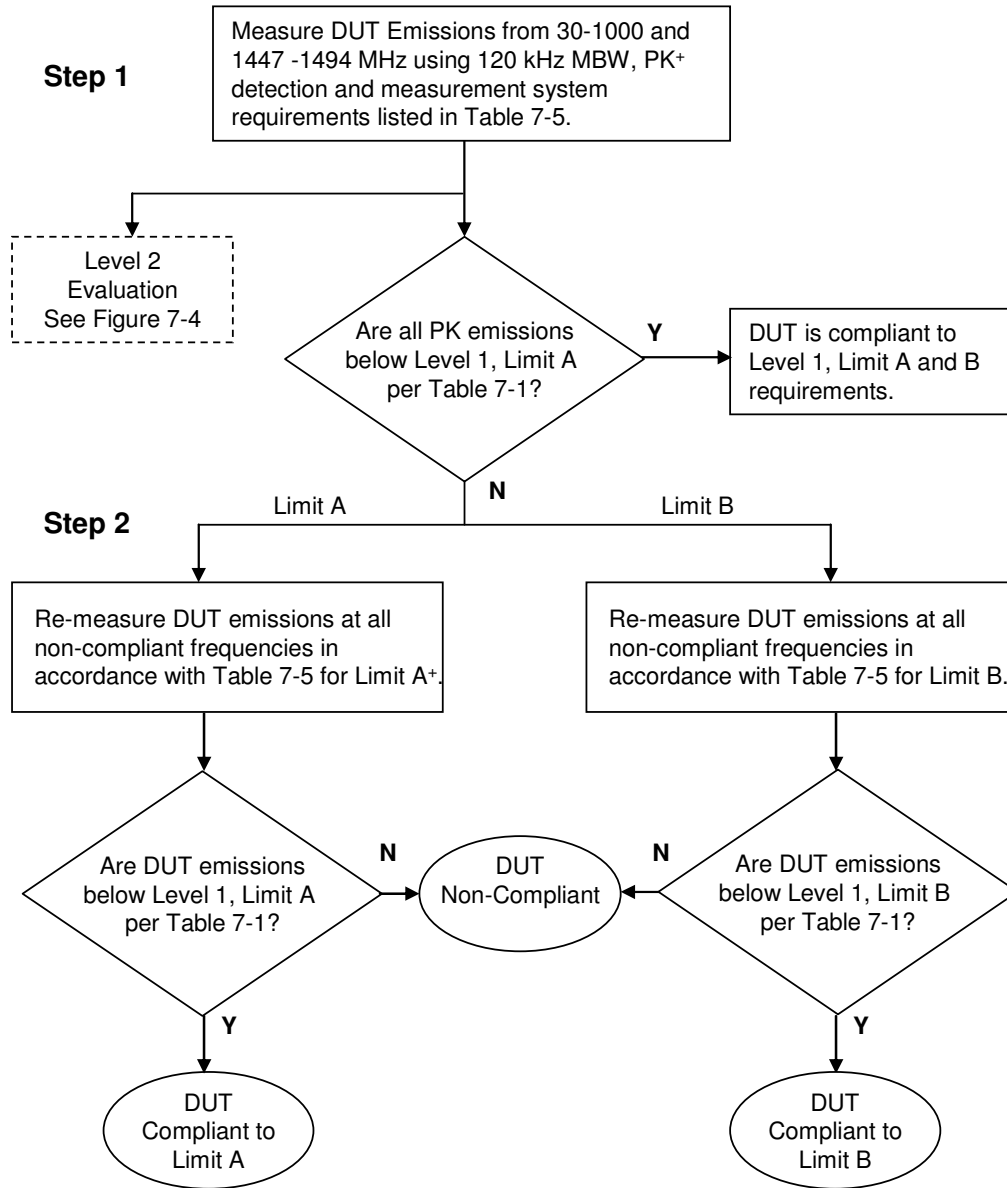
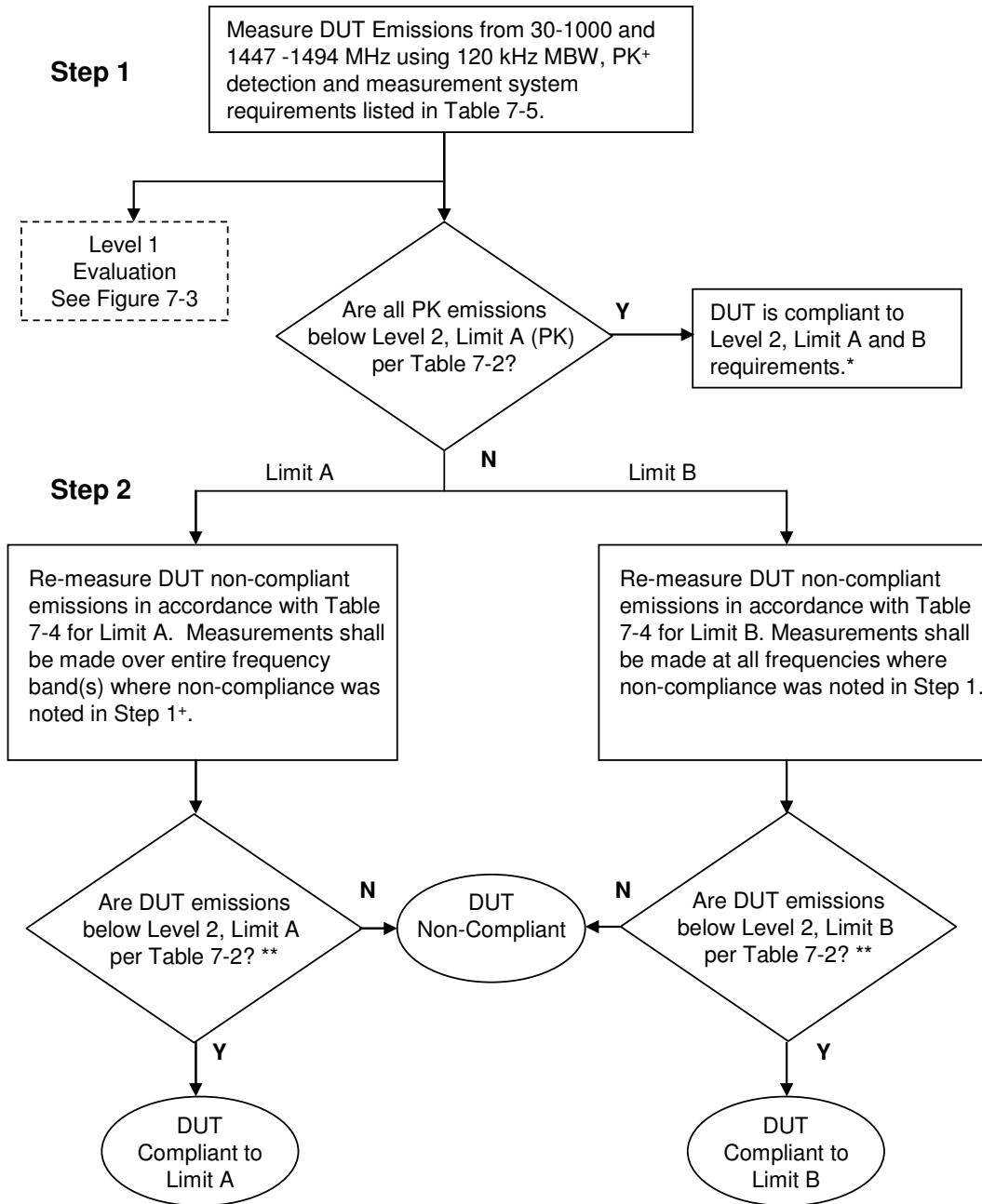


Figure 7-4: Recommended Process for Assessing DUT Emissions to RE310 Level 2 Requirements
(Excludes bands EU1, G1, G8)



+ Simultaneous PK and AVG measurements may be made using RF receivers with dual detector capability
 * Ambient requirements (6dB) do not apply when using 120 kHz MBW, PK detection to verify Level 2, Limit A requirements.
 ** Measurement system and test setup ambient requirements (6dB) apply when using 9/10kHz MBW to verify Level 2, Limit A requirements.



8.0 Conducted RF Emissions: CE 420

These requirements are applicable to the following component categories:

Electronic Modules: A, AS, AM

Shall meet Average Limits only.

Electronic Modules: AX, AY

Shall meet both Average and Quasi Peak Limits.

Electric Motors: EM

Shall meet both Average and Quasi Peak Limits.

Electronic Motors: BM

Shall meet Quasi Peak Limits only

These requirements are not applicable for electric motors/actuators that operate with intermittent duration AND with direct operator control via depression of a switch unless packaging requirements place the motor and/or it's wiring within 500mm of the vehicle's radio antenna. The FMC EMC department shall review and approve application of these requirements to these devices prior to commencement of testing.

These requirements may be relaxed or waived for components having a shielded power and power return wiring system implemented with shielded cable or by placement of multiple components in a common shielded enclosure. However this requires prior approval by the FMC EMC department upon their review of testing and/or analysis demonstrating that the "in-vehicle" packaging will not introduce alternate paths for coupling of conducted emissions exceeding CE420 levels on to unshielded power and return circuits.

8.1 Requirement

Conducted RF voltage emissions on the component power and power return circuits shall not exceed the requirements listed in Table 8-1. Requirements are limited to Long Wave (LW), Medium Wave (i.e. AM) and FM broadcast services.

Table 8-1: CE 420 Conducted Emissions Requirements

Band #	RF Service	Frequency Range (MHz)	Limits	
			Average (dbuV)	Quasi-Peak (dbuV)
EU1	Long Wave (LW)	0.15 - 0.28	77	89
G1	Medium Wave (AM)	0.53 - 1.7	54	66
JA1	FM 1	76 -90		36
G3	FM 2	87.5 - 108		36

8.2 Test Verification and Test Setup

The requirements of CISPR 25 (Edition 3), voltage method shall be used for verification of the component performance except where noted in this specification. If the DUT has separate power/power return circuits, separate tests shall be performed on each circuit. Circuits not being tested shall be connected directly to an automotive battery. This requirement may be waived if the multiple circuits are used only meet the operating current demands of the DUT (e.g. single power circuit, but with multiple connector pins). Under these conditions, the all power circuits are tied to the Artificial Network.

- Electronic hardware in the Load Simulator shall be powered from an automotive battery (see paragraph 4.5.4 for requirements). The battery negative terminal shall be connected to the ground plane.
- The power/power return wiring between the DUT and the Artificial Network shall be 200 +/-50 mm in length.
- The DUT shall be placed on an insulated support 50 mm above the ground plane. However, if the outer case of the DUT is metal and, when installed in the vehicle is electrically connected to the vehicle's sheet metal, the DUT shall be mounted and electrically connected to the ground plane during the test in a manner representative of the vehicle application. *This configuration is only permitted if documented in the product engineering specification and is representative of the vehicle application.* The DUT grounding configuration shall be documented in the EMC test plan and test report.
- If the DUT's power return is required to be locally grounded in the vehicle within 200 mm of the DUT (*must be specified in the DUT engineering specification*), the DUT power return shall be connected directly to the ground plane. Under these conditions, the Artificial Network connected to the DUT's power return may be omitted.

8.2.1 Measurement System Requirements

The measurement receiver (spectrum analyzer or stepped receiver) shall be compliant to CISPR 16-1-1 as specified in section 4.4 of CISPR 25 3rd edition. Measurement receivers using Fast Fourier Transform (FFT) techniques may be used with prior approval from the FMC EMC department. A list of approved measurement systems may be found at: www.fordemc.com.

Tables 7-3 and 7-4 in section 7.2.2 list the measurement system requirements when using either a swept (i.e. spectrum analyzer) or stepped EMI receiver. *Measurement system requirements are identical to those respective bands for RE 310.* For Bands EU1 and G1, it is recommended that the measurement time (stepped receivers) be equal to $1/f$, where f is the signal repetition rate. Swept receivers need to be adjusted accordingly. Measurement times used shall be documented in the EMC test plan.

8.3 Test Procedure

- a) Prior to measurement of DUT conducted emissions, test setup ambient levels (i.e. all equipment energized except DUT) shall be verified to be 6 db or more below the specified requirements listed in Table 8-1. Test setup ambient levels shall be at least 6dB below the specified limits otherwise testing shall not proceed until the associated test setup issues are resolved.
- b) Measurement of DUT conducted emissions shall be performed over each frequency band listed in Table 8-1.
- c) Tests shall be repeated for all DUT operating mode(s) delineated in the component EMC test plan.
- d) When assessing DUT performance to Quasi-Peak limits, the use of peak detection with the same measurement bandwidth is permitted as a quick pre-screen to increase testing efficiency. If the peak emissions are below the limit, the test data may be submitted as the final result. If the peak emissions exceed the band requirements, it will be necessary to re-sweep individual frequencies where the limit was exceeded using Quasi-peak detection. Peak and quasi-peak data shall be submitted in the test report.

9.0 Conducted Emissions: CE 421

These requirements are applicable to the following component categories:

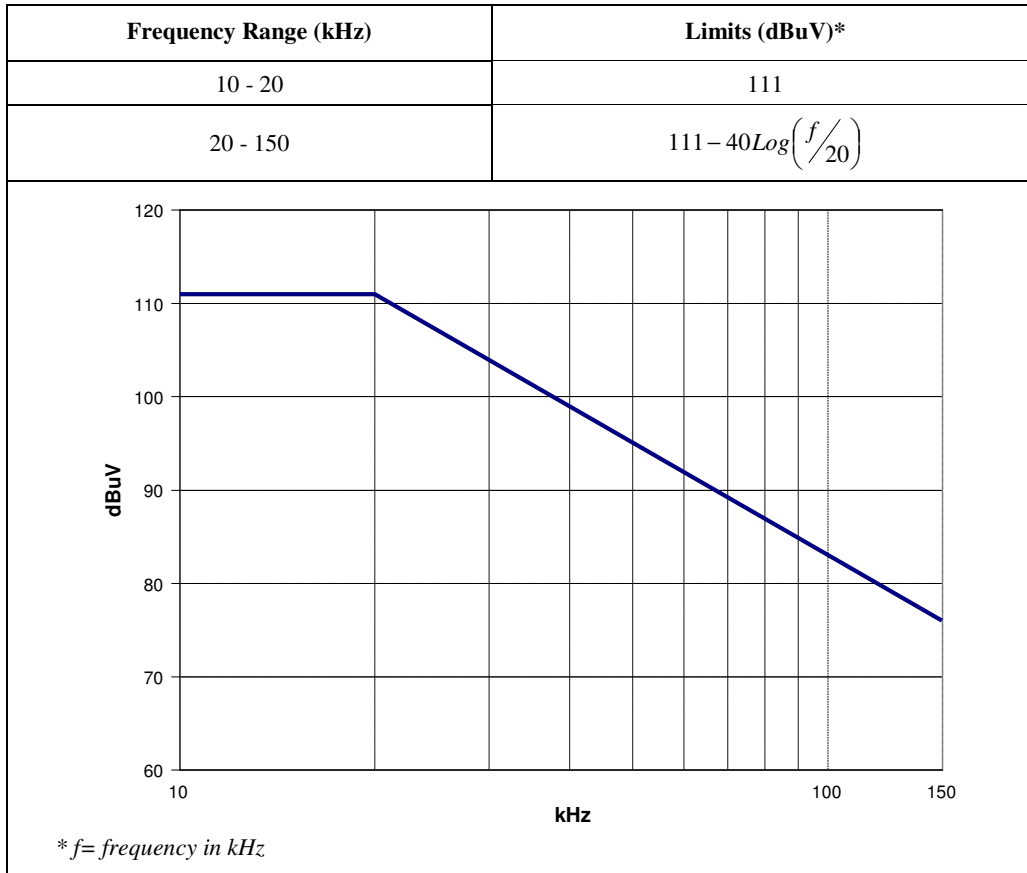
Electronic Modules: A, AS, AM, AX, AY

Electric Motors: EM

9.1 Requirement

Conducted voltage emissions on all component power circuits shall not exceed the requirements listed in Table 9-1.

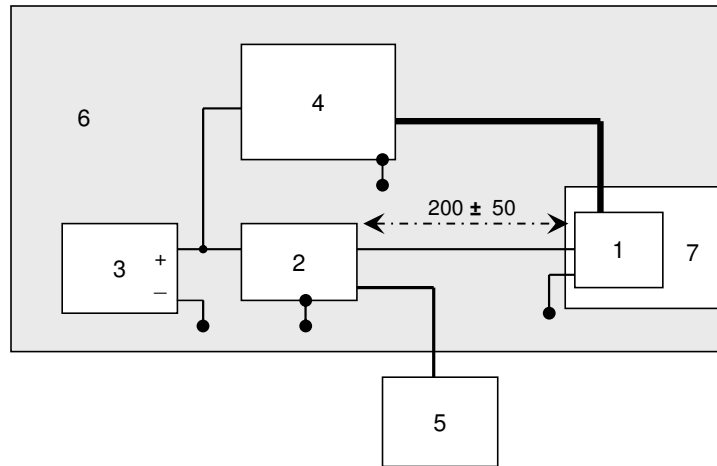
Figure 9-1: CE 421 Conducted Emissions Requirements



9.2 Test Verification and Test Setup

The test setup is identical to that used for CE 420 except only one Artificial Network is used regardless of how the DUT is grounded in the vehicle. The setup is shown in Figure 9-1. If the DUT has separate power circuits, separate tests shall be performed on each circuit. Circuits not being tested shall be connected directly to an automotive battery. This requirement may be waived if the multiple circuits are used only meet the operating current demands of the DUT (e.g. single power circuit, but with multiple connector pins). Under these conditions, all power circuits are tied to the artificial network.

Figure 9-2: CE 421 Test Setup

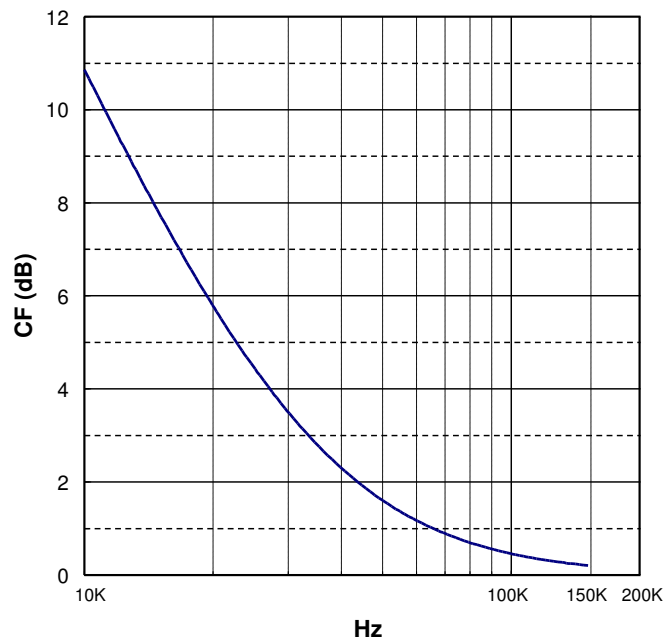


Key:

- | | |
|-----------------------|--|
| 1. DUT | 5. Measurement Receiver |
| 2. Artificial Network | 6. Ground Plane |
| 3. Automotive Battery | 7. Insulated Support ($\epsilon_r \leq 1.4$) |
| 4. Load Simulator | |

CE 421 requires application of a correction factor to the measured data to account for the insertion loss of the Artificial Network. Figure 9-2 illustrates 'typical' correction factor for a standard CISPR 25 artificial network. Correction for the actual Artificial Networks used for testing shall be measured by the test laboratory and used when verifying DUT performance relative to the requirements shown in Figure 9-1. The correction factor shall be determined using the procedure outlined in Annex I.

Figure 9-3: Typical Correction Factor for a CISPR 25 Artificial Network





9.2.1 Measurement System Requirements

The measurement receiver (spectrum analyzer or stepped receiver) shall be compliant to CISPR 16-1-1 as specified in section 4.4 of CISPR 25 3rd edition. Measurement receivers using Fast Fourier Transform (FFT) techniques may be used with prior approval from the FMC EMC department. A list of approved measurement systems may be found at: www.fordemc.com.

Table 9-2 lists the measurement system requirements when using either a swept (i.e. spectrum analyzer) or stepped EMI receiver.

Table 9-1: CE 421 Measurement System Setup Requirements

	Swept Receivers	Stepped Receivers
Detection Method	Average	Average
Measurement Bandwidth {MBW}⁽¹⁾ (kHz)	$0.2 \leq MBW \leq 1$	$0.2 \leq MBW \leq 1$
Video Bandwidth (kHz)	0.1	
Frequency sweep rate (sec/kHz)⁽²⁾	$\geq 0.03/MBW$	
Frequency Step Size (kHz)		$0.5 * MBW$
Dwell Time per Frequency Step (sec)		≥ 0.02

1 Any bandwidth in this range may be used.

2 Sweep rate is calculated from MBW given in kHz.

9.3 Test Procedure

The correction factor for the Artificial Network shall be applied to all measured data (i.e. test setup ambient, DUT conducted emissions) prior to verification the limits shown in Figure 9-1 using the equation below:

$$V_{CE}(f) = V_{raw}(f) + CF(f)$$

Where:

$V_{CE}(f)$ = DUT Conducted emissions (dBuV) at specific measurement frequency. $V_{CE}(f)$ is compared to the limits shown in Table 9-1

$V_{RAW}(f)$ = Conducted emissions (dBuV) from measurement port on Artificial Network at specific measurement frequency

CF = Correction factor (dB) for Artificial Network at specific measurement frequency

- Prior to measurement of DUT conducted emissions, test setup ambient levels (i.e. all equipment energized except DUT) shall be verified to be 6 db or more below the specified requirements listed in Figure 9-1. If ambient levels are less than 6 db below the specified limits, testing shall not proceed until the associated test setup issues are resolved. Plots of the test setup ambient shall be included in the test report.
- Measurement of the DUT's power line conducted emissions shall be performed over frequency range listed in Table 9-1.
- Tests shall be repeated for all DUT operating mode(s) delineated in the component EMC test plan.



10.0 Conducted Transient Emissions: CE 410

These requirements are applicable to the following component categories:

Electronic Modules: AX, AY

Electric Motors and Inductive Devices: BM, EM, R

10.1 Requirement

The component shall not produce transient voltages magnitudes exceeding +75 / - 100 volts on its power supply circuit(s).

10.2 Test Verification and Test Setup

The DUT shall be tested in accordance with ISO 7637-2, except where noted in this specification, using the test setup illustrated in Figure 10-1.

- The DUT power circuit(s) shall be connected directly to the Artificial Network through either mechanical or electromechanical switch with a single set of contacts. The switch shall have the following characteristics:
 - contact rating: $I \geq 30$ A or twice the rated current of the DUT (which ever is greater), continuous, resistive load
 - no suppression across relay contact;
 - single/double position contact electrically insulated from the coil circuit
 - Coil with transient suppression (*applies only to electromechanical relay*)

The actual switch used for testing shall be specified in the EMC test report.

- The wiring between the DUT and the Artificial Network shall be 200 +/-50 mm in length. No other connections shall be made between the switch and the DUT.
- The supply voltage to the DUT shall be +15 -0.5/+0 volts. The power supply shall have a short circuit current capability 100 amperes or twice the specified stall current of the DUT. The negative terminal of the power supply shall be connected to the ground plane.
- A digital sampling scope shall be used for the voltage measurements using a capable sampling rate of 1 Giga-samples per second (single acquisition capability) and a minimum memory depth of 2048 samples. The bandwidth shall be greater than 100 MHz. The voltage shall be measured using a 1:100 probe (< 4 pf). See ISO 7637-2 for additional requirements
- The DUT shall be placed on an insulated support 50mm above the ground plane. A DUT with an outer metal chassis may be electrically connected to the ground plane only if the DUT's design requires that its chassis must be grounded to the vehicle for functionality (*the DUT engineering specification must state this requirement*). The DUT's grounding configuration shall be documented in the EMC test plan and test report.
- If the DUT is an electric motor or actuator, it shall be tested in the "stall" condition unless analysis demonstrates this condition can not occur. If the motor contains internal protection (e.g. PTC device) that would limit or interrupt current to the DUT during a stall condition, testing shall be performed with the maximum rated mechanical load on the motor/actuator.

10.3 Test Procedures

- a) Close the external switch contacts (see Figure 9-1) and power up the DUT. Verify the DUT is functioning properly.
- b) Set the oscilloscope time base to 1 msec/div.
- c) Set the oscilloscope for single acquisition mode ("single shot"). Set the trigger level to +10 volts.
- d) Open and close the external switch contacts to verify the scope properly triggers. Do not proceed until triggering has been verified!
- e) Repeat steps a) through c) except the trigger level of the digital sampling scope shall be set to +80 volts .
- f) Adjust the oscilloscope sampling rate to the highest level available for the time base selected.

- g) If the DUT is of component categories AX, AY and EM, measure and record the peak transient voltages while exercising the DUT functions in operating modes identified in the EMC test plan. *This step may be omitted for component categories BM and R.*
- h) For all component categories with switched power circuits, measure and record peak positive transient voltages exceeding the trigger level while by turning the DUT off and on ten times (10 measurements for each condition) via the external switch shown in Figure 10-1.
- i) Repeat step e) through h) for each of the following time base values:
 - 100 usec/div;
 - 1 usec/div
 - 0.5 usec/div

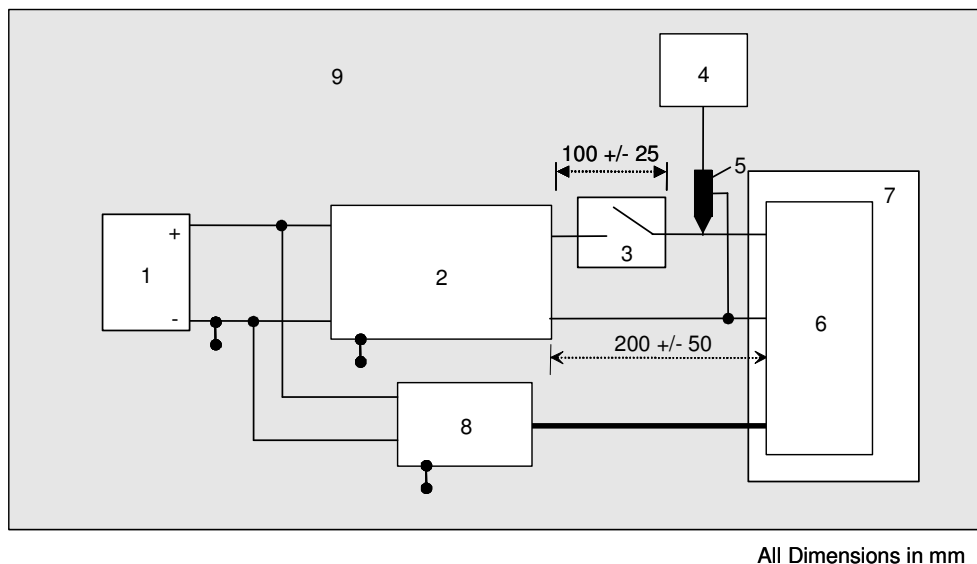
Alternative time base values may be selected if those listed are not available for the oscilloscope used. The lab shall use the closest time base value available. The time bases used shall be documented in the EMC test report.

- j) Re-adjust the trigger level of the digital sampling scope to -60 volts. Repeat steps e) through i) except record the peak negative transient voltages exceeding the trigger level.

Design Note

Although CI 410 requirements are validated at room temperature, the product should be designed to meet the same requirements at -45 degrees C or the coldest ambient temperature specified in the product's engineering specification

Figure 10-1: CE 410 Transient Emissions Test



Key:

- | | |
|---|--|
| 1. Power Supply | 6. DUT |
| 2. Artificial Network (AN) | 7. Insulated support ($\epsilon_r \leq 1.4$) |
| 3. Mechanical /Electromechanical Switch | 8. Load Simulator |
| 4. Digitizing Oscilloscope | 9. Ground Plane |
| 5. High Impedance Probe (1:100, C < 4pf.
See ISO 7637-2) Example: Agilent 10076A | |

11.0 RF Immunity: RI 112, RI 114, RI 115

Radiated immunity requirements cover the frequency range from 1 to 3100 MHz. Requirements are based on anticipated “off-vehicle” and “on-vehicle” RF sources (e.g. amateur radio, cellular phones). These requirements are applicable to the following component categories:

Electronic Modules: A, AS, AM, AX, AY, AW (excludes RI 112)

Electronic Motors: EM

RF immunity to hand portable transmitters (RI 115), applicability is limited to selected devices packaged inside the passenger or luggage compartments. See section 11.5 for details.

11.1 Generic Requirements

Component functional performance shall meet the acceptance criteria delineated in Table 11-1. Due to the wide frequency coverage, multiple test methods are needed for performance verification. Level 1 and Level 2 requirements are dependent on those test methods.

Table 11-1: RF Immunity Acceptance Criteria

Requirement Level	Functional Performance Status		
	Class A	Class B	Class C
1	I ⁽¹⁾	I	I
2	II ^(1,2)	II	I

- 1 For audio, video and RF functions, some degradation in performance (e.g. distortion) is permitted, but shall be defined and quantified in the component/subsystem's engineering specification and EMC Test Plan.
- 2 For audio components, volume level (measured at speaker terminals) shall not increase by more than 50%.

11.2 Generic Test Setup and Test Procedures

- The DUT wire harness shall be 1700 mm (+ 300/- 0 mm) long. The harness shall be routed 50 mm above the ground plane (excludes RI 114 bands 6 and 7) on an insulated support ($\epsilon_r \leq 1.4$) over the entire length between the DUT and the Load Simulator. *The harness can also be used for CISPR 25 Radiated Emission testing.*
- When performing testing per RI 112 and RI 114 (ALSE, Bands 4 and 5), the DUT shall be placed on an insulated support 50 mm above the ground plane. However, if the outer case of the DUT is metal and, when installed in the vehicle is electrically connected to the vehicle's sheet metal, the DUT shall be mounted and electrically connected to the ground plane during the test in a manner representative of the vehicle application. *This configuration is only permitted if documented in the product engineering specification and is representative of the vehicle application.* The DUT grounding configuration shall be documented in the EMC test plan and test report.
 - When performing testing per RI 114, Reverberation or ALSE, (Bands 6 and 7), a braided copper ground strap shall be used to connect the DUT case to the battery negative terminal. The strap shall be 1700 mm (+300/- 0 mm) with a width no greater than 13 mm. The strap shall be co-routed with the test harness. This method shall also be used if the DUT power returns require local grounding.
- When performing testing per RI 112 and RI 114, forward power shall be used as reference parameter for stress level characterization and during the actual test of the DUT. When performing testing per RI 115, net forward shall be used as reference parameter.
- When using pulse modulations, either peak envelope power (PEP) sensors or a spectrum analyzer are required to measure forward power however use of PEP sensors are preferred. If the spectrum analyzer is used, it shall be tuned to each individual frequency using zero span setting with a measurement bandwidth greater than or equal to 3 MHz (for both the resolution or IF bandwidth and the video bandwidth, if applicable). The same type of measurement device shall be used during both calibration and test. Alternative methods are not permitted.



11.3 Generic Test Procedures

- RF Immunity testing shall be performed with linear frequency step sizes no greater than those listed in Table 11-2.
- Peak conservation shall be used per ISO 11452-1. CW and modulation (AM & Pulsed) dwell times shall be a minimum of 2 seconds. Longer dwell times may be necessary if DUT function response times are expected to be longer. This information shall be documented in the EMC test plan.
- Amplifier output harmonics content shall conform to the requirements of ISO 11452-1 (2005). Field modulation and leveling shall conform to the requirements delineated in Annex B.
- The AM modulation frequency shall be 1 kHz at a level of 80%.
- Testing shall be initially performed using Level 2 requirements. If deviations are observed, the stress level shall be reduced until the DUT functions normally. The stress level shall then be increased until the deviation occurs. The stress level at this point shall be verified to meet the performance requirements delineated in Table 11-1. If the performance requirements are not met, the stress level shall be reported as the deviation threshold.

Table 11-2: RF Immunity Test Frequency Steps

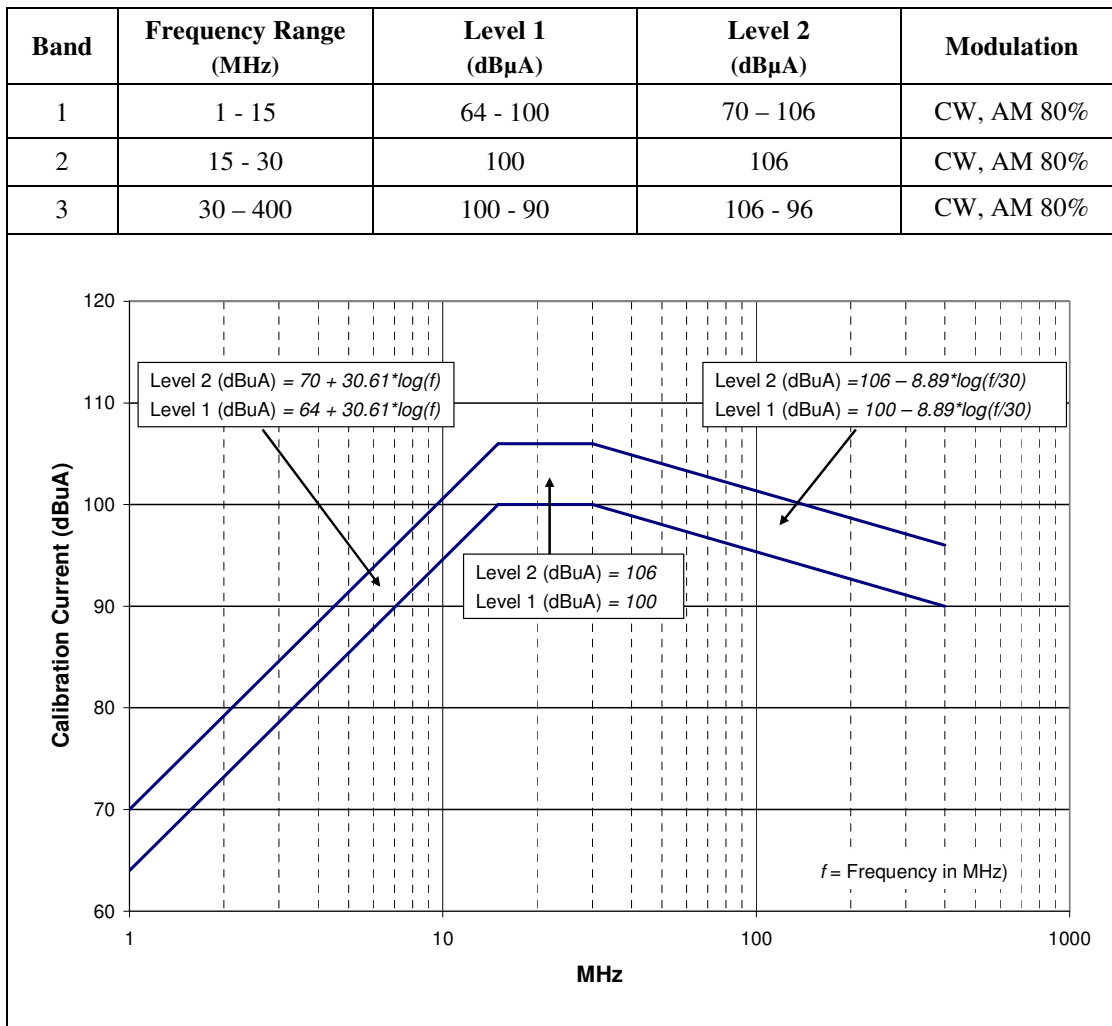
Frequency Range (MHz)	Frequency Step Size (MHz)
1 - 30	0.5
30 - 200	2
200 - 400	5
400 - 1000	10
1000 - 3100	20

11.4 Requirements 1 -400 MHz: RI 112

The device shall operate as specified in Table 11-1 when exposed to the RF current levels and modulation listed and illustrated in Figure 11-1. The currents are produced using the BCI test method.

RI 112 can not be used for component category AW (no wire harness). Alternative methods may be used (e.g. TEM cell), but only with prior authorization by the FMC EMC department. The test method used, including test setup detail shall be documented in the EMC test plan.

Figure 11-1: RI 112 Requirements using Bulk Current Injection (BCI)



11.4.1 Test Verification and Test Setup

Verification of component performance shall be in accordance with the BCI (substitution method) per (ISO 11452-4) except where delineated in this specification.

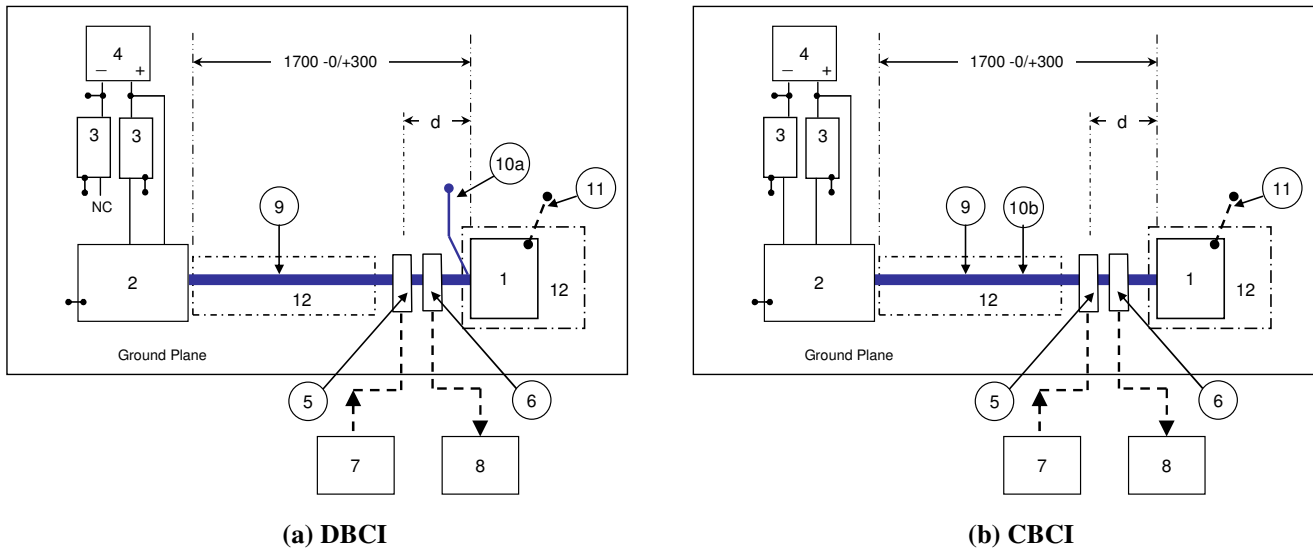
- The DUT shall be powered from an automotive battery (see paragraph 4.5.4 for requirements). The battery negative terminal shall be connected to the ground plane. The battery may be located on, or under the test bench. The standard test Setup shown in Annex G shall be used for the Load Simulator, battery and Artificial Networks.
- The test bench shall include a sufficiently large ground plane, such that the test harness lies in a straight line. Spacing between the edge of the ground plane and the test harness, DUT, Load Simulator etc shall conform to ISO 11452-4.
- The distance between the test Setup and all other conductive structures (such as the walls of the shielded enclosure) with the exception of the ground plane shall be ≥ 500 mm.
- In the frequency range from 1 MHz - 30 MHz all power return (i.e. ground) wires of the DUT wiring harness shall be terminated directly to the ground plane (DBCI) as illustrated in Figure 11-2a. The length of the wiring shall be 200 ± 50 mm. No power return wiring shall be routed around the BCI injection probe. These requirements may be waived if the power and power return wiring are twisted (*must be specified in the product engineering specification*) but must be documented in the EMC test plan.
- In the frequency range 30 MHz.- 400 MHz all wires of the DUT wiring harness shall be routed inside of the injection probe (CBCI) as illustrated in Figure 11-2b.
- If the DUT has multiple connectors, testing shall be repeated (1 – 400 MHz) with the injection probe placed around the individual harness associated with each individual DUT connector. Circuits contained in each harness shall be documented in the EMC test plan.
- The injection probe shall be insulated from the ground plane.
- An optional current monitoring probe may be used, but if used, it shall be placed 50 mm from the DUT. The monitor probe shall be insulated from the ground plane.

11.4.2 Test Procedure

Use the calibrated injection probe method (substitution method) according to ISO 11452-4.

- a) Use step frequencies listed in Table 11-2 and the modulation as specified in Figure 11-1.
- b) In the frequency range from 1 to 30 MHz, testing shall be performed at two fixed injection probe positions (**150 mm, 450 mm**).
- c) In the frequency range from 30 MHz to 400 MHz, testing shall be performed at two fixed injection probe positions (**450 mm, 750 mm**).
- d) If deviations are observed, the induced current shall be reduced until the DUT functions normally. Then the induced current shall be increased until the deviation occurs. This level shall be reported as the deviation threshold.
- e) Repeat testing for each harness connected to the DUT.
- f) The DUT operating mode(s) exercised during testing shall conform to that delineated in the EMC test plan.
- g) If a monitor probe is used during testing, it shall not be used to adjust the RF current delineated in Figure 11-1. The measured values are used for information only and may be included in the test report.

Figure 11-2: RI 112 DUT Harness Configurations



Key:

- | | |
|--|--|
| <ul style="list-style-type: none"> 1. DUT 2. Load Simulator 3. Artificial Network 4. Automotive Battery 5. Injection Probe 6. Monitor Probe (OPTIONAL) 7. RF Generation Equipment | <ul style="list-style-type: none"> 8. Current Monitoring Equipment (OPTIONAL) 9. DUT Wire harness 10a. DUT Power Return removed from wire harness and connected directly to sheet metal. Wire length is 200 ± 50 mm. 10b. DUT Power Return included in DUT wire harness 11. DUT Case Ground (see section 11.3.1) 12. Insulated Support ($\epsilon_r \leq 1.4$) d = Injection probe distance from DUT (see section 11.4.2) |
|--|--|



11.5 Requirements: 400 – 3100 MHz: RI 114

The device shall operate as specified in Table 11-1 when exposed to RF electromagnetic fields as delineated in Table 11-3.

Table 11-3: RI 114 Requirements (400 – 3100 MHz)

Band	Frequency Range (MHz)	Level 1 (V/m)	Level 2 (V/m)	Modulation
4	400 - 800	50	100	CW, AM 80% Pulsed PRR= 18 Hz, PD= 28 msec ⁽¹⁾
5	800 - 2000	50	70	CW, Pulsed PRR= 217 Hz, PD=0.57 msec
6	1200 - 1400	n/a	300 600 ⁽²⁾	Pulsed PRR= 300 Hz, PD = 3 usec, ⁽³⁾ with only 50 pulses output every 1 sec. ^(1,2)
7	2700 – 3100	n/a	300 600 ⁽²⁾	

1. Pulse Modulation limited to 400 – 470 MHz
2. 600 V/m requirements are only applicable to selected components associated with supplemental restraints system including frontal crash sensors. Contact FMC EMC department for specific applicability
3. Pulse duration (PD) shall be extended to 6 usec when testing using the reverberation (mode tuned) method. See 11.4.2.2 for additional detail.

11.5.1 Test Verification and Test Setup

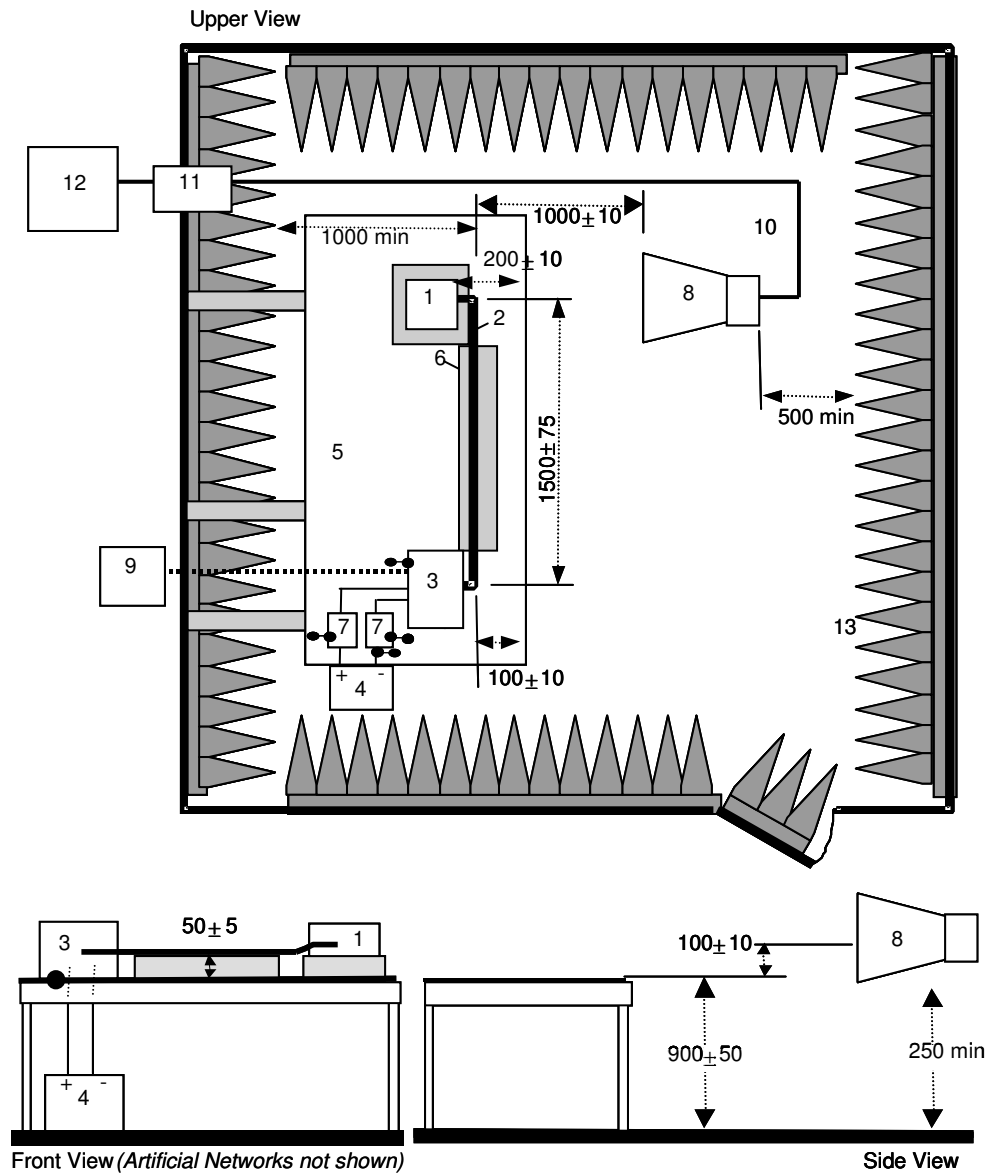
Verification of device performance shall be in accordance with either the following methods:

- ALSE Method (ISO 11452-2) except where noted in this specification. The tests is similar to that used for radiated emissions testing (see section 7.2).
- Reverberation, (Mode Tuned) Method (IEC 61000-4-21) except where noted in this specification.

11.5.1.1 ALSE Method (Bands 4 and 5)

- The DUT and any electronic hardware in the Load Simulator shall be powered from an automotive battery (see paragraph 4.5.4 for requirements). The battery negative terminal shall be connected to the ground plane bench. The battery may be located on, or under the test bench. The standard test setup illustrated in Annex G shall be used for the Load Simulator, battery and Artificial Networks.
- For frequencies ≤ 1000 MHz, the field-generating antenna shall be positioned in front of the middle of the harness. For frequencies above 1000 MHz, the antenna shall be moved 750 mm parallel to the front edge of the ground plane towards the DUT. The center of the antenna shall be pointed directly at the DUT instead of the center of the wiring harness (See Figure 11-3). Calibration procedures shall be performed in accordance with ISO 11452-2.
- Location of the DUT and Load Simulator requires that the harness shall be identical to that used for RE 310.

Figure 11-3: RI 114 ALSE Test Setup (1000 – 2000 MHz) excluding Bands 6 and 7



Key:

- | | |
|--|--|
| 1. DUT | 8. Transmitting Antenna |
| 2. Wire harness | 9. Support /Monitoring Equipment |
| 3. Load Simulator | 10. High quality double-shielded coaxial cable (50Ω) |
| 4. Automotive Battery | 11. Bulkhead connector |
| 5. Ground plane (bonded to shielded enclosure) | 12. RF Generation Equipment |
| 6. Insulated support ($\epsilon_r \leq 1.4$) | 13. RF absorber material |
| 7. Artificial Network | |

11.5.1.2 ALSE Method (Bands 6 and 7)

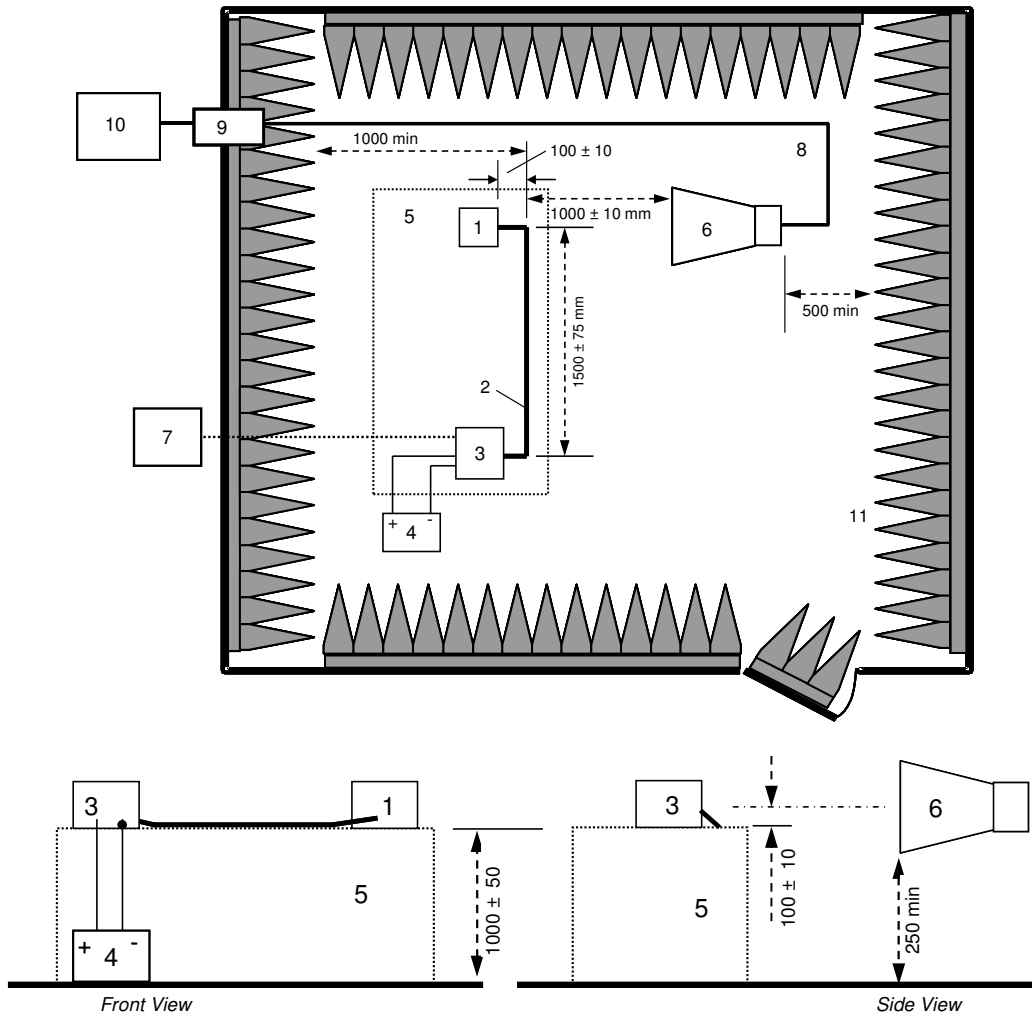
The test setup is illustrated in Figure 11-4

- A ground plane shall not be used for this test.
- The battery may be located on, or under the test bench.
- The DUT and its cable harness, along with the Load Simulator shall lie on an insulated support 1000 mm (+/-50 mm) above the floor of the test chamber. The dielectric constant of the insulated support shall be less than 1.4.
- Artificial Networks shall not be used.

11.5.1.3 Reverberation Method

- The test setup is illustrated in Figure C-1 of Annex C.
- The reverberation chamber shall be sized large enough to test a DUT within the chamber's working volume.
- Ground plane shall not be used for this test.
- The mechanical tuner shall be as large as possible with respect to overall chamber size (at least three-quarters of the smallest chamber dimension) and working volume considerations. Each tuner should be shaped such that a non-repetitive field pattern is obtained over one revolution of the tuner.
- The electric field probes shall be capable of reading and reporting three orthogonal axes.
- The RF signal generator shall be capable of covering the frequency bands and modulations specified.
- The transmit antenna shall be linearly polarized and capable of satisfying the frequency coverage requirements. The transmit antenna shall not directly illuminate the test volume.
- The receive antenna shall be linearly polarized and capable of satisfying the frequency coverage requirements. The receive antenna shall not be directed into the test volume.
- Associated equipment shall be present to record the power levels necessary for the required field strength.
- The DUT shall be at least 250 mm from the chamber walls, tuner, transmit antenna, and receive antenna.
- The DUT and its cable harness, along with the DUT and Load Simulator shall lie on an insulated support within the middle of the test volume. The dielectric constant of the insulated support shall be less than 1.4.
- Artificial Networks shall not be used.
- The power returns from the DUT shall be connected directly to the battery negative terminal.

Figure 11-4: RI 114 ALSE Test Setup for Bands 6 and 7



Key:

- | | |
|---|--|
| 1. DUT | 7. Support Equipment |
| 2. Test Harness | 8. Double Shielded Coaxial Cable (e.g. RG 223) |
| 3. Load Simulator | 9. Bulkhead Connector |
| 4. Automotive Battery | 10. RF Generation Equipment |
| 5. Dielectric Support ($\epsilon_r \leq 1.4$) | 11. RF absorber Material |
| 6. Transmit Antenna | |

11.5.2 Test Procedures

The DUT operating mode(s) exercised during testing shall conform to that delineated in the EMC test plan.

11.5.2.1 ALSE Method

Testing shall be performed using the substitution method. Refer to ISO 11452-2 for field characterization procedures for Bands 4 and 5. Refer to Annex A for field characterization procedures for Bands 6 and 7.

For both procedures, field characterization shall be performed at the Level 2 field strengths listed in Table 11-3. Field characterization at lower field strengths with subsequent power scaling for higher field strengths is not permitted.

When performing testing in Bands 6 and 7, the forward power required to achieve the field strengths listed in Table 11-3 is greatly influenced by the transmit horn antenna selected. The antenna near field gain compression characteristics can significantly impact the actual power needed to achieve the required field strengths at 1 meter. Given this issue, selection of the antenna should not be based simply on the published antenna gain. Also, the high power levels needed to achieve the desired field strength have been shown to significantly impact the VSWR of some antennas. A list of recommended antennas may be found at <http://www.fordemc.com>.

- a) When performing testing in Bands 6 and 7 using pulse modulation, CW shall not be used for leveling prior to application of pulsed modulation.
- b) Use the step frequencies listed in Table 11-2. Use the modulation as specified in Table 11-3.
- d) All modulation dwell time (i.e., time that RF is applied for per modulation type) shall be at least 2 sec.
- e) The test shall be performed using both horizontal and vertical antenna polarization.
- f) At test frequencies ≥ 1000 MHz, the DUT shall be tested in a minimum of three (3) orthogonal orientations unless otherwise stated in the EMC test plan.
- g) If deviations are observed, the field shall be reduced until the DUT functions normally. The field shall then be increased until the deviation occurs. This level shall be reported as deviation threshold.

11.5.2.2 Reverberation Method

- a) Use test frequencies according to Table 11-2. Use the modulation specified in Table 11-3 except for bands 6 and 7. For bands 6 and 7, increase the pulse duration (PD) to 6 usec.
- b) All modulation dwell time (i.e., time that RF is applied for per modulation type) shall be at least 2 s.
- c) Electric field probes shall not be used during the test.
- d) The test chamber shall be calibrated according to Annex C section C.1.1 (Field Uniformity Validation)
- e) Prior to collecting data, the procedures of Annex C, section C.2 (Calibration and DUT loading check) shall be performed.
- f) The transmit antenna shall be in the same location as used for calibration according to Annex C.
- g) The DUT shall be exposed to each field level and frequency at each mode tuner position.
- h) The chamber input power for the electric field levels is determined via the equation:

$$Test_Input_Power = \left[\frac{E_{test}}{\left\langle \vec{E} \right\rangle_{24or9} \cdot \sqrt{CLF(f)}} \right]^2$$

where:

E_{test} = Required field strength in V/m (see Table 11-3)

$CLF(f)$ = Chamber loading factor from Annex C, section C2, step g).

$\left\langle \vec{E} \right\rangle_{24or9}$ = Normalized electric field from the empty chamber calibration from Annex C, section C.1. It may be necessary to linearly interpolate (CLF and normalized electric field values) between the calibration frequency points.

- i) If deviations are observed, the field shall be reduced until the DUT functions normally. Then the field shall be increased until the deviation occurs. This level shall be reported as deviation threshold.

11.6 Requirements: RF Immunity to hand portable transmitters: RI 115

The device shall operate as specified in Table 11-1 when exposed to RF electromagnetic fields as delineated in Table 11-4. RI 115 is based on the potential risk of modules being exposed to hand portable transmitters (e.g. cell phones). **Specific applicability shall be agreed with the FMC EMC department prior to testing and documented in the test plan.**

Table 11-4: RI 115 Requirements for hand portable transmitters

Band	Frequency Band (MHz)	Test severity (Watts) ^(1, 2)		Modulation type
		Level 1	Level 2	
8	360-480	4.5	9.0	PM, 18 Hz, 50%
9	800 -1000	7.0	14.0	PM, 217 Hz, 12.5%
10	1600-1950	1.5	3.0	PM, 217 Hz, 12.5%
11	1950-2200	0.75	1.5	PM, 217 Hz, 12.5%
12	2400 -2500	0.1	0.2	PM, 1600 Hz, 50%
13	2500-2700	0.25	0.5	PM, 217 Hz, 12.5%

1: Test severity levels are only valid for the antenna identified in this specification

2: NET power delivered to the input port of the antenna, which established while the antenna is 1m from any object

11.6.1 Test Verification and Test Setup

Verification of component performance shall be performed using the test setup shown in Figure 11.5. References to wiring harness and LISN are not applicable in case of modules without wiring harness (e.g. remote entry key). All tests shall be performed in an absorber lined shielded enclosure (ALSE), which conforms to ISO 11452-2.

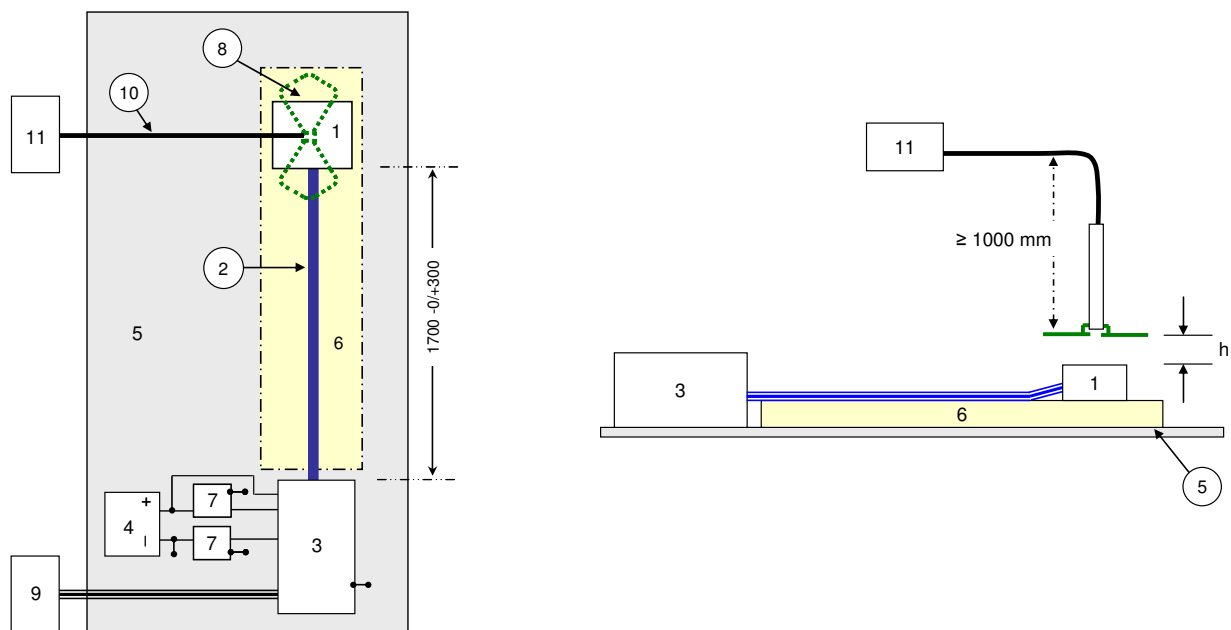
- This test procedure makes use of a small broadband antenna positioned above the DUT and it's wiring harness to simulate electromagnetic fields generated by hand portable transmitters operating in close proximity. The result of near field immunity tests is strongly influenced by the antenna type used and for this reason only Schwarzbeck antenna SBA9113 with elements 420NJ shall be used for this test.
- The separation between the test antenna and the DUT surfaces and harnesses shall be either 5 mm or 50 mm depending on expected proximity to intentional storage locations and product type as detailed in table 11-5 below. The test antenna is positioned in step sizes specified in table 11-5 to ensure all DUT surfaces are thoroughly exposed.
- The FMC EMC department shall be consulted with respect to antenna to DUT surface separation distance and positioning steps. This information shall be documented in the component level EMC test plan. Only one test antenna to DUT height shall be used for a given device.

Table 11-5: RI 115 Separation Distances and Antenna Positioning

DUT Surface or Harness description	Antenna Distance from DUT	Antenna Positioning Steps
DUT surfaces and first 300mm of their harnesses (measured from DUT connector) which are likely to be packaged between 50 to 200 mm of intentional and/or unintentional locations where a hand portable transmitter may be located.	50 mm	100 mm
Keys and similar devices which may come in direct contact with hand portable transmitters and all other DUT surfaces and first 300mm of their harnesses which are likely to be packaged less than 50 mm from intentional storage locations.	5 mm	30 mm

- The DUT shall be powered from an automotive battery (see paragraph 4.5.4 for requirements). The battery negative terminal shall be connected to the ground plane. The battery may be located on, or under the test bench. See Annex G regarding the standard test Setup for the Load Simulator, battery and Artificial Networks.
- The test harness shall be 1700 mm (+ 300/- 0 mm) long and routed 50 mm above the ground plane on an insulated support (ε_r ≤ 1.4) over the entire length between the DUT and the Test Fixture.
- The test bench shall include a sufficiently large ground plane, such that the plane extends beyond the test Setup by at least 100 mm on all sides.
- The distance between the test setup and all other conductive structures (such as the walls of the shielded enclosure) with the exception of the ground plane shall be ≥ 500 mm.
- The test antenna shall be mounted above the DUT and parallel to the ground plane. The DUT shall be positioned to ensure that the surface under test is facing the antenna.

Figure 11-5: RI 115 Test Setup



Key:

- | | |
|--|--|
| 1. DUT | 7. Artificial network |
| 2. Test harness | 8. Test antenna (Schwarzbeck antenna SBA9113 with elements 420NJ) |
| 3. Load Simulator | 9. Support Equipment |
| 4. Automotive Battery | 10. High quality double-shielded coaxial cable (cable can be no closer than 1000 mm to antenna elements. Place ferrite beads on cable (see Figure 11-6). |
| 5. Ground Plane | 11. RF Generation Equipment (see Figure 11-6) |
| 6. Dielectric Support (ε _r ≤ 1.4) | |

11.6.2 Test Procedure

Prior to testing, calibration of test setup shall be performed using a similar procedure to that delineated in Annex B of ISO 11451-3-2006. During calibration, the antenna shall be positioned such that its radiating elements are a minimum distance of 500 mm from any absorber material and 1000 mm from any object such as the DUT, the ground plane, antenna cable, and the test enclosure wall. This setup is illustrated in Figure 11-6.

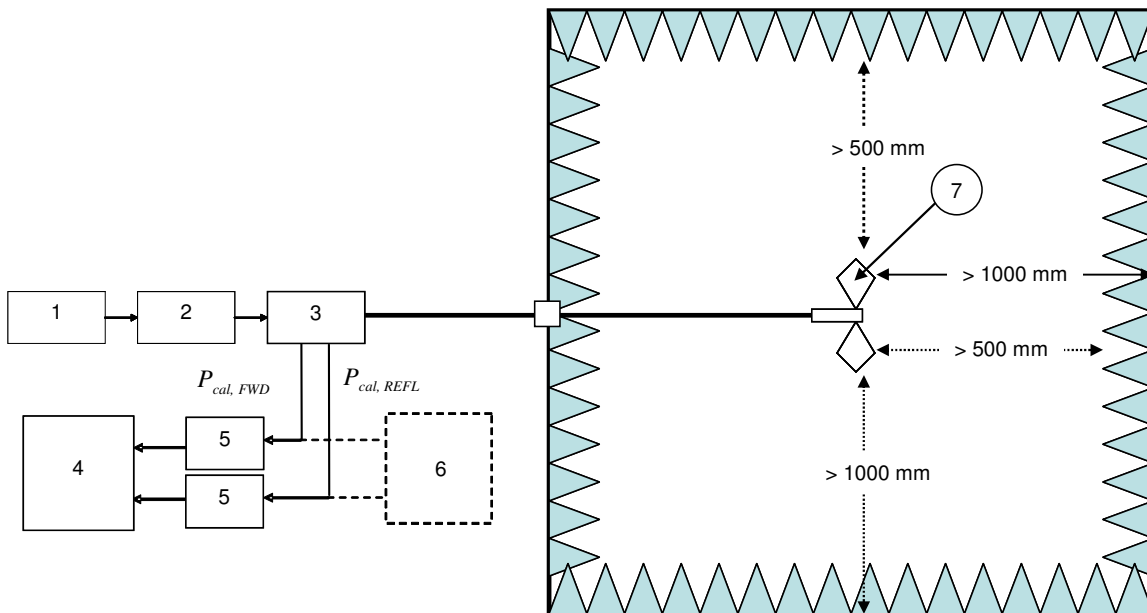
The net power levels specified in Table 11-4 are based on the measured forward and reverse power, per the following equation:

$$P_{ant,NET} = A \cdot P_{meas,FWD} - \frac{1}{A} \cdot P_{meas,REFL} \qquad A = \left[\frac{P_{ant,FWD}}{P_{meas,FWD}} \right]$$

Where:

- $P_{ant,NET}$ = the NET power, specified in Table 11-4, that is delivered to the antenna
- $P_{meas,FWD}$ = the FOWARD power, measured at the directional coupler
- $P_{meas,REFL}$ = the REFLECTED power measured at the directional coupler
- A = the cable attenuation ($A < 1$)

Figure 11-6: RI 115 Setup for Calibration



Key:

- | | |
|------------------------|--|
| 1. Signal Generator | 5. Peak Envelope Power Sensor |
| 2. RF Amplifier | 6. Spectrum Analyzer (may be used as an alternative to the power sensor) |
| 3. Directional Coupler | 7. Test Antenna: (Schwarzbeck antenna SBA9113 with elements 420NJ) |
| 4. RF Power Meter | |

Although not required prior to each test, the test laboratory shall make periodic checks of the antenna's VSWR to verify that it has not changed from the manufacturers published specifications.

The methodology for selection of surfaces and harnesses to be tested, in addition to antenna to DUT test distance and antenna positioning steps is delineated in sections 11.6.2.1 and 11.6.2.2 below. This information shall be documented in the EMC test plan.

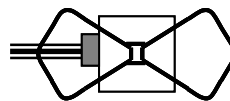
11.6.2.1 Antenna Positioning for Coupling to DUT

The usable test area of the broadband antenna is 100x100 mm when testing at a DUT-to-antenna separation of 50 mm. However, the footprint reduces to 30x30 mm when testing at 5 mm separation. It is therefore necessary to move the antenna in steps of 100 mm and 30 mm when testing at 50mm and 5mm respectively.

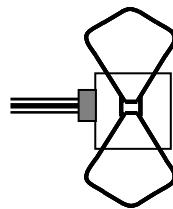
All surfaces of the DUT which are to be tested shall be partitioned to square cells of either 100x100, or 30x30 mm. The antenna shall be placed at a distance of 50 or 5 mm (specified in the test plan) and the centre of each cell shall be exposed to the centre and the elements of the antenna in two orthogonal orientations (four exposures in total). It is necessary to expose each cell to the centre and the elements of the antenna as E and H fields are in different places and move with test frequency.

The antenna shall be placed above the center of each cell, and the DUT shall be exposed to specified disturbance listed in Table 11-4 using the test sequence detailed below:

- a) Place the antenna in parallel with the DUT harness and aligned with the center of the first cell and expose DUT to stress levels specified in Table 11-4.



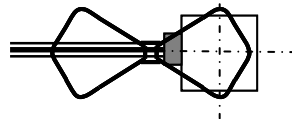
- b) Repeat step a) with antenna rotated 90 degrees



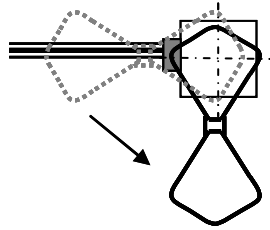
- c) Align antenna with the center of the next cell and repeat steps (a) and (b) until all cells have been exposed to 2 orthogonal orientation of the antenna .

Steps (d), (e) and (f) are NOT required when testing at 5mm distance.

- d) Move the antenna back to the first cell. Align antenna element in the center of the test cell (edges of the element aligned with the center of the cell) and expose DUT to the stress levels specified in Table 11-4.



- e) Repeat step d) with antenna rotated 90 degrees



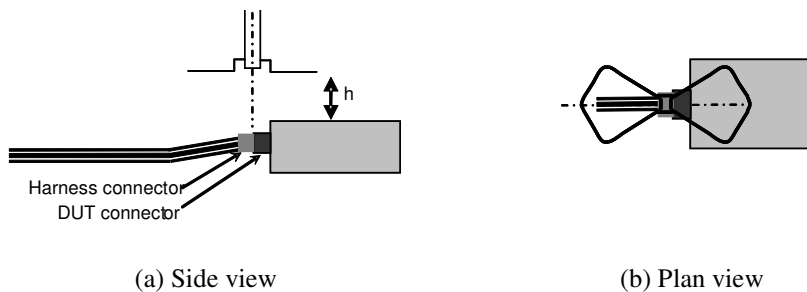
- f) Repeat steps (d) and (e) until all cells have been exposed. When testing DUTs with multiple cells, centers of some cells will be exposed to the elements of the antenna while performing steps (a) to (c) to the adjacent cell. In such cases, it is not required to carry out steps (d) and (e) that would result in a duplicate test. If there is any doubt over effective exposure of cells to the elements of the antenna, steps (d) and (e) shall be performed.
- g) Repeat steps a) through f) for each DUT surface defined in the EMC test plan. Testing requires rotation of the DUT such that the surface to be tested is parallel to the ground plane. Low permittivity material shall be used to support DUT so that the surface under test is facing up toward the antenna.

11.6.2.2 Antenna Positioning for Coupling to Harness

Position antenna central to the connector under test and parallel to harness. Align the center of antenna with the outermost edge of the DUT connector. Expose DUT to test signals specified in table 11.4. In cases where DUT has multiple connectors or connectors are wider than required cell width (30 or 100 mm) test shall be repeated multiple times.

If deviations are observed, the power shall be reduced until the DUT functions normally. The power shall then be increased until the deviation occurs. The power at this point shall be reported as deviation threshold.

Figure 11-7: RI 115 Antenna positioning for testing the harness





12.0 Magnetic Field Immunity: RI 140

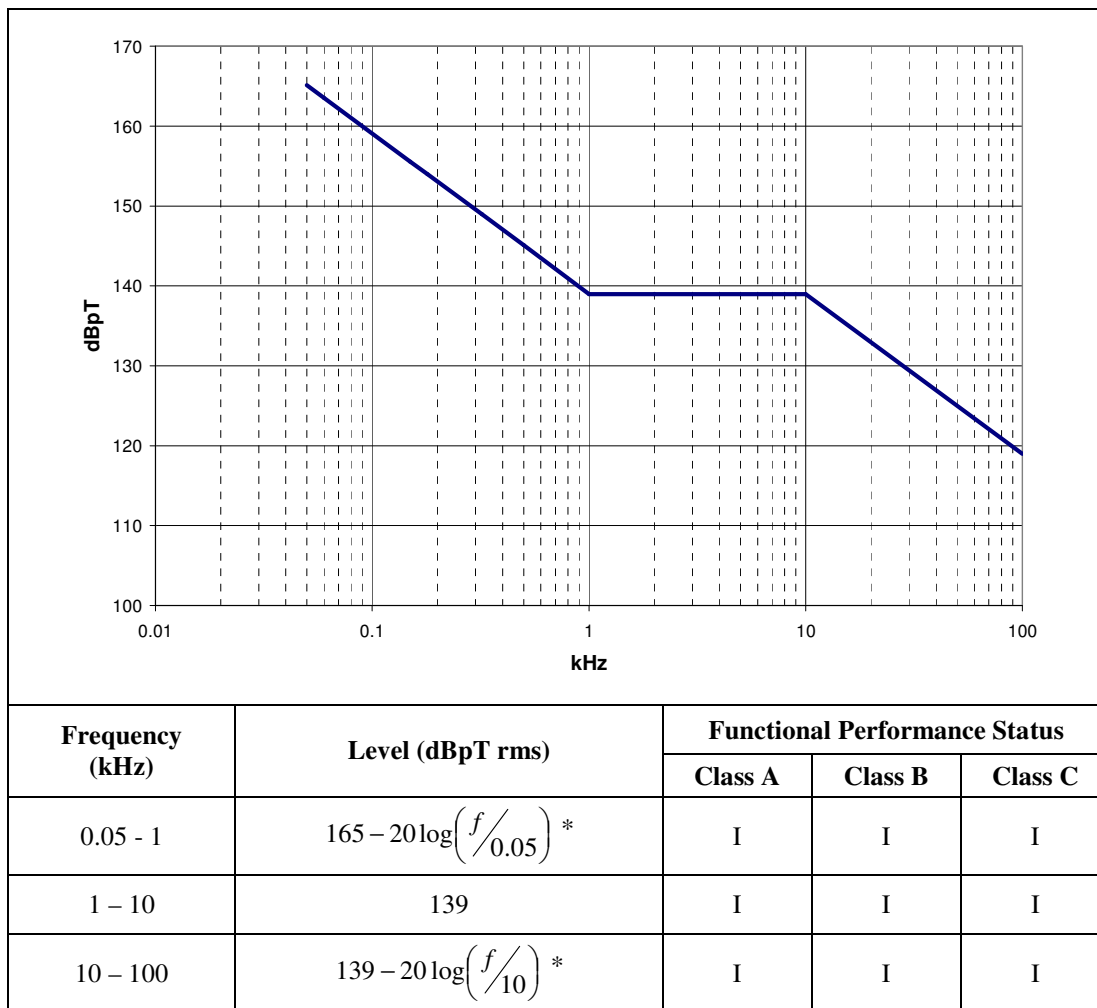
Magnetic field immunity requirements cover the frequency range from 50 Hz to 100 kHz. Requirements are based on anticipated “off-vehicle” electromagnetic sources (e.g. AC power lines) in addition to “on-vehicle” sources (e.g. charging system, PWM sources). These requirements are applicable to the following component categories:

Electronic Modules: AM

12.1 Requirements

The component including any attached magnetic sensors (if applicable) shall operate without deviation when exposed to the magnetic field levels delineated in Figure 12-1.

Figure 12-1: RI 140 Magnetic Field Immunity Requirements



* f = frequency in kHz



12.2 Test Verification and Test Setup

Verification of component performance shall be verified using the test method delineated in MIL-STD-461E, RS101 except where noted in this specification. The test setup shall be configured to facilitate direct exposure of the DUT to the fields listed in Figure 12-1 in addition to magnetic field exposure to any magnetic sensors that may be connected to the DUT. This may be accomplished using either of the following devices:

- 120 mm diameter magnetic radiating loop with self resonance greater than 100 kHz (e.g. ETS Lindgren Model 7603).
- Helmholtz coil with self resonance greater than 100 kHz (e.g. ETS Lindgren Model 6402M).

The respective test setup configurations are illustrated in Figure 12-2 and 12-3. Testing shall be performed at the frequencies listed in Table 12-1. For either test method, the loop current shall only be monitored by a current probe with sufficient bandwidth (use of shunt resistors are not permitted).

Table 12-1: RI 140 Test Frequency Requirements

Test Frequency Range (kHz)	Frequency Step (kHz)
.05 - 1	.05
> 1 – 10	0.5
> 10 - 100	5

The DUT shall be placed on a wooden table or insulated table for either test method. The Load Simulator and other support equipment shall be mounted to a ground plane; however no portion of the Load Simulator or ground plane shall be closer than 200 mm to the radiating loop or Helmholtz coils.

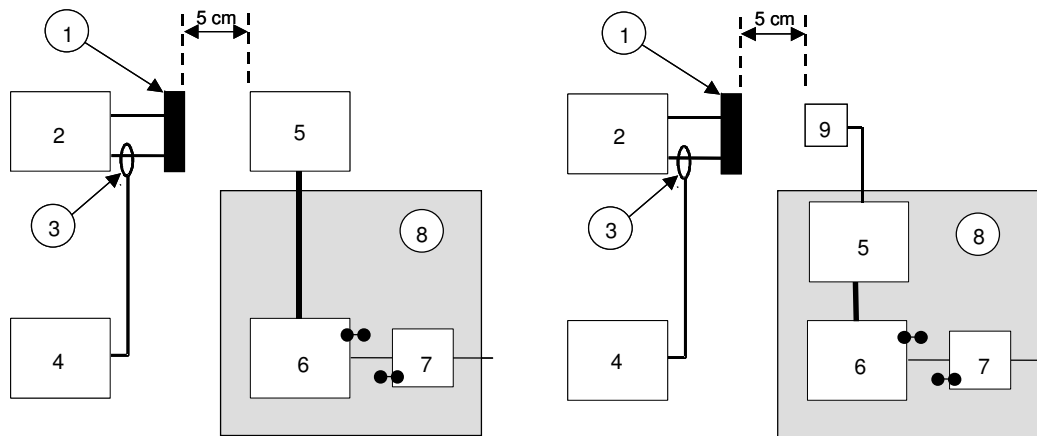
The DUT and any electronic hardware in the Load Simulator shall be powered from an automotive battery or a linear power supply (see paragraph 4.5.4 for requirements). The battery or power supply negative terminal shall be connected to the ground plane bench. The battery/power supply shall be placed on the floor below or adjacent to the test bench.

12.3 Test Procedures

The DUT operating mode(s) exercised during testing shall conform to that delineated in the EMC test plan.

12.3.1 Radiating Loop Method

- a) Prior to performing testing of the DUT, calibrate the radiation loop using procedures delineated in *MIL-STD-461E*, *RS101*.
- b) Partition each face of the DUT into 100 x 100 mm square areas and position the radiating loop face to the center of each of these areas. If the DUT face is less than 100 x 100 mm, place the radiating loop in the center of the DUT face. Separation between the face of the radiating loop and DUT surface shall be 50 mm. Orient the plane of the loop sensor parallel to the DUT faces and parallel to the axis of any connector.
- c) At each position, supply the loop with sufficient current to produce the corresponding magnetic field levels delineated in Figure 12-1 at each test frequency step listed in Table 12-1.
- d) Dwell time shall be at least 2 seconds. A longer dwell time may be necessary if DUT function response times are expected to be longer. This information shall be documented in the EMC test plan.
- e) If deviations are observed, the field shall be reduced until the DUT functions normally. Then the field shall be increased until the deviation occurs. This level shall be reported as deviation threshold.
- f) If the DUT has magnetic sensors attached to it, separate tests shall be performed exposing only the sensor while verifying correct operation of the DUT (see Figure 12-2).

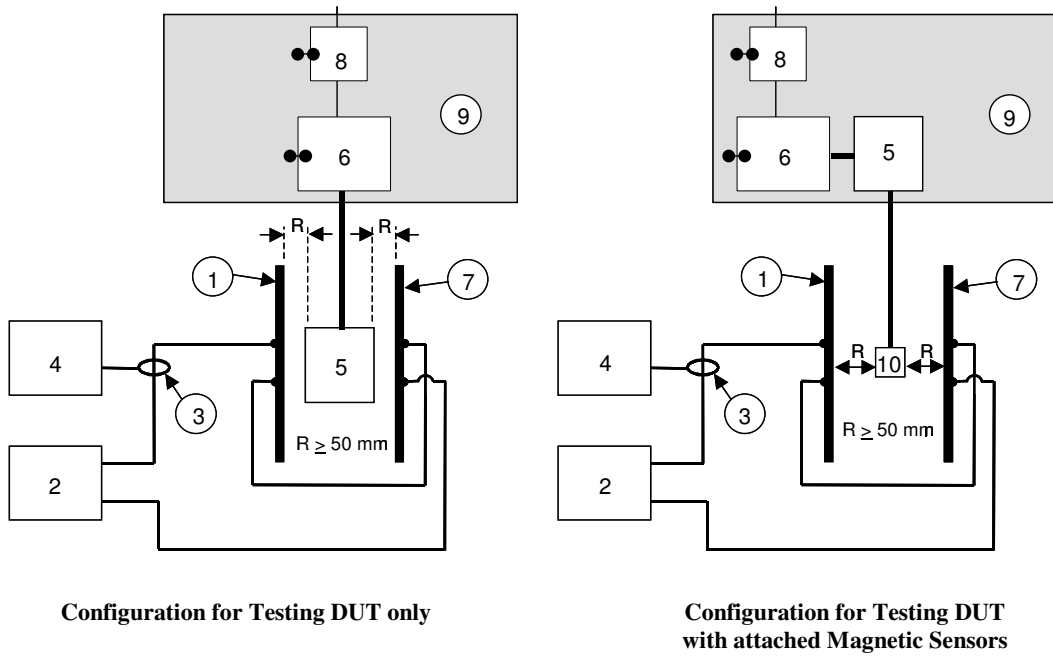
Figure 12-2: RI 140 Magnetic Immunity Test Setup: Radiating Loop

Configuration for Testing DUT only
Configuration for Testing DUT with attached Magnetic Sensors
Key:

- | | |
|-------------------------|-----------------------|
| 1. Radiating Loop | 6. Load Simulator |
| 2. Signal Source | 7. Artificial Network |
| 3. Current Probe | 8. Ground Plane |
| 4. Measurement Receiver | 9. Magnetic Sensor |
| 5. DUT | |

12.3.2 Helmholtz Coil Method

- a) Prior to performing testing of the DUT, characterize the Helmholtz Coil using procedures delineated in *MIL-STD-461E*, *RS101*. Select coil spacing based on the physical dimensions of the DUT.
 - For a DUT with dimensions less than one coil radius, the coils shall be separated by one coil radius. Separation between each surface of the DUT and either coil shall be at least 50 mm.
 - For a DUT with dimensions greater than one coil radius, the coils shall be separated such that the plane of the DUT face is at least 50 mm from the plane of either coil and the separation between the two coils does not exceed 1.5 radii.
- b) Supply the Helmholtz Coil with sufficient current to produce the corresponding magnetic field levels delineated in Figure 12-1 at each test frequency listed in Table 12-1.
- c) Dwell time shall be at least 2 seconds. A longer dwell time may be necessary if DUT function response times are expected to be longer. This information shall be documented in the EMC test plan.
- d) Reposition the DUT or Helmholtz coils successively such that the two coils are parallel to each face of the DUT and parallel to the axis of any connector.
- e) If deviations are observed, the field shall be reduced until the DUT functions normally. Then the field shall be increased until the deviation occurs. This level shall be reported as deviation threshold.
- f) If the DUT has magnetic sensors attached to it, separate tests shall be performed exposing only the sensor while verifying correct operation of the DUT (see Figure 12-3).

Figure 12-3: RI 140 Magnetic Immunity Test Setups for Helmholtz Coil



Key:

- | | |
|--|---|
| <ul style="list-style-type: none"> 1. Radiating Loop A 2. Signal Source 3. Current Probe 4. Measurement Receiver 5. DUT | <ul style="list-style-type: none"> 6. Load Simulator 7. Radiating Loop B 8. Artificial Network 9. Ground Plane 10. Magnetic Sensor |
|--|---|



13.0 Coupled Immunity: RI 130

These requirements are related to component immunity from wire-to-wire coupling of unintended transient disturbances. These disturbances originate from switching of inductive loads including solenoids and motors. These requirements are applicable to the following component categories:

Electronic Modules: A, AS, AM, AX, AY

Electric Motors: EM

13.1 Requirements

The device shall operate without deviation when exposed to coupled transient electromagnetic disturbances created from switch contact arcing and bounce. The requirements are delineated in Table 13-1. The source transient disturbance characteristics are identical to Modes 2 and 3; Pulses A2-1 and A2-2. See Annex D regarding details of these transient waveforms and the mode of application.

Table 13-1: RI 130 Coupled Immunity Requirements

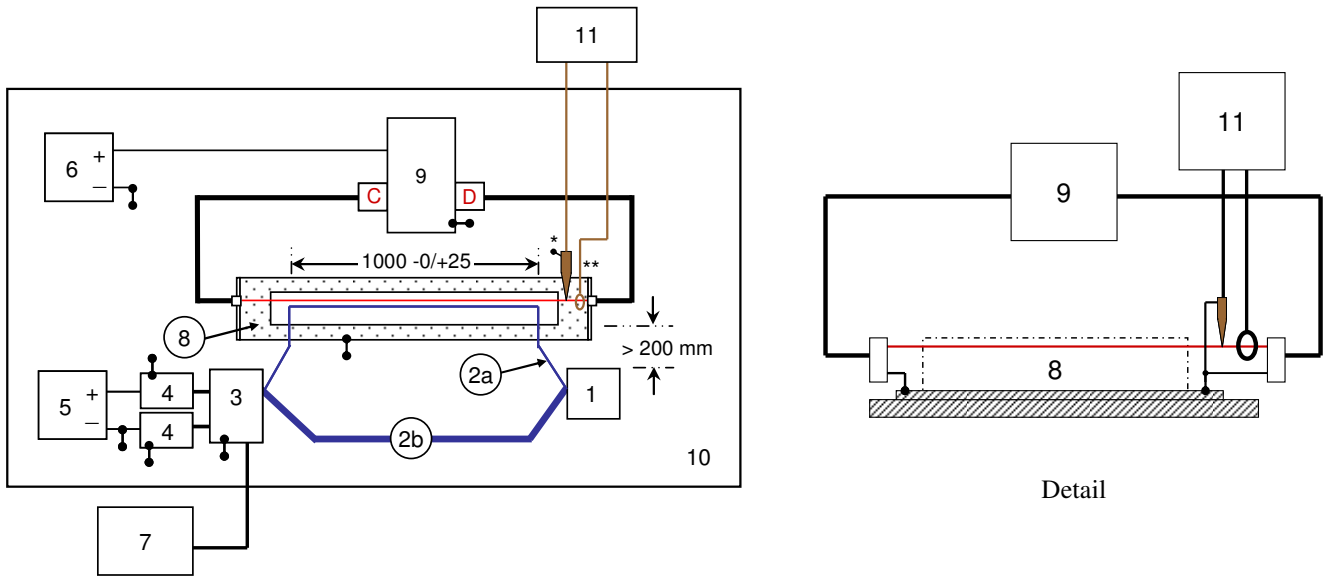
Mode	Pulse	Functional Performance Status		
		Class A	Class B	Class C
2	A2-1	I	I	I
	A2-2			
3	A2-1	I	I	I
	A2-2			

13.2 Test Verification and Test Setup

Verification shall be performed using the basic test setup shown in Figure 13-1. The setup involves removal of a individual wires from the DUT wire harness and placed in the test fixture for testing. Information regarding testing of twisted and/or shielded wires may be found in Annex H along with a basic description of the test fixture. Details regarding fabrication of the test fixture are found at <http://www.fordemc.com>. Information regarding the transient pulse characteristics and the transient generator may be found in Annex D and F respectively.

- The DUT and any electronic hardware in the Load Simulator shall be powered from a vehicle battery or a linear power supply (see paragraph 4.5.4 for requirements). The battery or power supply negative terminal shall be connected to the ground plane bench. The battery/power supply may be placed on the floor below or adjacent to the test bench.
- The DUT power and power returns shall be connected to the battery/power supply via Artificial Networks (ANs). The ANs shall conform to CISPR 25. The ANs measurement ports shall be terminated with 50 ohms.
- The Transient Generator shall be powered from a vehicle battery (See Section 4.5.4 for requirements). The metal case of the transient generator shall be connected to the ground plane. See Annex F regarding details of the transient generator.
- The DUT and all parts of the test setup shall be a minimum of 100 mm from the edge of the ground plane.
- A digital sampling oscilloscope shall be used for test voltage/current verification. The oscilloscope shall have the following capabilities:
 - A minimum capable sampling rate of 1 Giga-samples per second (single shot capability).
 - A minimum memory depth of 8 mega-samples for a single channel.
- Voltage and current probes are required to facilitate verification of the transient disturbance. Requirements for these probes are found in Figure 13-1.
- If the outer case of the DUT is metal and can be grounded when installed in the vehicle, the DUT shall be electrically bonded directly to the ground plane during testing. If the DUT case is not grounded in the vehicle, the DUT shall be placed on an insulated support 50 mm above the ground plane.

Figure 13-1: RI 130 Default Test Setup



Key

- | | | | |
|----|---|----|---|
| 1 | DUT | 7 | DUT Monitor/Support Equipment |
| 2a | DUT Circuit Wire to be Tested | 8 | Coupling Test Fixture |
| 2b | DUT Wire Harness | 9 | Transient Generator (see Annex F for details). Generator connected to Coupling test fixture via coaxial cable. Case of generator connected to the ground plane. |
| 3 | Load Simulator | 10 | Ground Plane |
| 4 | Artificial Network | 11 | Digital Oscilloscope (≥ 1 GS/sec, ≥ 8 Mega sample) |
| 5 | Automotive Battery or linear power supply (Powers DUT and Load Simulator) | * | 1:100 high impedance probe (C < 4 pf) per ISO 7637-2. Example: Agilent 10076A) |
| 6 | Automotive Battery (Powers Transient Test Generator) | ** | Current Probe (> 10 MHz, 30 A) Example: Agilent N2783A |



13.3 Test Procedures

Testing shall be repeated for all DUT operating modes listed in the EMC test plan.

- a) Configure the transient generator for Mode 3, Pulse A2-1 (see Annex F). Close SW0 to activate the transient generator. Using the oscilloscope, capture at least one complete transient sequence (see Figure D-12).
- b) Verify magnitude of the negative transient voltage disturbance measured at the test point (see Figure 13-1) is greater than 300 volts. When completed, open SW0 to deactivate the transient generator.
- c) Repeat steps a) and b) with transient generator configured for Mode 3, Pulse A2-2. Verify that the peak-to-peak transient current disturbance exceeds 20 amperes.
- d) Open SW0 to deactivate the transient generator. Configure the transient generator for Mode 2, Pulse A2-1.
- e) Activate the DUT and verify that it is functioning correctly.
- f) Place an individual DUT circuit wire or wire pairs (i.e. twisted wire pair) in the test fixture (*see Annex H for applicable circuit placement*).
- g) Close SW0 to activate transient generator.
- h) Expose the circuit wire(s) for 60sec. *A longer dwell time may be necessary if DUT function response times are expected to be longer. This information shall be documented in the EMC test plan.* Verify that DUT performance is not affected. (i.e. Status I)
- i) Repeat step h) with the transient generator configured in the following modes:
 - Mode 2, Pulse A2-2
 - Mode 3, Pulse A2-1
 - Mode 3, Pulse A2-2
- j) Repeat steps d) through i) for each DUT circuit wire.

14.0 Coupled Immunity: RI 150

These requirements are related to component immunity from wire-to-wire coupling of unintended continuous disturbances. These disturbances originate from high current PWM sources and the vehicle’s charging and ignition system. These requirements are applicable to the following component categories:

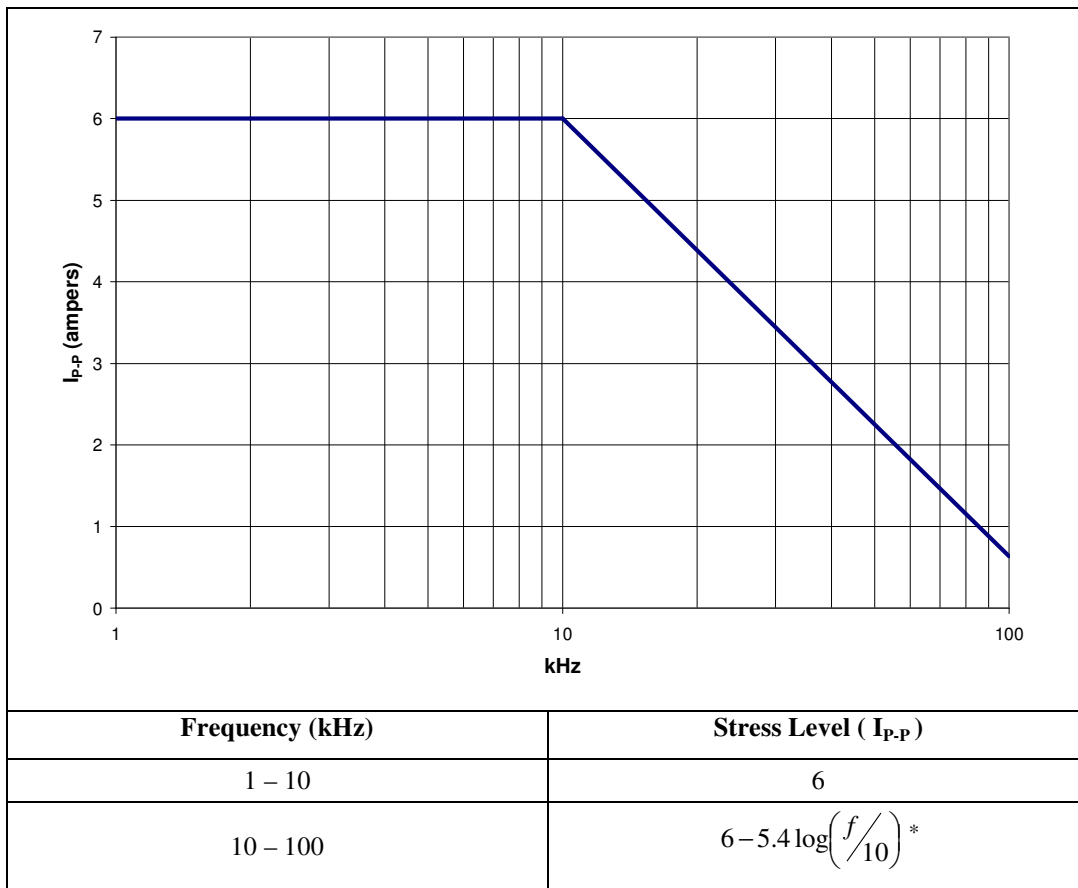
Electronic Modules: A, AS, AM, AX, AY

Electric Motors: EM

14.1 Requirements

The device shall operate without deviation (Status I) when exposed to sinusoidal electromagnetic disturbances delineated in Figure 14-1.

Figure 14-1: RI 150 Coupled Immunity Requirements

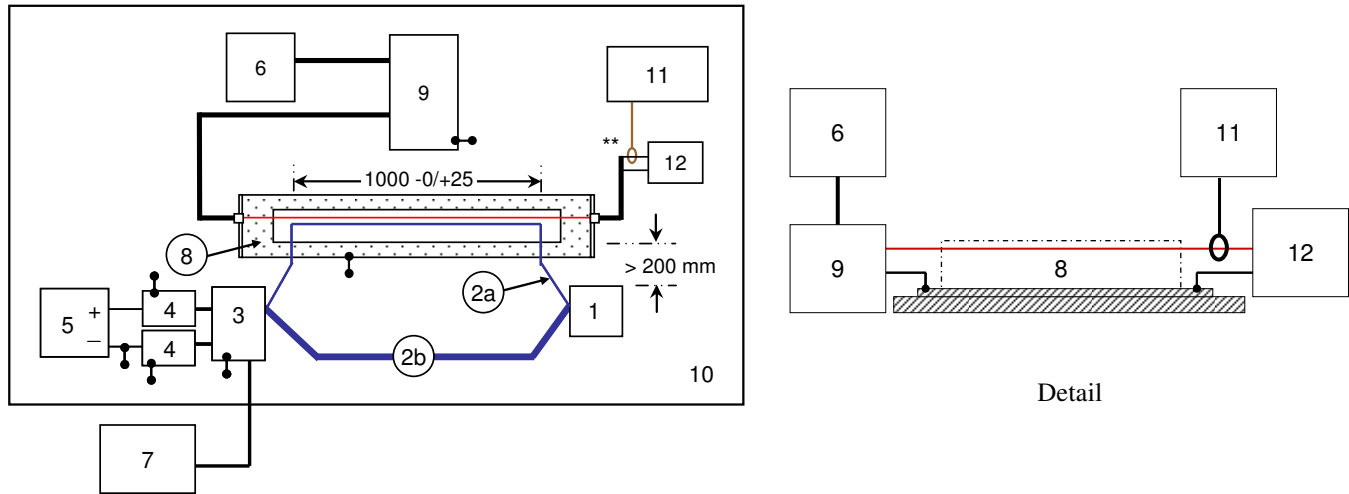


* *f* = frequency in kHz

14.2 Test Verification and Test Setup

Verification shall be performed using the test Setup shown in Figures 14-2. Except where noted in Figure 14-2, the setup of the DUT, Load Simulator and test harness is identical to that used for RI 130.

Figure 14-2: RI 150 Test Setup



Key

- | | | | |
|----|---|----|--|
| 1 | DUT | 7 | DUT Monitor/Support Equipment |
| 2a | DUT Circuit Wire to be Tested | 8 | Coupling Test Fixture |
| 2b | DUT Wire Harness | 9 | Amplifier (1kHz – 100 kHz) |
| 3 | Load Simulator | 10 | Ground Plane |
| 4 | Artificial Network | 11 | Digital Oscilloscope (≥1 GS/sec, ≥ 8 Mega sample) |
| 5 | Automotive Battery or linear power supply (Powers DUT and Load Simulator) | 12 | Amplifier Load Resistance (e.g. 4 ohms) |
| 6 | Signal Generator | ** | Current Probe (> 10 MHz, 30 A) Example: Agilent N2783A |



14.3 Test Procedures

Testing shall be repeated for all DUT operating modes listed in the EMC test plan.

- a) Activate the DUT and verify that it is functioning correctly.
- b) Place an individual DUT circuit wire or wire pairs (i.e. twisted wire pair) in the test fixture (*circuit placement requirements are identical to R1130*).
- b) At each test frequency increase the peak to peak current to the corresponding stress level listed in Figure 14-1. Use the frequency steps listed in Table 14-1.
 - Dwell time shall be 10 seconds. A longer dwell time may be necessary if DUT function response times are expected to be longer. This information shall be documented in the EMC test plan.
- c) Monitor DUT functions before, during, and after application of the stress levels in Figure 14-1 and verify that no performance deviations occur (i.e. Status I).

Table 14-1: RI 150 Test Frequency Requirements

Test Frequency Range (kHz)	Frequency Step (kHz)
> 1 – 10	0.5
> 10 – 100	5

15.0 Immunity from Continuous Power Line Disturbances: CI 210

The device shall be immune from continuous disturbances that occur on the vehicle’s low voltage (i.e. 13.5 VDC) electrical distribution system. These requirements are applicable to the following component categories:

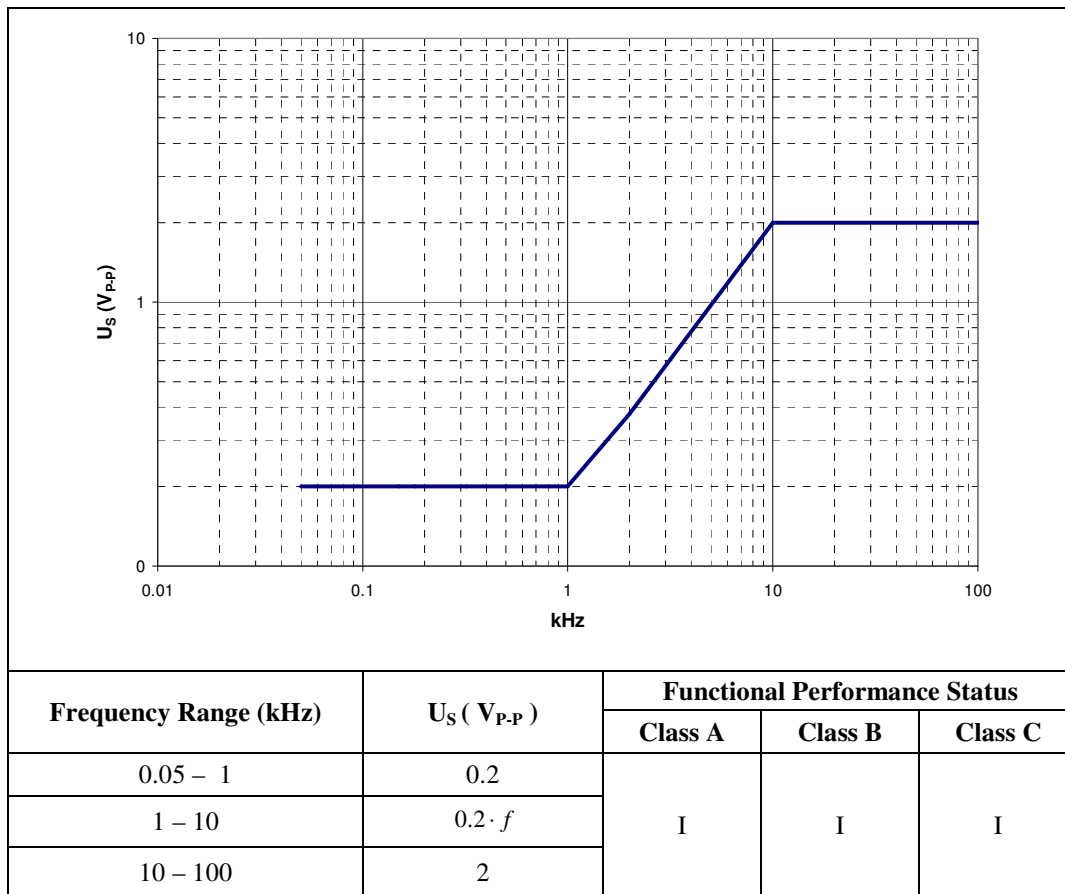
Electronic Modules: A, AM, AX, AY

Electric Motors: EM

15.1 Requirements

The devices shall operate in accordance to the requirements delineated in Figure 15-1.

Figure 15-1: CI 210 Requirements



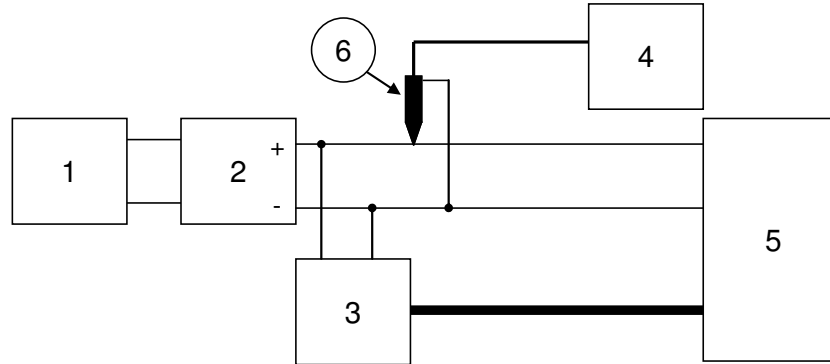
f = frequency in kHz

15.2 Test Verification and Test setup

Testing shall be performed using the test setup shown in Figure 15-2. The test harness connecting the DUT to the Load Simulator and modulated DC supply shall be ≤ 2000 mm in length. All DUT power/power return circuits shall be connected together at the modulated power supply.

Per previous versions of this requirement, a ground plane may be placed under the DUT and Load Simulator, but if used, the DUT and wire harness shall be placed on an insulated support 50mm above the ground plane. Additionally, the negative connection of the modulated DC supply and case of the Load Simulator shall be referenced to the ground plane

Figure 15-2: CI 210 Test Setup



Key

- | | |
|---|---|
| 1. Signal Source | 4. Oscilloscope |
| 2. Modulated Power Supply (DC coupled Audio Amplifier with output impedance < 100 milliohms may be used) | 5. DUT |
| 3. Load Simulator | 6. Passive High Impedance Probe (< 1Mohm, C< 10 pf) |

15.3 Test Procedures

- a) Without the DUT connected, adjust the DC voltage offset "U_P" of the modulated power supply to 13.5 volts. Initially set the AC voltage amplitude "U_S" to zero volts (see Figure 15-2).
- b) Connect and activate the DUT and verify it is functioning correctly. Verify that U_P remains at 13.5 VDC. Adjust the supply as required to achieve this voltage level.
- c) At each test frequency increase U_S as illustrated in Figure 15-3 to the corresponding stress level listed in Figure 15-1 while the DUT is operating. The dwell time shall be at least 2 seconds. A longer dwell time may be necessary if DUT function response times are expected to be longer. This information shall be documented in the EMC test plan.
- d) Monitor DUT function for any anomalies.
- e) Repeat Steps a) through d) using the test frequency steps listed Table 15-1.
- f) Repeat testing for all DUT operating modes listed in the EMC test plan.

Figure 15-3: CI 210 AC Stress Level (U_S) Superimposed on DUT Supply Voltage (U_P)

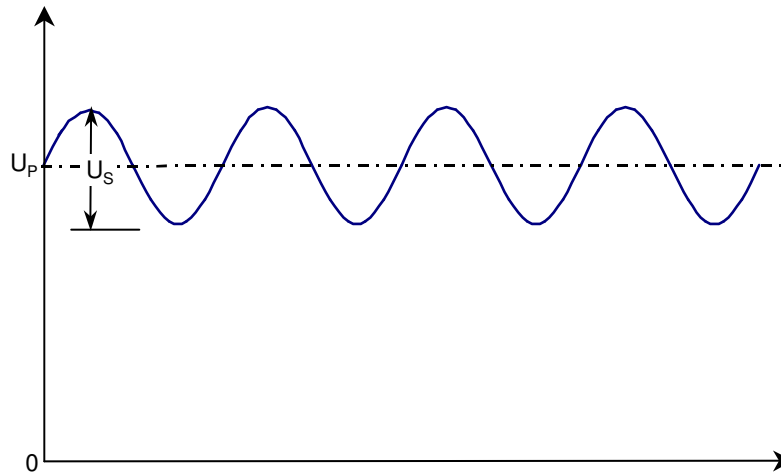


Table 15-1: CI 210 Test Frequency Requirements

Test Frequency Range (kHz)	Frequency Step (kHz)
0.05 - 1	0.05
> 1 - 10	0.5
> 10 - 100	5



16.0 Immunity from Transient Disturbances: CI 220

These requirements are related to immunity from conducted transients on power and control circuits connected directly to the vehicle's battery or indirectly by a switch or load (e.g. pull-up resistor). These requirements are applicable to the following component categories:

Electronic Modules: A, AM, AX, AY

Electric Motors: EM

Passive Devices: P (requirement may be waived via analysis. See section 6.0)

16.1 Requirements

Specific applicability of these transients and component performance requirements are listed in Table 16-1. In addition to these requirements, the component shall not be affected (Status I) by transient voltages generated by result of its own operation, including switching of inductive loads either internal or external to the device (i.e. Category AX).

Table 16-1: CI 220 Transient Immunity Requirements

Transient Pulse ^(1,2,3)	Application ⁽²⁾	Transient Mode ^(1,3)	Duration	Functional Performance Status		
				Class A	Class B	Class C
Pulse A1	Switched power supply circuits with maximum current < 5 amperes	Mode 1	120 sec	II	II	II
	Input circuits	Mode 2	20 sec	II	II	II
Pulse A2-1	Switched power supply circuits with maximum current < 5 amperes	Mode 1	120 sec	II	II	II
Pulse A2-1 Pulse A2-2	Input Circuits	Mode 2 Mode 3	20 sec	II	II	II
Pulse C-1 Pulse C-2	All power supply circuits & input circuits.	Mode 2 Mode 3	20 sec	I	I	I
Pulse E	Switched power supply circuits ≥ 5 amperes	n/a	24 pulses	II	II	II
	Input circuits			II	II	II
Pulse F1 ⁽⁵⁾	All power supply circuits	Mode 1	5000 pulses	I	I	I
Pulse F2 ⁽⁵⁾	All power supply circuits	Mode 1	10 pulses	II	II	II
Pulse G1 ⁽⁴⁾ Load Dump	All power supply circuits Input circuits	n/a	5 pulses	III	III	II
Pulse G2 Central Load Dump ⁽⁴⁾	All power supply circuits Input circuits	n/a	5 pulses	III	III	II

1 See Annex D-1 for transient pulse and mode description.

2 See Annex E for requirements with respect to application of transient pulses.

3 See Annex F for test generator requirements to produce transient pulses A1, A2, and C.

4 Selection of Pulse G1 or G2 depends on whether vehicle application includes central load dump (CLD) protection. Selection shall be approved by the FMC EMC group and documented in EMC test plan.

5 Pulses F1, F2 only applicable for components required to demonstrate compliance to ESA requirements of 72/245/EEC.

16.2 Test Verification and Test Setup

Verification of component performance shall be in accordance with ISO 7637-2 except where noted in this specification.

- Test pulses A, B, and C shall be generated using the transient generator described in Annex F.
- Test pulses E, F and G shall be generated using a transient generator conforming to the requirements of ISO 7637-2.
 - The test setup for application of Pulse G1 requires that a 0.5 ohm resistor be connected externally across the Test Pulse Generator. This modification is shown in Figure 16-5.
- Test pulse G2 shall be generated using the circuit illustrated in Figure 16-6. The diode bridge shall be designed to yield the open circuit voltage waveform shown in Figure D-10 of Annex D.
- The DUT and any electronic hardware in the Load Simulator shall be powered from a vehicle battery (see paragraph 4.5.4 for requirements). Artificial Networks shall not be used as part of the test setup.
- The test harness connecting the DUT to the Load Simulator and transient pulse generator shall be ≤ 2000 mm in length. Individual ground circuits may be part of the cable harness or split out as illustrated in the setup figures below. If the DUT has multiple power (e.g. battery direct, ignition/run, relay) and/or input circuits, these circuits shall be configured to facilitate individual application of test pulses.
- The DUT and test harness shall be placed on an insulated support 50 mm above the ground plane.
- A device powered from an external, unregulated supply located in another module shall be tested as a system with the sourcing module or an equivalent power supply. Details of this setup shall be documented in the EMC test plan.

Figure 16-1 illustrates the generic test setup for testing of a single DUT power supply circuit with a remote ground connection.

Figure 16-1: CI 220 Test Setup for Devices with a Single Power Supply Circuit

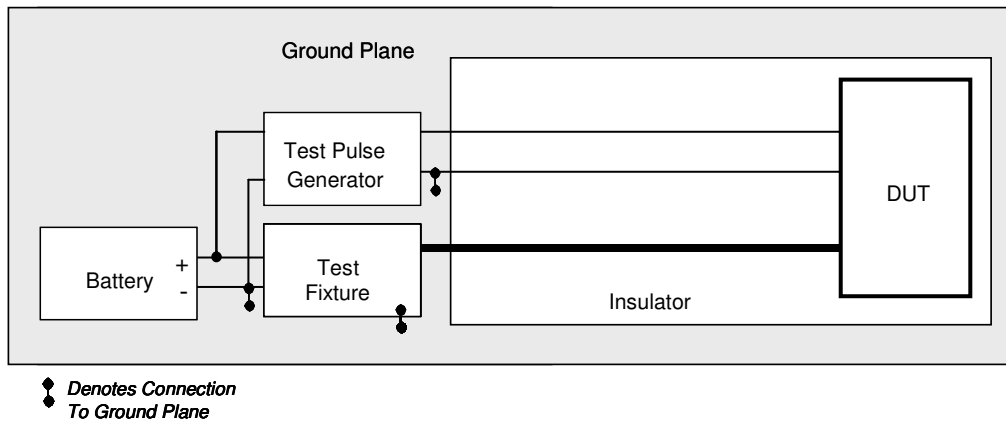


Figure 16-2 illustrates the test setup for devices with two supply circuits. In this configuration, the untested power supply circuit (U_1) is connected directly to the battery. If the device has additional power supply circuits operating at the same voltage, those circuits should also be connected directly to the battery.

Figure 16-2: CI 220 Test Setup for Devices with Two Power Supply Connections

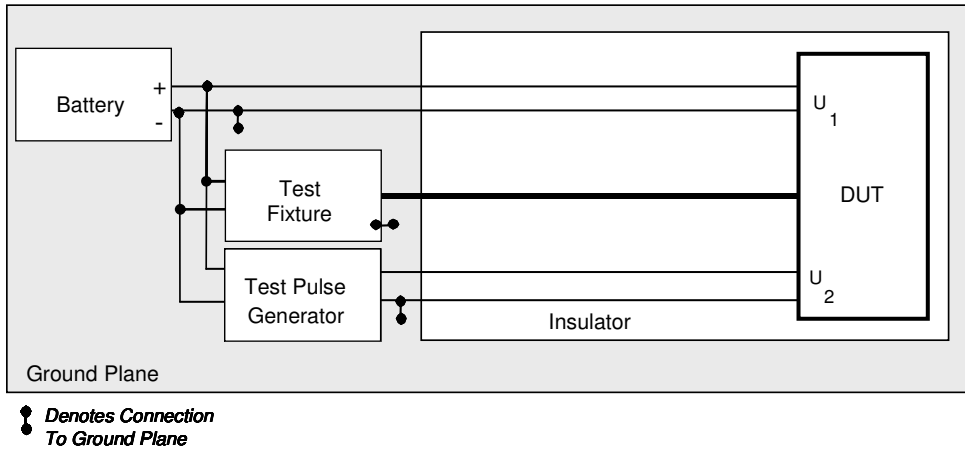


Figure 16-3 illustrates the setup used for testing of input circuits. These circuits may be directly or indirectly connected to switched battery circuits. Figure 16-4 illustrates the special case where the control circuit is connected to the battery indirectly using a pull-up resistor located in another module.

Figure 16-3: CI 220 Test Setup for Devices with Input Circuits

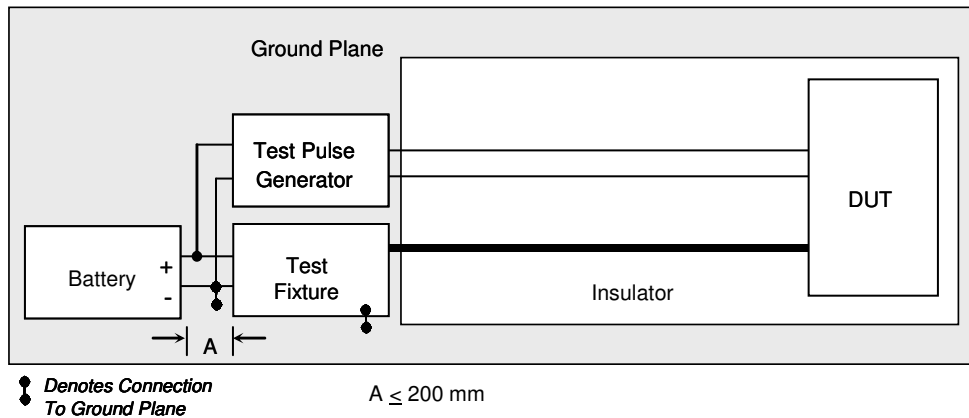


Figure 16-4: CI 220 Test Setup Detail (Input Circuits with Remote External Pull-Up Resistor)

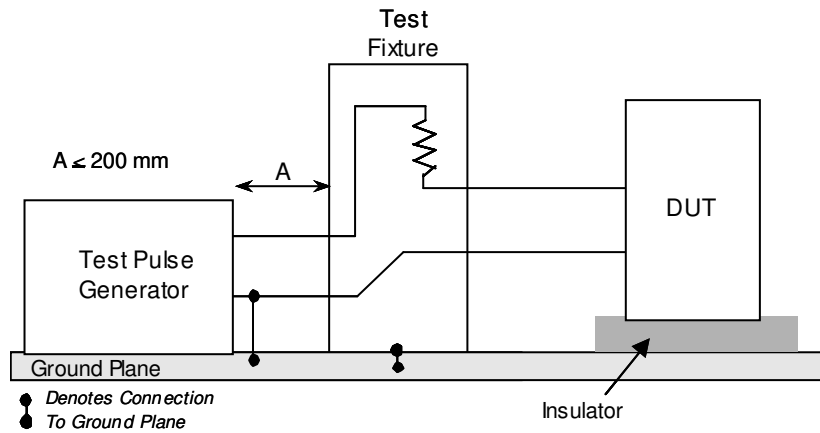


Figure 16-5: CI 220 Test Setup for Application of Pulse G1

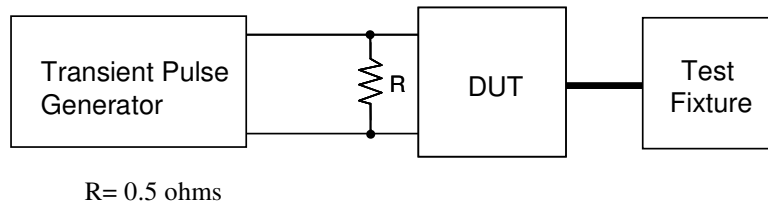
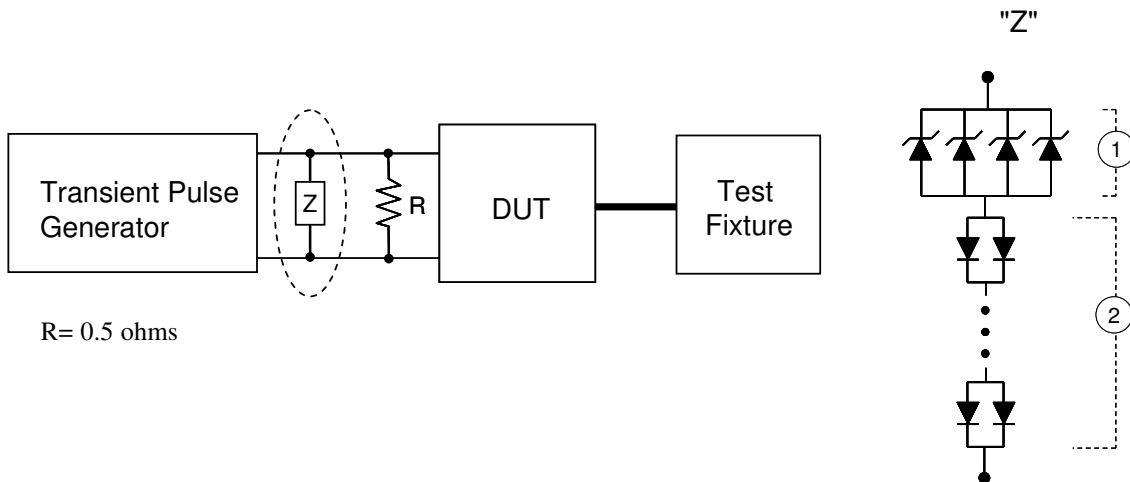


Figure 16-6: CI 220 Test setup for Application of Pulse G2



1. Zener diode: MR 2535L

2. Diode: 1N 5404

Diode configuration adjusted to yield voltage characteristics shown in Figure D-10 of Annex D.



16.3 Test Procedures

Test pulses shall be applied to power supply and input circuits in accordance with the requirements delineated in Annex E and documented in the EMC test plan.

- a) Prior to testing:
 - For Pulses G1 adjust the transient generator to the voltage level listed in Figure D-9 of Annex D with the DUT and "R" disconnected (open circuit condition). Pulse measurement shall be facilitated using an oscilloscope and voltage probe meeting the requirements delineated in ISO 7637-2.
 - For Pulse G2, adjust the transient generator to the voltage level listed in Figure D-10 of Annex D with the DUT and disconnected but with "R" connected. Pulse measurement shall be facilitated using an oscilloscope and voltage probe meeting the requirements delineated in ISO.
 - For Pulses A and C, verify that the output of the transient test circuit (open circuit conditions) produces waveforms typical of those illustrated in Annex D.
- b) Connect and activate the DUT. Verify that it is functioning correctly.
- c) Apply each test pulse listed in Table 16-1, except for Pulses G1 and G2, individually to each DUT battery or ignition circuit in addition to individual input circuits connected to battery or ignition circuits. Test pulses G1 and G2 are applied to all power and input circuits simultaneously.
- d) Prior to application of either Pulse G1 or G2, connect the 0.5 ohm resistor across the Transient Pulse Generator output as illustrated in Figure 16-5. Verify the waveforms conform to the loaded waveform requirements listed in Figures D-9 and D-10 of Annex D prior to application of the waveforms to the DUT.
- e) Monitor DUT functions before, during, and after application of each series of test pulses for the time stated in Table 16-1.



17.0 Immunity from Power Cycling: CI 230

These requirements are applicable to the following component categories:

Electronic Modules: A, AM, AX, AY

Electric Motors: EM

17.1 Requirements

The component shall be immune from voltage fluctuations, which occur during initial start of the vehicle's engine under cold temperature conditions. *This requirement is not representative of conditions where a warm engine is restarted.* The voltage waveforms representing these fluctuations are illustrated in Figure 17-1. Specific application of these waveforms is dependent on the method used to connect the component's power supply and control circuits. Application requirements for each waveform are listed in Table 17-1 along with the performance requirements for the component.

Table 17-1: CI 230 Power Cycling Requirements

Waveform ⁽¹⁾	Application	Duration	Functional Performance Status ⁽²⁾		
			Class A	Class B	Class C
A	Power & control circuits connected to battery via the IGN 1 (RUN) contact of the ignition switch. (i.e. circuits active in RUN but not START).	2 cycles separated by cooling period	II	II	II
B	Power & control circuits connected to battery via the IGN 2 (RUN/START) contact of the ignition switch (i.e. circuits active during RUN and START). Also includes connections to battery through a relay switch.		II	II	II
C	Power & control circuits connected to battery via the START contact of the ignition switch. (i.e. circuits active only during engine START).		II	II	II
D	Power & control circuits connected directly to Battery		II	II	II

1 Waveforms applied simultaneously to all power supply and control circuits.

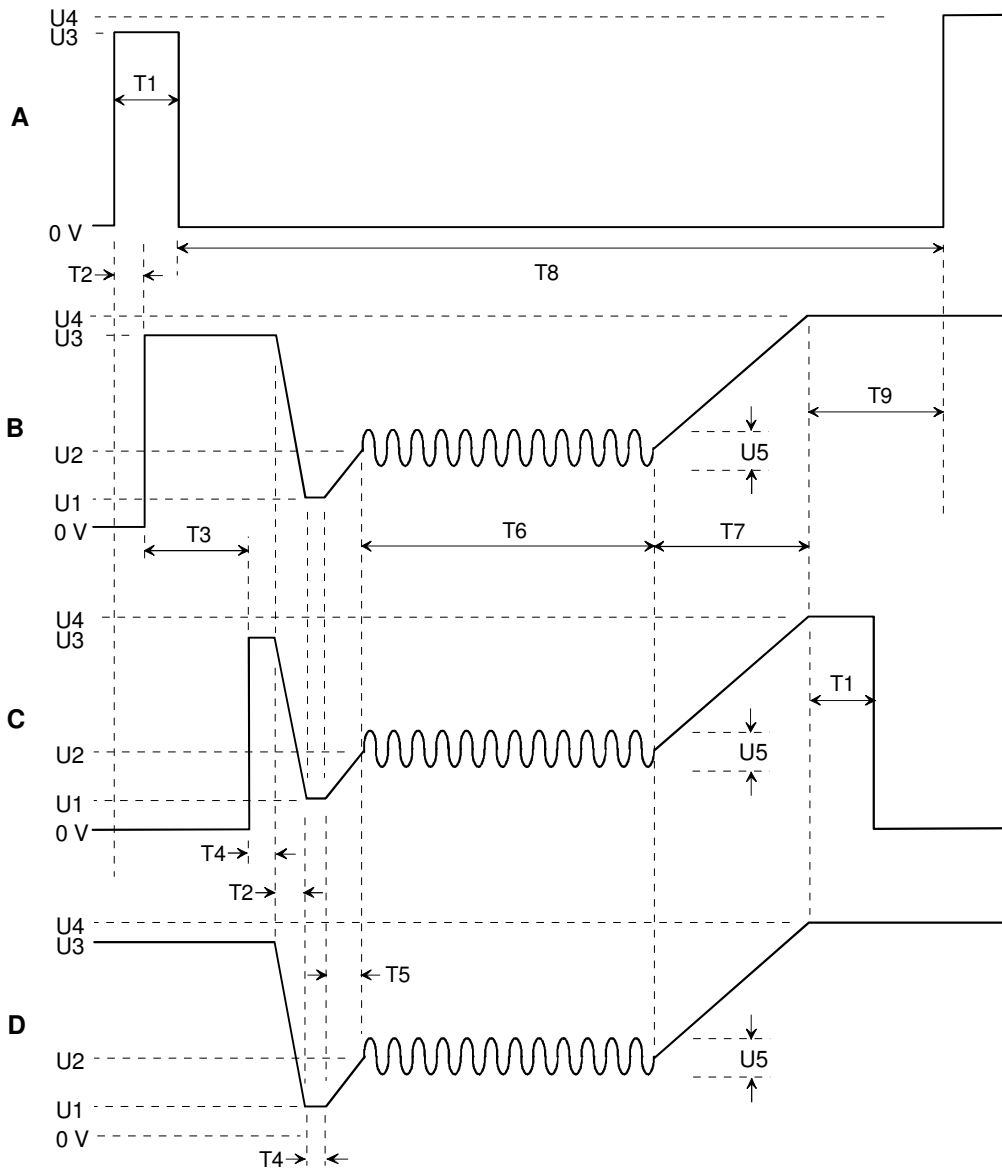
2 Any degradation in performance shall not inhibit the ability of the vehicle to start.

17.2 Test Verification and Test Setup

Testing shall be performed using the test Setup shown in Figure 17-2.

- The test harness connecting the DUT to the Load Simulator and transient pulse generator shall be < 2000 mm in length.
- Testing shall be performed at -40 +0 / - 5 degrees C or the coldest temperature specified in component's engineering specification. The temperature shall be documented in the EMC test plan.
- The DUT shall be placed on a dielectric support 50 mm above the metal floor of the thermal chamber.

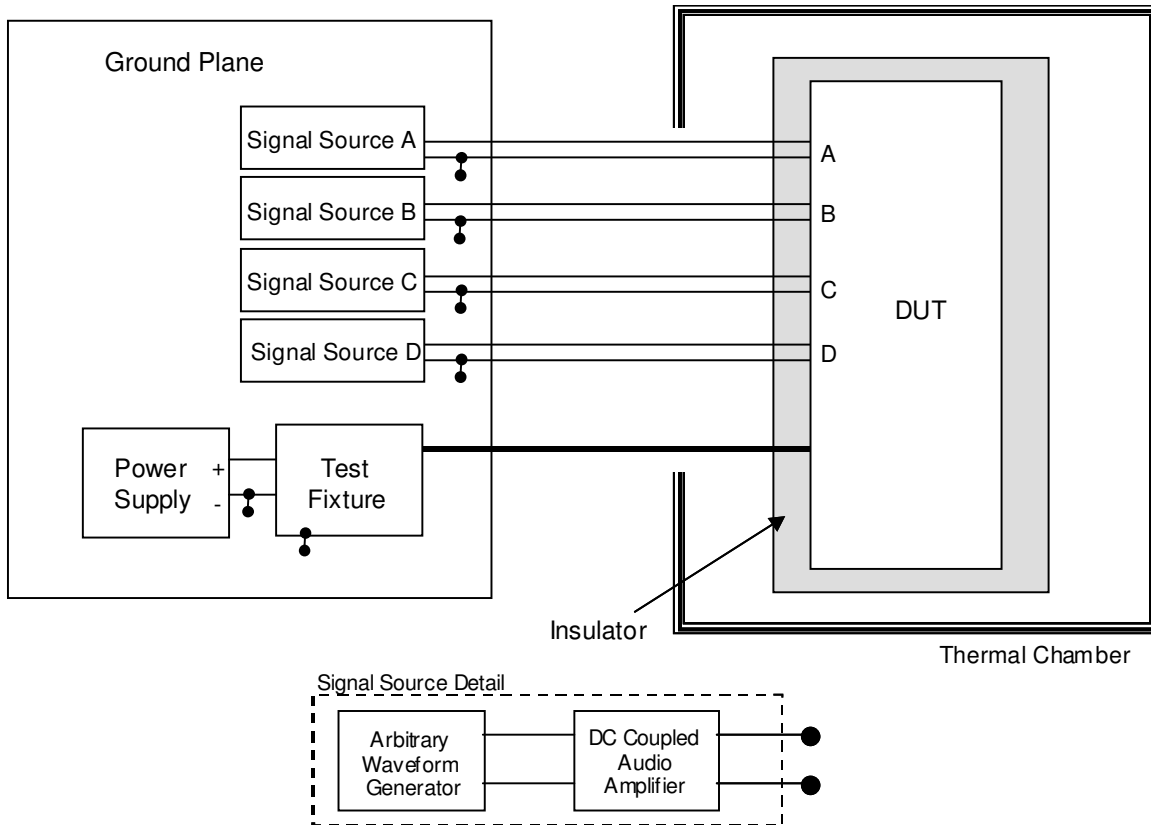
Figure 17-1: CI 230 Power Cycling Waveforms and Timing Sequence



Key

- | | |
|---------------|--------------------|
| T1 = 100 msec | T8 = 11 sec |
| T2 = 5 msec | T9 = 325 msec |
| T3 = 185 msec | U1 = 5 V |
| T4 = 15 msec | U2 = 9 V |
| T5 = 50 msec | U3 = 12.5 V |
| T6 = 10 sec | U4 = 13.5 V |
| T7 = 500 msec | U5 = 2 Vp-p @ 4 Hz |

Figure 17-2: CI 230 Power Cycling Test Setup



17.3 Test Procedures

All waveforms shall be applied simultaneously to all power supply and control circuits in accordance with the timing sequence shown in Figure 17-1. Verify waveforms prior to application to the DUT.

- a) Verify the waveforms prior to application to the DUT.
- b) Soak the DUT (unpowered) at the coldest operating temperature specified in component's engineering specification or at $-40 \pm 0 / - 5$ degrees C for one hour prior to testing unless otherwise stated in the EMC test plan. See section 17.2 for details.
- c) Apply the test sequence illustrated in Figure 17-1. Monitor DUT functions before, during and after the test.

While it is recommended to apply the test sequence with the DUT located in the thermal chamber (see Figure 17-2) the test may be performed with the DUT located outside of the thermal chamber provided that the test sequence is applied within ten (10) minutes of the DUT being removed from the thermal chamber following the hour long soak period (step b). If this approach is taken, the soak temperature shall be lowered an additional 10 degrees C. Deviations to this approach are only permissible if agreed to in writing by the FMC EMC department.
- d) Soak the DUT at the same temperature from step b) for 30 minutes and repeat c). If the DUT was tested outside of the thermal chamber, it shall be returned to that chamber within 10 minutes.



18.0 Immunity to Ground Voltage Offset: CI 250

Components shall be immune from AC ground offset voltages. Requirements include both continuous and transient disturbances.

These requirements are applicable to the following component categories:

Electronic Modules: A, AM, AX, AY

Electronic Controlled Electric Motors: EM

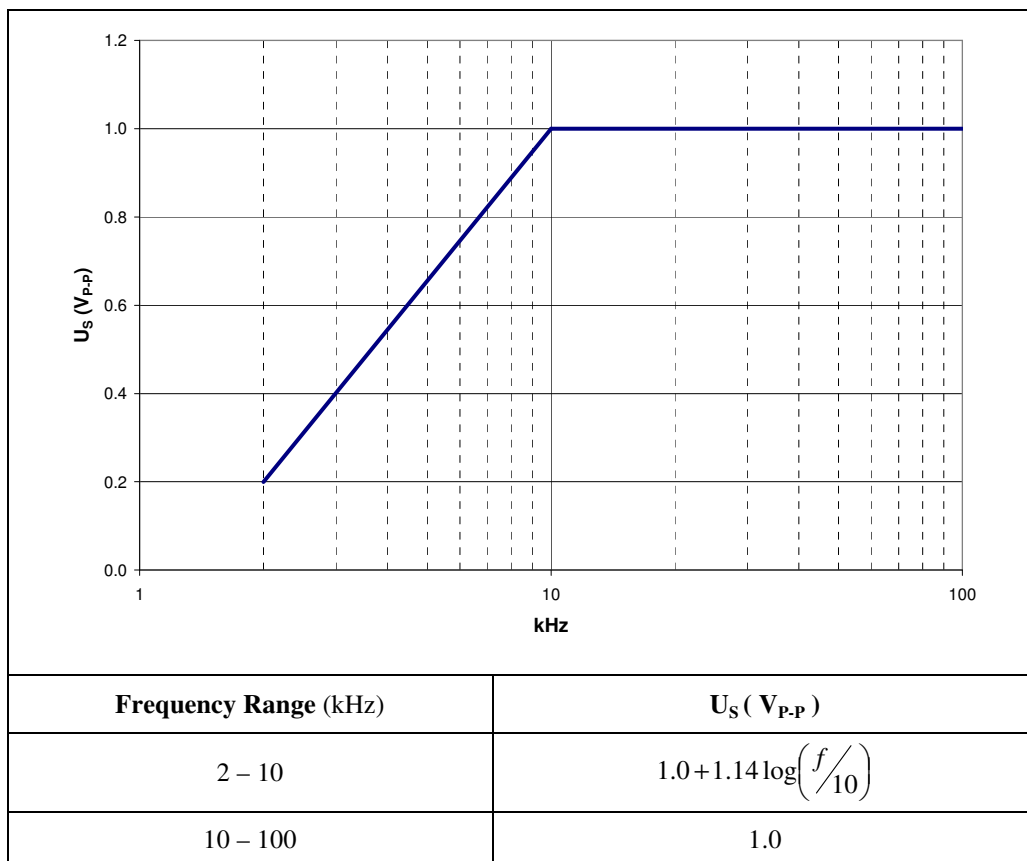
18.1 Requirements

Component functional performance shall meet the acceptance criteria delineated in Table 18-1. CI 250 requirements for continuous disturbances are delineated in Figure 18-1. CI 250 requirements for transient disturbances are delineated in Figures 18-2 through 18-4. Transient disturbances consist of a damped sinusoidal pulse with a resonant frequency of 100 kHz. The pulse is applied using the delay sequence illustrated in Figure 18-4. Delay times for the four sequences are listed in Table 18-2.

Table 18-1: CI 250 Acceptance Criteria (Continuous and Transient Disturbances)

Functional Acceptance Criteria		
Class A	Class B	Class C
I	I	I

Figure 18-1: CI 250 Requirements (Continuous Disturbances)



f = frequency in kHz

Figure 18-2: CI 250 Transient Pulse Detail

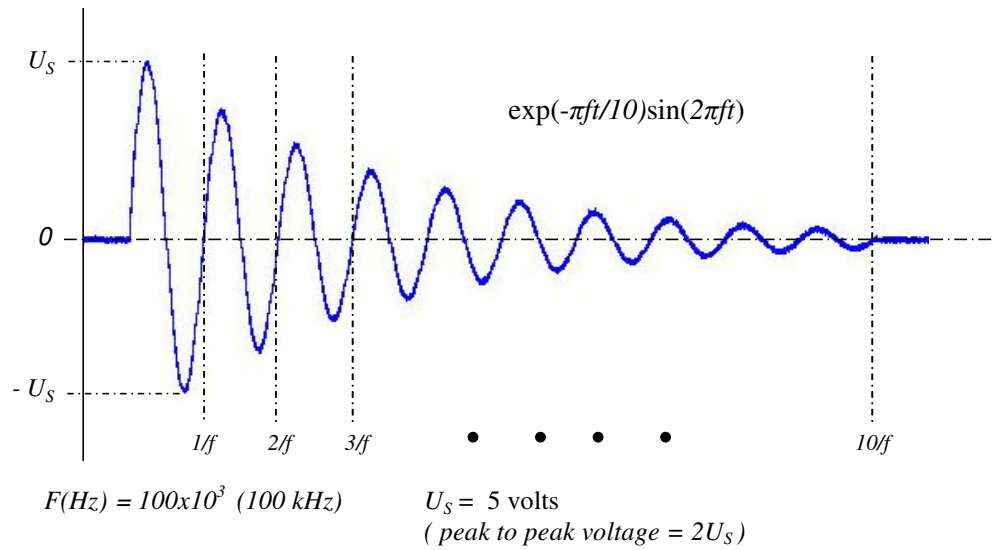


Figure 18-3: CI 250 Transient Pulse Delay Detail

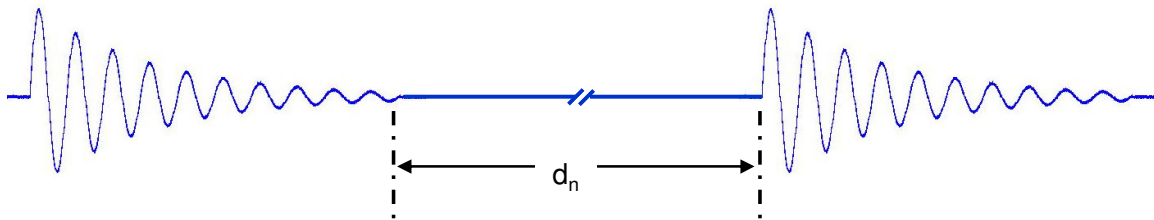


Figure 18-4: CI 250 Requirements (Transient Disturbance Sequence)

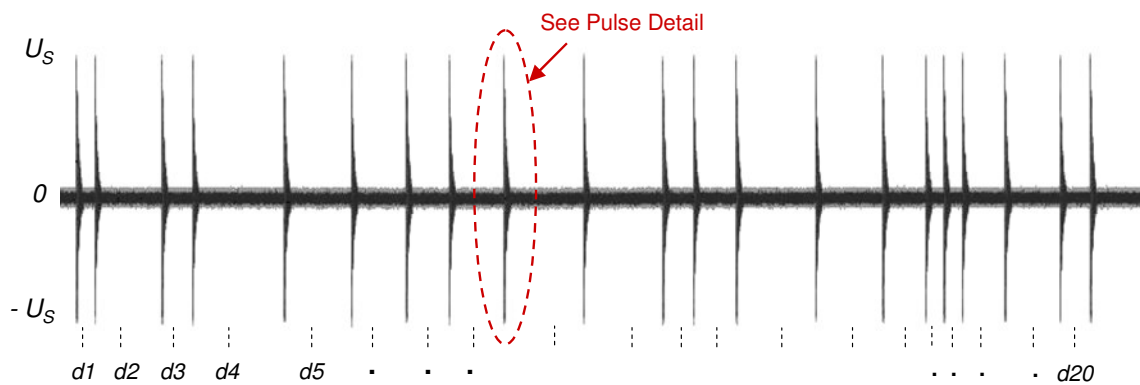


Table 18-2: CI 250 Delay Time Sequences 1 - 4

Sequence 1	d1	0.1 ms	d6	0.4 ms	d11	0.2 ms	d16	0.1 ms
	d2	0.5 ms	d7	0.3 ms	d12	0.3 ms	d17	0.1 ms
	d3	0.2 ms	d8	0.4 ms	d13	0.6 ms	d18	0.3 ms
	d4	0.7 ms	d9	0.6 ms	d14	0.5 ms	d19	0.4 ms
	d5	0.5 ms	d10	0.6 ms	d15	0.3 ms	d20	0.2 ms
Sequence 2	d1	0.2 ms	d6	0.8 ms	d11	0.4 ms	d16	0.2 ms
	d2	1.0 ms	d6	0.6 ms	d12	0.6 ms	d17	0.2 ms
	d3	0.4 ms	d8	0.8 ms	d13	1.2 ms	d18	0.6 ms
	d4	1.4 ms	d9	1.2 ms	d14	1.0 ms	d19	0.8 ms
	d5	1.0 ms	d10	1.2 ms	d15	0.6 ms	d20	0.4 ms
Sequence 3	d1	0.5 ms	d6	2.0 ms	d11	1.0 ms	d16	0.5 ms
	d2	2.5 ms	d6	1.5 ms	d12	1.5 ms	d17	0.5 ms
	d3	1.0 ms	d8	2.0 ms	d13	3.0 ms	d18	1.5 ms
	d4	3.5 ms	d9	3.0 ms	d14	2.5ms	d19	2.0 ms
	d5	2.5 ms	d10	3.0 ms	d15	1.5 ms	d20	1.0 ms
Sequence 4	d1	1 ms	d6	4 ms	d11	2 ms	d16	1 ms
	d2	5 ms	d6	3 ms	d12	3 ms	d17	1 ms
	d3	2 ms	d8	4 ms	d13	6 ms	d18	3 ms
	d4	7 ms	d9	6 ms	d14	5 ms	d19	4 ms
	d5	5 ms	d10	6 ms	d15	3 ms	d20	2 ms

dn represents the delay between consecutive pulses

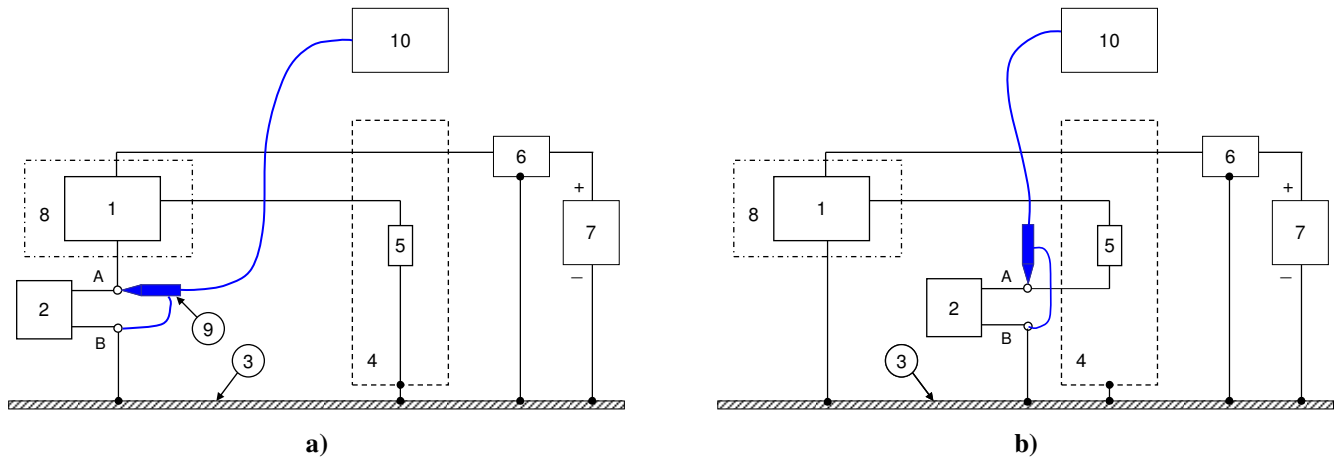
18.2 Test Verification and Test Setup

Testing shall be performed using either of the test Setups shown in Figure 18-5a or 18-5b. Selection of the test setup is based on analysis by the FMC EMC group of how the DUT will be grounded in typical vehicle applications. The test configuration shall be documented in the EMC test plan.

- The test harness connection between the DUT to the Load Simulator shall be ≤ 2000 mm. Individual ground circuits may be part of the cable harness or split out as illustrated in the figures. If the DUT has multiple ground circuits, they shall be test separately.
- Ground circuits not being tested shall be connected directly to the ground plane.
- The DUT and any electronic hardware in the Load Simulator shall be powered from an automotive battery or linear DC power supply (see paragraph 4.5.4 for requirements). Power circuits to the DUT shall be connected to the power supply. The power supply negative terminal shall be connected to the ground plane.
- The DUT and wire harness shall be placed on an insulated support 50 mm above the ground plane.
- The source used for generation of the continuous and transient disturbances is shown in Figure 18-5.

The signal source illustrated in Figure 18-6 includes two isolation transformers. The transformers are used to facilitate generation of the required disturbances into a 0.5 ohm load using most commercially available amplifiers. The transformers also facilitate DC isolation of amplifier from the DUT. Alternative configurations may be permitted if approved by the FMC EMC department.

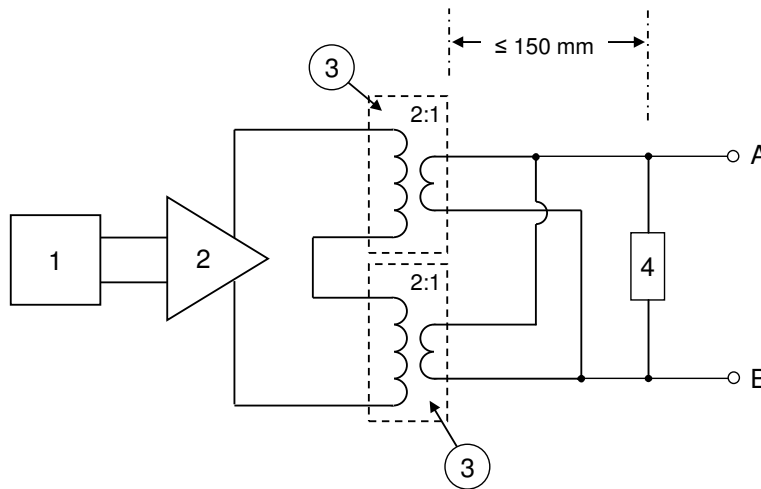
Figure 18-5: CI 250 Test Setup for Ground Offset of DUT



Key:

- | | |
|------------------------------------|---|
| 1. DUT | 6. Artificial Network |
| 2. Signal Source (see Figure 18-5) | 7. Power Supply (13.5 VDC) |
| 3. Ground Plane | 8. Insulative Support |
| 4. Load Simulator | 9. 10X high impedance probe (1M ohm, C < 10 pf) |
| 5. DUT External Load | 10. Digital Oscilloscope (> 100 MS/s, > 6MB memory depth) |

Figure 18-6: CI 250 Signal Source Requirements



Key:

- | | |
|---|--|
| 1. Arbitrary Waveform Generator | 3. Isolation Transformer (Use Solar 6220-1A or equivalent) |
| 2. Amplifier (recommend AE Techtron 7560 or equivalent) | 4. 0.5 Ohm (250 watt) Non-Inductive Resistive Load (Dale NH-250 or equivalent) |



18.3 Test Procedures

The waveforms shall be applied to one ground circuit at a time unless analysis demonstrates that testing each circuit individually is unnecessary. The analysis shall be documented in the EMC test plan and approved by the FMC EMC department prior to commencement of testing.

18.3.1 Procedure for Continuous Disturbances

- a) Connect the DUT and verify that it is functioning correctly in the operating mode specified in the EMC test plan.
- b) At each test frequency increase U_S to the corresponding stress level listed in Figure 18-1 while the DUT is operating.
 - Dwell time shall be at least 2 seconds. A longer dwell time may be necessary if DUT function response times are expected to be longer. This information shall be documented in the EMC test plan
- c) Monitor DUT function for any anomalies. If anomalies are noted, reduce the stress level to the point where normal DUT function resumes. Record the measured value of U_S where this threshold occurs.
- d) Repeat Steps b) and c) using the frequency steps listed Table 18-3.
- e) Repeat testing for all DUT operating modes listed in the EMC test plan.

Table 18-3: CI 250 Test Frequency Requirements

Test Frequency Range (kHz)	Frequency Step (kHz)
2 - 10	0.5
10 - 100	5

18.3.2 Procedures for Transient Disturbances

- a) Connect the DUT and verify that it is functioning correctly in the operating mode specified in the EMC test plan.
- b) Apply the test sequence shown in Figure 18-4 while the DUT is operating. Adjust the pulse amplitude (U_S) to the level shown in Figure 18-2 The waveform shall be symmetrical about zero volts (peak to peak value = $2U_S$).
- c) The test sequence shall be applied repeatedly for 60 seconds. During application of the sequence, monitor DUT function for any anomalies. If anomalies are noted, reduce the stress level to the point where normal DUT function resumes. Record the measured value of U_S where this threshold occurs.
- d) Repeat testing for all DUT operating modes listed in the EMC test plan.



19.0 Immunity to Voltage Dropout: CI 260

These requirements are applicable to the following component categories:

Electronic Modules: A, AS, AM, AX, AY

Electronic Controlled Electric Motors: EM

19.1 Requirements

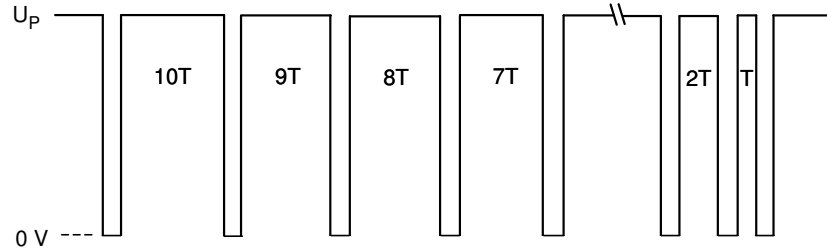
The component shall be immune from momentary voltage dropouts, which may occur over the life of the vehicle. Circuits affected include all power supply and control circuits. These requirements also apply to components that are connected to a regulated power provided by another module (e.g. sensors). Requirements are listed in Table 19-1. The purpose of this test is the verification of controlled recovery of hardware and software from power interruptions.

Table 19-1: CI 260 Voltage Dropout Requirements

Waveform	Application	Level	Duration	Functional Performance Status ⁽²⁾		
				Class A	Class B	Class C
A Voltage Dropout: High	All Power Supply and Input Circuits	See Figure 19-1	3 cycles separated by 20 s	II	II	II
B Voltage Dropout: Low	All Power Supply and Input Circuits	See Figure 19-2	3 cycles separated by 20 s	II	II	II
C Single Voltage Dropout	All Power Supply and Input Circuits	See Figure 19-3	3 cycles separated by 20 s	I	I	I
D Voltage Dip	All Power Supply and Input Circuits	See Figure 19-4	10 cycles separated by 20 s	II	II	II
E ⁽¹⁾ Battery Recovery	Limited to Power Supply Circuits with direct connection to battery.	See Figure 19-5	2 cycles separated by 20 s	II	II	II
F Random Bounce	All Power Supply and Input Circuits ⁽³⁾	See Figures 19-6, 19-7	60 s	II	II	II

- 1 Applicable only to direct battery connections
- 2 Performance Status checked after each waveform cycle
- 3 Waveform F limited to power circuits with maximum current less than 5 amperes

Figure 19-1: CI 260 Waveform A (Voltage Dropout: High)

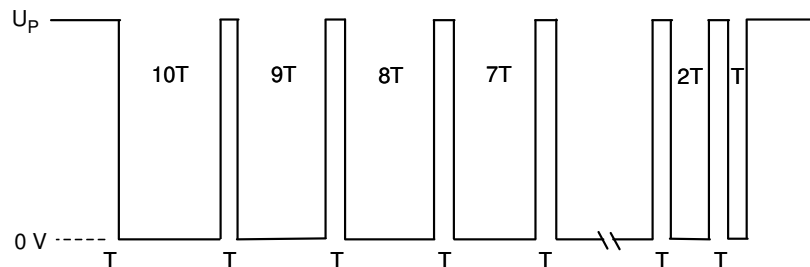


Key:

	Power from Vehicle Battery				Regulated Power from another Module			
U_P	13.5 VDC				Nominal Supply Voltage (e.g. 5 Vdc, 3 Vdc)			
$T^{(1)}$	100 us	300 us	500 us	2 ms	100 us	300 us	500 us	2 ms
	5 ms	10 ms	30 ms	50 ms	5 ms	10 ms	30 ms	50 ms

(1) Waveform transition times are approximately 10 us

Figure 19-2: CI 260 Waveform B (Voltage Dropout: Low)

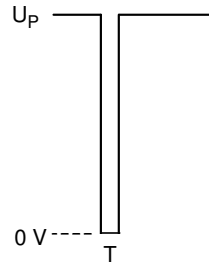


Key:

	Power from Vehicle Battery				Regulated Power from another Module			
U_P	13.5 VDC				Nominal Supply Voltage (e.g. 5 Vdc, 3 Vdc)			
$T^{(1)}$	100 us	300 us	500 us	2 ms	100 us	300 us	500 us	2 ms
	5 ms	10 ms	30 ms	50 ms	5 ms	10 ms	30 ms	50 ms

(1) Waveform transition times are approximately 10 us

Figure 19-3: CI 260 Waveform C (Single Voltage Dropout)

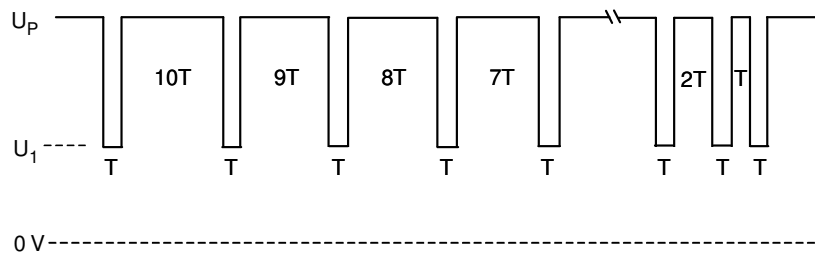


Key:

	Power from Vehicle Battery			Regulated Power from another Module		
U_p	13.5 VDC			Nominal Supply Voltage (e.g. 5 Vdc, 3 Vdc)		
$T^{(1)}$	100 us	300 us	500 us	100 us	300 us	500 us

(1) Waveform transition times are approximately 10 us

Figure 19-4: CI 260 Waveform D (Voltage Dip)

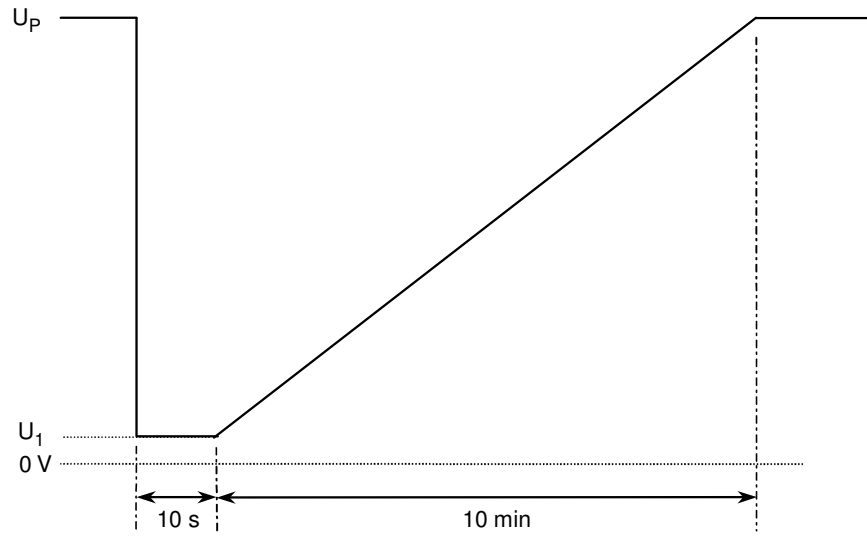


Key:

	Power from Vehicle Battery				Regulated Power from another Module			
U_p	13.5 VDC				Nominal Supply Voltage (e.g. 5 Vdc, 3 Vdc)			
U_1	5 V				80% of Nominal Supply Voltage			
$T^{(1)}$	100 us	300 us	500 us	2 ms	100 us	300 us	500 us	2 ms
	5 ms	10 ms	30 ms	50 ms	5 ms	10 ms	30 ms	50 ms

(1) Waveform transition times are approximately 10 us

Figure 19-5: CI 260 Waveform E (Battery Recovery)

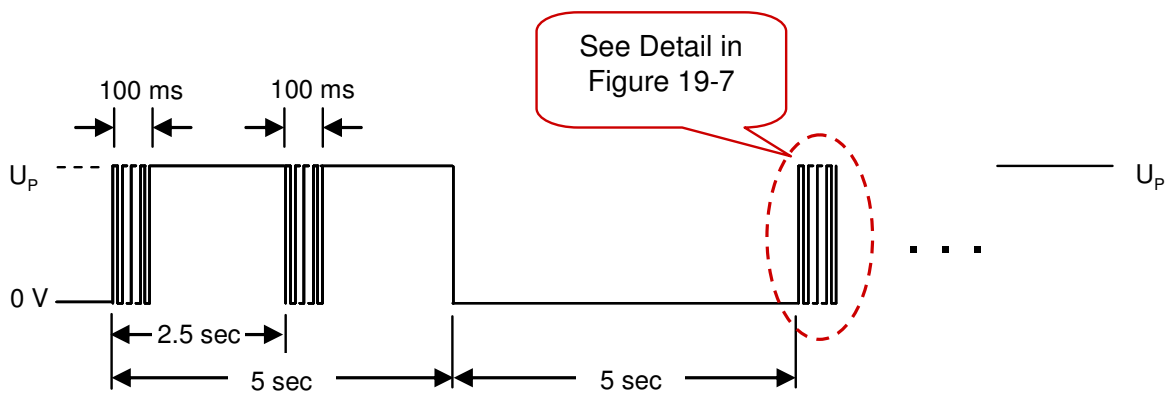


Key:

$U_p = 12.5 \text{ VDC}$

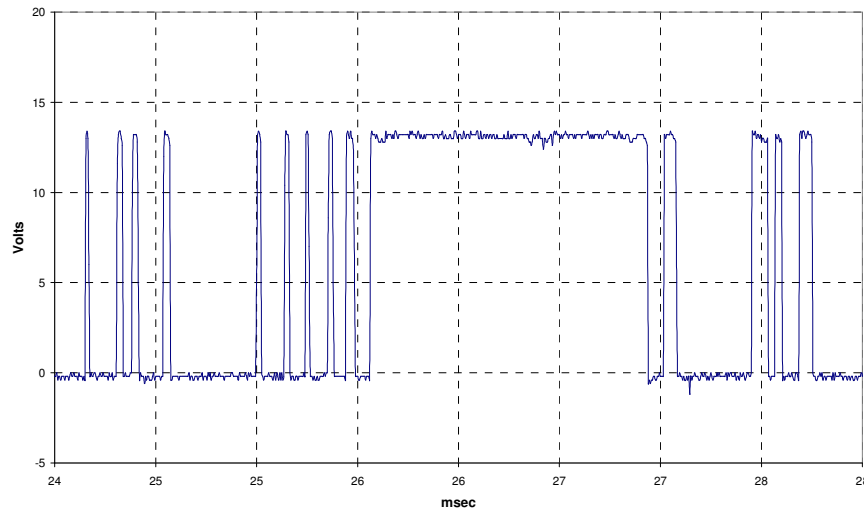
$U_1 = 5 \text{ V}$

Figure 19-6: CI 260 Waveform F (Random Bounce)



Waveform sequence ends with voltage U_p

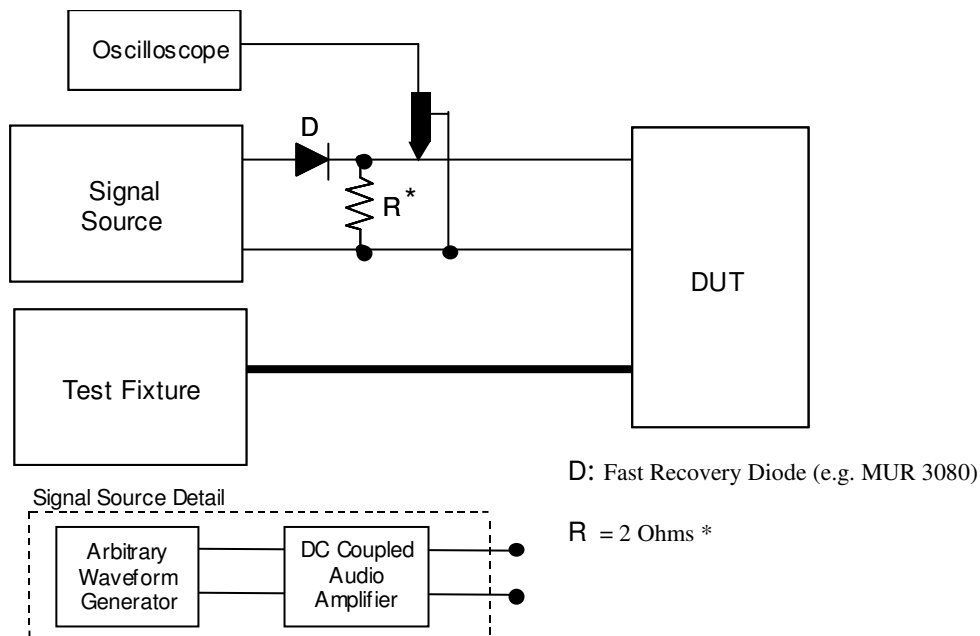
Figure 19-7: CI 260 Waveform F (Expanded)



19.2 Test Verification and Test Setup

Testing shall be performed using the test Setups shown in Figure 19-8 through 19-10. The test harness connecting the DUT to the Load Simulator and transient pulse generator shall be ≤ 2000 mm in length.

Figure 19-8: CI 260 Test Setup Detail for Waveforms A , B and C



* The resistor value may be increased when testing components powered from a regulated supply (category AS). The value of this resistor shall be mutually agreed to by the FMC EMC department and the component's D&R activity. The resistance value shall be documented in the component's EMC test plan.

Figure 19-9: CI 260 Test Setup Detail for Waveforms D and E

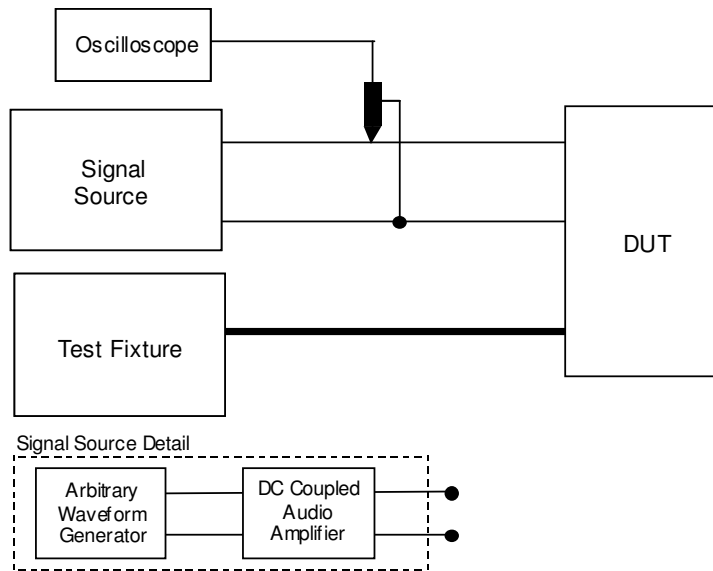
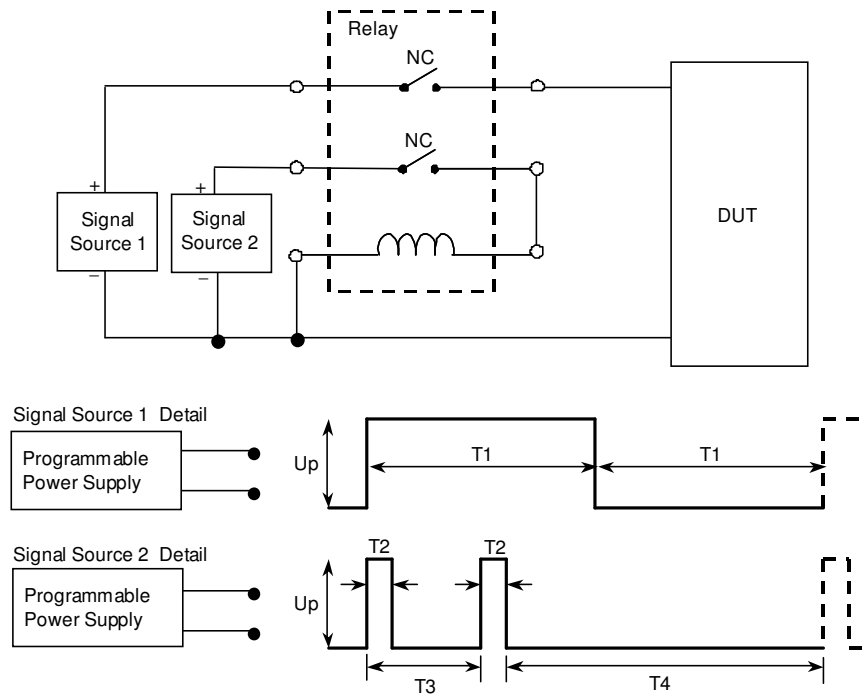


Figure 19-10: CI 260 Test Setup for Waveform F



Key:

- Up = 13.5 volts
- T1 = 5 sec
- T2 = 100 msec
- T3 = 2.5 sec
- T4 = 7.4 sec

Relay*:

12 volt AC relay: Potter & Brumfield KUP-14A15-12. No substitutions permitted without written authorization from the FMC EMC department. See Annex F for relay specifications.



19.3 Test Procedures

- Adjust DC offset of the signal generator/audio amplifier to 13.5 volts with the DUT disconnected (open circuit).
- Prior to testing, measure and verify that the test waveforms A, B, C, D and E match those waveforms illustrated in section 19.2. For waveform F, measure and verify that the test waveform voltages are similar to that illustrated in Figure 19-6 and 19-7. All measurements shall be made with the DUT disconnected from the waveform generator.
- Connect and activate the DUT. Verify that it is functioning correctly.
- Except for waveform E, apply each waveform into each power supply and control circuit separately. Apply waveform E simultaneously to all power circuits with direct battery connections.
- Application of the waveforms shall be in accordance with the requirements delineated in Table 19-1. Monitor DUT functions before and after application of each test waveform.
- Repeat testing for all DUT operating modes listed in the test.



20.0 Immunity to Voltage Overstress: CI 270

These requirements are applicable to the following component categories:

Electronic Modules: A, AM, AX, AY

Electronic Controlled Electric Motors: EM

Electric Motors: BM

Passive Modules and Inductive Devices: P, R

20.1 Requirements

The component shall be immune from potential voltage overstress. This requirement is applicable to all power supply or control circuits, either switched to, or directly connected to battery. The requirement is also applicable to control circuits directly connected to switched battery connections or through an external pull-up resistor. Requirements are delineated in Table 20-1. This requirement may be waived if analysis shows that the component will meet the requirements in Table 20-1. However, the FMC EMC department shall review and concur on this analysis to avoid this testing.

Table 20-1: CI 270 Requirements for Voltage Overstress

Requirement		Functional Performance Status	
Amplitude (V)	Duration	Class A	Class B and C
-14 (-0.7, +0)	≥ 60 sec	III	III
19 (+0.95, -0)	≥ 60 min	III	II
24 (+1.2, -0)	≥ 60 sec ⁽¹⁾	III	I/II ⁽²⁾

1. Applicable to devices connected directly to battery or via the ignition switch. For devices connected only to the start circuit, the duration time may be reduced to 15 sec.
2. Status I required for devices required for engine start (e.g.; PATS)

20.2 Test Setup and Verification

The DUT and any electronic hardware in the Load Simulator shall be powered from a DC power supply (see paragraph 4.5.4 for requirements). For these tests, the power supply shall have minimum short circuit capacity of 100 amperes.

A device that is reverse battery protected with a fused power circuit and a reverse biased diode in parallel with the device shall be tested in a configuration representative of the vehicle. Example: If a vehicle fuse is used to protect the device, testing shall be performed with the same fuse type. The fuse type shall be documented in the component engineering specification and the EMC test plan.

20.3 Test Procedures

- a) Apply -14 volts only to power circuits with direct battery connections. After 60 seconds, the same potential shall then be applied to the remaining switched power and control circuits for 60 seconds while maintaining the same potential on the direct battery connections. After completion of this test, apply normal +13.5 volts and verify that the DUT powers up and functions properly.
- b) Repeat step a) with 24 volts.
- c) Apply +19 volts to all power and control circuits. All circuits shall be tested simultaneously. Verify functionality per Table 20-1.



21.0 Electrostatic Discharge: CI 280

The component shall be immune from overstress due to Electrostatic Discharge (ESD). These requirements are applicable to the following component categories:

Electronic Modules: A, AS, AM, AX, AY, AW

Electric Motors: Categories EM

Passive Modules: P

**** ESD Testing shall be performed prior to any other EMC validation testing ****

21.1 Requirements

- The component shall be immune to ESD events that occur during normal handling and assembly. These requirements are listed in Table 21-1.
- The component shall be immune to ESD events that can occur during normal operation (i.e. powered). These requirements are listed in 21-2. This includes components in direct access from within the passenger compartment or trunk, or by direct access through an open window from a person outside the vehicle (e.g. door locks, turn signal stalk). The requirement also covers components that are not directly accessible.
- After exposure to ESD events listed in Tables 21-1 and 21-2, component I/O parametric values (e.g., resistance, capacitance, leakage current, etc.) shall remain within their specified tolerances. This may be performed immediately following ESD testing (recommended) or upon completion of all EMC related testing.

Table 21-1: CI 280 ESD Requirements: Handling (unpowered)

Discharge Sequence	Type of Discharge	Test Voltage Level	Minimum Number of Discharges at each polarity	Functional Performance Status		
				Class A	Class B	Class C
1	Contact discharge C = 150 pF, R = 2kΩ	± 4 kV	3	IV		
2 ⁽¹⁾	Contact discharge C = 150 pF, R = 2kΩ	± 6 kV	3			
3 ⁽¹⁾	Air discharge C = 150 pF, R = 2kΩ	± 8 kV	3			

1. This sequence is not applicable to connector pins

21.2 Test Verification and Test Setup

Testing shall be performed in accordance with ISO 10605-2001 except where noted in this specification. The test facility shall be maintained at an ambient temperature at (23 ±5) °C and a relative humidity from 20 % to 40 %

The ESD simulator waveform verification shall comply with ISO 10605-2001 with the following exceptions:

- Contact discharge rise time ≤ 1 ns
- Air discharge rise time ≤ 20 ns

The RC time constant shall be verified by calculation using the exponentially decaying portion of the waveform after the leading edge and/or ringing.

Table 21-2: CI 280 ESD Requirements: Powered (all component surfaces)

Discharge Sequence	Type of Discharge	Test Voltage Level	Minimum Number of Discharges at each polarity	Functional Performance Status		
				Class A	Class B	Class C
1	Air discharge C = 330 pF, R = 2kΩ	± 4 kV	3	I		
2	Contact discharge C = 330 pF, R = 2kΩ	± 4 kV	3			
3	Air discharge C = 330 pF, R = 2kΩ	± 6 kV	3			
4	Contact discharge C = 330 pF, R = 2kΩ	± 6 kV	3	II		
5	Air discharge C = 330 pF, R = 2kΩ	± 8 kV	3			
6	Contact discharge C = 330 pF, R = 2kΩ	± 8 kV	3			
7 ⁽¹⁾	Air discharge C = 330 pF, R = 2kΩ	± 15 kV	3			
8 ⁽²⁾	Air discharge C = 150 pF, R = 2kΩ	± 25 kV	3			

1. This sequence is not applicable to device surfaces that are not accessible to touch during normal operation including the diagnostic connector.
2. This sequence is applicable only to device surfaces that are directly accessible from outside the vehicle (e.g. keyless entry) or interior surfaces without touching any portion of the vehicle. (e.g. door lock switches, head lamp switch, cluster).

21.2.1 Handling Tests

The standard test setup for handling tests is illustrated in Figure 21-1. The DUT shall be placed directly on a dissipative mat and unpowered. When applying discharges to the DUT connector pins, All DUT power return terminals shall be connected to the ground plane via a grounding strap or wire with a maximum length of 200 mm. If there are multiple power return terminals which are not internally connected within the DUT, the logic return ground shall be connected to the ground plane and the remaining power return terminals shall be subjected to ESD pulses similar to all other I/O pins. For those devices which do not have a ground terminal (i.e. switches with internal LED's that are low-side sensed and/or latched by a controller, etc.), attach the low-side output (that would normally be connected to a controller I/O) to the ground plane.

21.2.2 Powered Tests

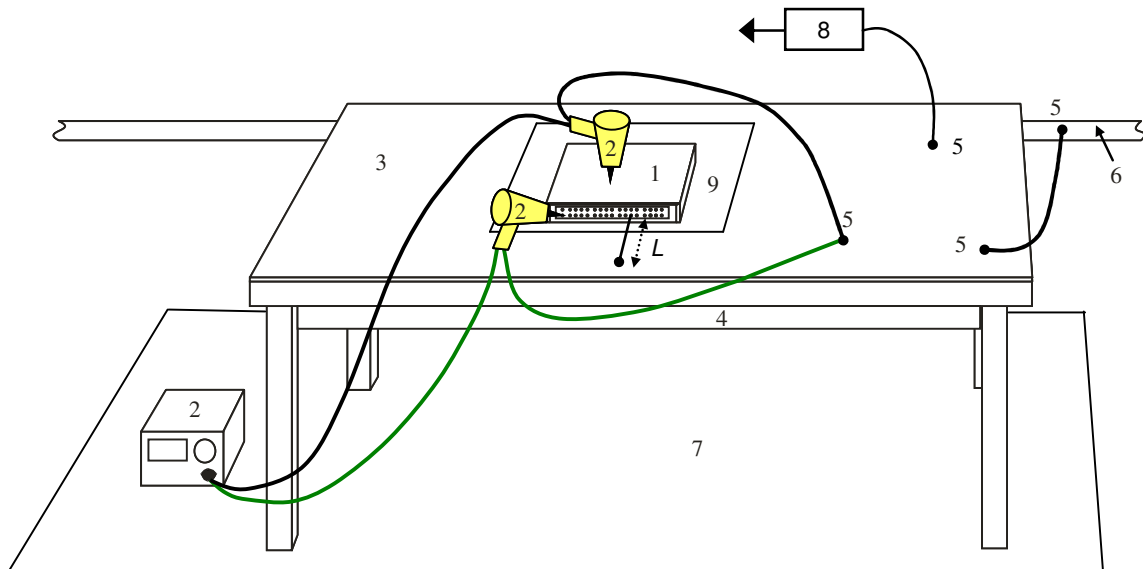
Figure 21-2 illustrates the standard Setup used when the DUT is powered and functioning. The DUT and any electronic hardware in the Load Simulator shall be powered from an automotive battery (see paragraph 4.5.4 for requirements).

The DUT and its attached test harness shall be placed on a clean, dielectric support ($\epsilon_r \leq 1.4$) support that is 50mm thick. The insulator lies directly on the ground plan. The test harness connecting the DUT and Load Simulator shall be 1700 mm (+300 / -0 mm) in length. The Load Simulator shall be connected directly to the ground plan. If the outer case of the DUT is metal and can be grounded when installed in the vehicle, the DUT it shall be placed directly on the ground plane. If there is uncertainty about how the DUT is installed in the vehicle, the DUT shall be tested in both configurations. The ground plane shall be attached to the negative terminal of the battery and to test facility ground. *As an alternative, the battery may be place on the floor of the facility.*

If the DUT has remote inputs that are accessible by the operator (e.g. switches) or communications bus circuits accessible via diagnostic connectors the associated circuit wires shall be split out of the main harness and terminated with representative switches and/or connectors (See Figure 21-2. Wiring for communication bus circuits (e.g. CAN) shall be configured such that the wiring is routed and connected directly to DUT. This requirement is illustrated in Figure 21-3.

Details of these remote connections shall be documented in the EMC test plan and approved by the FMC EMC department prior to commencement of testing. Detailed characteristics of switches and connectors to be used for testing shall be included in the EMC test plan.

Figure 21-1: CI 280 ESD Handling Test Setup

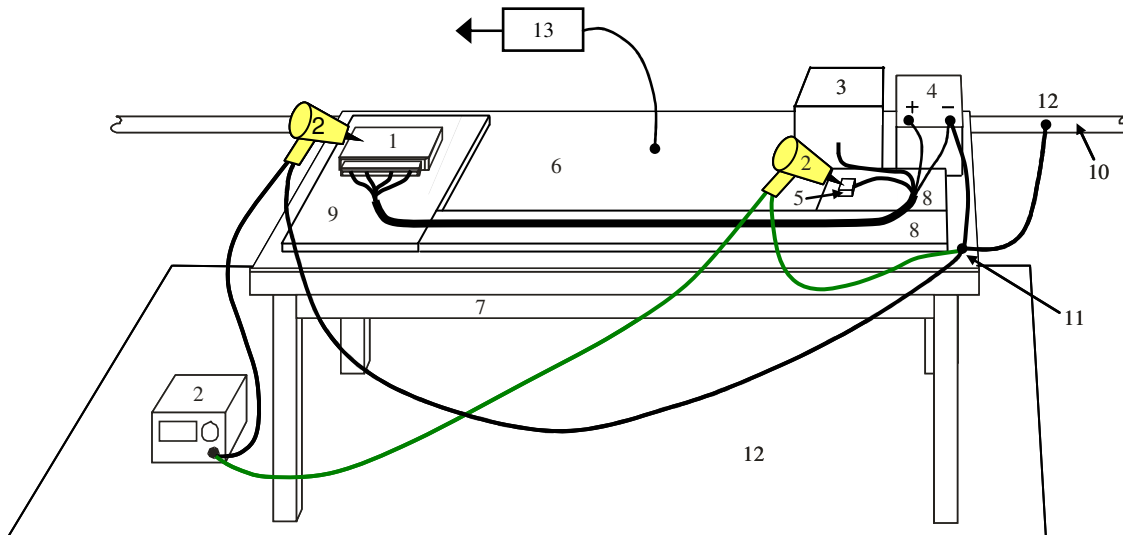


$L \leq 200 \text{ mm}$

Key

- | | |
|---|------------------------------------|
| 1. DUT | 5. Ground Plane Connection |
| 2. ESD Simulator | 6. Test Facility Ground connection |
| 3. Ground Plane | 7. Floor of Test Facility |
| 4. Wooden Table | 8. ~ 1 Meg ohm bleed-off Resistor |
| L: Ground Wire Length $\leq 200 \text{ mm}$ | 9. Dissipative Mat |
- Only used during application of ESD to connector pins

Figure 21-2: CI 280 ESD Powered Test Setup



Key

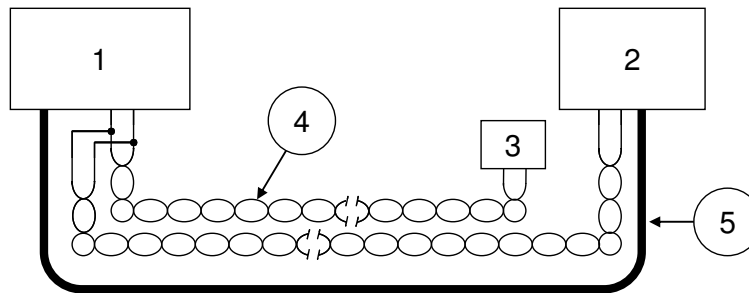
- | | |
|--|--|
| 1. DUT | 8. Harness Insulator Support |
| 2. ESD Simulator | 9. DUT Insulator Support (if needed) |
| 3. Load Simulator | 10. Test Facility Ground |
| 4. Battery | 11. Ground Plane Reference Termination |
| 5. Remote Switch and/or Diagnostic Connector | 12. Ground Plane Connection |
| 6. Ground Plane | 13. ~ 1 Meg ohm bleed-off Resistor |
| 7. Wooden Bench | |

21.3 Test Procedures

Testing shall be performed sequentially starting with handling tests followed by powered and direct access tests. Before testing commences, the discharge voltage of the ESD simulator shall be verified at the levels listed in Tables 21-1 and 21-2.

- Between individual discharges, the remaining charge shall be bled off using the bleed-off resistor (approximately 1M ohm resistance) by touching the discharge point and the ground plane. This step is particularly critical for devices with decorative chrome trim.
- Charge dissipation between discharges of some modules (instrument panels, large plastic modules etc.) may require use of an ionizer. If used, the air ionizer shall be turned off and removed before each discharge is applied.
- When testing is completed, parametric tests shall be performed to verify that the DUT meets the requirements delineated in Tables 21-1 and 21-2. Parametric testing shall be performed before commencement of any subsequent testing.

Figure 21-3: CI 280 Test setup (Communication Bus Connection Requirements)



Key

- | | |
|--------------------------------------|---|
| 1. DUT | 4. Diagnostic Wiring (e.g. CAN) wiring shown is twisted and same length as DUT harness. |
| 2. Load Simulator | 5. Other DUT circuits |
| 3. Diagnostic Connector (e.g. OBDII) | |

21.3.1 Handling (Unpowered) Tests

Prior to testing, the DUT shall be configured as delineated in section 21.2.

- Apply ± 4 kV contact discharge (sequence #1) to all DUT connector pins (*discharge sequence 2 and 3 are not applied*). Prior to commencement of testing verify that the DUT power return terminals are connected to the ground plane per Section 21.2.1). If connector body is non-metallic and the connector pins are recessed, an extension contact (< 25 mm) shall be installed to facilitate testing of the individual pins. If the connector body is metallic with recessed pins, extension contacts shall not be installed.
- Apply contact and air discharges according to the sequence shown in Table 21-1 on all exposed shafts, buttons, switches, and/or surfaces (including along all air gaps that exist between buttons, faceplates, etc.) that are a result of the design of the product. All discharge points shall be specified in the EMC test plan.

21.3.2 Powered Tests

All tests shall be performed while the DUT is in operation using the voltage levels and ESD network values listed in Table 21-2. Testing shall be limited to one DUT operating mode (specified in EMC test plan). Monitoring instrumentation and methods to determine DUT performance during testing shall be documented in the test report. Monitoring of particular DUT functions must not disturb its operation or couple in any of the ESD simulator discharge energy that the DUT would not normally experience. Also, steps should be taken to preclude potential damage of monitoring equipment during testing.

- Verify that the DUT is fully operational. If the DUT contains network functions (e.g. J1850, CAN, LIN), normal expected network traffic shall be simulated to represent that typical in the vehicle application. Details regarding specific network traffic messages, bus utilization etc, shall be documented in the EMC test plan.
- Perform contact and air discharges per Table 21-2 (sequence 1 through 6) to each exposed shaft, button, switch and/or surface of the DUT including air gaps that exist between buttons, faceplates, etc. that are a result of the design of the product. All discharge points shall be documented in the EMC test plan. For each of the required discharge voltages, three (3) discharges of positive and three (3) discharges of negative polarity shall be applied at each of the specified discharge points.
- If the DUT has surfaces located in the passenger compartment or trunk that may be touched, repeat step b) with discharge sequence 7 only.



- d) Repeat steps b) and c) for DUT remote inputs that are accessible by the operator (e.g. switch inputs). A representative switch may be used, but shall be approved by the FMC EMC department in writing prior to commencement of testing.
- e) Repeat step b), sequence 1 through 6 for DUT communications bus circuits accessible via diagnostic connectors. Apply contact and air discharges directly to the connector pins as illustrated in Figure 21-2.
- f) Perform air discharge ± 25 KV (sequence 8) to DUT surfaces that are:
 - Located in the passenger compartment, but are only in directly access from outside the vehicle (e.g. turn signal stalk switch, window switches).
 - Directly accessible from the outside of the vehicle (e.g. keyless entry keypad)

For each of the required discharge voltages, three (3) discharges of positive and three (3) discharges of negative polarity shall be applied at each of the specified discharge points.

- g) After all discharges have been carried out (including handling tests), functional performance and parametric tests shall be performed to verify that the DUT meets the requirements delineated in section 21.1.



Annex A (Normative): Field Calibration Procedure for ALSE Method Bands 6 and 7)

Due to the need for accurate generation of the high field strengths for Bands 6 and 7, field characterization shall be facilitated using the procedures outlined in this annex. These procedures replace those delineated in ISO 11452-2. This characterization procedure allows for use of either CW E-field probes or a receive antenna (DRG horn). For Bands 4 and 5, the field characterization delineated in ISO 11452-2 shall be used. The procedure outlined in this annex shall not be used for field characterization of Bands 4 and 5.

A.1 CW E-field Probe Method

When using this method, the orientation of the CW E-field probe axes with respect to surface of the dielectric support and the transmit antenna are specifically defined. Figures A-1 and A-2 illustrate positioning for two common probe styles. For some probes, special consideration must be given to assure they are oriented correctly. In Figure A-2, the probe handle must be tilted upward with respect to the surface bench (typically 35 degrees) and rotated around the axis normal to the bench surface (typically 135 degrees) to achieve proper alignment of the probe. Actual positioning shall be determined, based on the probe's specifications. For either probe, its phase center (probe axis origin) is 125 mm above the surface of the dielectric support, used during actual testing.

Calibration for vertical or horizontal polarization shall be relevant to the specific axis, not the vector resultant (e.g. E_{total}). Example: For vertical polarization, the field calibration shall be relative to the vertically aligned field probe sensor (i.e. Z axis sensor). For horizontal polarization, the field calibration shall be relative to the horizontally aligned field probe sensor (i.e. X axis sensor). Using this method requires the field probe *facilitate separate field axis readings*. Field probes that produce only a vector summation of the measured field shall not be used.

Additional requirements include:

- The phase center of the field probe is positioned 125 mm above the surface of the dielectric support used during actual testing.
- Peak forward power shall be the reference parameter for characterization of the field. This forward power shall be measured using either a peak envelope power (PEP) sensor (preferred method) or a spectrum analyzer. *A list of recommended power meters/sensors may be found at <http://www.fordemc.com>.* If a spectrum analyzer is used, it shall be tuned to each individual frequency using zero span setting with a measurement bandwidth greater than 3 MHz.
- Pulse modulation characteristics shall conform to that illustrated in Figure B-1 in Annex B.
- Characterization shall be performed using CW at the required field strengths in Table 11-3. **Characterization at lower field strengths with subsequent power scaling for higher field strengths is not permitted.**
- The E-field probe used shall be capable of measuring electric fields listed in Table 11-3 (e.g. 300 / 600 V/m).
- The E-field probe shall be specifically calibrated the following frequencies:
 - 1.3 GHz
 - 2.9 GHz

A.2 Pulsed E-field Probe Method

Use of E-field probes capable of direct measurement of a pulsed fields is permissible only with prior written approval from the FMC EMC department.. The probes shall meet the requirements delineated for CW field probes (section A.1) with the exception that measurement of CW fields is not required. Currently the only approved commercially available pulsed E-field probe is the Amplifier Research Model PL 7004.



A.3 Antenna Method

Figure A-6 illustrates the setup when using a receiving antenna for field characterization. This method may be used when using either CW or pulsed amplifiers. This method requires use of any of the following as the receive antenna:

- [ETS Lindgren DRG 3115](#)
- [Antenna Research: DRG 118/A](#)
- [Rohde & Schwarz: HF906](#)

Use of alternative antennas shall be approved by the FMC EMC group. Additional requirements include:

- The phase center of the antenna is positioned 125 mm above the surface of the dielectric support used during actual testing.
- Peak forward power shall be the reference parameter for characterization of the field. This forward power shall be measured using either a peak envelope power (PEP) sensor (preferred method) or a spectrum analyzer. *A list of recommended power meters/sensors may be found at <http://www.fordemc.com>.* If a spectrum analyzer is used, it shall be tuned to each individual frequency using zero span setting with a measurement bandwidth greater than 3 MHz.
- Pulse modulation characteristics shall conform to that illustrated in Figure C-4. The maximum RMS forward power (P_{pulse}) used for pulsed modulation testing shall be the same as the CW calibration power (P_{CW_CAL}) (i.e. $P_{PULSE} = P_{CW_CAL}$).
- Characterization shall be performed using the required field strengths in Table 11-3. **Characterization at lower field strengths with subsequent power scaling for higher filed strengths is not permitted.**

Figure A-1: Field Probe (Type A) Positioning Requirements (RI 114, Bands 6 and 7)

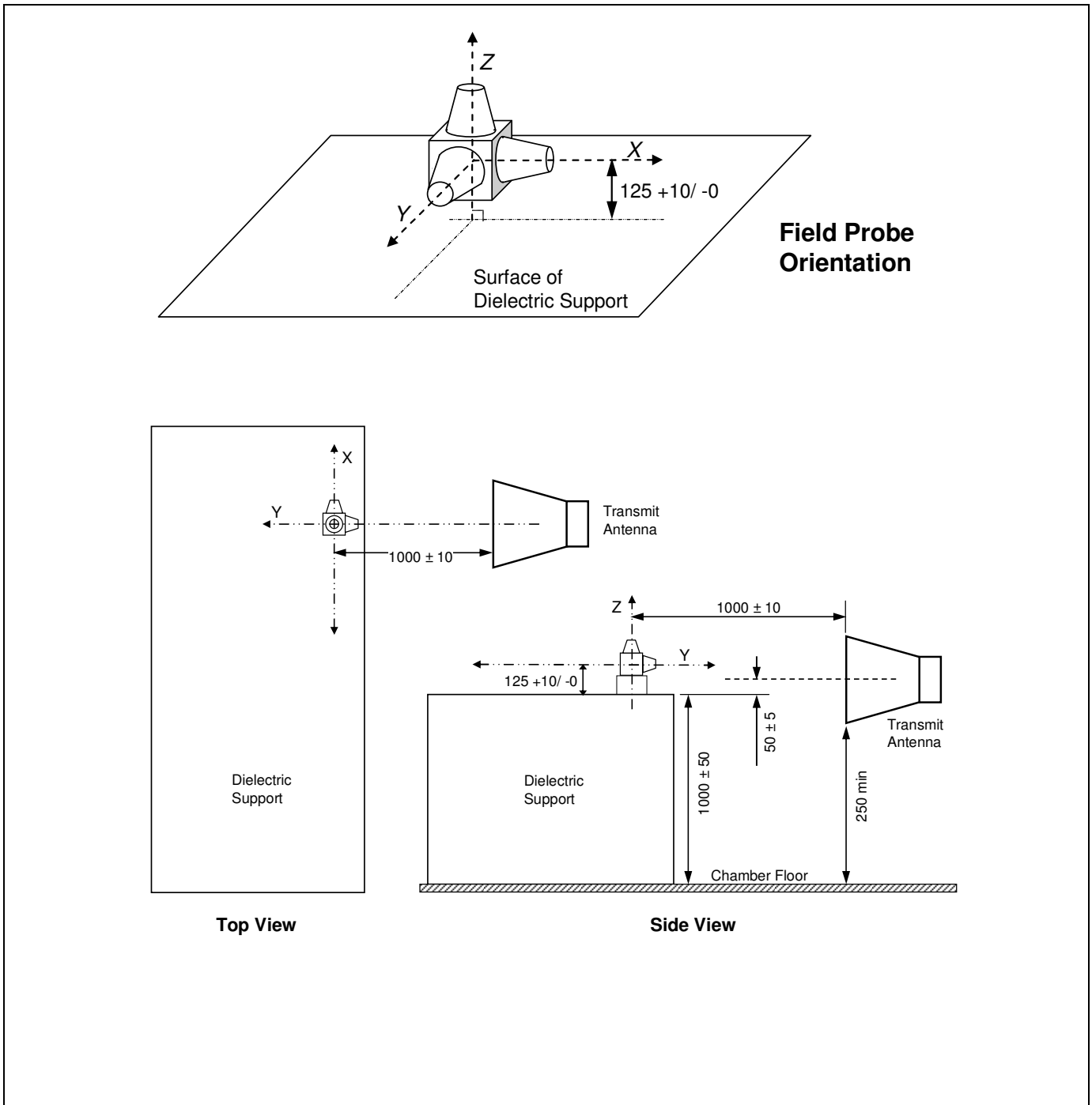


Figure A-2: Field Probe (Type B) Positioning Requirements (RI 114, Bands 6 and 7)

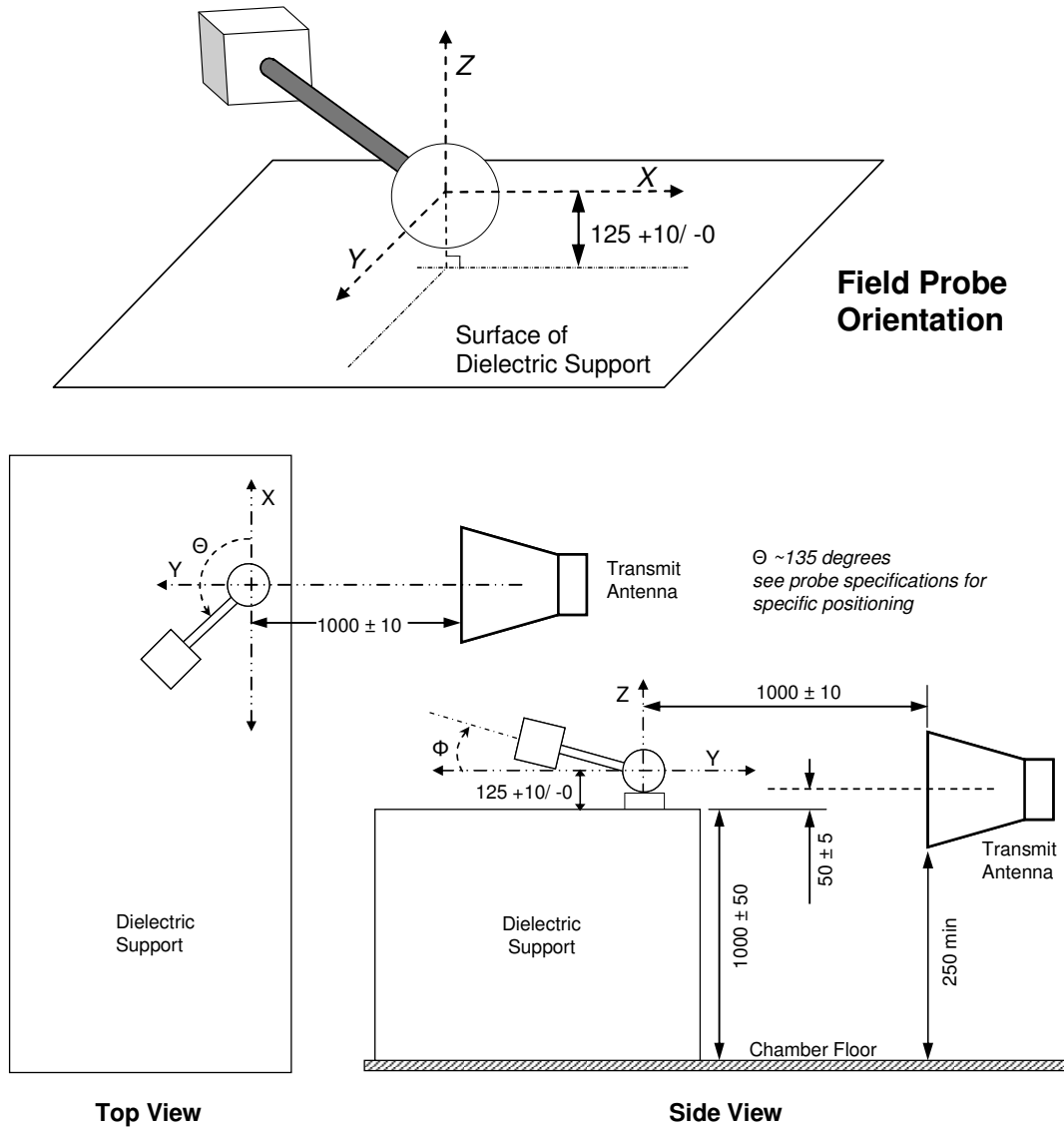
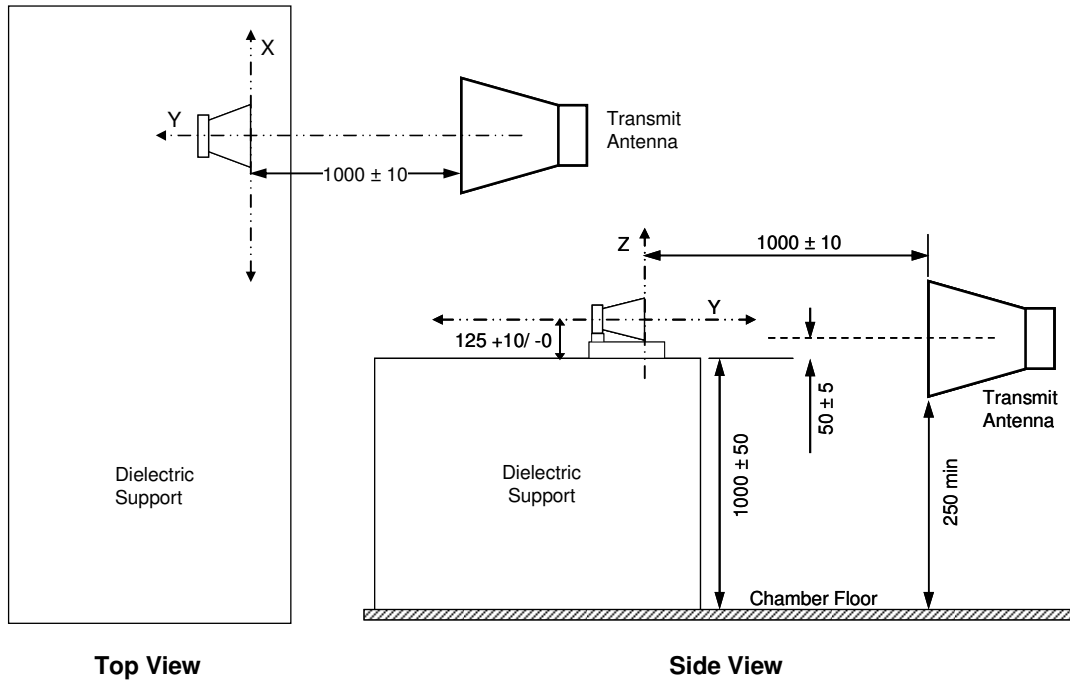


Figure A-3: Receive Antenna Positioning Requirements (RI 114, Bands 6 and 7)

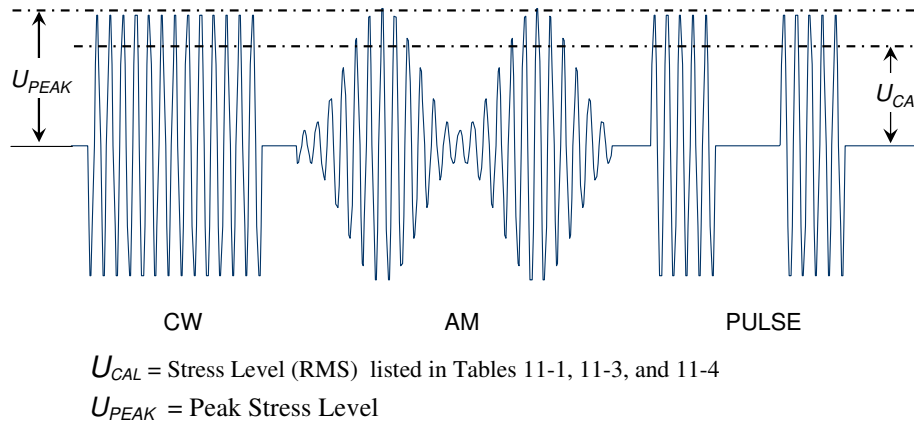


Annex B (Normative): Modulation and Leveling Requirements for RI 112, RI 114 and RI 115

B1 Peak Conservation

Peak Conservation, per Annex B of ISO 11452-1 (2005) shall be used for application of AM and Peak modulation during radiated immunity testing (see section 11). Peak conservation is illustrated in Figure B-1. Peak conservation shall be verified via physical measurement as part of the EMC laboratory's calibration process.

Figure B-1: RF Immunity Peak Conservation Profile



B2 Stress Leveling Process

During testing per RI 112, RI 114 and RI 115, there are a minimum of three distinct stages that occur at each test frequency as illustrated in Figure B-2.

Stage 1 consists of the leveling process to achieve the required stress level at each test frequency. Stage 1 is initiated by setting the signal generator output to produce a stress level > 10 dB below the required stress level (i.e. U_{CAL}). Signal generator values are derived based on the stress level calibration. The leveling process is critical to assure that the required stress level is not exceeded by more than 1.0 dB. Two factors may affect this

- 1 Selection of the stress increment "A" (see Figure B2)
 The lab may elect to use a small, fixed stress increment value during the leveling process however consideration shall be given toward minimizing the leveling time while not exceeding the target stress level by more than 1 dB. Alternatively, the selected stress increment may variable depending on difference between the measured stress level and the target stress level. The total leveling time should not exceed 6 seconds.
- 2 RF signal source overshoot during step changes in its output to the RF amplifier.
 Overshoot may not exceed 1 dB of the target stress level. A number of hardware and software parameters may be employed to minimize overshoot. The test laboratory should avoid step changes in electromechanical attenuation during the leveling process, which can be a significant source of overshoot. Although not required, use of signal generators with electronic attenuation is recommended.

Stage 2 occurs when the required stress level has been achieved. The stress level shall remain constant for a minimum dwell time of 2 seconds unless longer times are documented in the DUT's EMC test plan. During this time, CW, AM, or Pulse modulation may be used. The laboratory may perform separate tests for each modulation type or cascade the modulation types at each frequency (recommended). This later approach is illustrated in Figure B-3. If this approach is taken, the laboratory shall take steps to differentiate DUT anomalies attributed to a specific modulation type.

When the dwell time is completed, the required stress level shall be reduced by > 10 dB (Stage 3). At this time, the next test frequency is selected and the process described above is repeated. By default, the time duration of Stage 3 is affected only by

the time it takes to move to the next frequency and initiate the leveling procedure (Stage 1). This is hardware and/or test software dependent.

Figure B-2: RF Immunity Generic Leveling/Dwell Process

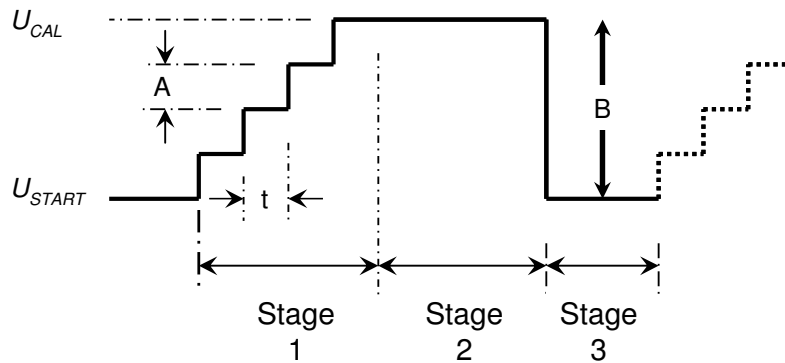
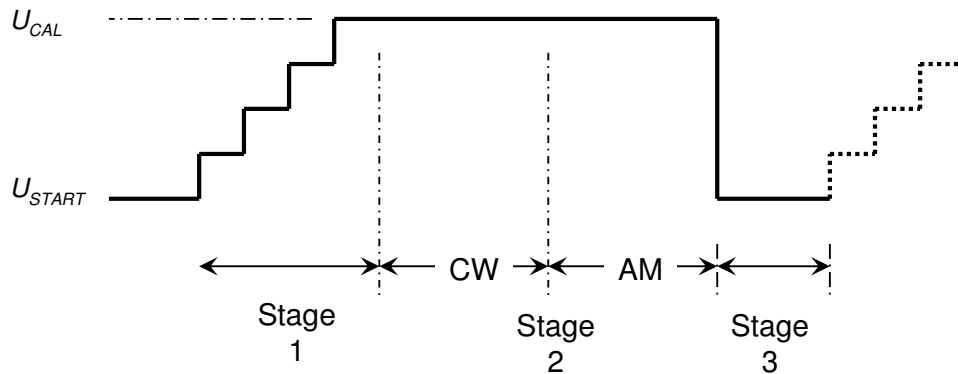


Figure B-3: RF Immunity Example of Combined CW and AM Dwell



Key

- | | |
|---|--|
| Stage 1: Leveling Stage | U_{START} : Initial Stress Level : >10 dB below U_{TARGET} |
| Stage 2: Dwell Stage (default 2 secs) | U_{TARGET} : Target Stress Level |
| Stage 3: Stress Removed. Switch to next frequency (hardware/ software dependent) | A: Stress Increment (may be fixed or variable) |
| t: time required to measure RF power (hardware/software dependent) | B: Post Dwell Level: > 10 dB below U_{TARGET} of next test frequency |

B3 DUT Functional Deviation Threshold Procedure

Determination of DUT functional deviation (anomaly) threshold levels shall be accomplished using the following procedure:

- 1 Reduced stress level until the DUT functional deviation disappears,
- 2 Increase the stress level by steps not exceeding 1 dB, until the functional deviation reappears.
- 3 Record the stress level from step 2 as the functional threshold level

Annex C (Normative): Mode Tuning Chamber Calibration

C1 Mode Tuning Chamber Calibration (Based on IEC 61000-4-21)

C1.1 Chamber Calibration and Loading Validation

The empty chamber calibration shall be performed prior to the use of the chamber for testing using the procedures of this Appendix. Prior to each DUT test, a loading validation shall be performed according to the procedures of C2.

All calibrations are antenna specific. Changing antennas prior to a test shall require a new calibration. One loading validation (outlined in C2) is sufficient at the start of a test with multiple samples. Multiple loading validations are not required in between tests if the DUT being tested has not been significantly modified to affect its size and shape (i.e. circuit board alterations).

C1.1.1 Field Uniformity Validation

- a) Remove all non-essential equipment from the test chamber including DUTs, simulators, cameras, etc.
- b) Place the transmitting antenna as indicated in the notes of Figure C1 directing it into a corner. The transmitting antenna shall not be moved during the field uniformity validation. The transmit antenna shall be linearly polarized and rated for the frequencies being tested. The transmit antenna shall remain in a fixed location for all calibrations and testing.
- c) Place the receive antenna within the working volume of the chamber defined in the notes of Figure C1. The receive antenna, probe, or chamber working volume shall not be in the direct path of the transmit antenna. The receive antenna shall be linearly polarized and rated for the frequencies being tested. The receive antenna shall also be cross polarized with respect to the transmit antenna.
- d) Place an electric field probe (capable of reading three orthogonal axes) on the perimeter of the chamber working volume as shown in Figure C1.
- e) At the lowest test frequency ($f_s = 400$ MHz), inject an appropriate amount of RF power, into the transmit antenna. RF power shall be applied for an adequate dwell time to ensure that the amplitude measuring device and the electric field probes have time to respond properly. Harmonics of the RF input to the chamber must be at least 15 dB below the carrier frequency.
- f) Step the tuner through 360° in discrete steps (mode-tuning) so that the amplitude measuring device connected to the receive antenna (e.g., spectrum analyzer, power meter, etc.) and electric field probes captures the minimum number of samples required as indicated in Table C1.

An appropriate amount of input power is dependent on the size and material of the test chamber as well as the noise floor of the electric field probe and amplitude measuring equipment.

- g) Record the received power, the field strength for each axis of the electric field probe, and the input power for each step of the mode tuner. From these values compute the maximum received power, average received power (P_{MaxRec} , P_{AveRec}), the maximum field strength for each axis of the electric field probe ($E_{\text{Max x}}$, $E_{\text{Max y}}$, $E_{\text{Max z}}$), and the average input power (P_{Input}) over one tuner rotation. All calculated values shall be in linear units (i.e. Watt, not dBm and V/m, not dBV/m). Ensure that the power measurement instruments have an equipment noise floor at least 20 dB below the maximum received power (P_{MaxRec}) for proper average data collection.

P_{Input} is the forward power averaged over one tuner rotation. The number of samples used to determine P_{Input} should be at least the same number of samples used for chamber calibration. All power measurements are relative to the antenna terminals (both forward and receive).

- h) Repeat steps e) through g) in log spaced frequency steps as indicated in Table C1 until the frequency is at least 4000 MHz (10 fs).
- i) Repeat steps e) through g) for each of the eight probe locations shown in Figure C1 and for eight antenna locations until 4000 MHz (10 fs). If the receive antenna will be in a specific position during routine testing, the antenna shall be in one of these positions during the eight runs.

The order of steps f) and h) may be interchanged, i.e., step through all the frequencies at each step of the tuner.



- j) Above 4000 MHz (10-fs), only three antenna locations and electric field probe positions must be evaluated. Repeat steps e) through g) for the remainder of the calibration frequencies as indicated in Table C1. One of the probe locations shall be the center of the working volume and one of the antenna positions shall be the typical receive antenna position as described in step i).

The receive antenna shall be moved to a new location within the working volume of the chamber for each change in probe location. The receive antenna shall be oriented in a different direction for each position (a change in angle of 20 degrees or greater is recommended). The electric field probes do not have to be oriented along the chamber axis during calibration as long as the electric field probe axes remain consistent with each probe position. A proper separation distance shall be maintained between the antenna and probe at each probe location. It is recommended that each probe location be at least 1 m (minimum distance 0.25 m) from any previous location.

- k) Normalize each of the maximum electric field probe measurements (each of the 24 rectangular components below 10 fs, and 9 rectangular components above 10 fs) to the square-root of the average input power using the data from step g).

$$\begin{aligned}\vec{E}_x &= \frac{E_{Max_x}}{\sqrt{P_{Input}}} \\ \vec{E}_y &= \frac{E_{Max_y}}{\sqrt{P_{Input}}} \\ \vec{E}_z &= \frac{E_{Max_z}}{\sqrt{P_{Input}}}\end{aligned}$$

Where:

$E_{Max_{x,y,z}}$ = Maximum measurement from each probe axis (24 or 9 measurements)

$\vec{E}_{x,y,z}$ = Normalized maximum measurement from each probe axis

P_{input} = Average input power to transmit antenna during the tuner rotation at which EMax x, y, z was recorded

- l) For each calibration frequency below 10 fs (4000 MHz), calculate the average of the normalized maximum of each probe axis of the electric field probe measurements:

$$\begin{aligned}\langle \vec{E}_x \rangle &= (\sum \vec{E}_x) / 8 \\ \langle \vec{E}_y \rangle &= (\sum \vec{E}_y) / 8 \\ \langle \vec{E}_z \rangle &= (\sum \vec{E}_z) / 8\end{aligned}$$

- m) For each calibration frequency below 10 fs (4000 MHz), calculate the average of the normalized maximum of all the electric field probe measurements:

$$\langle \vec{E} \rangle_{24} = \sum (\vec{E}_{ix} + \vec{E}_{iy} + \vec{E}_{iz}) / 24$$

i = 1, 2, to 8 (number of probe locations)

Note: < > indicates arithmetic mean, i.e.,

$$\langle \vec{E} \rangle_{24} = \sum (\vec{E}_{ix} + \vec{E}_{iy} + \vec{E}_{iz}) / 24$$

represents the sum of the 24 rectangular electric field normalized maximums divided by the number of measurements.

- n) Repeat step l) for each frequency above 10 fs (4000 MHz), replacing 8 with 3.
o) Repeat step m) for each frequency above 10 fs (4000 MHz), replacing 24 with 9.

- p) For each frequency below 10 fs, verify that the chamber meets the field uniformity requirements by the following procedure:
- q) Field uniformity is indicated by the standard deviation from the mean value of the maximum electric field values obtained at each of the probe location during one complete rotation of the tuner. This standard deviation is calculated from data for each probe axis independently and the total data collected.
- r) The standard deviation is the following:

$$\sigma = \alpha * \sqrt{\frac{\sum \left(\vec{E}_i - \langle \vec{E} \rangle \right)^2}{n-1}}$$

Where:

i = 1, 2, to 8 (number of probe locations)

n = Number of measurements

\vec{E}_i = Maximum normalized electric field probe measurement

$\langle \vec{E} \rangle$ = Arithmetic mean of the normalized electric field measurements

$\alpha = 1.06$ for $n \leq 20$ and 1 for $n > 20$

σ = Standard deviation for a given axis (x, y, or z)

Example for the x-axis

$$\sigma_x = 1.06 * \sqrt{\frac{\sum \left(\vec{E}_{ix} - \langle \vec{E}_x \rangle \right)^2}{8-1}}$$

Where:

i = 1, 2, to 8

\vec{E}_{ix} = Maximum normalized electric field probe measurement of x axis

$\langle \vec{E}_x \rangle$ = Arithmetic mean of normalized axes from all eight measurement locations

Example for all axes:

$$\sigma_{24} = 1 * \sqrt{\frac{\sum \left(\vec{E}_{ix,y,z} - \langle \vec{E} \rangle_{24} \right)^2}{24-1}}$$

Where i = 1, 2, to 8

$\vec{E}_{ix,y,z}$ = Maximum normalized electric field probe measurements of all axes (x, y, and z)

$\langle \vec{E} \rangle_{24}$ = Arithmetic mean of normalized Emax x, y, z axes from all 24 measurements

σ_{24} = Standard deviation of all axes (x, y, and z)

The standard deviation is expressed in terms of dB relative to the mean:

$$\sigma(dB) = 20 * \log \frac{\sigma + \langle \vec{E}_{x,y,z} \rangle}{\langle \vec{E}_{x,y,z} \rangle}$$

The chamber meets the field uniformity requirements if the standard deviation from the individual axes (x, y, and z), and the total data set (all axes) are less than 3 dB (a maximum of three frequencies per octave may exceed the allowed standard deviation by no greater than 1 dB).

C1.1.2 Receive Antenna Calibration

The receive Antenna Calibration Factor (ACF) for an empty chamber is established to provide a comparison with a loaded chamber. The ACF for each frequency is:

$$ACF = \left\langle \frac{P_{AveRec}}{P_{Input}} \right\rangle_{8 \text{ for } \leq 10 f_s, 3 \text{ for } \geq 10 f_s}$$

Where:

P_{Input} is the average input power from C1.1.1 g) for the location at which the average received power P_{AveRec} from C1.1.1 g) was measured

C1.1.3 Chamber Insertion Loss

The chamber Insertion Loss (IL) for the chamber is given by the following:

$$IL = \left\langle \frac{P_{MaxRec}}{P_{Input}} \right\rangle_{8 \text{ for } \leq 10 f_s, 3 \text{ for } \geq 10 f_s}$$

Where:

P_{Input} is the average input power from C1.1.1 g) for the location at which the maximum received power P_{MaxRec} from C1.1.1 g) was measured.

C1.1.4 Maximum Chamber Loading Verification

The following procedure is used to determine if the chamber is affected by a DUT which loads (absorbs a significant amount of energy) the chamber. This procedure should be performed once in the life of the chamber or whenever the chamber has undergone major structural modifications. Prior to each test, a chamber calibration shall be performed according to C2.

- Install a significant amount of absorbing material (e.g., foam absorber) in the chamber to load the chamber to the amount expected during normal testing (a factor of sixteen or 12 dB is typical).
- Repeat the calibration procedure from C1.1 using eight or three locations of the field probes according to the frequency (eight < 10 fs, three > 10 fs). The electric field probes and receive antenna should be a minimum of 0.25 m away from any absorbing material. Determine the chamber loading by comparing the ACF of an unloaded chamber with the ACF of a loading chamber as follows:

$$Loading = \frac{ACF_{Empty Chamber}}{ACF_{Loaded Chamber}}$$

- Repeat the field uniformity calculations as described in C1.1.1.
- If either the field uniformity of the individual rectangular components or the field uniformity for all axes (x, y, and z) is greater than the allowed standard deviation indicated in C1.1.1 d), then the chamber has been loaded to the point where field uniformity is unacceptable. Reduce the amount of loading and repeat the loading effects evaluation.

C2 Calibration and DUT Loading Check

The following procedure shall be performed prior to each test of the DUT. The DUT and any necessary supporting equipment must be installed into the chamber. If the chamber was initially tested under maximum loading conditions, the loading check prior to each test is optional.

- a) Place the receive antenna within the working volume (see C1.1.1 j)) at least 0.25 m from the DUT and supporting equipment.
- b) At the lowest test frequency ($f_s = 400$ MHz), inject an appropriate amount of RF power, into the transmit antenna. Harmonics of the RF input to the chamber must be at least 15 dB below the carrier frequency.
- c) Operate the chamber and the tuner for the desired number of steps as indicated in Table C1 (alternatively, mode stirring is allowed with a maximum stir speed of 16.5 seconds per tuner revolution). RF power shall be applied for an appropriate amount of dwell time to ensure that the amplitude measuring device has time to respond properly.
- d) Calculate the maximum received power, average received power (P_{MaxRec} , P_{AveRec}), and the average input power (P_{Input}) over one tuner rotation. All calculated values shall be in linear units (i.e. W, not dBm; V/m, not dBV/m). Ensure that the power measurement instruments have an equipment noise floor at least 20 dB below the maximum received power (P_{MaxRec}) for proper average data collection.
- e) Repeat step d) for each frequency defined in 3.4.
- f) The Chamber Calibration Factor (CCF) for each frequency is as follows:

$$CCF = \left\langle \frac{P_{AveRec}}{P_{Input}} \right\rangle_n$$

Where:

CCF = Normalized average received power over one tuner rotation with the DUT and support equipment in the chamber

P_{AveRec} = Average received power over one tuner rotation from step g).

P_{Input} = Forward power averaged over one tuner rotation from step g).

n = Number of antenna locations the CCF is evaluated over. Only one is required, however multiple antenna positions may be used and the CCF averaged over the number of locations.

- g) Determine the Chamber Loading Factor (CLF) for each frequency as follows:

$$CLF = \frac{CCF}{ACF}$$

Where:

CCF = Ratio of the average received power to the input power obtained from step f).

ACF = Ratio of the average received power to input power obtained in the antenna calibration of C1.1.2. Use linear interpolation to obtain the ACF.

If the reciprocal value of the magnitude of the chamber loading factor is larger than that measured in C1.1.4 for more than 10% of the frequencies, the chamber is loaded and the field uniformity is affected. If this happens, the field uniformity measurements of C1.1.1 must be repeated with the DUT in the test chamber.

If the P_{AveRec} measured in C2 d) is within (i.e., not greater than or less than) the values recorded for all eight locations in C1.1.1 g), the CLF calculation is not necessary and the value of CLF is one (1).

C3 Q and Time Constant Calibration.

These measurements are conducted to ensure that the chamber can support the pulse waveforms outlined in 3.4.3.

- a) Calculate the Quality factor, Q, of the chamber using the CCF of C2 f) for each frequency:

$$Q = \left(\frac{16\pi^2 V}{\eta_{Tx} \eta_{Rx} \lambda^3} \right) (CCF)$$



Where:

η_{Tx} , η_{Rx} = Antenna efficiency factors for the transmit and receive antenna which can be assumed to be 0.75 for a log periodic antenna and 0.9 for a horn antenna.

V = Chamber volume (m³)

λ_c = Wavelength at the specific frequency

CCF = Chamber Calibration Factor

If the CLF was assumed to be one (1) from step C2 g), the ACF from C1.1.2 shall be used in place of the CCF when computing chamber Q.

b) Determine the chamber time constant, τ , for every frequency using the following:

$$\tau = \frac{Q}{2\pi f}$$

Where:

Q = Value calculated in step a) above

f = Test frequency (Hz)

c) If $\tau > (0.4 * \text{the pulse width})$ given in 3.4.3 for more than 10% of the test frequencies, absorber material must be added and the Q measurement must be repeated. The CLF calculations must be repeated if absorber material is to be added.

Table C-1: Independent Samples and Frequencies for RI 114 Reverberation Method

Frequency Range (MHz)	Number Of Samples (i.e. independent tuner positions or intervals) Recommended for Calibration and Test)	Number Of Frequencies (logarithmically spaced) Required for Calibration
400 to 1000	12	20
1000 to 4000	6	15
> 4000	6	20/decade

Calibration shall consist of eight probe locations below 10 fs (4000 MHz) and three locations above 10 fs (4000 MHz).

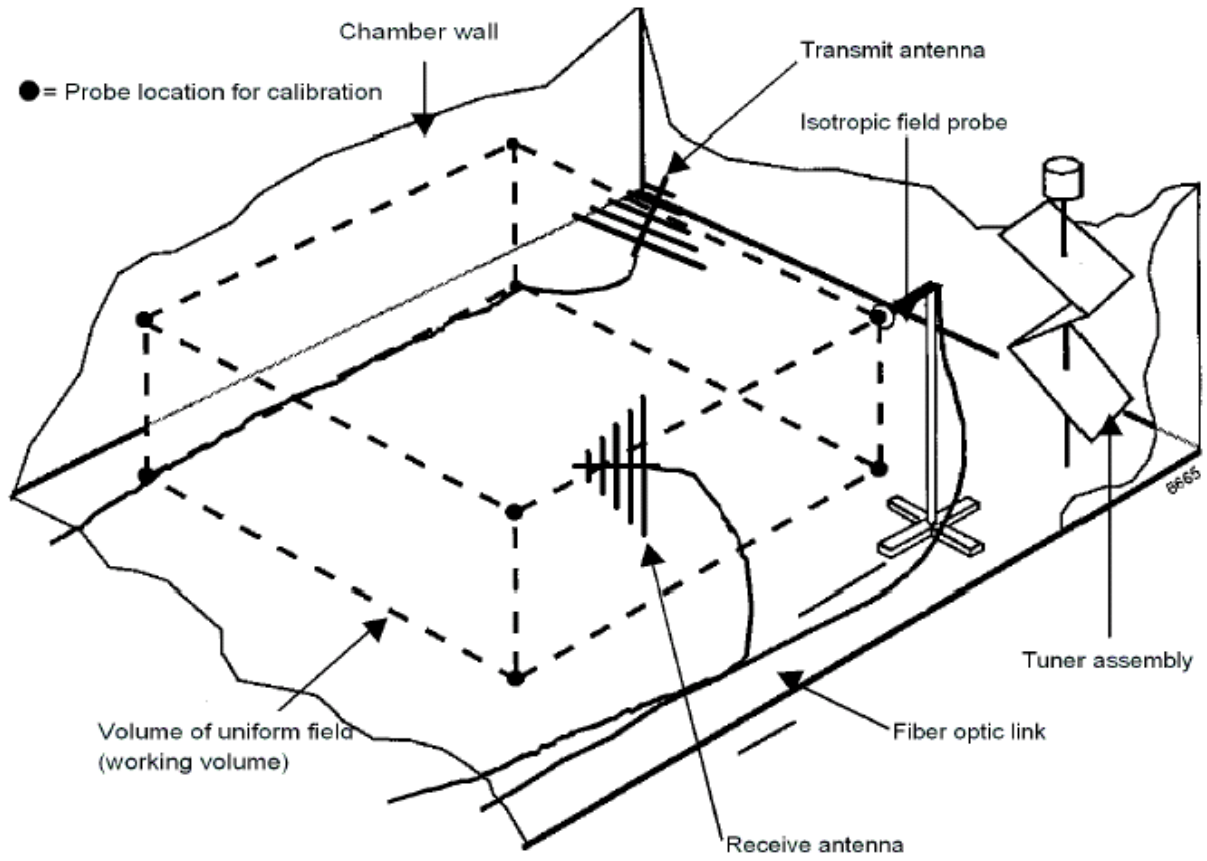
The locations selected shall enclose the "working volume" as shown above. The working volume should be located at least 1 meter from the chamber walls, mode tuning device, and transmitting antenna.

The receive antenna must be located in the working volume for calibration purposes as described in C1.1.1 c). The transmit antenna shall be pointed into a corner at least 0.25 m away from the chamber surface. The transmit antenna shall remain in a fixed location for all calibrations and testing.

The working volume may be sized to suit the size of the DUTs to be tested.

The minimum separation distance may be reduced less than 1 m provided that the separation distance is always at least 0.25 m.

Figure C-1: RI 114 Reverberation Test Configuration (Mode Tuning)



Annex D (Normative): CI 220 Transient Waveform Descriptions

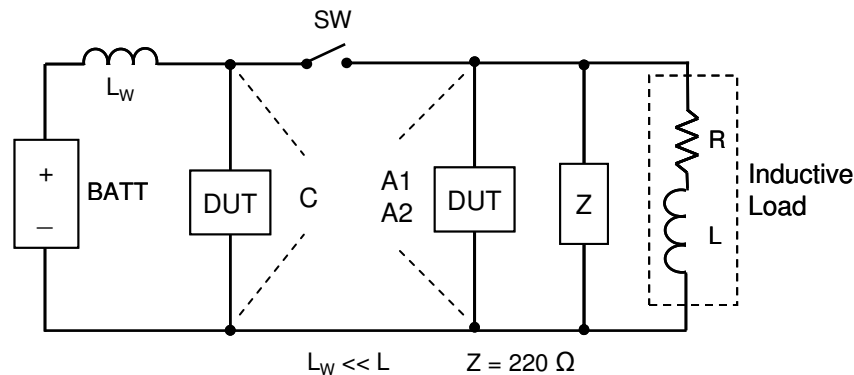
CI220 transient immunity testing consists of both standard pulses as delineated in ISO 7637-2 in addition to non-standard pulses including those produced by electromechanical switching of an inductive load. These non-standard transient pulses have been included to produce transient waveforms that are absent in ISO 7637-2, but are prevalent in the vehicle's electrical power distribution system. Non-standard transients created from this approach are highly affected by a number of factors including but not limited to resistive/capacitive loads sharing the same circuit as the inductive load. Although consecutive transients events produced in this manner are often not repeatable as compared to standard ISO test pulses, experience has shown that this random behavior can produce anomalies that are frequently missed when using only the standard repetitive ISO pulses.

This annex provides information about the characteristics of the CI 220 transient pulses delineated in this specification. This information shall also be considered during initial design of the component or subsystem.

D.1 Test Pulses A1, A2, C, E

Figure E-1 illustrates a simplified automotive circuit consisting of an ignition switch used to activate or deactivate the inductive load (e.g. power door lock). L_W represents the series wiring inductance between the battery, and ignition switch. The load inductance "L" is significantly greater than the series inductance of the wiring (typically 1 uH/meter).

Figure D-1: Simplified Automotive Circuit for Transient Immunity



Test Pulse A1 represents the voltage transient produced during switching of higher current (1 – 5 ampere) inductive loads that share the same circuit with the DUT. "Z" represents the impedance of the other electrical loads sharing the same circuit with the DUT and the inductive load. The value of "Z", which is set to 220 Ω , simulates minimally loaded circuits. Figure D-2 illustrates Pulse A1. The peak pulse voltage levels will vary between –250 to –300 volts.

Test Pulse A2 represents the voltage transient produced during switching of a lower current (< 1 ampere) inductive loads that shares the same circuit with the DUT. The characteristics of Pulse A2 can vary significantly depending on the impedance of the other loads sharing the same circuit as the DUT. Given this dependency, two separated conditions exist for Pulse A2. They are:

Pulse A2-1

Occurs when the circuit consists only of the DUT and the switched inductive load.

Pulse A2-2

Occurs when the circuit includes other electrical loads that share the same circuit as the DUT and the switched inductive load.. The other electrical loads are predominately capacitive (e.g. wiper motor filter capacitor)

Figures D-3 and D-4 illustrate waveforms that typify Pulses A2-1 and A2-2. When external circuits effects are not considered, the transient (Pulse A2-1) is largely the result of contact arcing. The characteristics of this transient consist of a high frequency repetitive pulse with peak positive voltages levels between +100 to +300 volts and peak negative voltage levels are between –280 to –500 volts. Duration of individual pulses (see Figure D-3b) may vary between 100 nsec to 1 usec. The characteristics illustrated in Figure D-3 were measured when the contacts open, however similar transients can occur when the switch contact bounce during closure. A2-1 transients are also commonly referred to as "showering arc transients."

When the external circuit is predominately capacitive, the transient produced (Pulse A2-2) is significantly different than Pulse A2-1. When the switch contacts open, a damped sinusoidal transient ($f_{res} \sim 2\text{kHz}$) is produced. When the switch contacts bounce during closure a higher frequency, damped sinusoidal transient ($f_{res} \sim 180\text{kHz}$) is produced. During this phase, there is a corresponding current transient with a magnitude approximately $30 A_{p,p}$ (see Figure D-4c). *When attempting to measure Pulse A2-2, on an oscilloscope, it is recommended to trigger on the transient current.*

Figure D-2: CI 220 Pulse A1 Composite Waveform

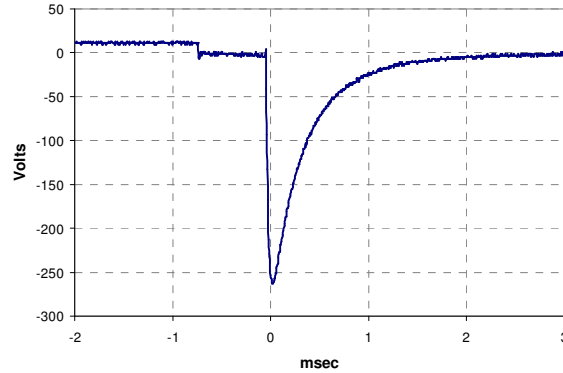
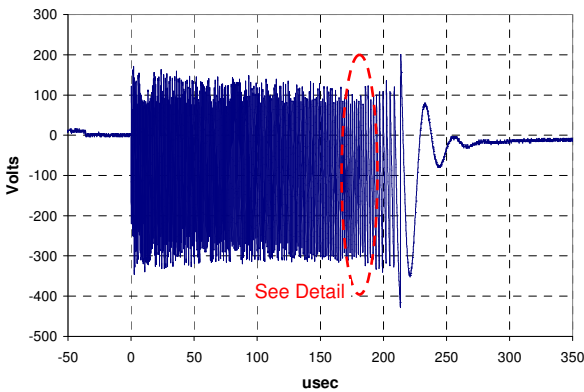
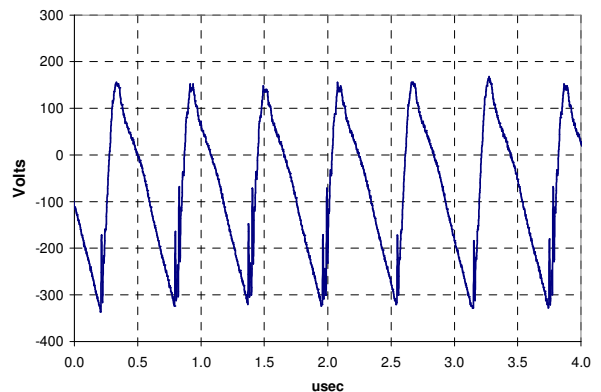


Figure D-3: CI 220 Pulse A2-1 Pulse Characteristics

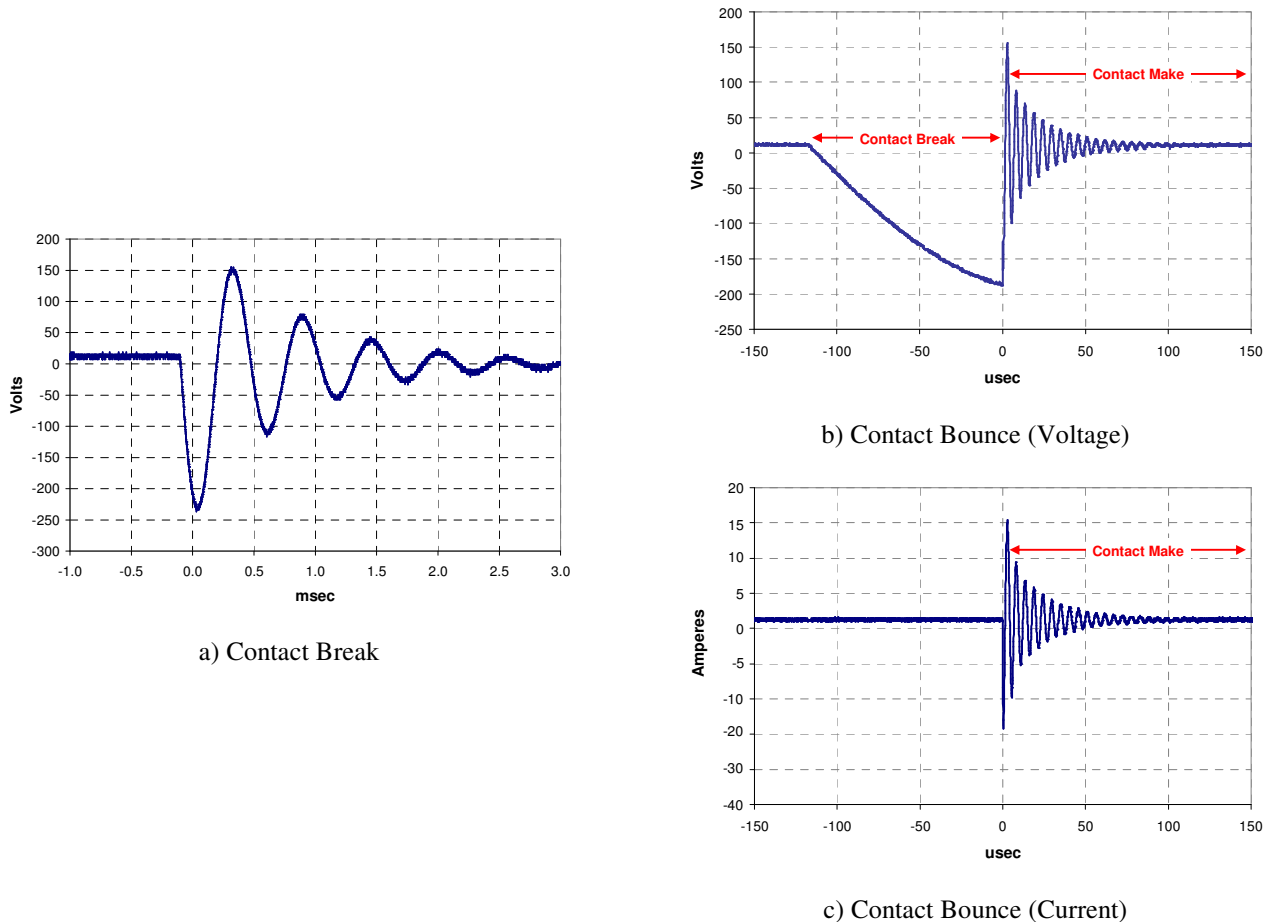


a) Contact Break and Bounce



b) Contact Break and Bounce (Detail)

Figure D-4: CI 220 Pulse A2-2 Pulse Characteristics

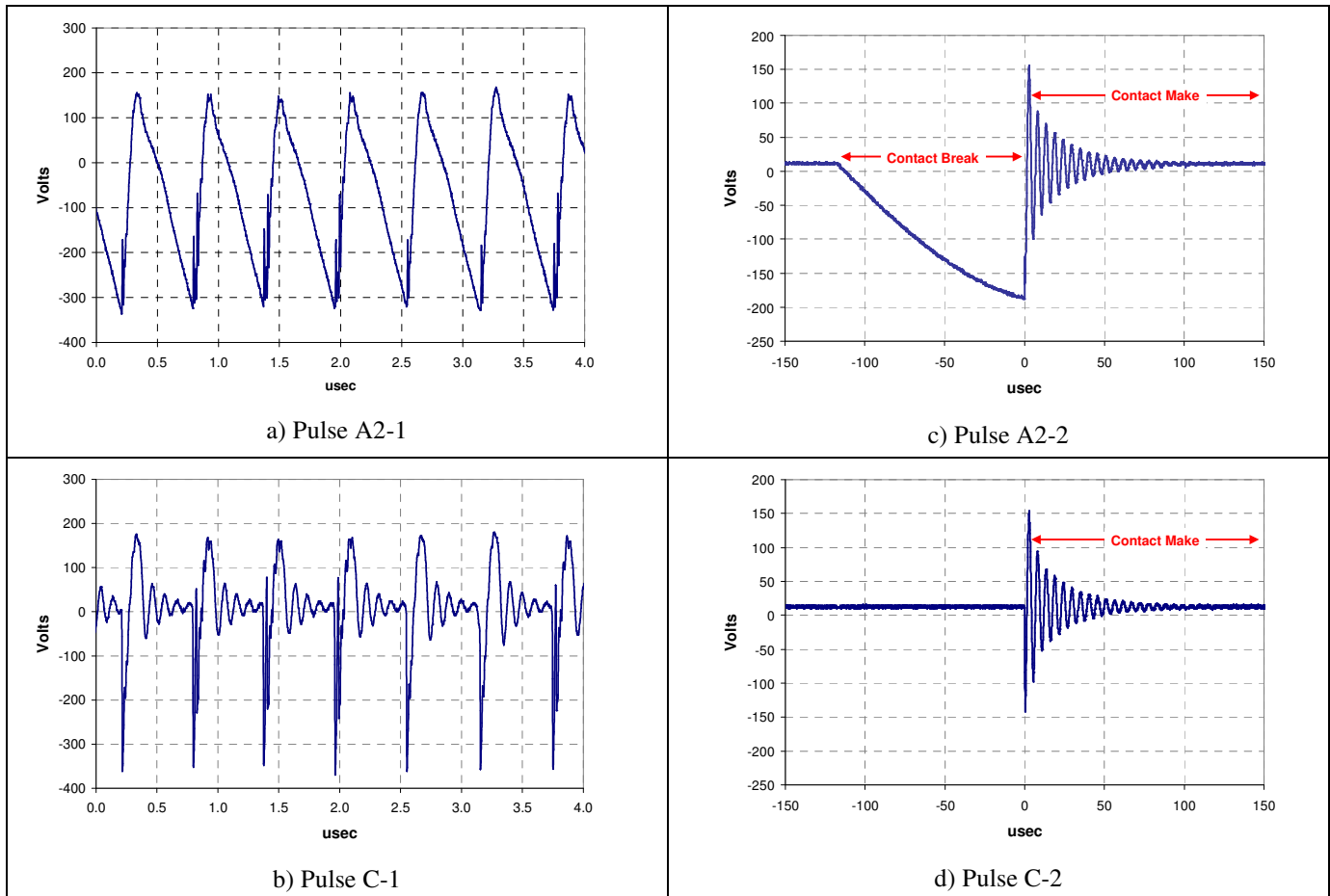


Test Pulse C represents the voltage transient produced as a result of switch contact arcing and contact bounce during switching of an inductive load. The transient characteristics are a function of the series wiring inductance and the current produced during arcing (switch contact break) or contact bounce. Pulse C is directly related to Pulse A2. Given this dependency, two separated conditions exist (Pulse C-1, C-2) corresponding to Pulses A2-1 and A2-2 respectively.

Pulse C-1 characteristics are illustrated in D-5b. The characteristics of this transient consist of a high frequency damped sinusoidal pulse ($f_{res} \sim 10$ MHz) with peak positive and negative voltages levels approximately ± 150 volts. Duration of the sinusoidal transient pulse is varies between 100 nsec to 1 usec.

Pulse C-2 characteristics are illustrated in D-5d. The characteristics of this transient consist of a lower frequency damped sinusoidal pulse ($f_{res} \sim 180$ kHz) with peak positive and negative voltages levels approximately ± 150 volts. Duration of the sinusoidal transient pulse is approximately 50 usec.

Figure D-5: CI 220 Pulse C Characteristics



Pulse E represents the voltage transient produced during switching of a higher current (> 5 ampere) inductive load that shares the same circuit with the DUT. The test pulse is equivalent to Test Pulse 1 delineated in ISO 7637-2. Pulse E is similar to Pulse A-1 except that it occurs when higher current loads (> 5 amperes) share the same circuit as the inductive load. The pulse can also occur on circuits with high capacitive loads ($> 2\mu\text{f}$). Pulse E characteristics are illustrated in Figure D-6.

D.2 Test Pulse F1 and F2

Pulse F1 simulates the interruption of a current through an inductance switched in series with the DUT. The test pulse is equivalent to Test Pulse 2a delineated in ISO 7637-2. Application of this test pulse is limited only for power supply circuits and **only for components required to meet the ESA requirements of European directive 72/245/EEC.**

Pulse F2 simulates the interruption in current to brush commutated motor, which is low-side switched. The test pulse is equivalent to test pulse 2B delineated in ISO 7637-2. Application of this test pulse is limited only for power supply circuits and **only for components required to meet the ESA requirements of European directive 72/245/EEC.**

Figure D-6: CI 220 Pulse E Characteristics

Pulse E - Parameters

U_p	13.5 V
U_s	-100 V
t_r	1 us
t_d	2 ms
t_1	5 s
t_2	200 ms
t_3	≤ 100 us
R_i	10 ohms

Waveform voltage begins and ends at U_p

Parameters listed are for open circuit conditions.

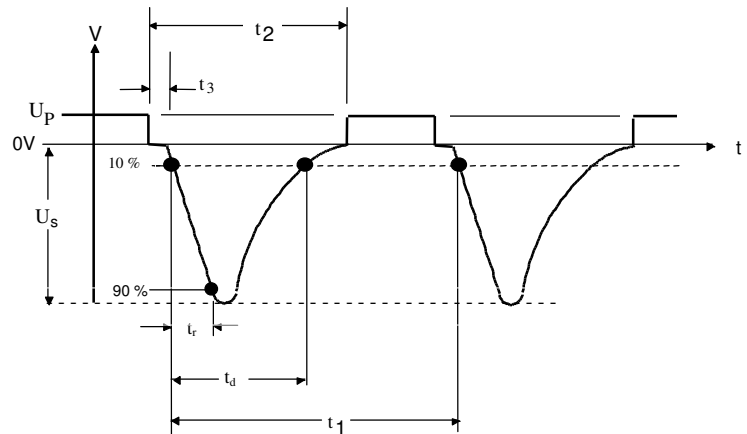


Figure D-7: CI 220 Pulse F1 Characteristics

Pulse F1 - Parameters

U_p	13.5 V
U_s	37 V
t_r	10 (-0.5 / +0) us
t_d	50 us
t_1	0.2 - 5 s
R_i	2 ohms

Waveform voltage begins and ends at U_p

Parameters listed are for open circuit conditions.

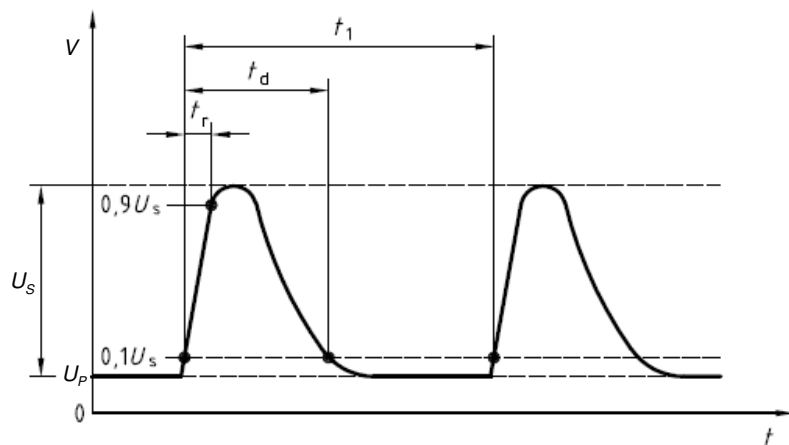
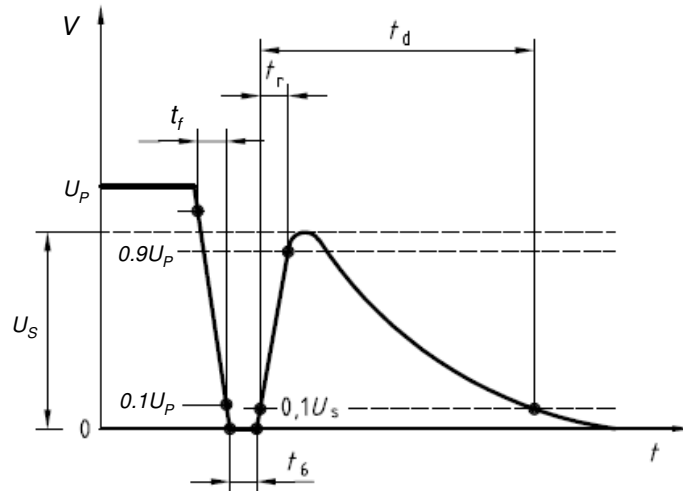


Figure D-8: CI 220 Pulse F2 Pulse Characteristics

Pulse F2 - Parameters

U_p	13.5 V
U_s	10 V
t_r	1 ± 0.5 ms
t_f	1 ± 0.5 ms
t_6	1 ± 0.5 ms
t_d	0.2 – 2 s
R_i	< 0.5 ohms

Parameters listed are for open circuit conditions.



D.3 Test Pulses G1 and G2

Pulse G1 represents the transient produced due to sudden disconnection of the battery from the alternator. The test pulse is equivalent to Test Pulse 5a delineated in ISO 7637-2 (2004-06-15). Pulse G1 characteristics are illustrated in Figure D-9.

Pulse G2 represents a voltage clamped transient produced due to sudden disconnection of the battery from an alternator fitted with Central Load Dump (CLD) Protection. Pulse G2 characteristics are illustrated in Figure D-10.

Figure D-9: CI 220 Pulse G1 Characteristics

Pulse G1 - Parameters

Open Circuit Conditions	
U_p	13.5 V
U_s	60 V
t_r	10 (-5 /+0) ms
t_d	300 ms +/-20%
R_i	0.5 Ohms

Loaded Conditions ($R_L = R_i$)	
U_p	13.5 V
U_s	30 V
t_r	10 (-5 /+0) ms
t_d	150 mS +/-20%
R_i	0.5 Ohms

Waveform voltage begins and ends at U_p

All voltage values are with respect to 0 volts unless otherwise specified.

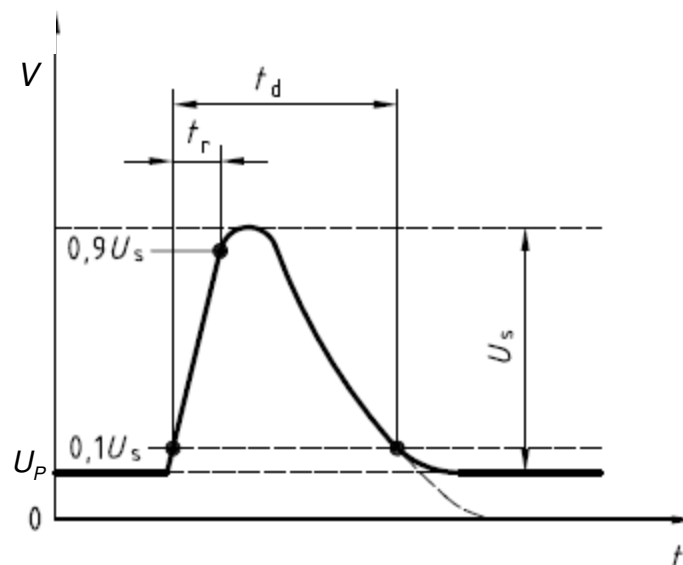


Figure D-10: CI 220 Pulse G2 Characteristics

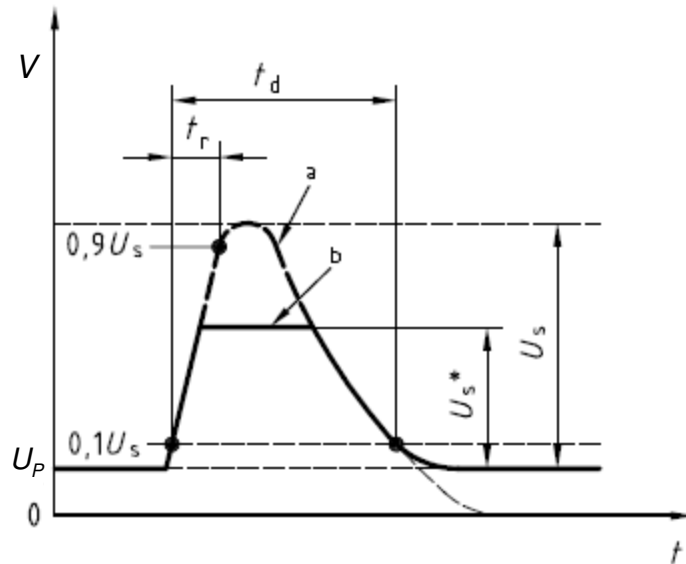
Pulse G2 Parameters

U_p	13.5 V
U_s	30 V
U_s^*	21.5 (-1/+0) V
t_r	10 (-5/+0) ms
t_d	150 mS +/-20%
R_i	0.5 Ohms

All voltage values are with respect to 0 volts unless otherwise specified.

Voltage values listed are across a 0.5 ohm resistive load (see section 16.3).

- a: Unsuppressed pulse
- b: Suppressed pulse



D.4 Transient Application Mode

Application of transient pulses A1, A2 and C to the DUT are facilitated using three different operating modes.

Mode 1 represents a condition where the test pulse is applied at a fixed repetition rate as shown in Table D-1 below. Mode 1 is applicable for pulses A1 and A2 only when applied to DUT switched power supply circuits.

Table D-1: CI 220 Mode 1 Characteristics

Transient Pulse	Pulse Repetition Rate (PRR)	Duration
A1	0.2 Hz, 10% duty cycle	120 sec
A2-1		

Mode 2 represents a condition where test pulses are applied using a pseudo- random timing sequence as illustrated in Figure D-11. Mode 2 is only used with test pulse A1 when applied to DUT inputs. The time "T" is 50 ms.

Mode 3 represents a condition where test pulses are applied using pseudo- random bursts as illustrated Figure D-12. The timing sequence is identical to that used for Mode 2. Mode 3 is used only with test pulses A2-1, A2-2, C-1, and C-2. The bust time "T" is 50ms.

Modes 2 and 3 is also used when performing testing per RI 130 (see section 13).. Modes 1, 2 and 3 are produced by the transient generator circuit presented in Annex F.

Figure D-11: CI 220 Mode 2 Characteristics

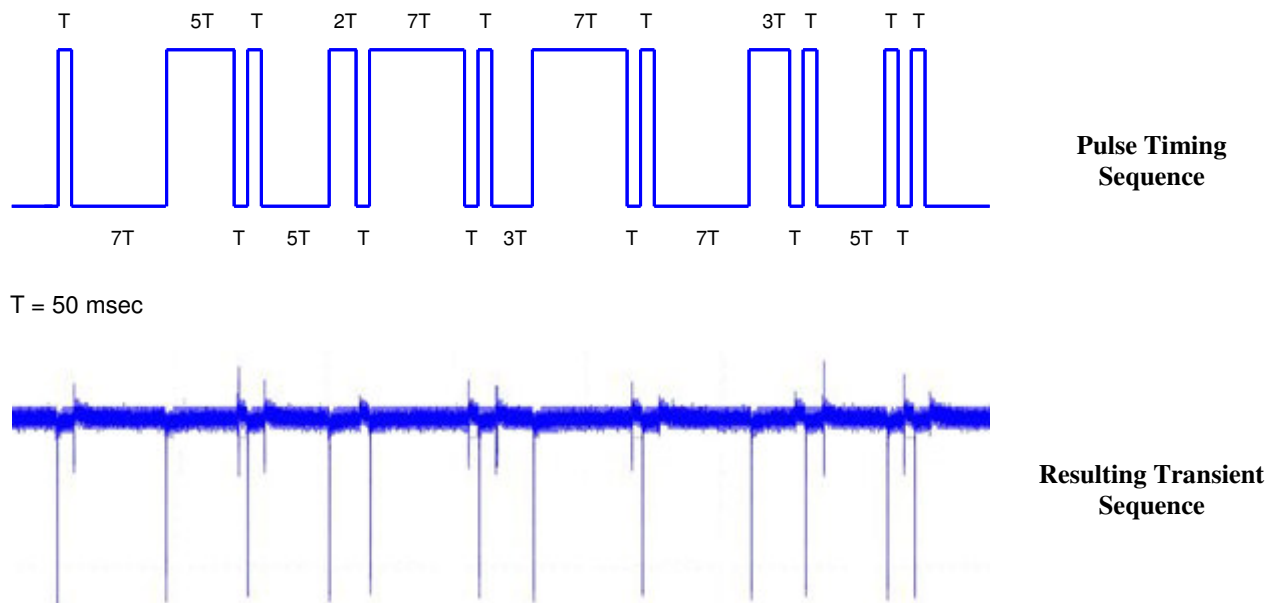
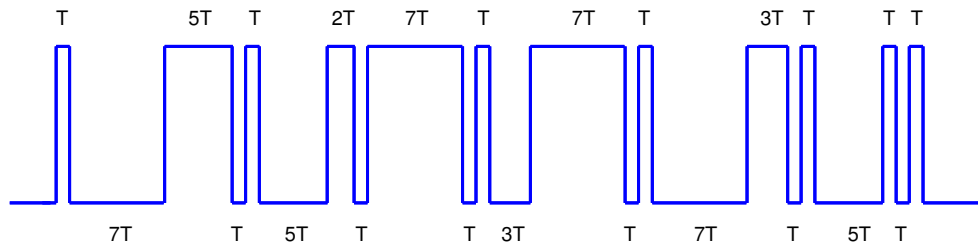
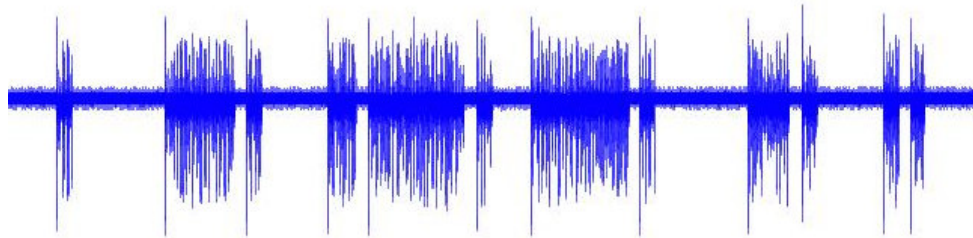


Figure D-12: CI 220 Mode 3 Characteristics



Pulse Burst Timing Sequence

$T = 50 \text{ msec}$



Resulting Transient Burst

Annex E (Normative): Transient Waveform Application

Applications of Test pulses A, C, E and G are largely dependent on how the DUT is connected to the power distribution system. This annex provides basic information with respect to application for each transient test pulse. The figures presented represent typical configurations including the ignition switch, remote switch (SW2), inductive load, the DUT and external electronic loads "Z" connected at various points on the power distribution system. Proper application of transient pulses requires analysis of how the actual component (DUT) will be used. In many cases the actual device configuration will be some combination of the generic configurations presented.

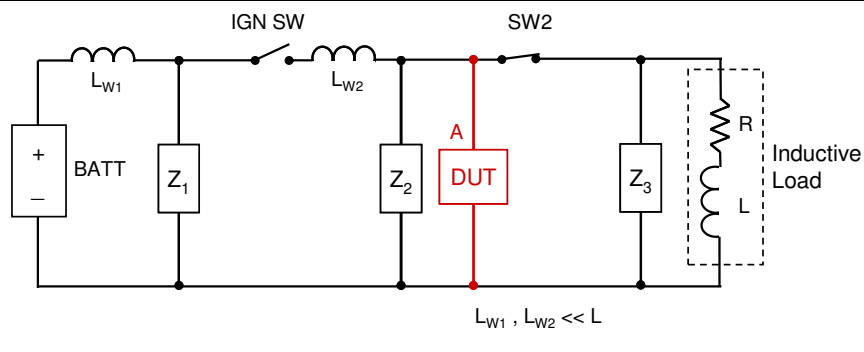
Application of Pulse F1 nor F2 are limited to power supply circuits for components required to demonstrate compliance to the ESA requirements delineated in 72/245/EEC.

<p>Configuration 1</p> <p>DUT power circuit "A" shares the same circuit as the inductive load (e.g. window lift motor). The DUT and inductive load are switched via SW2. Transient pulses A1, A2 and E will be present at "A" if IGN SW remains closed and SW2 opens. Pulses C and G (load dump) will be present at "A" when IGN SW and SW2 are closed.</p>	
	<p>Pulse Application</p> <p>Apply transient pulses A1, A2-1, A2-2, C1, C2, E, G1, G2 to DUT power connection "A".</p>

<p>Configuration 2</p> <p>DUT power circuit "A" remains powered when inductive load is deactivated by SW2. The DUT has an input circuit "B" that is connected to circuit containing inductive load. Transient pulses A1, A2 and E will be present at "B" when SW2 opens. Pulse C will be present at "A" if IGN SW remains closed and SW2 opens or bounces. Pulses C and G (load dump) will be present at "A" and "B" when IGN SW and SW2 are closed.</p>	
	<p>Pulse Application</p> <p>Apply transient pulse C-1, C-2, G1, G2 to DUT power connection "A".</p> <p>Apply transient pulses A1, A2-1, A2-2, E to DUT input "B".</p> <p>Apply transient pulse C-1, C-2, G1, G2 to "A" and "B" simultaneously</p>

Configuration 3

DUT power circuit "A" shares same circuit as inductive load when SW2 is closed. The DUT and inductive load are switched via ignition switch or ignition relay. Transient pulses A1, A2 and E will be present at "A" if SW2 remains closed and IGN SW opens. Transient pulse C will be present at "A" if IGN SW remains closed and SW2 opens or bounces. Pulse C and G (load dump) will be present at "A" when IGN SW is closed.

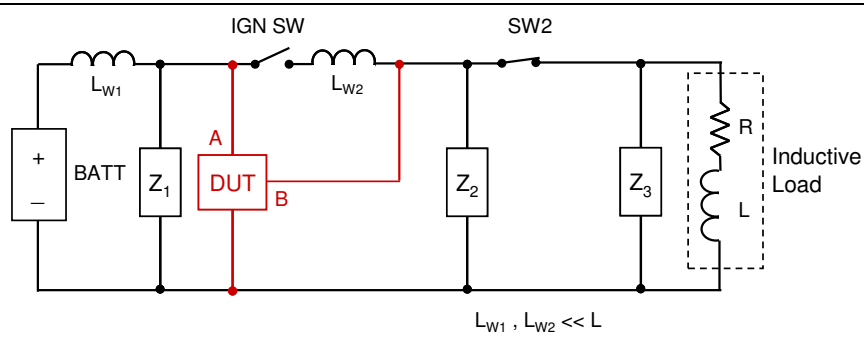


Pulse Application

Apply transient pulses **A1, A2-1, A2-2, C-1, C-2, E, G1, G2** to DUT power connection "A"

Configuration 4

DUT power circuit "A" is directly connected to battery. DUT also has an input or secondary power circuit "B" that is connected to ignition switched circuits. Transient pulse C will be present at "A" if SW2 is closed and IGN SW opens or bounces. Transient pulses A1, A2 and E will be present at "B" if SW2 is closed and IGN SW opens. Pulse C will be present at "B" if IGN SW is closed and SW2 opens or bounces. Pulse C and G (load dump) will be present at "A" and "B" when IGN SW is closed.



Pulse Application

Apply transient pulses **A1, A2-1, A2-2, C-1, C2** and **E** to "A" and "B" separately

Apply transient pulse **C-1, C-2, G1, G2** to "A" and "B" simultaneously.

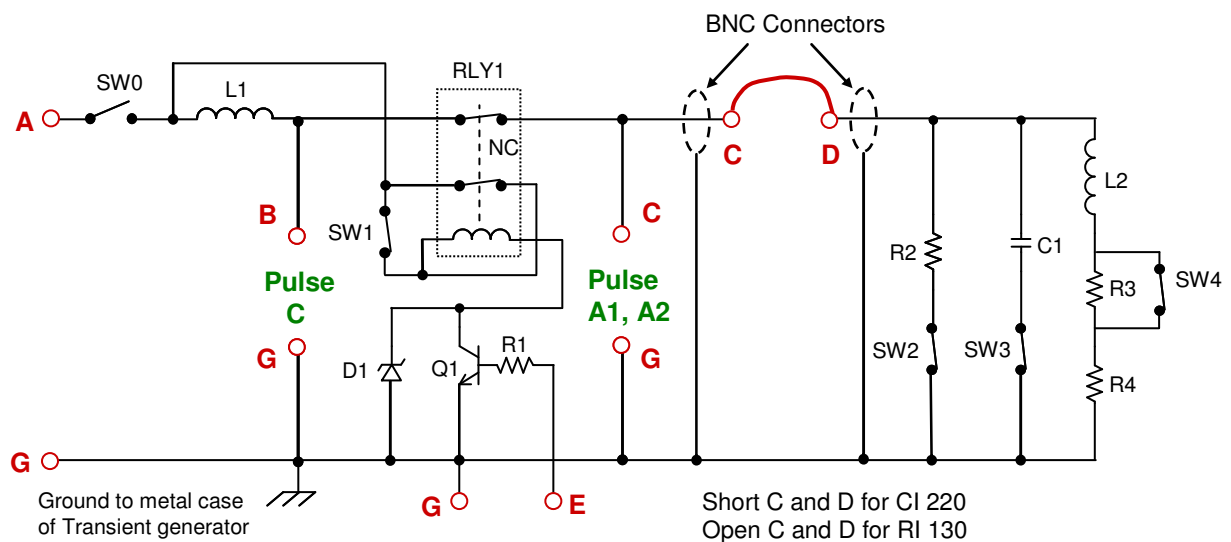
Annex F (Normative): Transient Test Generator

The test generator presented in this annex produces transients for the following test methods:

- RI 130
- CI 220 Pulses A1, A2, and C

Figure F-1 illustrates the transient generator circuit that will produce CI 220 transient pulses A1, A2, and C in Modes 1, 2 and 3. The circuit contains a few critical components that may not be substituted without permission from the FMC EMC department. These components are highlighted in the figures. Specific details about these test circuits including contact locations for critical components may be found at <http://fordemc.com>. Selection of test pulses and operating modes is facilitated by simple switch settings. Table F-1 summarizes these switch configurations and associated test pulse/operating mode.

Figure F-1: Transient Generator Circuit for RI 130 and CI 220



Key

R1: 51 ohms, 25W	L2: 100 mH inductor (Osborne Transformer Part Number 32416)*
R2: 220 ohms \pm 5% , 2W	D1: Zener Diode, 39 V, 5W (IN5366A)
R3: 33 ohms \pm 5% , 10W	Q1: NPN transistor (TIP 41)
R4: 6 ohms \pm 5% , 50W	SW0 – SW4: Single Throw Switch (10 contact rating)
C1: 100 nF ceramic capacitor, 400V	RLY1: 12 volt AC Relay** Use normally closed (NC) contacts (Potter & Brumfield KUP-14A15-12)*
L1: 5 uH inductor (Osborn Transformer Part Number 8745) *	

* Critical Component, no substitutions permitted without written authorization from the FMC EMC department.

** See Table F-1 for relay specifications

Figure F-2: Transient Generator (External Connections)

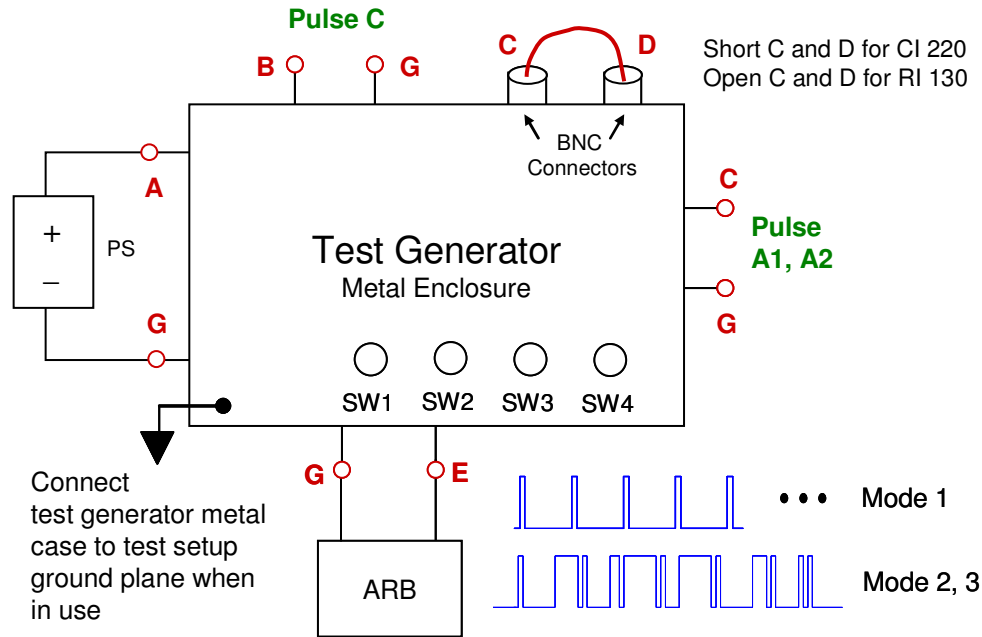


Table F-1: CI 220 Transient Generator Switch Settings

Pulse	Mode *	SW1	SW2	SW3	SW4
A1	1, 2	Closed	Closed	Closed	Closed
A2-1	1	Closed	Open	Open	Open
A2-1, C-1	2	Closed	Open	Open	Open
A2-2, C-2	2	Closed	Open	Closed	Open
A2-1, C-1	3	Open	Open	Open	Open
A2-2, C-2	3	Open	Open	Closed	Open

* See Annex D for description of Mode operating conditions

The transient generator uses a Potter and Brumfield (P&B) 12 VAC relay. Specifications for this relay are listed in Table F-2. While the relay is readily available in North America, it may be difficult to locate in other parts of the world.

However, almost any 12 AC relay can be used for this performing testing per this specification. Before using alternative relays, voltage measurements shall be performed and compared to those waveforms illustrated in this annex. The results of these measurements shall be reviewed and approved by the FMC EMC department prior to using an alternative relay.

When using these relays for the purposes delineated in this specification, it is recommended that the relay be replace after 100 hours of usage.



Table F-2: CI 220 Transient Generator (P&B Relay Specifications)

Contact Arrangement:	3 Form C, 3PDT, 3 C/O
Contact Current Rating (Amps.):	10
Coil Magnetic System:	Mono-stable
Coil Selection Criteria:	Nominal Voltage
Actuating System:	AC
Input Voltage (VAC):	12
Coil Suppression Diode:	Without
Coil Resistance (Ω):	18
Coil Power, Nominal (VA):	2.70
Mounting Options:	Plain Case
Termination Type:	.187 x .020 Quick Connect Terminals
Enclosure:	Enclosed
Contact Material:	Silver Cadmium Oxide
Approved Standards:	UL Recognized, CSA Certified

Annex G (Normative): Load Simulator Requirements

The Load Simulator is a shielded enclosure that contains all external electrical interfaces (sensors, loads etc.) normally connected to the DUT. The Load Simulator also serves as an RF boundary for the DUT cable harness in addition to serving as an interface to support and monitoring equipment required during testing.

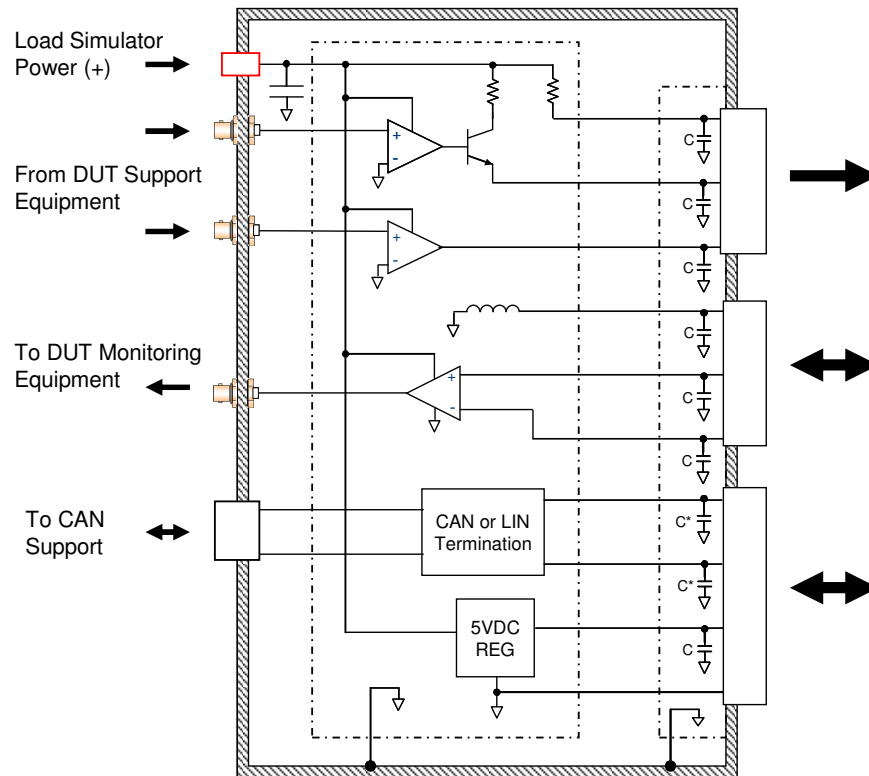
A typical Load Simulator is illustrated in Figure G-1. The circuits shown serve as examples of what can be contained within the Load Simulator. Actual circuit content is specific to the DUT's functionality. However, the following requirements shall be followed when designing the Load Simulator.

- **All interface circuits within the Load Simulator except CAN shall include a capacitance of 10 nF** located between each interface circuit and the Load Simulator chassis unless actual electrical loads are used. Omission of the 10 nF capacitor shall require approval from the FMC EMC department prior to commencement of testing. *The 10 nF capacitance value represents the interface capacitance for most modules.* **If the Load Simulator contains a CAN interface (includes MS or HS CAN), the capacitance shall be 470 pF.** The capacitors shall be package as close as possible to the Load Simulator/DUT harness interface connector. Figure G-1 illustrates location of these capacitors. It is recommended to use surface mount capacitors on a separate PCB mounted directly to the interface connectors. This minimizes lead inductance between the interface circuit and Load Simulator chassis. Filter pin connectors may be used, but only with prior approval of the FMC EMC department.
- If the DUT contains CAN communications, the circuits illustrated in Figure G-2 shall be located within the Load Simulator. Configuration A shall be used for devices that contain internal CAN bus termination. Configuration B shall be used for devices that contain no termination.
- Production intent components shall be used for the loads wherever possible. This is particularly critical for inductive and pulse width modulated (PWM) circuits. If actual loads are not available, simulated loads may be used, but shall accurately represent the impedance (resistance, capacitance and inductance) that is expected in a production vehicle. **Simple resistive loads shall not be used unless approved by the FMC EMC department**
- If the DUT is powered from another electronic module (e.g. sensors), the module's power supply shall be accurately simulated from within the Load Simulator. Other active devices may be contained within the Load Simulator, but appropriate steps shall be taken to prevent potential influences of RF energy on device operation.
- In general, all inputs and outputs shall be referenced to power ground established at one point within the Load Simulator and connected to the Load Simulator metal chassis. The only exception to this for CI 250, where it is required to introduce a voltage offset between the ground plane and the loads contained in the Load Simulator. See Section 18-2 for additional detail.

Figure G-3 illustrates the Load Simulator in a typical test setup.

- The Load Simulator chassis shall be electrically bonded to the test setup ground plane via direct connections (screws) and/or ground straps. Alternative bonding methods (e.g. copper tape with conductive adhesive) is not permitted.
- DUT inputs requiring external signal sources are facilitated via the Load Simulator. Although fiber optic media is recommended for these connections, coaxial cables may be used to connect remote support equipment to the Load Simulator. However, if coaxial connections are used, all cabling shall have ferrite beads installed on the cable at intervals not exceeding 150 mm. Use of ferrite beads other than the type delineated in Figure G-3 shall be reviewed and approved by the FMC EMC department as part of the laboratory recognition process (see <http://www.fordemc.com>).
- Fiber optic media shall be used to connect DUT outputs to remotely located monitoring equipment. The frequency bandwidth of the fiber optic media shall be selected to be compatible with the operating bandwidth of the monitored DUT signal, but limited to avoid unintentional RF energy from coupling to, and potentially affecting the test monitoring instrumentation. Use of non-optical interfaces to monitoring equipment is permitted only with prior approval by the FMC EMC department. Details concerning signal monitoring and support equipment interface shall be documented in the EMC test plan
- All fiber optic media shall require prior verification to be immune to the RF stress levels delineated in section 11 of this specification.
- Wires connecting the battery to the Artificial Networks and Load Simulator shall have ferrite beads installed on the cable at intervals exceeding 150 mm.

Figure G-1: Load Simulator (Typical Design)

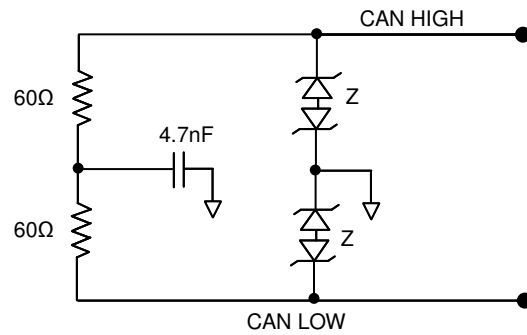


$C = 10 \text{ nF}$

Value is mandatory for all Load Simulator applications unless otherwise specified in product EMC specification. Deviation requires approval by FMC EMC department and noted in EMC test plan..

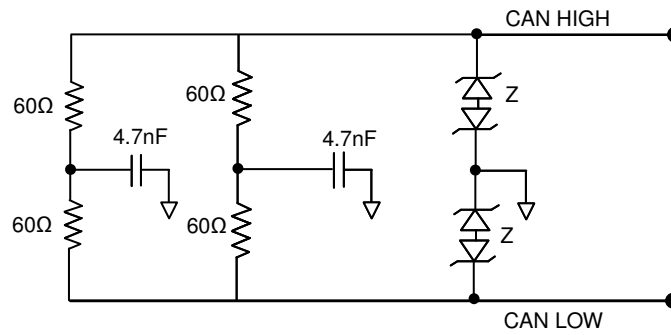
$C^* = 470 \text{ pf}$ (CAN and LIN Interfaces Only)

Figure G-2: Load Simulator CAN Interface Circuit Design Requirements



Configuration A

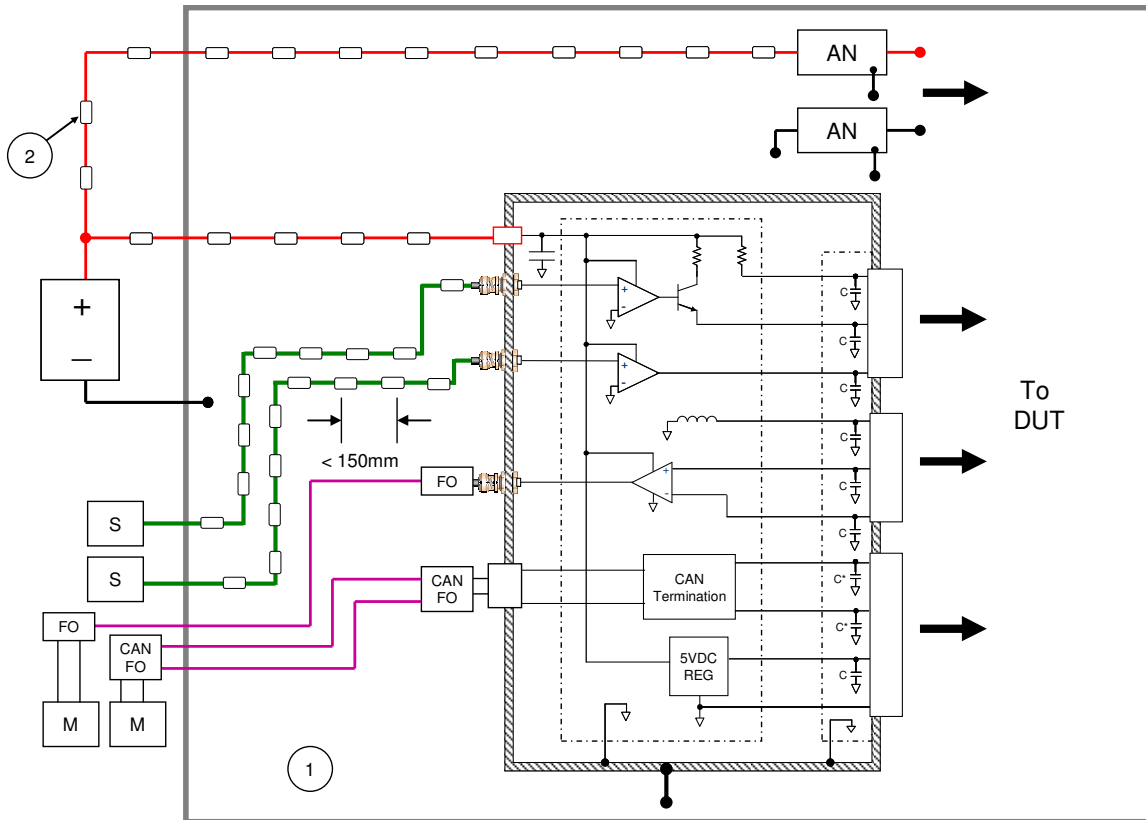
Devices with internal CAN Termination



Configuration B

Devices with no internal CAN Termination

Figure G-3: Load Simulator Test setup



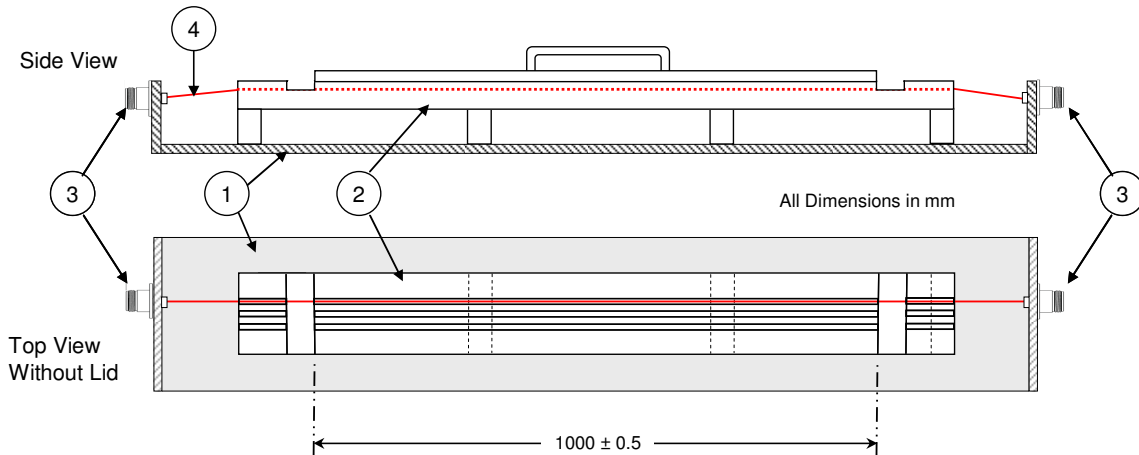
Key

- 1. Ground Plane
- 2. Ferrite Bead (*Fair-Rite Type 43 or equivalent*)
- ↓ Signal Ground Reference
- FO Fiber Optic Media
- M Monitor Equipment
- ⏏ Load Simulator Chassis connection to Signal Ground Reference
- ⏏ Ground Plane Electrical Connection
- S Support Equipment

Annex H (Normative): RI 130, RI 150 Test Fixture and Application

The test fixture used for RI 130 and RI 150 is illustrated in Figure H-1. The fixture consists of a wire support fixture mounted to an aluminum plate. The wire support fixture is constructed from Delrin® 570 NC000. Detailed construction plans for this fixture may be found at www.fordemc.com.

Figure H-1: RI 130/150 Test Fixture (Top View)

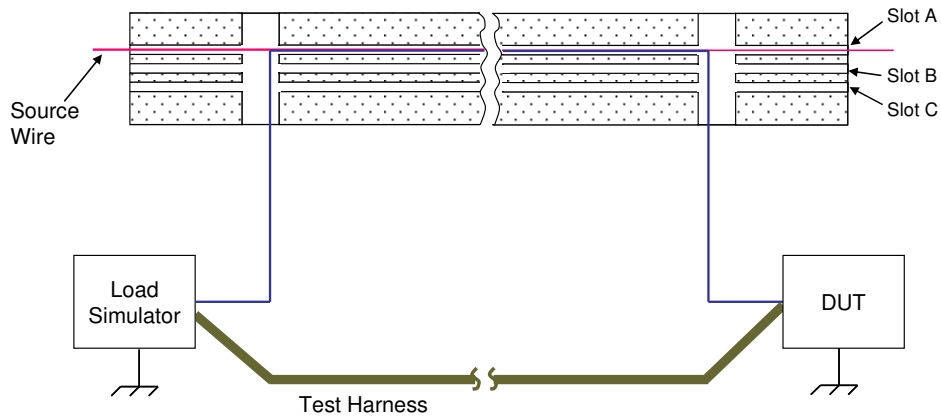


Key

Aluminum Plate	Wire Support (Delrin® 570 NC000)
Type N Connector	14 AWG Copper Wire

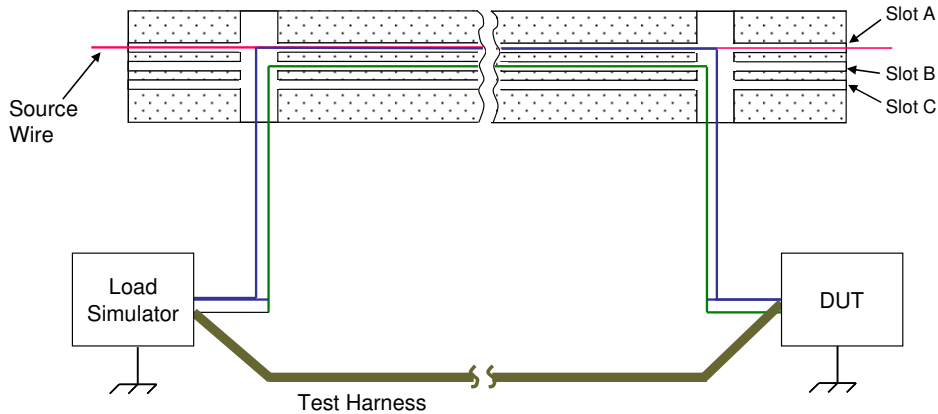
The fixture contains a single copper wire ("source wire") that is connected to the signal source that generates the disturbances for RI 130/RI 150. The DUT is tested by placing individual wires in the slot immediately above the source wire (Slot A). This is illustrated in Figure H-2 below.

Figure H-2: RI 130/150 Test setup (Default DUT Wire Location)



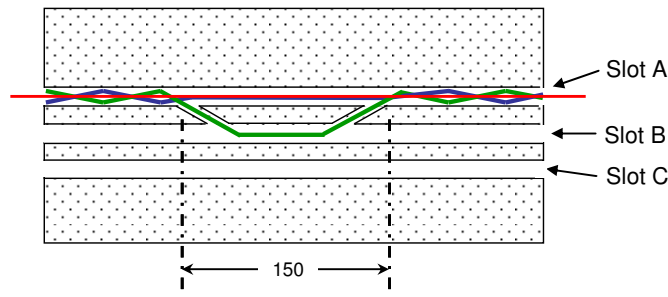
If the DUT contains circuit loads that have a dedicated signal return back to the DUT (a signal return not shared by any other circuit load), each wire of the circuit pair shall be placed in the separate slots (Slots A and B) located in the test fixture as illustrated in Figure H-3. *Dedicated signal returns shall always be located in Slot B unless specified in the EMC test plan.*

Figure H-3: RI 130/150 Test Setup (DUT with Dedicated Return Wire)



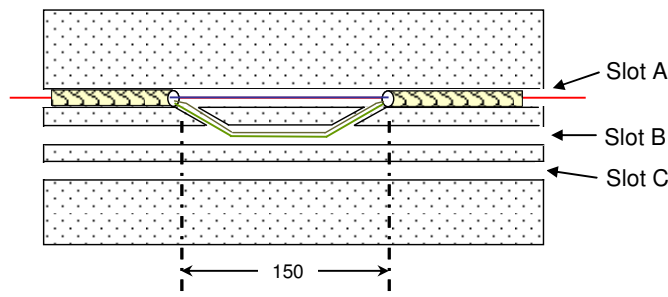
If the DUT contains twisted pair circuits, each twisted wire pair shall be placed in Slot A as illustrated in Figure H-4. However it is required that the wire pair is untwisted for 150 mm. This is facilitated via the section located in the center test fixture. *The inclusion of this untwisted and unshielded section simulates the device connector or use of an in-line connector.*

Figure H-4: RI 130/150 Test setup (Configuration for a Twisted Wire Pair)



If the DUT contains shielded circuits (excludes RF antenna cables), each shielded circuit pair shall be placed in Slot A as illustrated in Figure H-5. However it is required that the circuits are unshielded for 150 mm. This is facilitated via the section located in the center test fixture. The setup is similar to that used for a twisted wire pair.

Figure H-5: RI 130/150 Test setup (Configuration for Shielded Twisted Wire Pair)



Annex I (Normative): Method for Determining Correction Factor for CE 421

CE 421 requires voltage measurements similar to that required for CE 420, but at frequencies below that specified in CISPR 25. In order to make these measurements, a correction factor (CF) must be applied. Although this correction factor accounts for the insertion loss between the Artificial Network's DUT and measurement ports, it is not the same as insertion loss (e.g. S21) values typically published by the manufacturer of the Artificial Network.

Figure I-1 illustrates the test setup for CE 421 using a standard CISPR 25 Artificial Network. At 100 kHz, the impedance seen at the DUT connection of the Artificial Network is approximately 3 ohms. The resulting loss due to impedance mismatch at the DUT connection port is approximately 20 dB. This same loss is seen at the measurement port, which is the insertion loss (e.g. S21) published by the manufacturer of the Artificial Network.

At frequencies below 100 kHz, the impedance of the Artificial Network is proportionally lower (*impedance converges to the DC resistance of the 5 uH inductor*) and the resulting mismatch loss increases. However, the loss at the measurement port becomes greater than that seen at the DUT connection because of the increasing loss through the series capacitance at lower frequencies. The correction factor (CF) represents this loss at frequencies between 10 kHz to 150 kHz.

The correction factor may be determined using the following procedure:

Step 1 (see Figure I-2):

- a) Short the power supply connection port (A, B) using a 25 mm wide copper braided strap.
- b) Connect a 50 ohm termination resistor across Port (C, B)
- c) Connect Port (P, B) to the output of a 50 ohm signal generator and to the input of a 50 ohm measurement receiver. Coaxial cables shall be used for these connections. Cable lengths shall not exceed 1000 mm in length.
- d) Measure and record the signal level ($P_{OUT} (dBm)$) over the frequency range from 10 kHz to 150 kHz using frequency steps per Table 9-1.

Step 2 (see Figure I-3):

- a) Remove the 50 ohm termination from Port (C, B) and connect it to Port (P,B).
- b) Remove the measurement receiver from Port (P, B) and connect it to Port (C, B).
- c) Measure and record the signal level ($P_{IN} (dBm)$) over the frequency range from 10 kHz to 150 kHz at the same frequencies used to measure P_{OUT} in Step 1.

Step 3:

Calculate the correction factor (CF) at each test frequency (ref Table 9-1) using the measurement data from Steps 1 and 2 via the following expression:

$$CF(dB) = P_{OUT}(dBm) - P_{IN}(dBm)$$

Only the value of (CF) is applied when performing CE 421. The overall insertion loss of the Artificial Network as published by the manufacturer shall not be used when performing CE 421.

Figure I-1: CE 421 Test Setup using Standard CISPR 25 Artificial Network

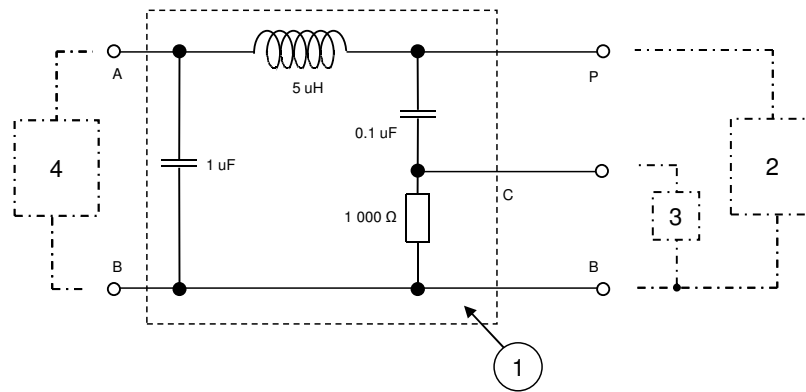


Figure I-2: CI 421 Setup for Measurement of P_{OUT}

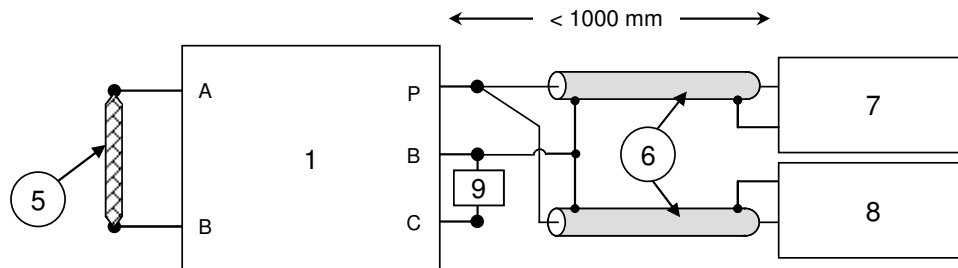
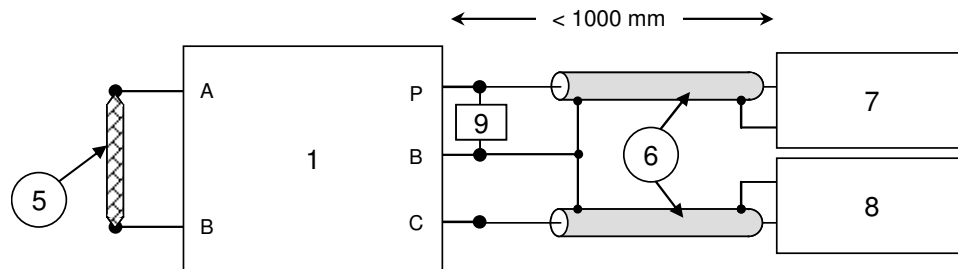


Figure I-3 CI 421 Setup for Measurement of P_{IN}



Key:

- | | |
|--|---|
| 1. Artificial Network (per CISPR 25) | 6. 50 ohm Coaxial Cable (RG 58 or equivalent) |
| 2. DUT | 7. 50 ohm Signal Generator |
| 3. Measurement Receiver | 8. 50 ohm Measurement Receiver |
| 4. Power Supply | 9. 50 ohm Termination |
| 5. Braided Ground Strap (> 25 mm wide) | |