SURFACE VEHICLE RECOMMENDED PRACTICE	J2962™-3	SEP2021
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Communication Transceivers Qualification Requirements - Ethernet

RATIONALE

Historically, original equipment manufacturers (OEMs) had their own communication transceiver (or ethernet PHY) qualification requirements that varied over time. The intent of this standard is to minimize test variation and to consolidate requirements among OEMs.

FOREWORD

The purpose of this recommended practice is to define a common test plan for approval of ICs that contain ethernet communication physical layer components (PHYs). This document will define test circuits, bus load requirements, test procedures, and pass/fail criteria to validate PHYs.

NOTE: Understanding of this document requires a working knowledge of ISO EMC publications.

TABLE OF CONTENTS

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1. SCOPE

This SAE Recommended Practice covers the requirements for ethernet physical layer (PHY) qualification. Requirements stated in this document provide a minimum standard level of performance for the PHY in the IC to which all compatible ethernet communications PHY shall be designed. When the communications chipset is an ethernet switch with an integrated automotive PHY (xBASE-T1), then the testing shall include performance for all switch PHY ports as well as each controller interface. No other features in the IC are tested or qualified as part of this SAE Recommended Practice. This assures robust serial data communication among all connected devices regardless of supplier.

The goal of SAE J2962-3 is to commonize approval processes of ethernet PHYs across OEMs.

The intended audience includes, but is not limited to, ethernet PHY suppliers, component release engineers, and vehicle system engineers.

2. REFERENCES

2.1 Applicable Documents

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

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

SAE J1113-12 Electrical Interference by Conduction and Coupling - Capacitive and Inductive Coupling via Lines Other than Supply Lines

2.1.2 ISO Publications

Copies of these documents are available online at http://webstore.ansi.org/.

ISO 7498 Data Processing Systems - Open Systems Interconnection Standard Reference Model

ISO 7637-1 Road Vehicles - Electrical Disturbances from Conduction and Coupling - Part 1: Definitions and General Considerations

ISO 7637-2 Road Vehicles - Electrical Disturbances from Conduction and Coupling - Part 2: Electrical Transient Conduction Along Supply Lines Only

ISO 7637-3 Road Vehicles - Electrical Disturbances from Conduction and Coupling - Part 3: Electrical Transient Transmission by Capacitive and Inductive Coupling via Lines Other than Supply Lines

ISO 10605 Road Vehicles - Test Methods for Electrical Disturbances from Electrostatic Discharge

ISO 11452-4 Road Vehicles - Component Test Methods for Electrical Disturbances from Narrowband Radiated Electromagnetic Energy - Part 4: Harness Excitation Methods

2.1.3 IEC Publications

Available from IEC Central Office, 3, rue de Varembe, P.O. Box 131, CH-1211 Geneva 20, Switzerland, Tel: +41 22 919 02 11, www.iec.ch.

IEC 61000-4-2	Testing and Measurement Techniques - Electrostatic Discharge Immunity Test
IEC 61000-4-21	Testing and Measurement Techniques - Reverberation Chamber Test Methods
IEC 62228-1	General Part and Conditions
IEC 62228-5	Integrated Circuits - EMC Evaluation of Transceivers - Part 5: Ethernet Transceivers

2.1.4 IEEE Publications

Available from IEEE Operations Center, 445 and 501 Hoes Lane, Piscataway, NJ 08854-4141, Tel: 732-981-0060, www.ieee.org.

IEEE Std 802.3 Clause 96	Physical Coding Sublayer (PCS), Physical Medium Attachment (PMA) Sublayer and Baseband Medium, Type 100BASE-T1
IEEE Std 802.3 Clause 97	Physical Coding Sublayer (PCS), Physical Medium Attachment (PMA) Sublayer, and Baseband Medium, Type 1000BASE-T1
IEEE Std 802.3 Clause 98	Auto-Negotiation for Single Differential-Pair Media

2.1.5 Other Publications

CISPR 25	Limits and Methods of Measurement of Radio Disturbance Characteristics for the Protection of Receivers Used On-Board Vehicles
OPEN Alliance Specification	IEEE 100BASE-T1 System Implementation Specification
OPEN Alliance Specification	TC10 Wake-up and Sleep Specification for Automotive Ethernet

3. DEFINITIONS

The definitions provided in SAE J1213-1 apply to this document. Additional or modified definitions, acronyms, and abbreviations included in this document or relevant to the communication of information in a vehicle are catalogued in this section.

3.1.1 DATA LINK LAYER

Provides the reliable transfer of information across the physical layer. This includes message qualification and error control.

3.1.2 ELECTRONIC CONTROL UNIT (ECU)

An on- or off-vehicle electronic assembly from which automotive ethernet messages may be sent and/or received.

3.1.3 MAY

The word “may” is used to indicate an option.

3.1.4 PROTOCOL

Formal set of conventions or rules for the exchange of information between ECUs. This includes the specification of frame administration, frame transfer, and physical layer.

3.1.5 RADIATED EMISSIONS

Radiated emissions consists of energy that emanate from the communications bus wires. Electric field strength in dBμV/m is the typical measure of radiated emissions.

3.1.6 RADIATED IMMUNITY

A property that ensures that the communications bus wires should not suffer degraded functional operation within its intended electromagnetic environment.

3.1.7 SHALL

The word "shall" is to be used in the following ways:

a. To state a binding requirement on the communications interfaces which comprise the ECU, which is verifiable by external manipulation and/or observation of an input or output.

b. To state a binding requirement upon an ECU that is verifiable through a review of the document.

3.1.8 SHOULD

The word "should" is used to denote a preference or desired conformance.

3.1.9 WAKE-UP PULSES (WUP)

When a PHY supports OPEN Alliance TC10 wake up, this pattern of signals on the communications link brings the PHY out of sleep low-power state to wake state.

4. ACRONYMS

AM	Amplitude Modulation
BCI	Bulk Current Injection
CBCI	Common Mode BCI
CW	Continuous Wave
DBCI	Differential Mode BCI
DUT	Device Under Test
EMC	ElectroMagnetic Compatibility
ESD	Electrostatic Discharge
Gbps	Gigabits per Second
ISO	International Standardization Organization
Kbps	Kilobits per second
LED	Light Emitting Diode
Mbps	Megabits per Second
MCU	Microprocessor Control Unit
MII	Media Independent Interface

PAMn	Pulse Amplitude Modulation (Level n)
PK	Peak
QP	Quasi-Peak
RE	Radiated Emissions
RMII	Reduced Media Independent Interface
RGMII	Reduced Gigabit Media Independent Interface
SGMII	Serial Gigabit Media Independent Interface
Vbatt	Power Supply for the ECUs Present in a Communication Network (12 V Nominal)
WUP	Wake-Up Pulses

5. REQUIRED TEST CIRCUIT

5.1 Primary and Monitor DUT

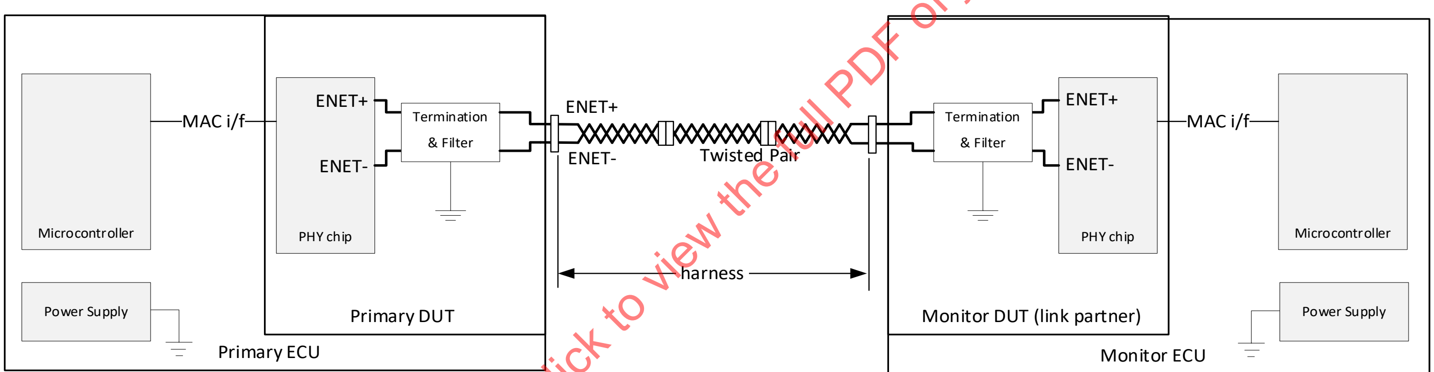


Figure 1 - Example of typical testing setup

5.1.1 Microcontroller Based DUT Behavior

5.1.1.1 The monitor DUT is the link partner to the primary DUT (see Figure 1).

5.1.1.2 Monitor DUT initiates traffic and indefinitely reattempts communication.

5.1.1.3 The primary DUT responds to traffic initiated from the monitor DUT.

5.1.1.4 Data transmission shall be a minimum of 90% of the available bandwidth in both directions.

5.1.1.5 The primary DUT configuration settings and registers shall be the same throughout all testing phases (i.e., there are no special settings for a particular test). Certain test modes (such as low-power mode) that might allow different settings shall be documented in the test procedure.

5.1.1.6 The monitor DUT configuration settings and registers shall be the same throughout all testing phases (i.e., there are no special settings for a particular test).

5.1.1.7 For devices with multiple MAC interfaces, radiated immunity (near field), radiated immunity (uniform field), and radiated emissions need to be tested for each interface separately.

5.1.1.8 For multiport devices, all ports need to be tested with each MAC configuration in radiated immunity (near field), radiated immunity (uniform field), and radiated emissions. All active ports need to be enabled.

5.1.1.9 At least two samples of the primary DUT shall be tested. The preference is that three samples should be tested through the whole suite of tests.

- Any failures in the primary DUT samples shall be considered a failure for compliance according to SAE J2962-3 (this SAE Recommended Practice).

- If the monitor DUT is identical design and configuration to the primary DUT, it shall be considered the second sample for all tests except ESD, BCI, and nearby RF.

5.1.1.10 The primary DUT shall provide a means to determine link status. The method shall be one of the following:

- The link indication status LED that can be observed via closed circuit camera or oscilloscope during testing. The link indication shall remain on while the link partners are actively linked in communications. The link status shall be off when the link-up has been lost.

- The primary DUT board shall provide a means to read the PHY link status via an interface that could be observed outside the test chamber. One example is to provide an interface that could be used to send status registers over fiber optic cable to outside the test chamber.

5.1.1.11 The primary DUT shall provide a means to determine fault status. The method shall be one of the following:

- The fault indication status LED that can be observed via closed circuit camera or oscilloscope during testing. The fault indication shall remain on while the fault is present. The fault indication shall be off when no faults are present.

- The primary DUT board shall provide a means to read the PHY fault status via an interface that could be observed outside the test chamber. One example is to provide an interface that could be used to send status registers over fiber optic cable to outside the test chamber.

5.1.1.12 The primary DUT settings for PSD shall be set to the same level throughout all tests. The specific setting shall be measured and documented in the test report.

5.1.1.13 Electromagnetic shielding shall be documented for the primary and monitor DUTs.

- The preferred shielding would be plastic or no enclosure.

- If metal shielding is used, then the details about grounding of the enclosure shall be documented.

5.1.2 Primary and Monitor DUT Application Circuit

The MDI interface circuit for the primary and monitor DUTs should be similar. The diagram in Figure 2 is for illustrative reference. The PHY vendor shall recommend the optimal circuit design that performs best with the chipset. This includes impedance balance, tolerance stack-up, and other design characteristics. The optimal design shall be documented in the test report.

The interface circuit (including ESD) components shall be selected to comply with IEEE MDI return loss requirements.

See Appendix A for informative guidelines regarding board layout.

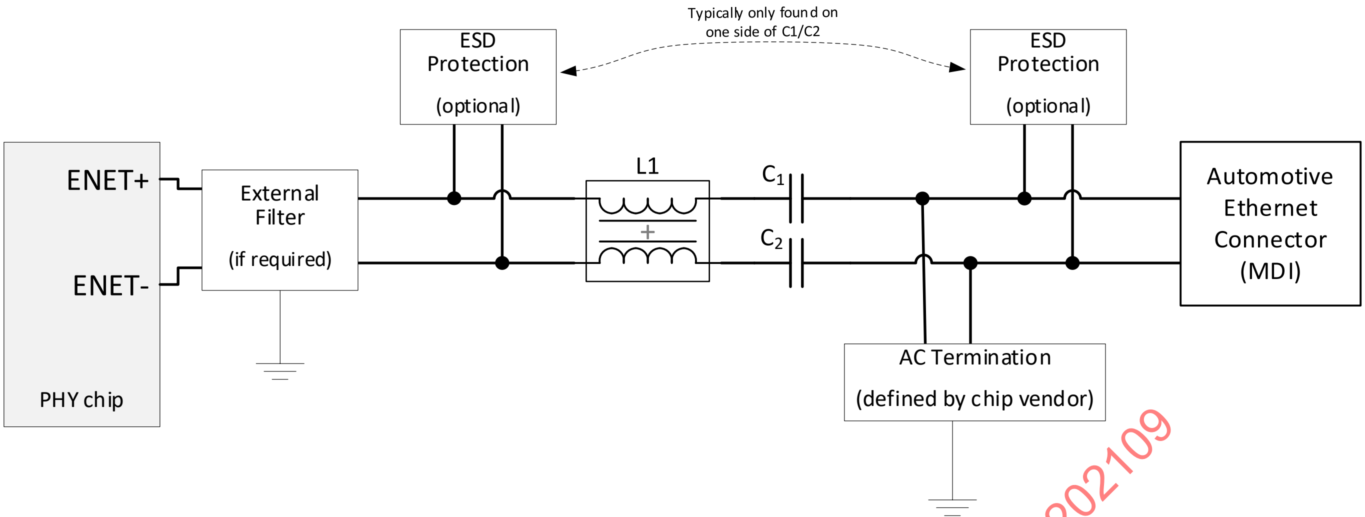


Figure 2 - Primary DUT or monitor DUT example circuit (informative)

Table 1 - Typical PHY interface component values

Ref	Typical Value	Tolerance	Voltage Rating	Comments
L1 (100 Mbps)	~200 µH	See OPEN alliance for requirement	≥50 V	Automotive CMC
C1, C2 (100 Mbps)	100 nF	±10%	≥100 V	
L1 (1 Gbps)	~80 µH to ~100 µH	See OPEN alliance for requirement	≥50 V	Optional with shielded twisted pair as recommended by chipset vendor
C1, C2 (1 Gbps)	10 nF, 100 nF	±10%	≥100 V	As determined by the PHY vendor

5.2 Primary and Monitor DUT ESD Protection Options

PHY vendor shall propose one or more ESD protection options (including no external components).

The PHY vendor shall clearly document each ESD protection option so that developers may use the reference design in their product development. The documentation shall include schematics, component selection, and board layout guidance.

5.3 Network Harness Requirements

The test circuit consists of a cable that conforms to cable properties listed in Clause 96.7 (100 Mbps) and/or Clause 97.6 (1 Gbps) of the latest published of IEEE 802.3.

The test cable shall be 1.7 to 2.0 m in overall length and include two in-line connectors equally spaced in the cable sample (see Figure 3 for example). These in-line interconnects represent a typical vehicle wiring harness, and also shall be required for the inductive coupled immunity testing (Section 10). Each cable segment which makes up the cable harness shall have a length within 10% of the length of the other two segments.

The cable harness with the two in-lines shall be used for all the tests. A second harness may be used in inductive coupled immunity testing (Section 10), which allows the removal of the connector plastic shell. All test harnesses shall be assembled according to the requirements listed above.

For devices with multiple communications interfaces, each interface shall have wiring with in-line connectors to the link partner. All communication lines shall be actively communicating during testing.

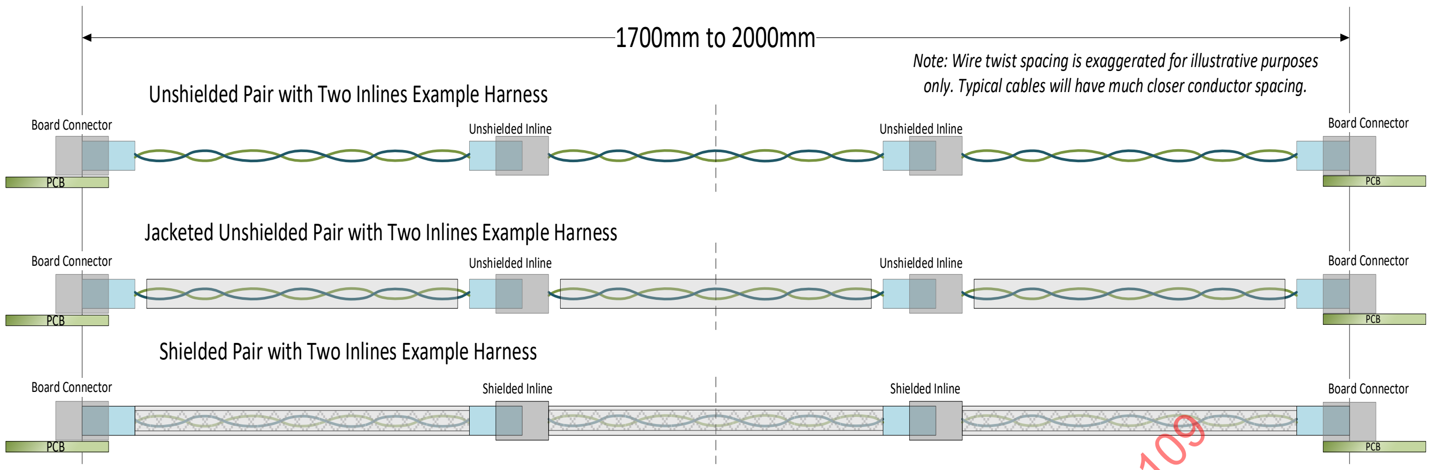


Figure 3 - Cable harness examples

The cable properties, connector designations, and configuration details shall be included in the final test report. A supplier shall confirm that the DUT passes with at least one of the cable systems described in this section. More cable types may be tested and documented at the supplier discretion. A supplier might include results for shielded and unshielded cables or various different connector/cable brands. Each cable type tested shall be fully documented in the test report.

5.3.1 100 Mbps (IEEE 802.3 - Clause 96.7) Link Segment Properties

- Unshielded without jacket (UTP): Preferred cable type.
- Jacketed and unshielded (JUTP): If only tested with jacket, then jacket will be required for using this PHY in future applications.

5.3.2 1 Gbps (IEEE 802.3 - Clause 97.6) Link Segment Properties

- Jacketed and unshielded (JUTP): Preferred cable type.
- Shielded twisted pair (STP): If only tested with shield, then shield will be required for this PHY to be used in future applications.

5.4 Pass Fail Acceptance Criteria

For communications channels, it is expected that the traffic flow is not adversely affected by external EMC noise sources. To evaluate the acceptance of a device, five categories of failure are defined as shown below:

a. Never acceptable for PHY:

   1. PHY damage

   2. User intervention (power cycle)

b. Acceptable passing criteria for PHY:

   1. Link self recovery (link status loss with minimal loss of packets after recovery)

   2. Packet loss (some percentage of transmitted packets lost)

   3. No loss of packets (use BER from IEEE)

With respect to active mode communications, there is little difference between items b.1 and b.2 above. When the link is active and the PHYs are “linked” together as shown by a status indicator of the PHY chipset, then the amount of interference that disrupts individual packets is very near to disabling the link status completely. Therefore, for the purpose of this document, link loss should be considered the same as packet loss.

The following defines the acceptance methodology used in this document.

5.4.1 Waveform Comparison Pass/Fail Criteria

The following are the pass/fail acceptance criteria for potentially destructive testing for handling ESD (6.2), active ESD (6.3), active DCC (Section 7), and bulk current injection (Section 9). The following requirements shall be met after the test has completed. Since the tests could potentially affect the circuitry of the DUTs, a comparison of output waveforms is done to ensure no damage has occurred to the MDI circuit.

The DUT shall generate a pattern of repeated transitions for pre- and post-test comparison. Before and after test scope plots shall be provided with test results. Set the scope as per Table 2. The plots shall contain at least one “+1” to “-1” edge and one “-1” to “+1” edge.

- All after-test plots shall be compared with the pre-test plot taken before the test.
- The overlay of the pre-test and after-test plots shall not deviate by more than ±10% of the measured peak-to-peak voltage of the pre-test plot as shown in Figure 5.
- Each DUT shall have a unique set of plots for comparison (i.e., post-test plots for DUT#2 shall not be compared with the pre-test plots for DUT#1).

Test point is shown as in Figure 4. The primary DUT shall be the generic PHY as shown in 5.1.2; the monitor DUT shall be a 100 Ω passive differential termination. (Each line is 50 Ω passive termination to ground.) The test point is measured at the termination. All DUTs to be evaluated shall have waveform plots measured before and after testing. Intermediate plots are optional and would help the testing authority to determine if certain tests led to degradation of the circuitry.

Table 2 - Test mode reporting settings

PHY	100BASE-T1	1000BASE-T1
Test Mode Pattern	Mode 2	Mode 2
Scope horizontal setting	10 ns/div	5 ns/div
Scope vertical setting (1)(2)	0.2 V/div	0.2 V/div

(1) The full peak to peak waveform shall be shown on the plot even if the vertical setting must be adjusted.
(2) When adjusting vertical setting, all plots in the report shall be shown at the same scaling for vertical and horizontal settings for comparison.

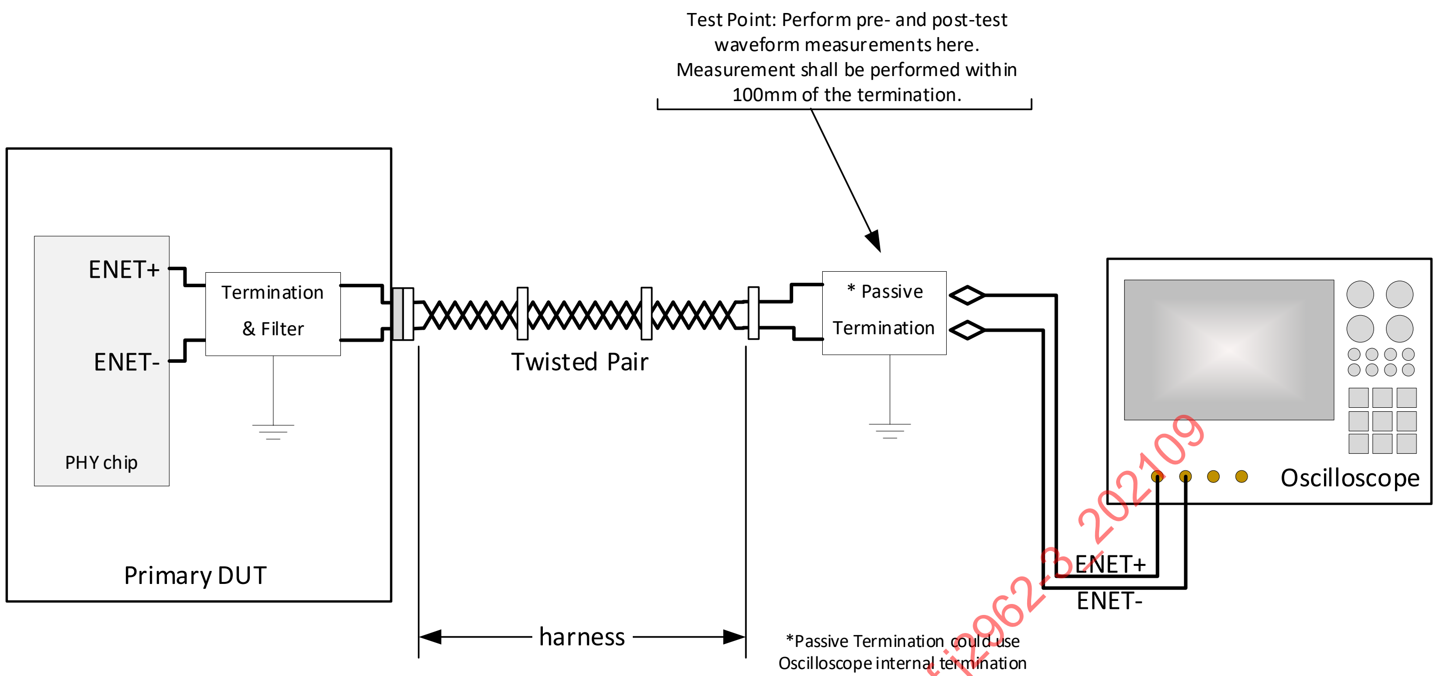
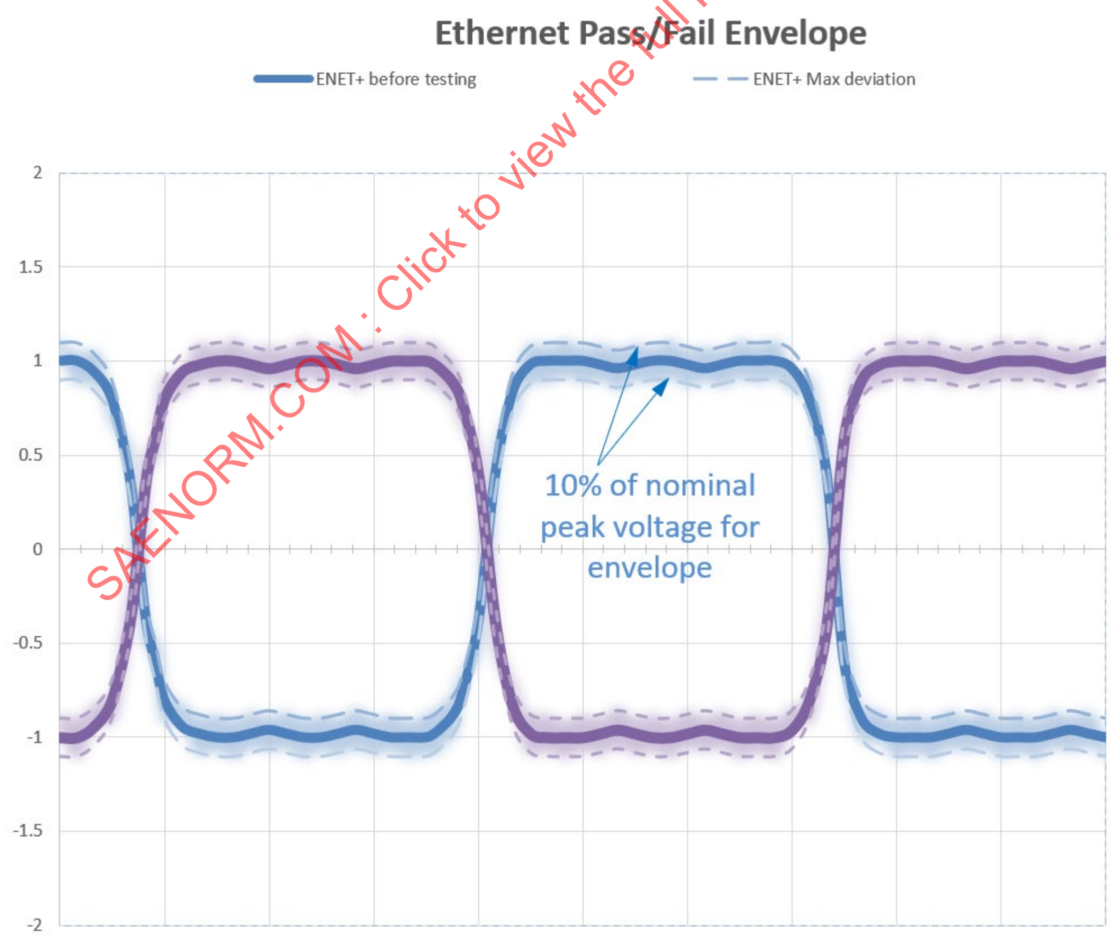


Figure 4 - ESD circuit configuration for waveform measurement



Note: Voltage and time scale may differ based on actual measurements

Figure 5 - Waveform plot example - pass fail criteria for before/after plots

5.4.1.1 Waveform Performance Testing Procedure

Place chipset in test mode as listed in Table 1 and measure the waveform at the connector pins of the monitor DUT in order to get a stable/repeatable signal. While in the test mode, the waveform plot might only show two levels (not multiple PAM levels).

5.4.1.2 Acceptance Criteria

5.4.1.2.1 Prior to any potential destructive testing of the DUTs, each DUT shall be measured according to the setup shown in Figure 4 to determine a baseline pre-test measurement.

5.4.1.2.2 The pre-test peak voltage measurements shall be used to set the ±10% region. For example, if the peak voltage measured in pre-testing is 1.1V (peak), then the post-test measurements shall not deviate more than 0.11 V from the original waveform sample in order to be judged as passing.

5.4.1.2.3 Referring to the diagram in Figure 5, the post-test sample waveform shall not deviate more than 10% of nominal peak signal voltage after testing has been performed.

5.4.1.2.4 Intermediate plots should be taken throughout the testing procedures, but only the final plot for each DUT shall be required in the documentation report along with the initial pre-test plot.

5.4.2 Communications Disruption Pass/Fail Criteria

The primary and monitor DUTs shall be placed in the testing chamber according to the test setups described in bulk current injection (Section 9), conducted immunity (Section 10), RF disturbance (Section 11), and nearby RF (Section 12). The DUTs shall be setup to communicate as according to 5.1.1.2 and 5.1.1.3. The DUTs shall be evaluated during testing to ensure that communications are not disrupted beyond the criteria described in 5.4.3 and 5.4.4

5.4.2.1 Normal Operation Mode Test Sequence

During normal mode operation, the DUT(s) are expected to operate without failures (as defined in 5.4.3) when exposed to an external interference field as described in the steps shown in Figure 6.

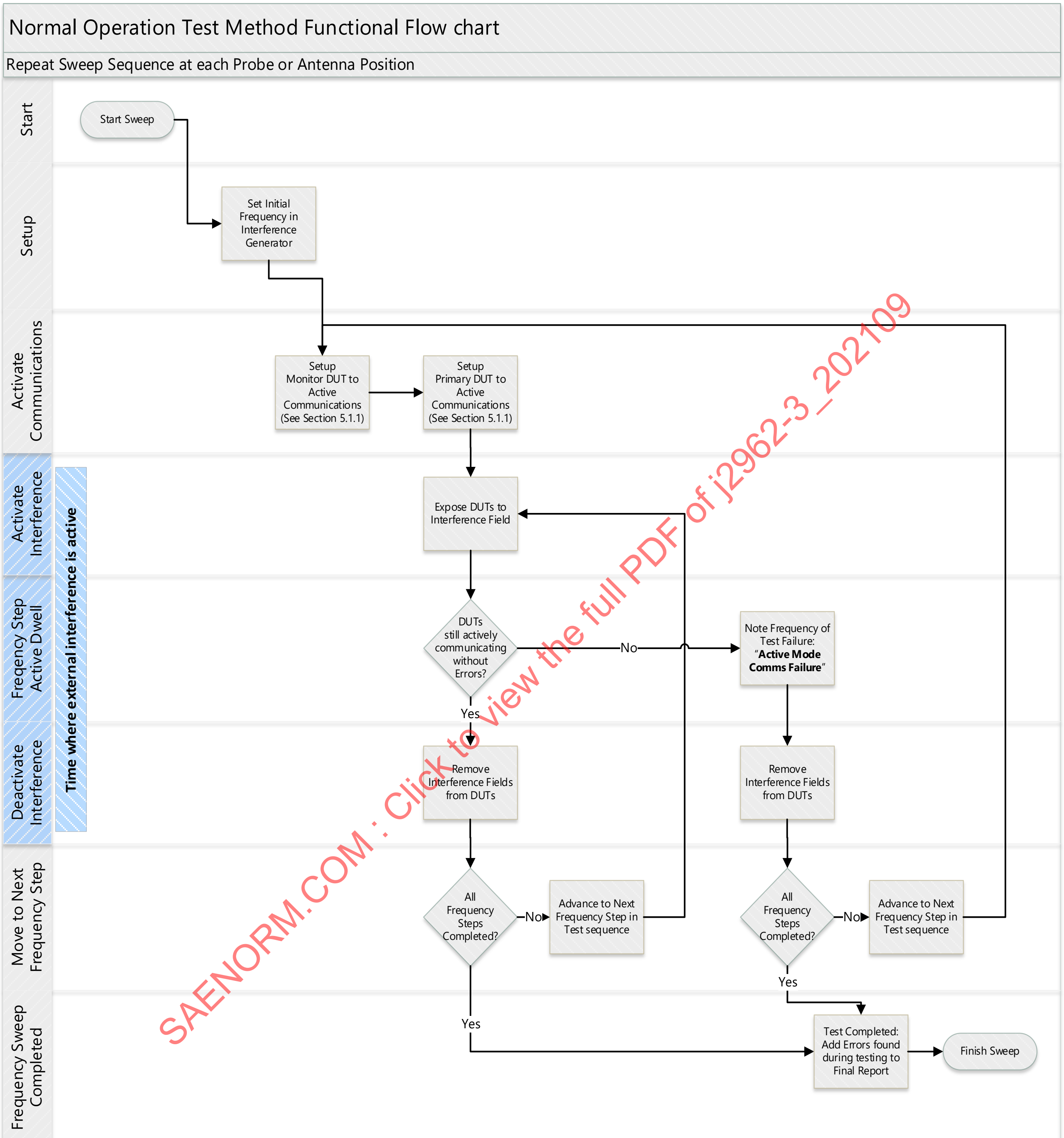


Figure 6 - Normal operation test method functional flow chart

5.4.3 Active Mode Pass/Fail Criteria

The acceptance criteria for non-destructive testing radiated emissions (Section 8), bulk current injection (Section 9), conducted immunity (Section 10), RF disturbance (Section 11), nearby RF disturbance (Section 12) is as follows:

5.4.3.1 Acceptance Criteria

In order to have passing test results, all the following conditions shall be met:

5.4.3.1.1 During testing, no unexpected reset of the primary or monitor DUT PHY shall be allowed.

5.4.3.1.2 No loss of link during testing. A link status LED indicator or an optical communications link outside of chamber shall be required for confirmation.

5.4.4 Sleep Modes Sequences

5.4.4.1 Wake Sleep Overview (Normative)

For devices that support wake/sleep, the immunity testing shall also include test cases for the low-power/sleep mode to ensure that the communications channel does not wake up inadvertently when sleeping, and also confirms that device does not enter sleep without being commanded.

Wake/sleep conformance shall be confirmed in testing for bulk current injection (Section 9), RF disturbance (Section 11), and nearby RF disturbance (Section 12).

It shall possible to determine unambiguously the “active” or “sleep mode” states throughout the testing. Determining wake/sleep status may be accomplished in many ways, including, but not limited to:

- Observable change in current draw by the primary DUT.
- LED connected to INH output.
- Channel activity LEDs that indicate communications is occurring.
- Response message(s) received from primary DUT to monitor DUT could be monitored during test via optical link from equipment outside chamber.
- Message traffic counters (registers) could be monitored during test where a state change could be noted.
- TC10 register readings that indicate each port state(s) could be read via optical link from outside equipment.

5.4.4.1.1 Relevant Terms

a. Unwanted sleep: During active mode testing, the exposure to external fields shall not cause the DUT to enter the low power sleep mode. Typically, this should be caught during normal active mode testing. There is no need for a specific test here.

b. Unwanted wake up: The DUT should be placed into sleep mode, and then the EMC interference pattern shall be injected through the full sweep similar to active mode testing. The DUT should not wake at any time throughout the sweep in order to pass this testing.

c. Wanted wake up: At each frequency step in the sweep, the command to sleep is issued and confirmed prior to an external field being applied. Then the external field is activated and while in the presence of the field, the DUT shall be commanded by another link partner to wake (using a wake up pulse—WUP) which should exit low power mode. In order to pass and move to next frequency step, the DUT shall wake. This testing could be very time consuming at all frequency steps due to setting the initial conditions for each step. Requirements should include timing allowed for successful wake up (i.e., it shall wake up in the presence of interference within the dwell time window, but not necessarily according to the strict timing in TC10).

d. Wanted sleep: The DUT is placed in active mode at the beginning of each frequency step. Then the external field is activated and while in the presence of the field, a link partner should send a command to sleep while the external field is present. Failure would be that device does not enter low power mode as commanded. Requirements should include timing allowed for successful sleep (i.e., shall sleep in in the presence of interference within the dwell time window, but not necessarily according to the strict timing in TC10).

5.4.4.2 DUT Configuration for Wake/Sleep

- The DUT and the PHY in the DUT shall be capable of being configured to wake on wake-up pulses (WUP) as defined in OPEN Alliance TC10.

- The DUT PHY shall be capable of being placed into sleep mode with wake ups enabled.

- A method to determine the active mode or sleep (low power) state of the PHYs shall be easily determined during each testing phase.

- For switch devices with multiple ports, the test should only cover the case where all ports are in the same wake/sleep mode together. It should not be necessary to test individual port wake sleep status.

- Individual ports shall not be evaluated for wake/sleep, but the entire switch (all ports) shall be expected to either remain in wake or sleep together. It shall not be required to test all the ports individually.

5.4.4.3 Separate Wake/Sleep Test Method Procedures (Normative)

5.4.4.3.1 Unwanted Sleep Test Sequence

The following test only applies to devices that support TC10 wake/sleep features. The purpose of this test is to ensure that the DUT does not enter sleep mode until requested by a TC10 sleep command. The normal mode test sequence should catch this error state, so no specific test sequence needs to be defined for this.

5.4.4.3.2 Unwanted Wake-Up Test Sequence

The following test only applies to devices that support TC10 wake/sleep features. The purpose of this test is to ensure that the DUT does not wake up in the presence of external interference while following the steps outlined in Figure 7.

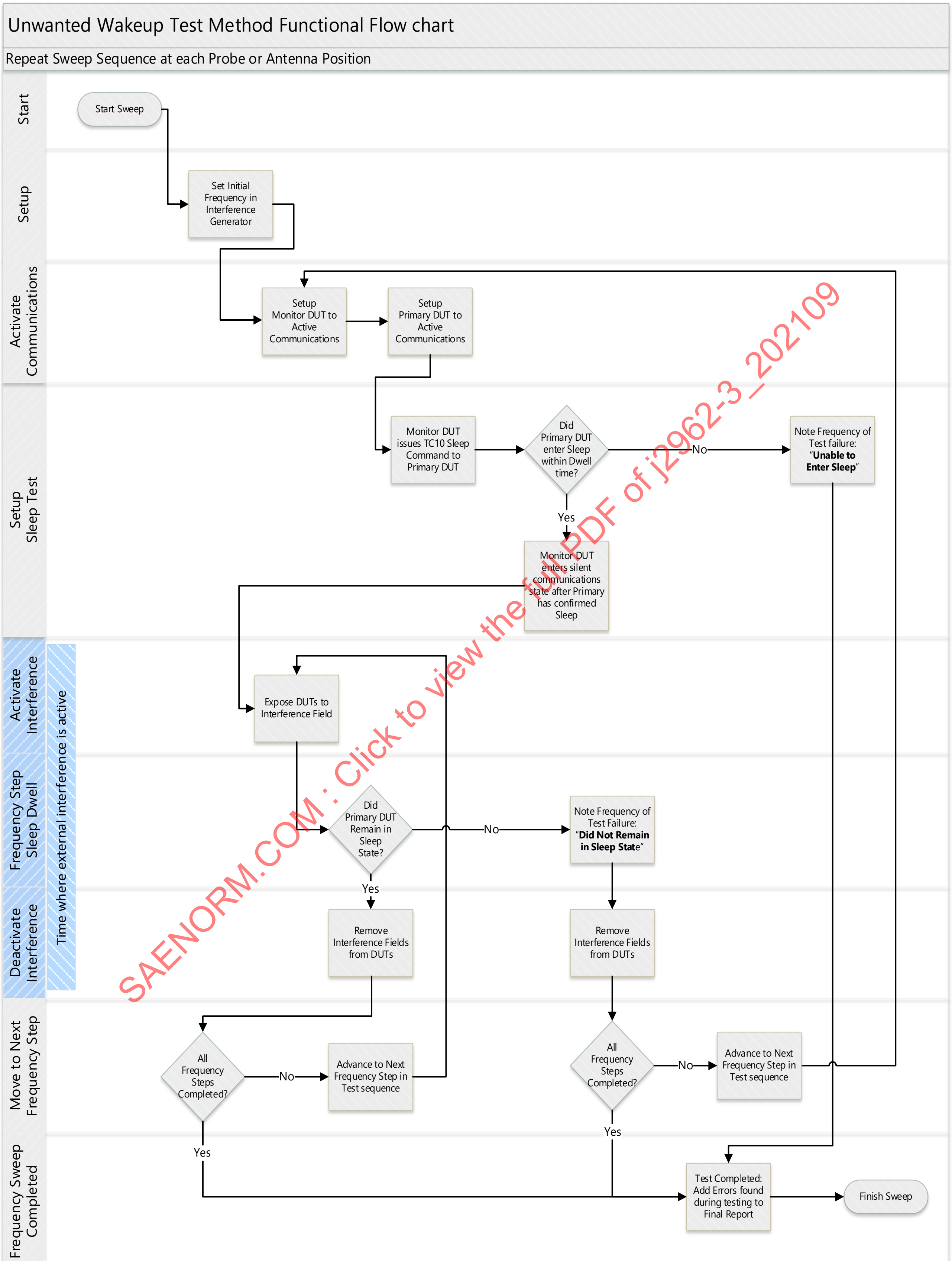


Figure 7 - Unwanted wake-up test method functional flow chart

5.4.4.3.3 Wanted Wake-Up Test Sequence

The following test only applies to devices that support TC10 wake/sleep features. The purpose of this test is to ensure that the primary DUT wakes in the presence of external interference while following the steps outlined in Figure 8.

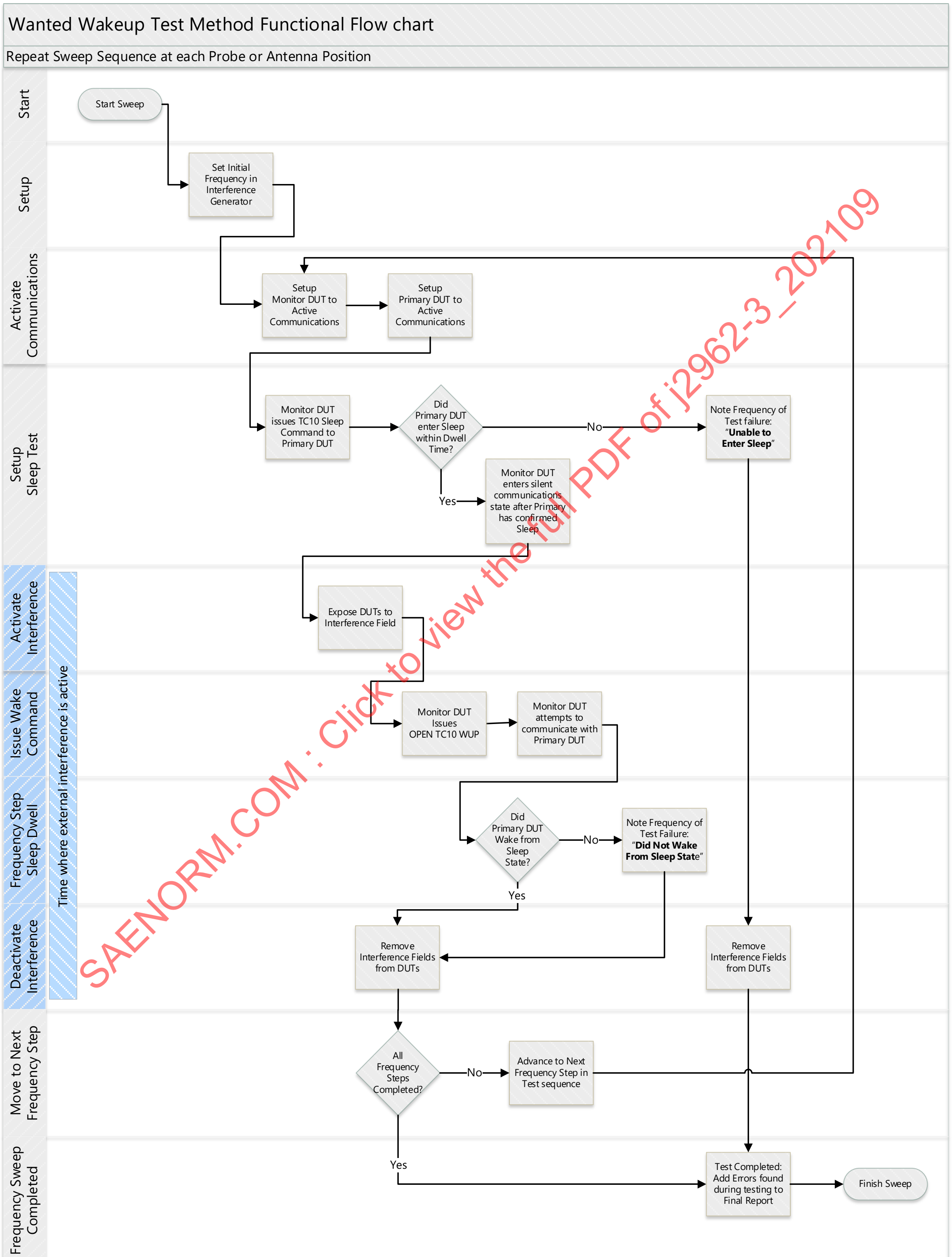


Figure 8 - Wanted wake-up test method functional flow chart

5.4.4.3.4 Wanted Sleep Test Sequence

The following test only applies to devices that support TC10 wake/sleep features. The purpose of this test is to ensure that the primary DUT enters the sleep state up in the presence of external interference while following the steps outlined in Figure 9.

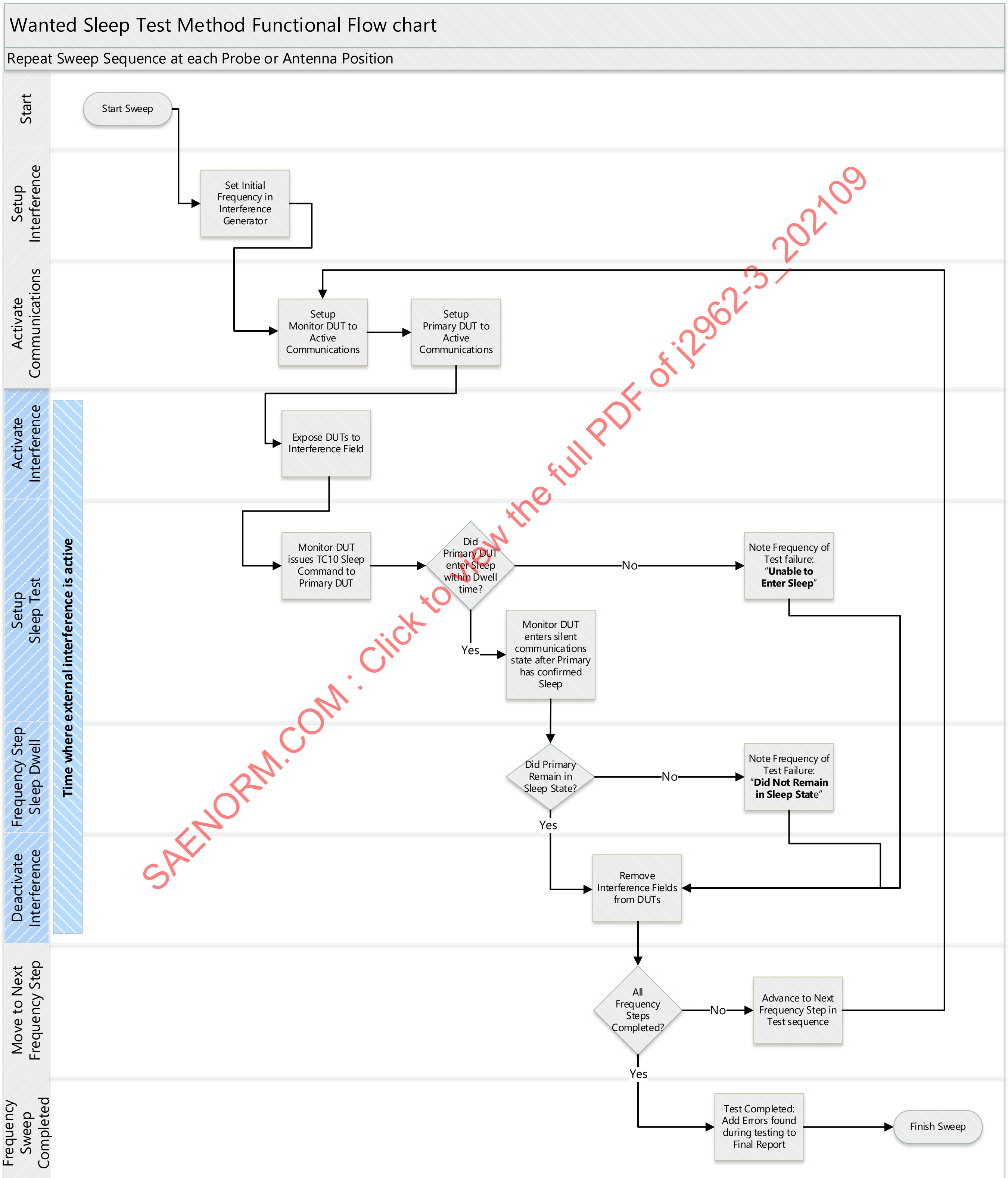


Figure 9 - Wanted sleep test method functional flow chart

5.4.4.4 Optional Combined Wake/Sleep Test Method Procedure (Normative if Used)

5.4.4.4.1 Optional Combined Normal/Wake/Sleep Test Sequence

This test method is optional and can be used instead of the individual unwanted wake, wanted wake, and wanted sleep tests described in the charts above. Performing this sequence might shorten the overall testing time.

The following test only applies to devices that support TC10 wake/sleep features. The purpose of this test is to ensure that the primary DUT correctly handles the main wake and sleep modes in the presence of external interference while following the steps outlined in Figure 10.

This test method would only be used if the PHY vendor can coordinate with the testing facility to ensure the DUT firmware is able to step through the testing sequence while the testing facility equipment is stepping through the frequency interference steps.

Dwell times at each frequency step shall be long enough to allow each of the state changes to be tested simultaneously. In this suggested method, the dwell time is proposed to be about 4 seconds.

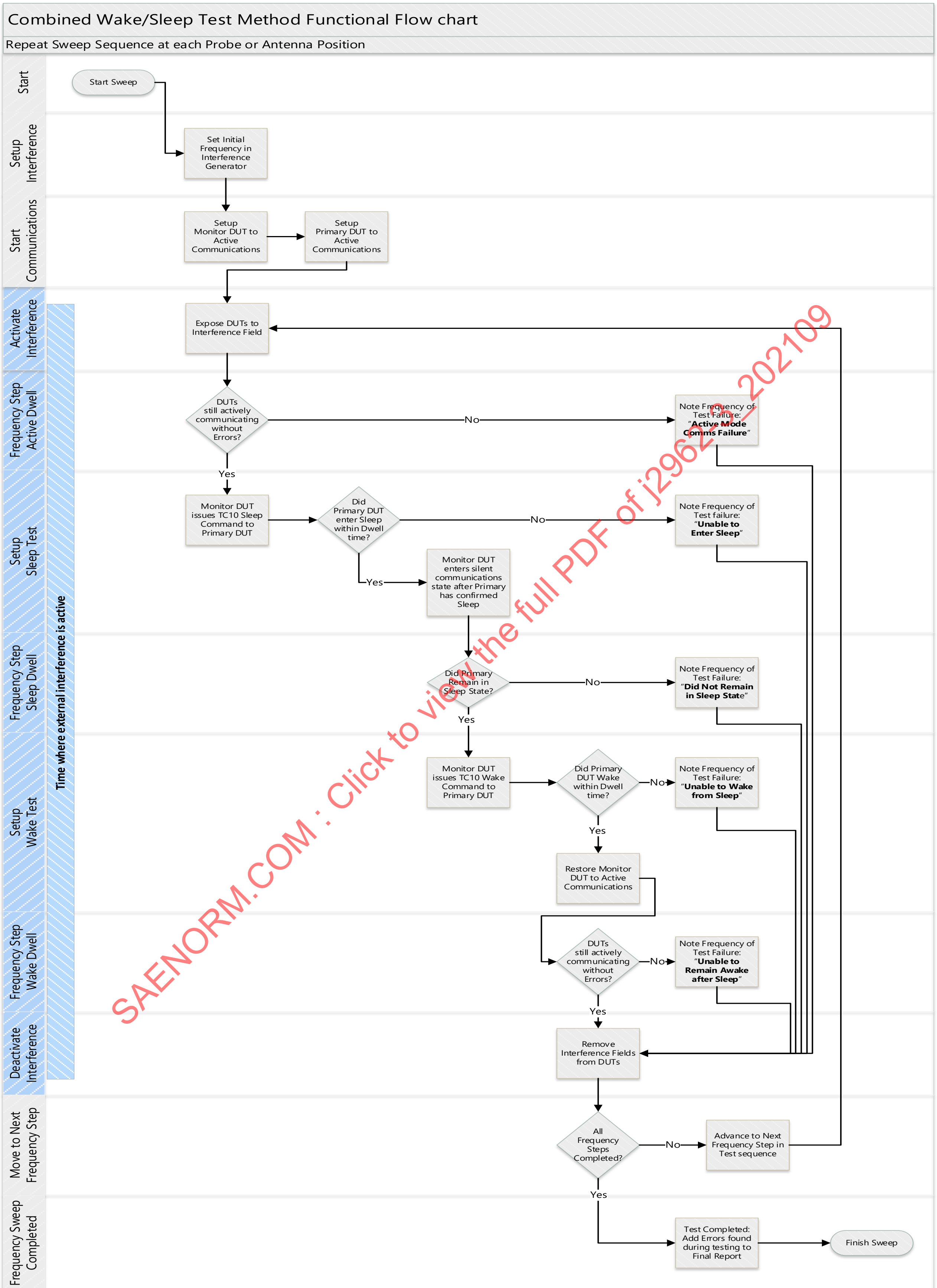


Figure 10 - Combined wake/sleep test method functional flow chart

5.4.5 Sleep Modes Pass/Fail Criteria

5.4.5.1 Wake/Sleep Acceptance Criteria

Conformance shall be confirmed by monitoring the active/wake/sleep status of the primary DUT PHY .

5.4.5.1.1 Each frequency step shall dwell for a minimum of 1 second to maximum of 2 seconds in time.

5.4.5.1.2 During unwanted wake-up testing, the primary DUT shall not wake when exposed to the entire sweep of frequencies as described in bulk current injection (Section 9), inductive coupled immunity (Section 10), RF disturbance (Section 11), and nearby RF disturbance (Section 12).

5.4.5.1.3 For unwanted sleep testing, the normal active mode testing as performed in 5.4.3 should be adequate for proof that the primary DUT did not enter sleep when it has not been requested.

5.4.5.1.4 During wanted wake-up testing, the primary DUT shall wake in the presence of fields described in Sections 9, 10, 11, and 12 during the field step dwell time. Failure to transition to the wake state during the field interference dwell time shall be regarded as a test fail

5.4.5.1.5 During wanted sleep testing, the primary DUT shall enter sleep when requested in the presence of fields described in Sections 9, 10, 11, and 12 during each field step dwell time. Failure to transition to the sleep state during the field interference dwell time shall be regarded as a test fail.

5.5 Preferred Order for Testing Execution

ESD tests—both unpowered and powered (6.2 and 6.3)—and direct capacitor coupling (Section 7) shall be performed prior to any other testing. All remaining tests for radiated emissions, BCI, conducted immunity, near field radiated immunity, and radiated immunity (8, 9, 10, 11, and 12) may be performed in any order.

Following completion of all testing per the EMC test plan, measurements shall be performed to verify that the DUT I/O parametric values (e.g., resistance, capacitance, leakage current, eye diagram, etc.) remain within their specified tolerances. (as described in 5.1.2).

All DUT test samples shall each pass all EMC tests using the same default configuration settings; it is not allowed to change settings for any test except to read the waveform results in 5.4.1.

6. ESD TESTING

6.1 ESD Handling Overview

There are two types of ESD immunity testing that the DUTs shall endure in the automotive environment. The first is ESD as a result of handling at the supplier, manufacturing plant, or service dealership. In this first case, the device is not powered. The second type of ESD is due to exposure of the DUT to discharges present in the vehicle. This second case could occur when the vehicle is being serviced, or even when the customer is attaching other electronics to the vehicle systems (e.g., plugging a brought in phone, or attaching a trailer for towing).

6.1.1 ESD testing shall be performed before the rest of the tests.

6.1.2 The same hardware configuration shall be used for all tests.

6.1.3 Two PHYs shall pass all tests with the same external components for ESD protection with the primary DUT configuration.

6.2 Handling ESD (Unpowered)

6.2.1 Requirements

The component shall be immune to ESD events that occur during normal handling and assembly. These requirements are listed in Table 3.

Table 3 - ESD handling requirements

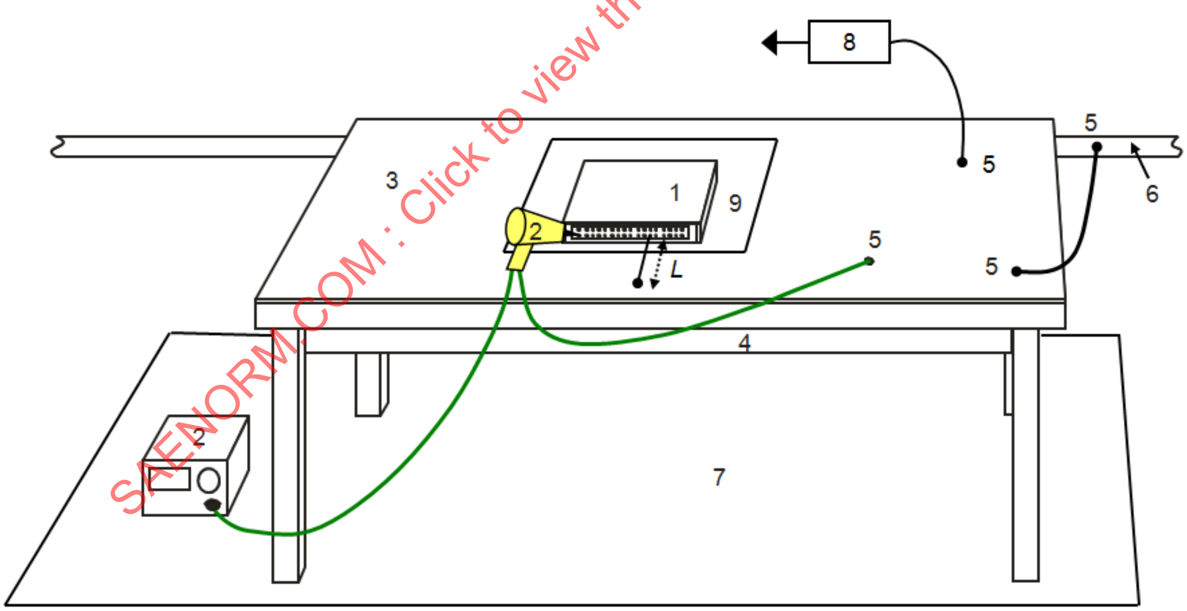
Discharge Sequence	Type of Discharge	Test Voltage Level	Minimum Number of Discharges at Each Polarity	Plots Required
0	None	Pre-test	N/A	Pre-test required
1	Contact discharge C = 150 pF, R = 2 kΩ	+4 kV	3	After test optional
2		-4 kV	3	After test required

6.2.2 Handling ESD Test Setup

Testing shall be performed in accordance with ISO 10605, except where noted in this specification. The test facility shall be maintained at an ambient temperature of 23 °C ± 5 °C and a relative humidity from 0 to 40%.

The standard test setup for handling tests is described and illustrated in Figure 11. The primary DUT shall be placed directly on a dissipative mat and unpowered. The setup for powered test is shown in 6.3.2.

For sequences #1 and #2 from Table 3, apply discharges to the primary DUT connector pins (as described in ISO 10605), where all primary DUT power return terminals shall be connected to the ground plane via a grounding strap or wire with a maximum length of 200 mm.



Key:			
1	Primary DUT	6	Test facility ground connection
2	ESD simulator	7	Floor test facility
3	Ground plane	8	~ 1 MΩ bleed-off resistor
4	Wooden table	9	Dissipative mat
5	Ground plane connection	L	Ground wire length ≤200 mm

Figure 11 - ESD handling test setup

6.2.3 Handling ESD Test Procedure

6.2.3.1 Perform injection individually at each of the communications pins on the DUT by touching the probe to the discharge point.

6.2.3.2 Between individual discharges, the remaining charge shall be bled off using the bleed-off resistor (approximately 1 MΩ resistance) by touching the discharge point and the ground plane.

6.2.3.3 Repeat each of the discharges until all communications lines have been exposed to a pulse for a number of times as described in Table 3.

6.2.4 Handling ESD Pass/Fail Criteria

Waveform measurement shall pass acceptance criteria according to 5.4.1.

6.3 ESD Powered

6.3.1 ESD Requirements

The component shall be immune to ESD events that occur during normal vehicle operation. These requirements are listed in Table 4.

Table 4 - ESD powered requirements

Discharge Sequence	Type of Discharge	Test Voltage Level	Minimum Number of Discharges at Each Polarity	Plots Required
0	Pre-test measurement			Pre-test required
1	Air discharge	+4 kV	3	After test optional
2	C = 330 pF, R = 2 kΩ	-4 kV	3	After test optional
3	Contact discharge	+4 kV	3	After test optional
4	C = 330 pF, R = 2 kΩ	-4 kV	3	After test optional
5	Air discharge	+6 kV	3	After test optional
6	C = 330 pF, R = 2 kΩ	-6 kV	3	After test optional
7	Contact discharge	+6 kV	3	After test optional
8	C = 330 pF, R = 2 kΩ	-6 kV	3	After test optional
9	Air discharge	+8 kV	3	After test optional
10	C = 330 pF, R = 2 kΩ	-8 kV	3	After test optional
11	Contact discharge	+8 kV	3	After test optional
12	C = 330 pF, R = 2 kΩ	-8 kV	3	After test optional
13	Air discharge	+15 kV	3	After test optional
14	C = 330 pF, R = 2 kΩ	-15 kV	3	After test required

NOTE: Bus functionality is expected to be disrupted during ESD pulse injection. This is acceptable; the DUTs shall self-recover and no damage nor degradation shall be observed in the pass/fail criteria after testing.

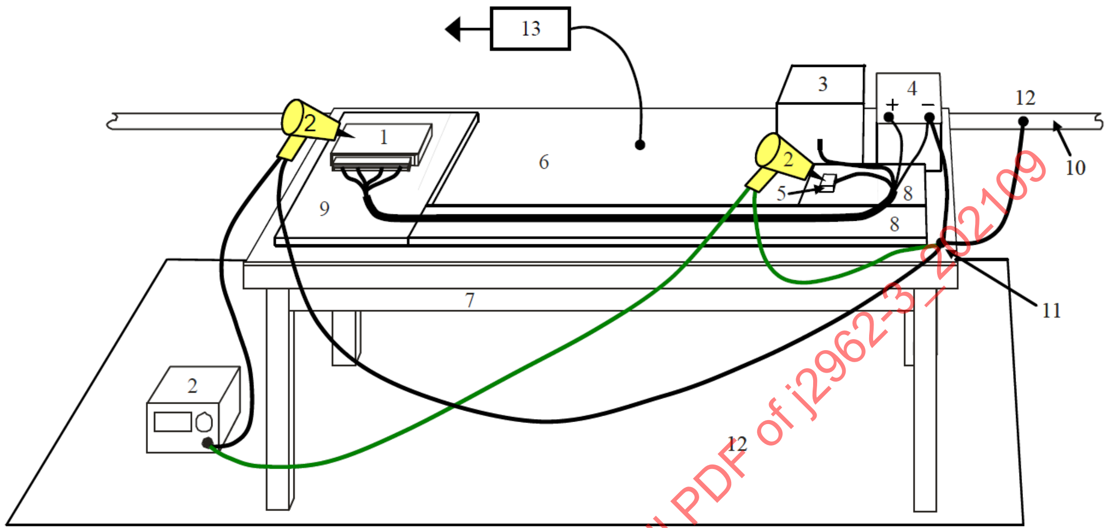
6.3.2 ESD Powered Test Setup

Testing shall be performed in accordance with ISO 10605, except where noted in this specification. The test facility shall be maintained at an ambient temperature of 23 °C ± 5 °C and a relative humidity from 0 to 40%.

Figure 12 illustrates the standard setup used when the primary DUT is powered and functioning. The primary DUT and any electronic hardware in the monitor DUT shall be powered from an automotive battery 12.5 to 13.5 V. The battery negative terminal shall be connected to the ground plane bench. The battery may be located on, or under, the test bench.

The primary DUT and its attached test harness shall be placed on a clean dielectric support that is 50 mm thick. The insulator lies directly on the ground plane. The test harness connecting the primary DUT and the Monitor DUT shall be 1700 mm (+300 mm/-0 mm) in length (as defined in 5.3). The monitor DUT shall be placed on the ground plane and electrically connected to the ground plane during the test.

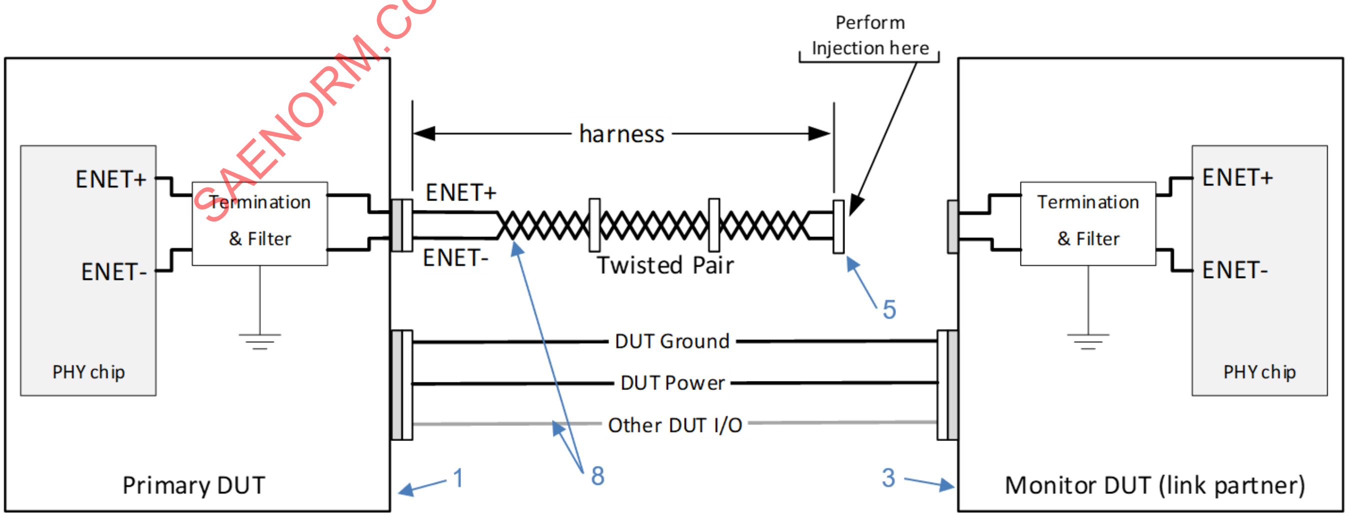
Wiring for communication bus circuits shall be configured such that the wiring is routed and connected directly to the primary DUT.



Key:

1	Primary DUT	8	Harness on the insulator support
2	ESD simulator	9	DUT insulator support
3	Monitor DUT (disconnected)	10	Test facility ground
4	Automotive battery	11	Ground plane reference termination
5	Discharge point	12	Ground plane connection (refer to ISO 10605)
6	Ground plane	13	~1 MΩ bleed-off resistor
7	Wooden bench		

Figure 12 - Powered ESD test setup



- Monitor DUT is connected between Discharges to confirm communication link-up.
- Communications lines are disconnected during Discharge Injection.
- Power/Ground and other DUT I/O are always connected unless connectors are shared.

Figure 13 - Powered ESD test diagram

6.3.3 ESD Test Procedure

6.3.3.1 While performing the discharges, the monitor DUT communications harness is disconnected, and the pulse is injected on the communications pins at the monitor DUT end (see Figure 13, arrow #5) of the communications harness. The primary DUT should be powered, and attempting to establish a communications link even though the monitor DUT is not connected.

6.3.3.2 Between individual discharges, the remaining charge shall be bled off using the bleed-off resistor (approximately 1 MΩ resistance) by touching the discharge point and the ground plane.

6.3.3.3 Between each voltage discharge level, the monitor DUT communications harness shall be reconnected to ensure that the communications between DUTs is still functioning. Communications could be confirmed by verification of the link status indicator.

6.3.3.4 If the DUT does not have an enclosure, perform injection to the ground plane of the primary DUT at four corners of the PCB being cautious to not inject the pulse to anything but the ground plane access point. The harness shall be connected to the monitor DUT with active communications while injecting to the PCB ground points.

6.3.3.5 If the DUT has an enclosure, perform injection to four corners of the case enclosure. The harness shall be connected to the monitor DUT with active communications while injecting to the case enclosure.

6.3.3.6 Primary DUT (and monitor DUT) shall be continuously powered and functional throughout the complete test sequence and pass/fail verification.

6.3.4 Powered ESD Pass/Fail Criteria

- Bus functionality is expected to be disrupted during the ESD discharges; this is acceptable.
- For tests 6.3.3.1 through 6.3.3.3, communication shall recover without power cycling or resetting the primary DUT once the ESD discharges are completed.
- For tests 6.3.3.4 or 6.3.3.5, the microcontrollers on the DUTs can be reset to restore the same operating mode before the test pulses were applied to the primary DUT enclosure/ground plane. The vendor should demonstrate and document that the failure to resume operation is not due to the PHY or communications network.
- Waveform measurement shall pass acceptance criteria according to 5.4.1.

7. DIRECT CAPACITOR COUPLING

The purpose of this test is to ensure that the primary DUT shall not be damaged as a result of excessive transients that may occur as a result of unique inductive wiring harness crosstalk. This test applies to applications using unshielded cables only as defined by 5.4.

7.1 DCC Requirements

The component shall not be damaged when exposed to direct capacitor coupling (DCC) per ISO 7637-3 for the slow transient pulse with an amplitude of ±30 V (e.g., Us = ±30 V). Coupling capacitors shall be 100 nF.

The primary DUT shall withstand ten pulses with a minimum of 2 seconds between pulses (e.g., t_1 = 2 seconds) on both PHY+ and PHY- simultaneously.

NOTE: Bus functionality is expected to be disrupted when using a 100 nF coupling capacitor during injection. This is acceptable.

7.2 DCC Test Setup

The DCC test shall be performed before radiated emissions and BCI tests.

Two PHYs shall pass all tests with the same external components for ESD protection with the primary DUT configuration.

The test setup shall comply with the ISO 7637-3 definition of slow transient pulse.

The total harness length shall be as defined in 5.4. The primary DUT and the test harness shall be placed on an insulated support 50 mm above the ground plane. The primary DUT shall be isolated from ground. The monitor DUT shall be placed on the ground plane and electrically connected to the ground plane during the test.

This DCC test applies to unshielded cables only. An adaptor may be used between the primary DUT and the cable harness that provides a DCC injection point with the coupling network. This adaptor will avoid the need to make modifications to the test harness used in other testing.

The primary DUT and any electronic hardware in the monitor DUT shall be powered from an automotive battery 12.5 to 13.5 V. The battery negative terminal shall be connected to the ground plane bench. The battery may be located on, or under, the test bench. The two DUTs shall be communicating with each other as described in 5.1.1.1 through 5.1.1.4.

7.3 DCC Test Procedure

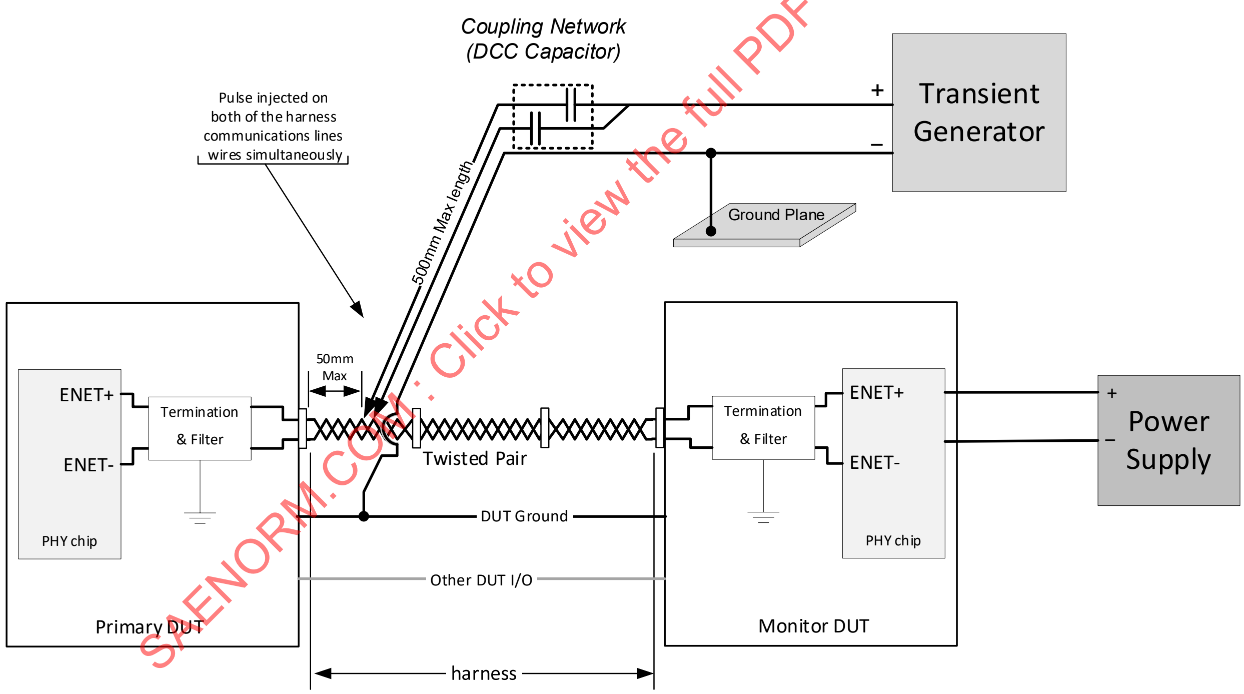


Figure 14 - DCC injection detail

The test equipment shall comply with the ISO 7637-3 definition of slow transient pulse.

Primary DUT and monitor DUT shall be continuously powered and functional throughout the complete test sequence and pass/fail verification. Bus functionality is expected to be disrupted when using a 100 nF coupling capacitor; this disruption is acceptable during pulse injection. Communication shall recover without power cycling or resetting the DUTs once the DCC probes are removed.

7.4 DCC Pass/Fail Criteria

Waveform measurement shall pass acceptance criteria according to 5.4.1.

8. RADIATED EMISSIONS

Two PHYs shall pass the test.

One test may prove both PHYs if same PHY is used in primary DUT and monitor DUT. For all the testing with the horn antenna, the primary and monitor DUT positions shall be swapped and another test shall be run.

8.1 RE Requirements

The field strength level of the radiated emissions shall not exceed the levels of Table 5.

Table 5 - Radiated emissions level requirements

ID #	RF Service (User Band) (MHz)	Frequency Range (MHz)	Limit (dBµV/m)	Conditions	Antenna	Notes
3	TX DoT 1	45.2 to 47.8	20 PK and 12 AVG	MBW 9/10 kHz Step size ≤5 kHz Time/step ≥5 ms	Biconical	Horizontal and vertical orientations
4	4 Meter	62.5 to 88.1	20 PK and 12 AVG		Biconical	
5	FM 1	75.2 to 90.9	20 PK and 12 AVG		Biconical	
6	FM 2	86.6 to 109.1	20 PK and 12 AVG		Biconical	
7	2 Meter	140.6 to 176.3	20 PK and 12 AVG		Biconical	
8	DAB	172.4 to 242.4	20 PK and 12 AVG		Biconical	
9	RFA/TPMS 1	310 to 320	20 PK and 14 AVG		Log	
10	Tetra	380 to 422	25 PK and 14 AVG		Log	
11	RFA/TPMS 2	429 to 439	25 PK and 19 AVG		Log	
11a	RKE	868 to 870	30 PK and 24 AVG		Log	
11b	RKE	902 to 904	30 PK and 24 AVG		Log	
12	GPS	1574 to 1576	4 AVG		Horn	
12a	BEIDOU BDS B1I	1559 to 1563	4 AVG		Horn	
13	GLONAS	1598 to 1605	20 AVG		Horn	
14	Wi-Fi	2400 to 2490	TBD	For information only (these might become regulated bands in the future)	Horn	Similar setup as CISPR25
15	Wi-Fi	5170 to 5290	TBD		Horn	
16	DSRC	5850 to 5925	TBD		Horn	

NOTE: Table 5 only applies to PHY qualification. Individual OEM requirements could list more bands with a limit that an ECU shall not exceed in order to pass overall emissions levels at the module level.

8.2 RE Test Setup

The requirements of CISPR 25 Edition 3, ALSE method, shall be used for verification of the primary DUT performance except where noted in this specification.

8.2.1 Co-location of multiple receiving antennas in the same test chamber to support automated testing for reduced test times is not permitted.

8.2.2 The primary DUT and any electronic hardware shall be powered from an automotive battery 12.5 to 13.5 V. The battery negative terminal shall be connected to the ground plane bench. The battery may be located on, or under, the test bench.

8.2.3 The total harness length shall be as defined in 5.3. The harness shall lie on an insulated support 50 mm above the ground plane.

8.2.4 The monitor DUT shall be placed closer to the power supply.

8.2.5 The primary DUT shall be placed on an insulated support 50 mm above the ground plane. The primary DUT shall be isolated from ground.

8.2.6 The monitor DUT shall be placed on the ground plane and electrically connected to the ground plane during the test.

8.2.7 For some DUTs, deviations from the standard test setup may be necessary to facilitate testing. If testing setup deviations are required, the test setup has to be approved directly with applicable OEMs.

- The MAC/PHY interface shall be active to ensure that the management interface with the host microcontroller is utilized throughout the testing.
- Each microcontroller interface configuration shall be tested to achieve device approval. Untested MAC interface configurations shall not be approved according to this SAE Recommended Practice.

8.2.8 If the primary DUT has an embedded voltage regulator, the regulator shall be operating during all tests.

8.2.9 If the voltage regulator is a switching regulator, all frequencies of operation desired to be approved shall be tested.

8.2.10 For devices with multiple communications channels, see 13.2.

8.3 RE Test Procedure

- One primary DUT orientation is required for all frequencies.
- Measurement of primary DUT radiated emissions shall be performed over all frequency bands listed in Table 5.

8.4 RE Pass/Fail Criteria

Any emissions above the specified limit lines shall not be accepted (as per 5.4.3) as compliant in the test report. Bands that are "for information only" should be accepted even if the suggested limit is exceeded. Plots showing peak and/or average emissions as required for all frequency ranges and all antenna orientations shall be included in the report. Plots shall include limit lines as defined in Table 5.

9. BULK CURRENT INJECTION

9.1 BCI Overview

Two PHYs shall pass the test.

If the primary and monitor DUTs are identical, their positions shall be swapped and another test shall be run.

9.2 BCI Requirements

Component functional performance shall meet the acceptance criteria delineated in Table 7 (illustrated in Figure 15) using the step sizes defined in Table 6.

Table 6 - RF immunity test frequency steps

Frequency Range (MHz)	Frequency Step Size (MHz)
1 to 30	0.5
30 to 200	2
200 to 400	5

Table 7 - BCI immunity testing limits and modulation

Frequency Range (MHz)	Immunity Level Requirement (dBµA)	Modulation
1 to 2	90	CW and AM 80%
2 to 15	90 to 106	
15 to 60	106	
30 to 400	106 to 100	

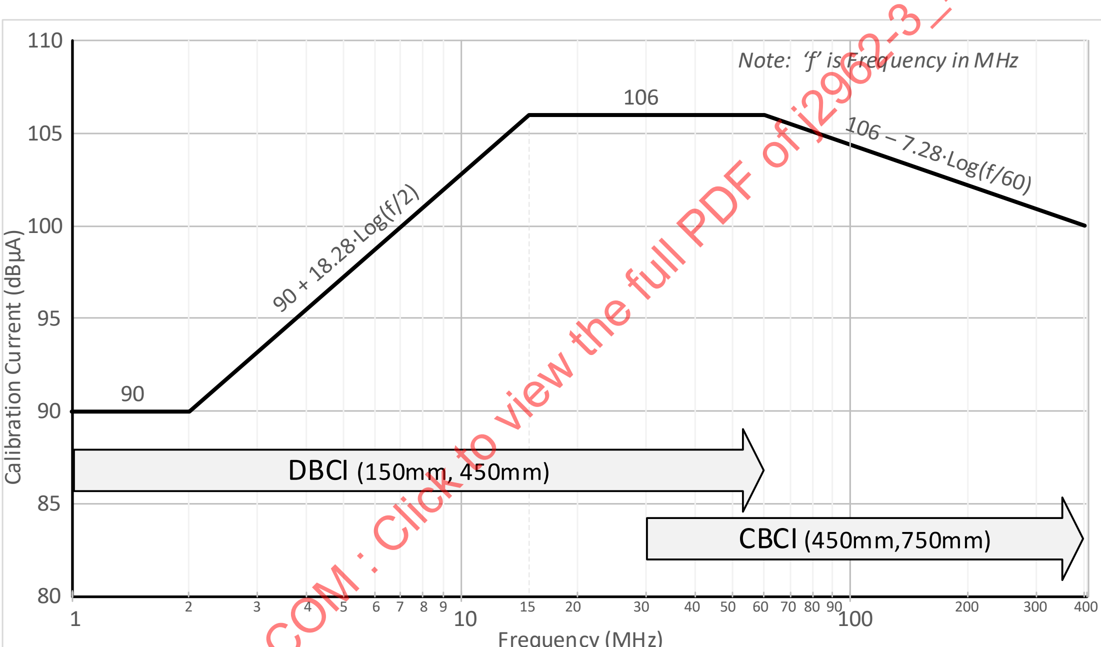


Figure 15 - BCI immunity testing limits

9.3 BCI Test Setup

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

9.3.1 The primary DUT and any electronic hardware in the monitor DUT shall be powered from an automotive battery 12.5 to 13.5 V. The battery negative terminal shall be connected to the ground plane bench. The battery may be located on, or under, the test bench.

9.3.2 The Battery positive connection shall be routed through the artificial network to the harness near the monitor/load box DUT. Battery positive line is then routed with the harness from the monitor/load DUT through the injection probe to the primary DUT. The artificial network chassis is tied to the ground plane.

9.3.3 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, primary DUT, monitor DUT, etc., shall conform to ISO 11452-4.

9.3.4 The total harness length shall be as defined in 5.3. The harness shall lie on an insulated support 50 mm above the ground plane.

9.3.5 The primary DUT housing shall be placed on an insulated support 50 mm above the ground plane. Primary DUT signal ground return shall be connected as described in 9.3.8 and 9.3.9.

9.3.6 The monitor DUT housing shall be placed on the ground plane and any enclosure electrically connected to the ground plane during the test. Monitor DUT ground return shall be connected to the ground plane.

9.3.7 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.

9.3.8 DBCI

In the frequency range of 1 to 60 MHz, the power return ground wire of the primary DUT wiring harness shall be terminated directly to the ground plane (DBCI) as illustrated in Figure 16A. The length of the wiring shall be 200 mm ± 50 mm. No power return ground wiring shall be routed around the BCI injection probe.

9.3.9 CBCI

In the frequency range of 30 to 400 MHz, all wires of the primary DUT wiring harness shall be routed inside of the injection probe (CBCI) as illustrated in Figure 16B. Grounding of harness shall be made through the monitor DUT as shown.

9.3.10 Communications interface setup instructions for single channel and multiple communications channels devices.

9.3.10.1 For devices with a single channel, the interface shall be routed inside the probe. All other harness lines shall be routed outside the probe The untested wiring shall remain as close as possible to the outer case of the injection probe.

9.3.10.2 For devices with multiple MDI communications interfaces, one interface of each speed grade shall be tested separately. Only the specific communication line(s) under test and the power and ground return as dictated by 9.3.2, 9.3.8, and 9.3.9 shall be routed inside the probe. The untested wiring shall remain as close as possible to the outer case of the injection probe. All communication lines shall be actively communicating. See Figure 16.

9.3.10.3 For devices with multiple MDI communications interfaces, in addition to the requirements listed in 9.3.10.2, all communications channels and power/ground as dictated by 9.3.2, 9.3.8, and 9.3.9 shall be tested bundled together inside the probe. All communication lines shall be actively communicating. See Figure 16.

9.3.11 The injection probe shall be insulated from the ground plane.

9.3.12 Three fixed injection probe positions are defined (150 mm, 450 mm, and 750 mm). Use:

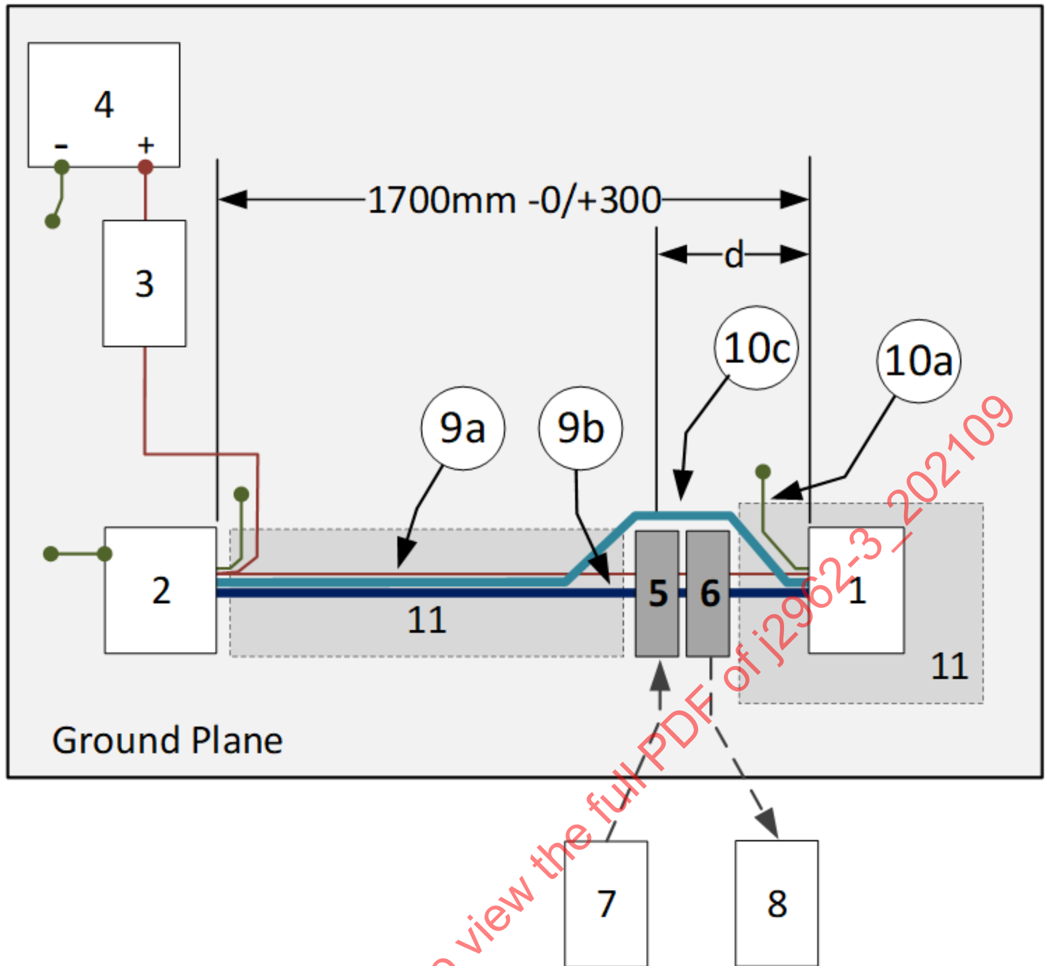
- Only 150 mm and 450 mm injection probe positions when performing DBCI.

- Only 450 mm and 750 mm injection probe positions when performing CBCI.

9.3.13 Direct monitoring of the receiver input lines is optional. See 9.5 for pass/fail criteria.

9.3.14 If the primary DUT has an embedded voltage regulator, this output shall be monitored during all tests.

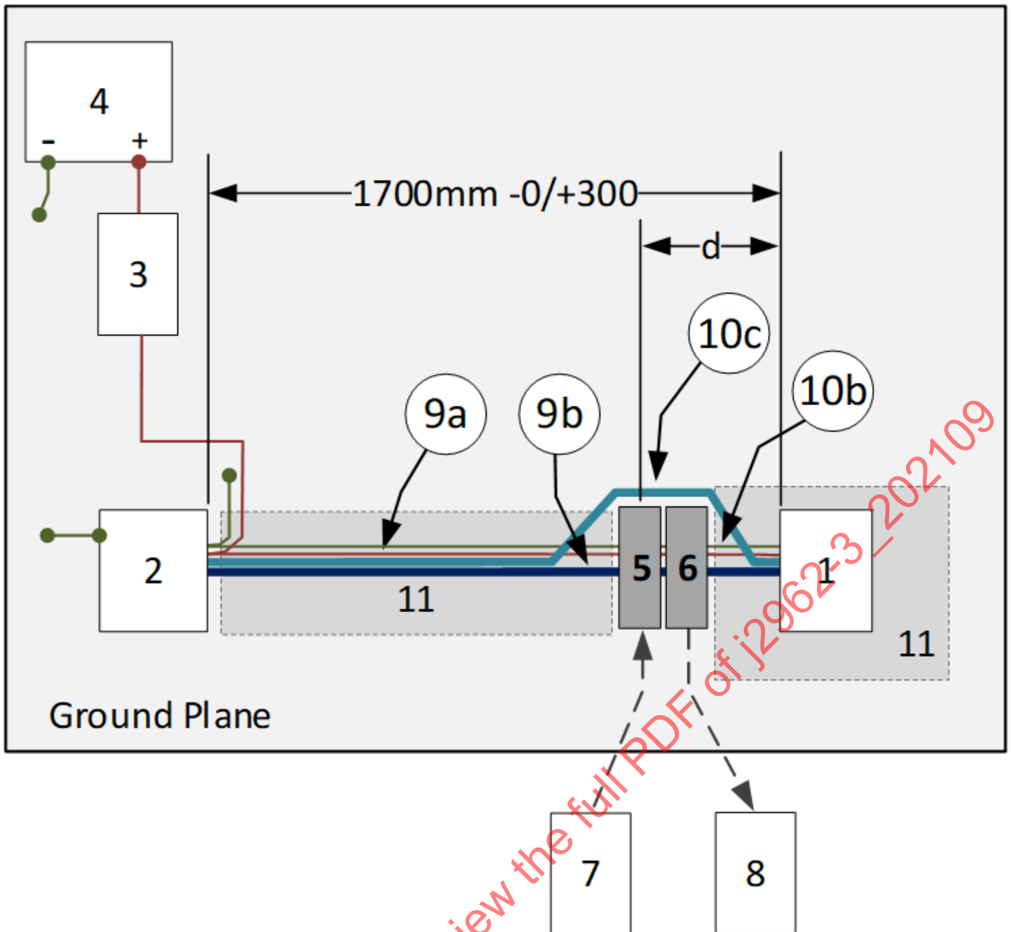
9.3.15 If the primary DUT has voltage regulators, the voltage regulators shall have a load of 10% or 90% of maximum rated current. The choice of 10% or 90% load shall be whichever condition regulation is more difficult to maintain.



Key:

1	Primary DUT	10a	Primary DUT power return removed from wire harness and connected directly to ground plane sheet metal (wire length is 200 mm ± 50 mm)
2	Monitor DUT		
3	Artificial network		
4	Automotive battery		
5	Injection probe	10b	Primary DUT power return included in wire harness
6	Monitor probe (optional)		
7	RF generation equipment	10c	Remainder of harness routed around injection probe
8	Current monitoring equipment (optional)		
9a	Full wire harness	11	Insulated support ($\varepsilon_r \leq 1.4$)
9b	Communication line(s) under test	d	Injection probe distance from primary DUT

Figure 16A - DBCI



Key:			
1	Primary DUT	10a	Primary DUT power return removed from wire harness and connected directly to ground plane sheet metal (wire length is 200 mm ± 50 mm)
2	Monitor DUT		
3	Artificial network		
4	Automotive battery		
5	Injection probe	10b	Primary DUT power return included in wire harness
6	Monitor probe (optional)		
7	RF generation equipment	10c	Remainder of harness routed around injection probe
8	Current monitoring equipment (optional)		
9a	Full wire harness	11	Insulated support ($\varepsilon_r \leq 1.4$)
9b	Communication line(s) under test	d	Injection probe distance from primary DUT

Figure 16B - CBCI

Figure 16 - BCI test setup

9.4 BCI Test Procedure

9.4.1 Active Mode - PHY in Normal Communication Mode

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

- Use step frequencies listed in Table 6 and the modulation as specified in Table 7.
- Any deviations observed shall be thresholded and reported for each frequency.
- The primary DUT operating modes exercised during testing shall include operational and all low power modes.
- Dwell shall follow requirements in 5.4.5.1.1.

9.4.2 Low Power Mode

9.4.2.1 PHY in Sleep Mode

Test shall be repeated with the primary and monitor DUTs for each low power or sleep mode implemented by the device.

9.4.2.2 Sleep mode BCI testing shall follow procedure in 5.4.5.

9.5 BCI Pass/Fail Criteria

9.5.1 Active Mode - PHY in Normal Communication Mode

9.5.1.1 Single PHY in a Package

The primary DUT and monitor DUT shall continue to communicate successfully (as defined in 5.4.3) at all times during the test. In the case where there are multiple channels, the link status of all active channels in the primary DUT shall be monitored to ensure that no loss of link occurs during the test sweep.

9.5.1.2 Multiple PHY in Single Package

Separate MDIO (or SPI) ports might needed to monitor registers confirming link status.

9.5.1.3 Multiple PHY in Switch

In the case of switches, the test could optionally use loopback testing between the primary and monitor DUT channels so only one channel's registers are monitored outside the test chamber. For the following example in Figure 17, traffic would originate at monitor channel M1, and then loop back through all the ports until the traffic reaches the bottom channel P5; this data would be evaluated for data integrity.

Figure 17 - Example loopback configuration with arrows showing flow of data (informative only)

9.5.1.4 Communications Channel Integrity Verification

After complete BCI testing, the waveform measurement shall pass acceptance criteria according to 5.4.1.

9.5.2 Low Power Mode(s) - PHY in Sleep Mode

9.5.2.1 Unwanted Sleep Conformance

No specific testing for this is required since this would be covered in the active mode testing 9.5.1.

9.5.2.2 Unwanted Wake Conformance

The primary DUT shall not wake when exposed to external field according to 5.4.4.3.2.

9.5.2.3 Wanted Wake Conformance

The primary DUT shall wake upon receiving WUPs from monitor DUT according to 5.4.4.3.3.

9.5.2.4 Wanted Sleep Conformance

The primary DUT shall enter sleep mode in conformance with 5.4.4.3.4.

10. INDUCTIVE COUPLED IMMUNITY

10.1 ICI Overview

This testing is used to evaluate robustness of wiring harness proximity to adjacent noise generating wire-to-wire noise transients in a bundle. In a typical vehicle application, communications wires may be routed alongside switched power feeds and inductive loads such as relays, solenoids, and motors. Communications are expected to be robust in the presence of noise generated on adjacent wiring. Refer to ISO 7637-3 for more details about transient testing characteristics.

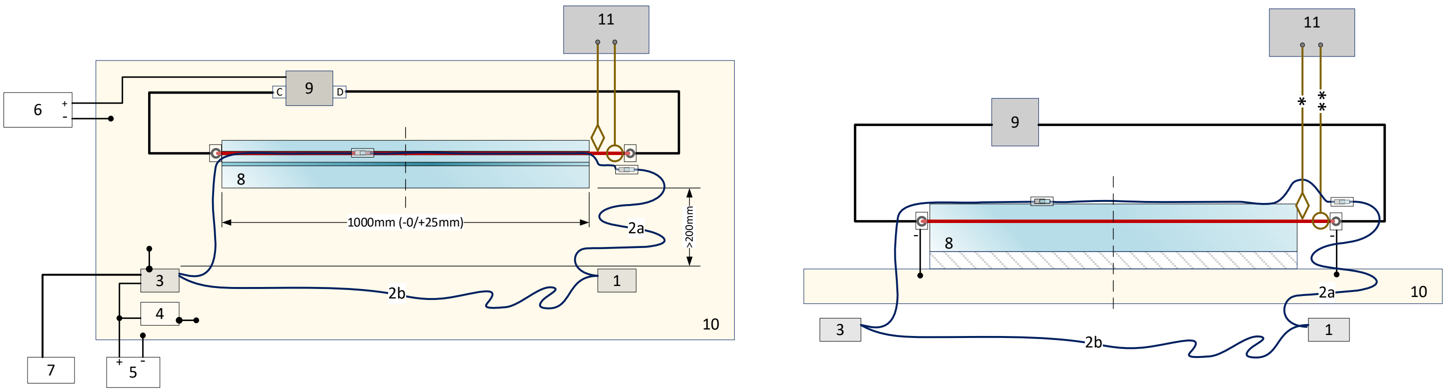
10.2 ICI Requirements

The communications network shall operate without deviation when exposed to transient electromagnetic disturbances on adjacent wires. The disturbances are created from switch contact arcing and bounce.

10.3 ICI Test Setup

10.3.1 The power supply negative terminal shall be connected to the ground plane bench. The power supply may be placed on the floor below or adjacent to the test bench.

10.3.2 The DUT power shall be connected to the power supply via artificial network (AN). The AN shall conform to CISPR 25. The AN's measurement ports shall be terminated with 50 Ω.



Key:

1 Primary DUT
2a DUT communications circuit wire to be tested (the wire is routed in the slot of the fixture with one of the in-lines placed near the center of the fixture)
2b Remainder of DUT wire harness including Vbatt/ground return and other signal wires (these are the untested wires per 10.3.8)
3 Monitor DUT
4 Artificial network
5 Power supply
6 Automotive battery
7 DUT monitor/support equipment
8 Coupling test fixture (aggressor wire located in the fixture, shown in red, is connected via grounded BNC to the transient generator; DUT harness is placed in slot directly above the aggressor wire)
9 Transient generator (see 10.7 for details); generator connected to coupling test fixture via coaxial cable; case of generator connected to the ground plane
10 Ground plane
11 Digital oscilloscope (≥1 GS/s, ≥8 mega sample)
* 1:100 high impedance probe (C < 4 pf) per ISO 7637-2; example: Agilent 10076A
** Current probe (>10 MHz, 30 A); example: Agilent N2783A

Figure 18 - Coupled immunity test setup

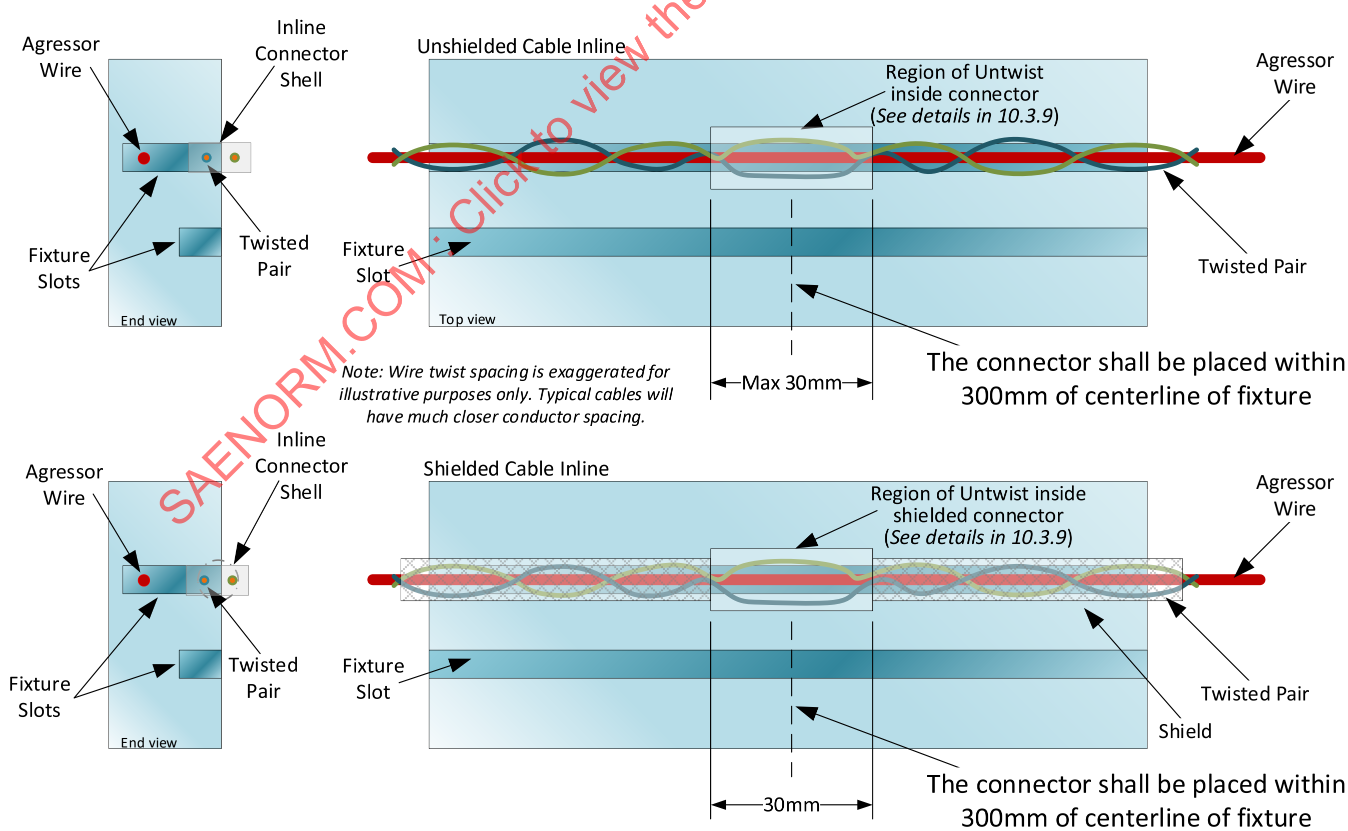


Figure 19 - Fixture detail with in-line placement

10.3.3 The transient generator shall be powered from a vehicle battery or power supply. The metal case of the transient generator shall be connected to the ground plane. See 10.7 regarding details of the transient generator. Referring to Figure 20, closing SW0 exposes the cable and connector to the noise from the aggressor wire.

10.3.4 The DUT and all parts of the test setup shall be a minimum of 100 mm from the edge of the ground plane.

10.3.5 A digital sampling oscilloscope shall be used for test voltage/current verification. The oscilloscope shall have the following capabilities:

10.3.5.1 A minimum capable sampling rate of 1 giga-samples per second (single shot capability).

10.3.5.2 A minimum memory depth of 8 mega-samples for a single channel.

10.3.6 Voltage and current probes are required to facilitate verification of the transient disturbance. Requirements for these probes are found in Figure 18.

10.3.7 If the DUT case is not metal, the DUT shall be placed on a dielectric support 50 mm above the ground plane.

10.3.7.1 If the outer case of the DUT is metal, the case of the DUT shall be electrically bonded directly to the ground plane (similar as might be implemented in a vehicle) during testing. This should be documented thoroughly in the test report so OEMs would know that the DUT might not be suitable for use in ECUs with non-metal housings.

10.3.8 Untested wires shall be bundled together and lie directly on the ground plane. The cable harness shall not be coiled, but stretched in an “S” pattern across the ground plane. The distance between the untested wires and the test fixture shall be greater than 200 mm. See Figure 18.

10.3.9 The required test setup would be a cable harness, whether unshielded or shielded, which includes two in-line connectors that are approved for use with the communications link. One of the in-line connectors shall be placed into Slot A of the fixture such that the connector shall be ±300 mm from the center of the fixture. The harness should be sufficiently long to allow connections to the primary and monitor DUTs to be located at least 200 mm away from the fixture. The in-line connector shall be oriented such that the pins inside are stacked relative to the aggressor wire as shown on the left side of Figure 19.

NOTE: It is allowed to remove the outer plastic shell of the connector as long as it does not modify the position of the wire twisting and pin alignment; this allows the connector to fit inside the slots of the fixture. Additionally, if the connector does not fit inside the slot, it is allowed to leave the fixture cover open with the in-line connector placed just above the slot opening and tape holding the wires into the slot.

10.3.10 If the DUT contains multiple communications circuits, each circuit pair shall be individually placed in Slot A of the fixture as described in 10.3.9; each communications pair shall be tested individually using the procedure in 10.4.

10.3.11 The monitor DUT (link partner) shall be connected during coupled immunity testing. The monitor DUT shall be communicating with the primary DUT throughout testing.

10.4 ICI Procedure

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

10.4.1 Calibration Steps

a. Configure the transient generator for Mode 3, Pulse A2-1 (see 10.7). Close SW0 to activate the transient generator. Using the oscilloscope, capture at least one complete transient sequence (see Table 8).

b. Verify magnitude of the negative transient voltage disturbance measured at the test point (see Figure 21) is greater than 300 V. 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 A.

10.4.2 Testing Steps

a. Open SW0 to deactivate the transient generator. Configure the transient generator for Mode 2, Pulse A2-1.

b. Activate the DUT and verify that it is functioning correctly.

c. Place an individual DUT communications circuit wire with in-line connector in Slot A of the test fixture as shown in Figure 19. Ensure that the orientation of the in-line connector pins is as shown on the left side of the drawing.

d. Close SW0 to activate transient generator.

e. Expose the communications circuit wire(s) for 60 seconds. Verify that DUT communications performance is not affected as per 10.5.

f. Repeat step (h) with the transient generator configured in the following modes:

   1. Mode 2, Pulse A2-2.

   2. Mode 3, Pulse A2-1.

   3. Mode 3, Pulse A2-2.

g. Repeat steps (a) through (f) for remaining DUT communications circuit wires (the other circuits such as power/ground do not need to be tested in this fixture).

10.5 ICI Pass/Fail Criteria

The primary DUT and monitor DUT shall continue to communicate successfully (as defined in 5.4.2) at all times during the test.

10.6 Coupled Immunity Transient Waveform Descriptions (Informative)

The transient immunity requirements are comprised of standard pulses (Pulse 1, 2a, 2b, 3a, 3b) as delineated in ISO 7637-2. These transient pulses, which are produced directly from electromechanical switching of an inductive load are prevalent in the vehicle's electrical power distribution system. These transients 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 transient events produced in this manner are often not repeatable as compared to standard ISO test pulses, experience has shown that this random behavior may produce anomalies that are frequently missed when using only the standard repetitive ISO pulses.

10.7 Coupled Immunity Transient Generator (Informative)

The transient generator circuit should produce the pulses necessary for testing coupled immunity. Figure 20 illustrates the transient generator circuit that should produce transient Pulses A1 and A2, in various modes. The transient generator is capable of generating multiple types of pulses; for testing according to this document, only a few modes are necessary.

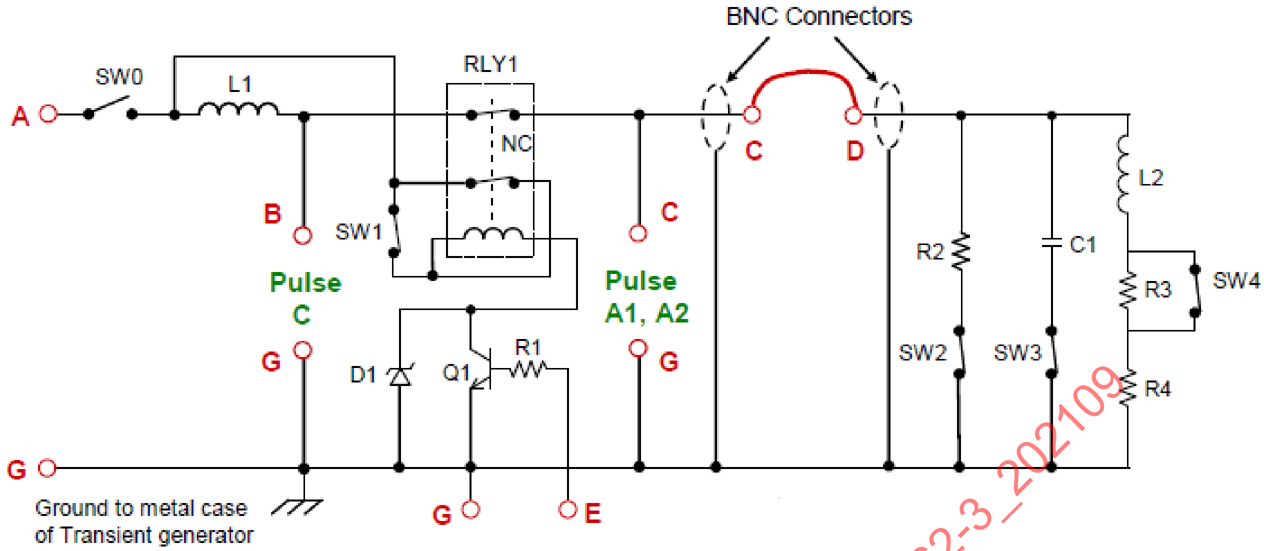


Figure 20 - Transient generator circuit

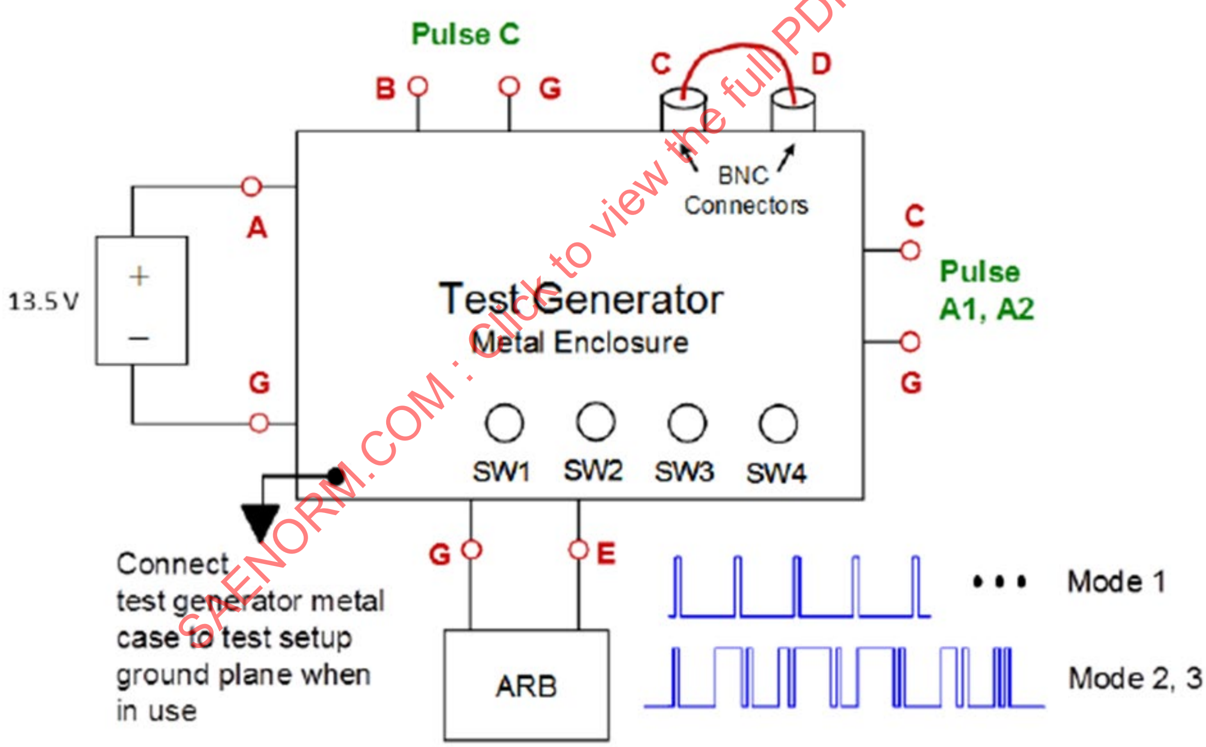


Figure 21 - Transient generator external connections

10.7.1 The circuit contains a few critical components that may not be substituted without permission from the applicable OEM EMC departments. These components are highlighted in the figures. Selection of test pulses and operating modes is facilitated by simple switch settings. Table 8 summarizes these switch configurations and associated test pulse/operating mode.

10.7.2 The transient generator uses a Potter and Brumfield (P&B) 12 VAC relay. Specifications for this relay are listed in Table 9. While the relay is readily available in North America, it may be difficult to locate in other parts of the world.

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

10.7.4 The generator may be configured for different pulse types as per Table 8.

Table 8 - Transient generator switch settings

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

* Not all modes of the transient generator are used for SAE J2962-3 tests.

Table 9 - 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	0.187 x 0.020 quick connect terminals
Enclosure	Enclosed
Contact material	Silver cadmium oxide
Approved standards	UL recognized, CSA certified

11. RF DISTURBANCE IMMUNITY

11.1 RF Disturbance Overview

This testing evaluates the robustness of the communications system when exposed to large free-field electromagnetic disturbances from radio transmitters outside the vehicle. The DUT(s) shall operate throughout exposure to RF electromagnetic fields as delineated in Table 10.

Use ALSE method (ISO 11452-2) or reverberation (mode tuned) method (IEC 61000-4-21). See 5.1.1.9 regarding testing different samples.

11.2 RF Disturbance Requirements

Table 10 - RF disturbance immunity requirements (360 to 3100 MHz)

Band	Frequency Range (MHz)	Acceptance Level (V/m)	Modulation
5	360 to 806	100	CW, AM 80%; PM PRR= 18 Hz, PD= 28 ms[(1)]
6	806 to 2000	60	CW, PM: PRR= 217 Hz, PD= 576 µs
7	1200 to 1400	600	PM PRR= 300 Hz, PD= 3 µs[(2)] with only 50
8	2700 to 3100	600	pulses output every 1 second

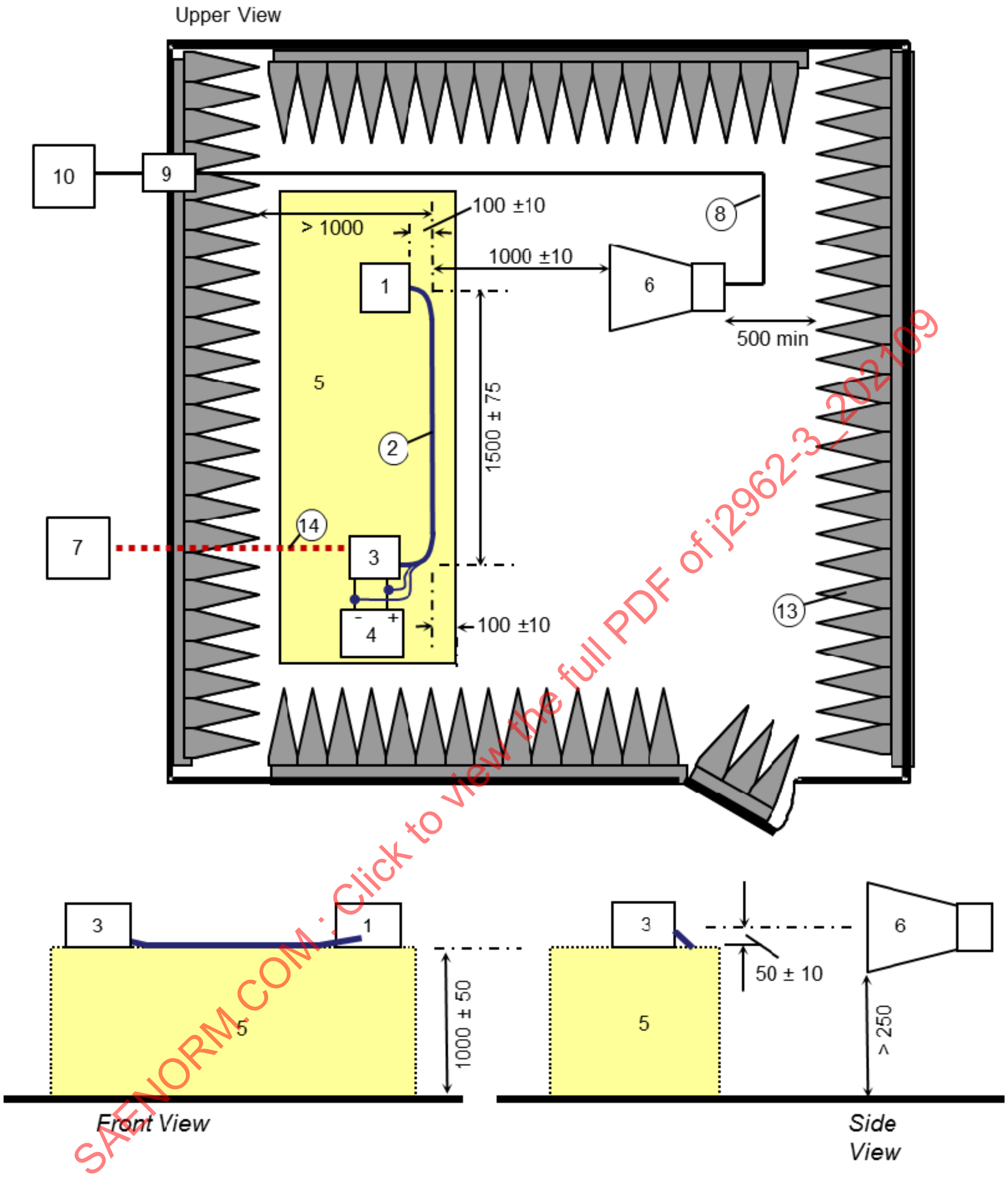
(1) Pulse modulation limited to 400 to 470 MHz. CW and AM modulation apply over the entire band (360 to 806 MHz).

(2) Pulse duration (PD) shall be extended to 6 µs when testing using the reverberation (mode tuned) method.

Table 11 - RF immunity test frequencies: bands 5 through 8 (380 to 3100 MHz)

Band 5		Band 6		Band 7	Band 8
360.00	527.72	806.00	1233.60	1200.00	2700.00
364.90	535.77	814.90	1252.36	1213.29	2734.12
369.86	543.93	823.90	1271.42	1226.72	2768.68
374.90	552.22	833.01	1290.76	1240.30	2803.67
380.00	560.64	842.21	1310.40	1254.03	2839.10
384.07	569.18	851.51	1330.34	1267.92	2874.98
388.18	577.86	860.92	1350.58	1281.95	2911.32
392.34	586.66	870.43	1371.13	1296.15	2948.11
396.54	595.60	880.04	1391.99	1310.50	2985.37
400.78	604.68	889.76	1413.17	1325.01	3023.10
405.07	613.90	899.59	1434.67	1339.68	3061.31
409.41	623.25	909.53	1456.50	1354.51	3100.00
413.79	632.75	919.57	1478.66	1369.51	
418.22	642.40	929.73	1501.16	1384.67	
422.70	652.19	940.00	1524.00	1400.00	
427.22	662.13	954.30	1547.19		
431.80	672.22	968.82	1570.73		
436.42	682.46	983.56	1594.63		
441.09	692.86	998.53	1618.89		
445.81	703.42	1000.00	1643.52		
450.58	714.14	1013.72	1668.53		
455.41	725.03	1029.14	1693.91		
460.28	736.07	1044.80	1719.69		
465.21	747.29	1060.70	1745.85		
470.19	758.68	1076.84	1772.42		
475.22	770.24	1093.22	1799.38		
480.31	781.98	1109.86	1826.76		
485.45	793.90	1126.74	1854.56		
490.65	806.00	1143.89	1882.77		
495.90		1161.29	1911.42		
501.21		1178.96	1940.50		
506.58		1196.90	1970.03		
512.00		1215.11	2000.00		
519.80					

11.3 RF Disturbance Setup



Key:			
1	Primary DUT	7	Support equipment
2	Test harness	8	Double shielded coaxial cable (e.g., RG 223)
3	Monitor DUT	9	Bulkhead connector
4	Automotive battery	10	RF generation equipment
5	Dielectric support ($\varepsilon_r \leq 1.4$)	11	RF absorber material
6	Transmit antenna		

Figure 22 - ASLE setup example