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Road vehicles — Supply voltage of 48 V — Electrical requirements and tests

Véhicules routiers — Tension d'alimentation de 48 V — Exigences électriques et essais

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 22, *Road vehicles*, Subcommittee SC 32, *Electrical and electronic equipment and general system aspects*.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Road vehicles — Supply voltage of 48 V — Electrical requirements and tests

1 Scope

This document covers requirements and tests for the electric and electronic components in road vehicles equipped with an electrical system operating at a nominal voltage of 48 V DC.

This includes the following:

- general requirements on 48 V DC electrical systems;
- voltage ranges;
- slow voltage transients and fluctuations (not including EMC).

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 16750-1, *Road vehicles — Environmental conditions and testing for electrical and electronic equipment — Part 1: General*

ISO 16750-2, *Road vehicles — Environmental conditions and testing for electrical and electronic equipment — Part 2: Electrical loads*

ISO/IEC 17025, *General requirements for the competence of testing and calibration laboratories*

EN 13018, *Non-destructive testing — Visual testing — General principles*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at https://www.iso.org/obp
- IEC Electropedia: available at http://www.electropedia.org/

3.1
component
a part that is directly installed in a vehicle and is the Device Under Test (DUT)

3.2
fire
self-supporting combustion which spreads, uncontrolled, with time and in space and may result in bright light, heat, smoke, burning or a combination of all the above

3.3
ground for 12 V/24 V electrical system
$GND_{12/24}$
ground pin on the 12 V/24 V electrical system

3.4
ground for 48 V electrical system
GND_{48}
ground pin on the 48 V electrical system

3.5
12 V/24 V positive voltage connection pin
$U_{12/24}$
positive voltage connection pin on the 12 V/24 V electrical system

3.6
48 V positive voltage connection pin
U_{48}
positive voltage connection pin on the 48 V electrical system

3.7
nominal 12 V/24 V supply voltage
U_N
voltage of the 12 V/24 V external supply distribution system

3.8
nominal 48 V supply voltage
U_{48N}
voltage of the 48 V external supply distribution system

3.9
maximum operating temperature
T_{max}
highest temperature of operation of the DUT

3.10
minimum operating temperature
T_{min}
lowest temperature of operation of the DUT

3.11
room temperature
T_{RT}
ambient temperature at which the test is performed

3.12
test temperature
T_{test}
temperature of the DUT at which the test is performed

4 Functional status

4.1 General

A component may include several functions which might have different functional statuses for the same value of the influencing parameter. For the purpose of this document the influencing parameter is the supply voltage.

The functional status is a minimum requirement.

The component functional behaviour, (including derating), relating to each chosen functional status level and the customer perception (e.g. visual, acoustic, tactile and thermal), shall be defined and agreed between the customer and supplier and described in the required component documentation. See Annex A for application examples.

4.2 Functional status 1 (FS1)

The function shall meet a specified performance without deviation. Derating or switch-off is not allowed.

4.3 Functional status 2 (FS2)

The function shall meet a specified performance with a specified variation below or above the specified performance of FS1. Derating is allowed, switch-off is not allowed.

4.4 Functional status 3 (FS3)

The function may not provide the specified performance. Derating or switch-off is allowed. The function shall automatically recover and return to the specified performance level if the necessary operating conditions are met.

4.5 Functional status 4 (FS4)

The function may not provide the specified performance. Derating or switch-off is allowed. The function shall recover and return to specified performance only after a change in vehicle operational status (e.g. change of ignition status, vehicle restart) has occurred and if the necessary operating conditions are met.

4.6 Functional status 5 (FS5)

The DUT fails to perform one or more functions whilst the test parameters are applied, the DUT does not set itself on fire as defined in 3.2. After application is terminated, the DUT can no longer be used unless it is repaired or replaced

5 Supply voltage range

The supply voltage ranges are described in Figure 1.

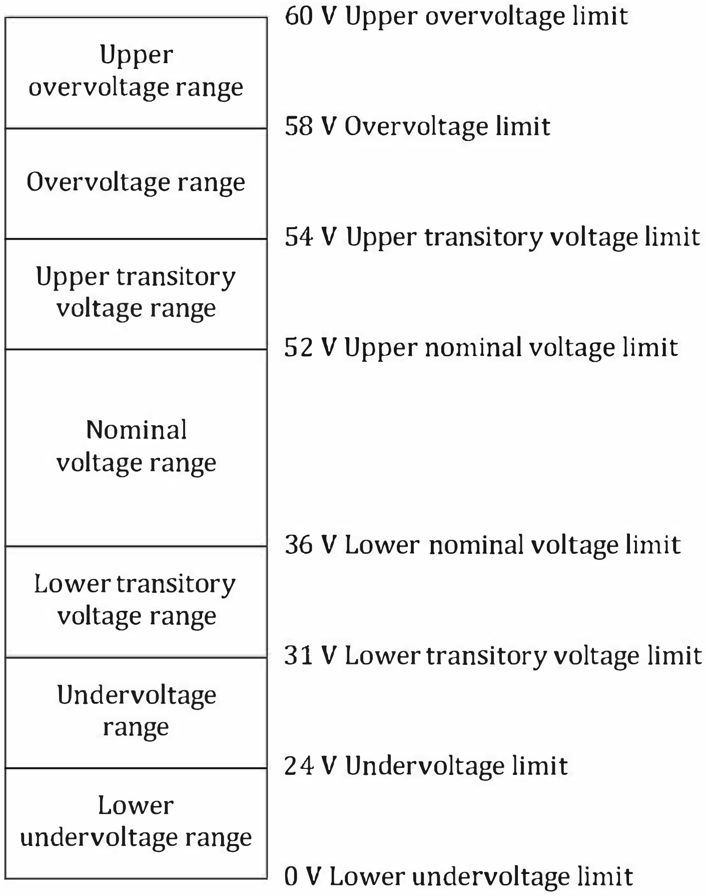


Figure 1 — Supply voltage ranges

Upper overvoltage range (58 V – 60 V):

Reason for being in this voltage range could be a control error.

Overvoltage range (54 V – 58 V):

This voltage range may occur due to (short term) return of electrical energy or maybe a control error.

The system may operate only temporarily in this range.

Upper transitory voltage range (52 V – 54 V):

This range is intended for calibrating the storage media and for uptake of recovered energy.

The system may operate only temporarily in this range.

Nominal voltage range (36 V – 52 V):

The system is expected to operate in this range most of the time.

Lower transitory voltage range (31 V – 36 V):

The voltage may for example be in this range during boost or during cold crank.

The system may operate only temporarily in this range.

Undervoltage range (24 V – 31 V):

The voltage may for example be in this range during cold crank.

The system may operate only temporarily in this range.

Lower undervoltage range (0 V – 24 V):

Storage protection.

The voltage is not expected to be in this range except for short term discontinuities in the supply voltage or due to long term parking.

6 Functional categories

The required performance, (e.g. torque of an electrical motor or flow rate of a water pump), shall be specified for each relevant function of the DUT. The performance specified is then used as a reference to enable the selection of a functional status level for each relevant function. The functional categories which specify the changes in functional status of the DUT as a function of the 48 V supply voltage are described in Table 2. Use Table 2 to select the required category for each function of the DUT. Examples for the different functional categories are given in Table 1.

Table 1 — Functional categories

Functional category	Example of functions or components
FC I	Communication, diagnostic
FC II	Voltage conversion from 48 V to 12 V Functions relevant to vehicle safety Functions relevant to propulsion. Components which act as 48 V sources.
FC III	Components/functions relevant to starting. Components/functions that need to operate during starting (cranking).
FC IV	Comfort functions
FC Z	To be used if the above definitions of functional categories are judged to be unsuitable for the DUT. In this case, functional status is to be agreed between supplier and customer for each test.

Table 2 — Functional status

Voltage range	Test	Functional category				
		I	II	III	IV	Z
60 V < U_{48} ≤ 70 V	Test-03 Short term overvoltage	FS1	FS2	FS2	FS3	As agreed
58 V < U_{48} ≤ 60 V	Test-06 Long term overvoltage	FS3	FS3	FS3	FS3	As agreed
54 V < U_{48} ≤ 58 V	Test-07 Overvoltage with consumer components which may supply electrical energy	FS1	FS2	FS3	FS3	As agreed
52 V < U_{48} ≤ 54 V	Test-02 Lower and upper transitory voltage ranges	FS1	FS2	FS3	FS2	As agreed
52 V < U_{48} ≤ 54 V	Test-09 Voltage ripples	FS1	FS2	FS3	FS2	As agreed
36 V ≤ U_{48} ≤ 52 V	Test-01 Nominal voltage range	FS1	FS1	FS1	FS1	As agreed
31 V ≤ U_{48} < 36 V	Test-02 Lower and upper transitory voltage ranges	FS1	FS2	FS2	FS3	As agreed
31 V ≤ U_{48} < 36 V	Test-08 Decrease and increase of supply voltage	FS1	FS2	FS2	FS3	As agreed

Table 2 *(continued)*

Voltage range	Test	Functional category				
		I	II	III	IV	Z
31 V ≤ U_{48} < 36 V	Test-09 Voltage ripples	FS1	FS2	FS2	FS3	As agreed
31 V ≤ U_{48} < 36 V	Test-10 Reinitialization	FS1	FS2	FS2	FS3	As agreed
24 V ≤ U_{48} < 31 V	Test-05 Starting profile	FS1	FS2	FS2	FS3	As agreed
24 V ≤ U_{48} < 31 V	Test-08 Decrease and increase of supply voltage	FS1	FS3	FS3	FS3	As agreed
24 V ≤ U_{48} < 31 V	Test-10 Reinitialization	FS1	FS2	FS2	FS3	As agreed
0 V ≤ U_{48} < 24 V	Test-08 Decrease and increase of supply voltage	FS3	FS3	FS3	FS3	As agreed
0 V ≤ U_{48} < 24 V	Test-10 Reinitialization	FS3	FS3	FS3	FS3	As agreed

NOTE Not all of the tests in this document are listed in Table 2. Tests that are not listed in the table state their requirements in the individual test clauses.

7 Operating modes

The following operating modes apply.

The DUT is electrically operated with test voltage U_N and U_{48N} as defined in 3.7 and 3.8 (unless otherwise specified in the test procedure) with all electrical connections made.

If the component requires a cooling system, it shall be operated and adjusted if necessary, as described in the component specifications:

- operating mode 2.1: system/component functions are not activated (e.g. sleep mode);
- operating mode 2.2: electrical systems/components controlled to and operating at typical operating mode;
- operating mode 2.3: electrical systems/components controlled to and operating at minimum load. No activated loads (e.g. standby);
- operating mode 2.4: electrical systems/components controlled to and operating at maximum load.

Minimum, typical and maximum operating loads should be defined for each function by agreement between the supplier and customer.

NOTE Since the application scope is different, these operating modes definitions are not strictly identical to the definitions of the ISO 16750-1. Operating modes 1, 3 are used in ISO 16750-1 but are not needed in this document.

8 General tests conditions

8.1 Standard tolerances

Unless otherwise stated, the tolerances specified in Table 3 apply for the measurement values in all the tests given in this standard.

Table 3 — Standard tolerances

Abbreviation	Meaning	Tolerance limits
f	Frequency	±1 %
T	Temperature	±2 °C
RH	Relative humidity	±5 %
t	Time	+5 % to 0 %
U	Voltage	±0,5 %
I	Current	±2 %
R	Resistor	±10 %

8.2 General values

Unless otherwise specified, all tests shall be performed at:

— nominal 12 V/24 V voltage (U_N) as defined in ISO 16750-1;

— nominal 48 V voltage (U_{48N}): 48 V;

— room temperature (T_{RT}): +23 °C ±5 °C;

— relative humidity (RH_{test}): 25 % to 75 %;

— test temperature (T_{test}): room temperature.

8.3 Sampling rate and value resolution

Before each test, it shall be ensured that the sampling rate/bandwidth, the measurement range of the measuring system and the resolution of the measured values are set to values appropriate for the test to be performed and, where necessary, adjusted to suit. All measured values shall be recorded along with the maximum and minimum, or peak, values.

8.4 Description of interfaces

All interfaces to the DUT which enable functional performance of the DUT along with the specific test parameters to be met shall be defined. Examples of such are, electrical connectors and wiring, mechanical attachments, coolant mechanisms, etc.

8.5 Restrictions on performing the tests

The testing laboratory shall be organised and operated in accordance with ISO/IEC 17025. All the testing equipment used for making measurements shall be calibrated in accordance with ISO/IEC 17025 (or as determined or recommended by the manufacturer) and shall be traceable to a national metrology laboratory.

8.6 Number of tested samples

Final validation shall be performed with at least two DUTs, during initial design validation phases this requirement is waived.

8.7 Test voltages

Unless explicitly specified otherwise, voltage profiles indicated refer to the terminal voltages of the DUT and shall be measured and documented in the test report. The specified voltages shall be measured referenced to their respective grounds at connector or terminals of the DUT.

All 48 V components that are equipped with an interface for 12 V/24 V supply, or communication interfaces, shall also satisfy the corresponding requirements for the 12 V/24 V supply:

— during the 12 V/24 V supply system tests, the voltage in the 48 V supply system is U_{48N}, unless required otherwise in the individual tests;

— during the 48 V supply system tests, the voltage in the 12 V/24 V supply system is U_N, unless indicated otherwise in the individual tests.

All 48 V components that are equipped with an interface to any other supply voltage level shall also satisfy the corresponding standards.

8.8 Test procedure

The test procedure shall be defined in conjunction with the customer and documented within a test plan. For each test, as applicable, the permitted error memory entries and the functional statuses for each function of the component shall be agreed with the customer and documented within the test plan.

Details of the test setup, operating loads (e.g. triggering, original sensors, original actuators and replacement circuitry) and the required boundary conditions shall be agreed between the customer and the supplier and documented in a test plan and in the resultant test report. Components that are electrically both a source and a sink shall be tested in both modes of operation.

The test equipment shall ensure that all interfaces which are required to meet the specified performance of the DUT are populated and functional to the required level. Signals or messages which shall be received from or transmitted to the vehicle controller in order to ensure the DUT functions as expected may be simulated if a full vehicle or HIL simulation is not used.

In all cases, program and data storage devices shall remain in FS1 until the component is deactivated. If the device has non-volatile memory, the integrity (not the current status) of the non-volatile memory shall be ensured at all times.

Damage to the DUT is not permitted in FS1 to FS4. The permissible limit values specified in the data sheets (e.g. electrical, thermal or mechanical) of the electric/electronic components in the DUT shall not be exceeded. Evidence of this is provided at least by the parameter check as described in 8.9.

An electrical test begins when the DUT has started up completely and is in FS1.

Before and after every test, the DUTs shall be subjected to a parameter check as described in 8.9 in accordance with specifications. The DUT shall be in a steady state of temperature at the beginning of each test.

During each test, the key parameters to be monitored shall be recorded as described in 8.10. Component resets shall be monitored and documented in an appropriate form to be included in the test report.

Damaged DUTs (FS5) shall be removed from the test cycle, analysed regarding the root cause for the failure and documented. In such cases, the test shall be repeated with a new DUT, or the following test in the test plan shall be performed with a new DUT. The procedure shall be agreed with the customer.

The physical analysis as described in 8.11 shall be carried out on at least one DUT following completion of all the electrical tests. All component parts including hardware, software or calibrations of the DUT undergoing final validation stage, shall be recorded. Any change in these parts shall require revalidation or justification of no impact.

8.9 Parameter check

A set of sensitive parameters called key parameters shall be defined both in the component specifications and in consultation with the customer, e.g. quiescent current consumption, operating currents, output voltages, contact resistances, input impedances, signal rates (rise and fall times) and bus specifications. These parameters shall be checked before the start and after the completion of each test to verify that they match the specification.

The key parameters shall be measured and the functional behaviour of the components at T_{RT} and U_{48N} shall be checked. For components with error memory, the error memory shall be read out and documented and then deleted before the start of the test. After the test, the error memory shall again be read out and documented.

The results and data from the before/after tests may differ only within the specified permissible tolerances. Any changes in the measured values exceeding the measurement accuracies shall be indicated as such. The results shall be examined for trends and drifts so that any abnormalities, ageing or malfunctions of the component can be identified.

The components shall be inspected visually in accordance with EN 13018 for external damage/changes, for example cracks, chipping/peeling, discolouration, distortion, etc., without opening the DUT.

All the results shall be documented in the test report.

8.10 Continuous parameter monitoring with drift analysis

A list of key parameters shall be defined within the specification of the component.

These parameters shall be those which are necessary for the end user to understand, in order to achieve both full functional performance and reliable operation, when integrated within a vehicle.

The parameters shall also include those which are necessary to be understood to ensure compatibility with the vehicle systems to which the component is interfaced.

Such specifications may include, but not be limited to, written documents, drawings and/or schematic diagrams.

Examples of parameters which are recommended to be considered are: quiescent current consumption, peak and rated operating currents and voltages, contact resistances, input impedances, signal rates (rise and fall times) and bus specifications.

The key parameters to be monitored shall be recorded throughout the test.

In the case of components with error memory, the error memory shall be monitored at the beginning and at the end of each test and the entries shall be documented in the test report.

The data collected from the continuous parameter monitoring shall be examined for trends and drifts in order to identify abnormalities, ageing or malfunctions of the component.

8.11 Physical analysis

DUT (ECU or system) shall be opened and a visual inspection shall be performed in accordance with EN 13018. Component level physical analysis is optional.

Additional analyses (e.g. x-ray, Scanning Electron Microscope (SEM) analysis, cross section investigation and metallographic examination of the hardware design and connecting technology) shall be agreed between the customer and the supplier.

Any changes in the component beyond defined tolerances shall be documented and approved by the customer.

The results shall be documented and evaluated in the test report.

9 General requirements

9.1 General

This document covers the electric behaviour at the DC terminals of all 48 V DC components. For the energy storage systems electrochemical part is not tested while the management system is tested alone as an independent DUT.

9.2 Prerequisites regarding the system in which the component is applied

— Static direct voltages are limited to ≤60 V.

— A short circuit of the 48 V supply to the 12 V/24 V system or any GND due to a single error in the wiring harness is prevented by appropriate measures in the vehicle.

— There is a common ground for the 12 V/24 V system and the 48 V system, which are connected via physically separate grounding bolts/connections except for the power ground of components that convert power between 48 V and 12 V/24 V such as DC/DC converters.

— The polarity of the 48 V supply is prevented from reversing by the use of appropriate measures within the vehicle (e.g. Poka-Yoke).

— Jump starting by direct connection with the 48 V power supply is prevented by the use of appropriate measures applied within the vehicle.

— The 48 V system shall not induce additional constraints on existing 12/24 V components as those are not specifically designed for use upon a vehicle which uses a dual power distribution system.

— If a screwed or plugged 12 V/24 V and a 48 V connection are nearby, the system shall prevent accidental inversion by design.

9.3 Component requirements

— Any single fault condition within devices or at their external interfaces connecting to both the 48 V and the 12 V/24 V electrical system, shall not create a short circuit between the two electrical systems nor result in an overvoltage on any part of the 12 V/24 V electrical system.

— Devices with separate GND connections for the 48 V and the 12 V/24 V electrical system shall provide countermeasures to avoid accidental connection of the two GND domains.

— The loss of any ground connection to the DUT shall not disrupt or destroy the communication within the connected network interface (e.g. bus system) or any other connected electrical system.

— If the voltage exceeds the upper transitory limit, countermeasures shall be taken via the component that is causing entry into the overvoltage range, such that the voltage exits the overvoltage range at the lower boundary.

— A device shall include measures to protect its 48 V net connections against a short circuit developing from an accidental drop of a conductive element that could bridge the terminals.

— Where a DUT has connections to a different voltage supply level such as a 12 V/24 V supply, it shall be guaranteed and proven that no voltage or voltage curve within the limits defined for the 48 V supply causes the destruction or loss of function of the DUT on, for example, the 12 V/24 V side. This also applies if the test pulse damages the DUT such that it no longer provides the expected function on the 48 V side.

10 Tests and requirements

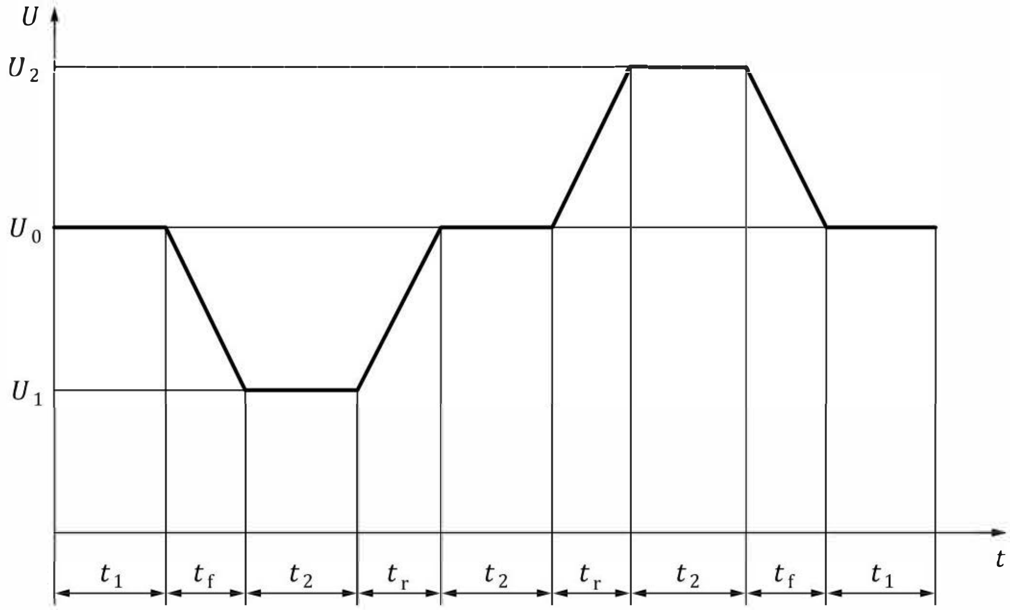
10.1 Test-01: nominal voltage range

10.1.1 Purpose

The purpose of this test is to verify the component functionality in the nominal voltage range.

10.1.2 Test

Set the supply voltage at the relevant inputs of the DUT as defined in Figure 2 and Table 4.



Key

t time

U test voltage

Figure 2 — Test profile for test-01: nominal voltage range

Table 4 — Test parameters for test-01: nominal voltage range

Operating mode	2.4
U_0	44 V
U_1	36 V
U_2	52 V
t_1	30 s
t_2	60 s
t_r	50 ms (0,16 V/ms)
t_f	50 ms (0,16 V/ms)
Number of cycles	5

10.1.3 Procedure

Continuously monitor the DUT and repeat the profile, without pause, until the required number of test cycles defined in the test parameters table have been completed.

10.1.4 Requirement

All DUT functions shall comply with the definition of the selected functional category defined in Table 2.

10.2 Test-02: lower and upper transitory voltage ranges

10.2.1 Purpose

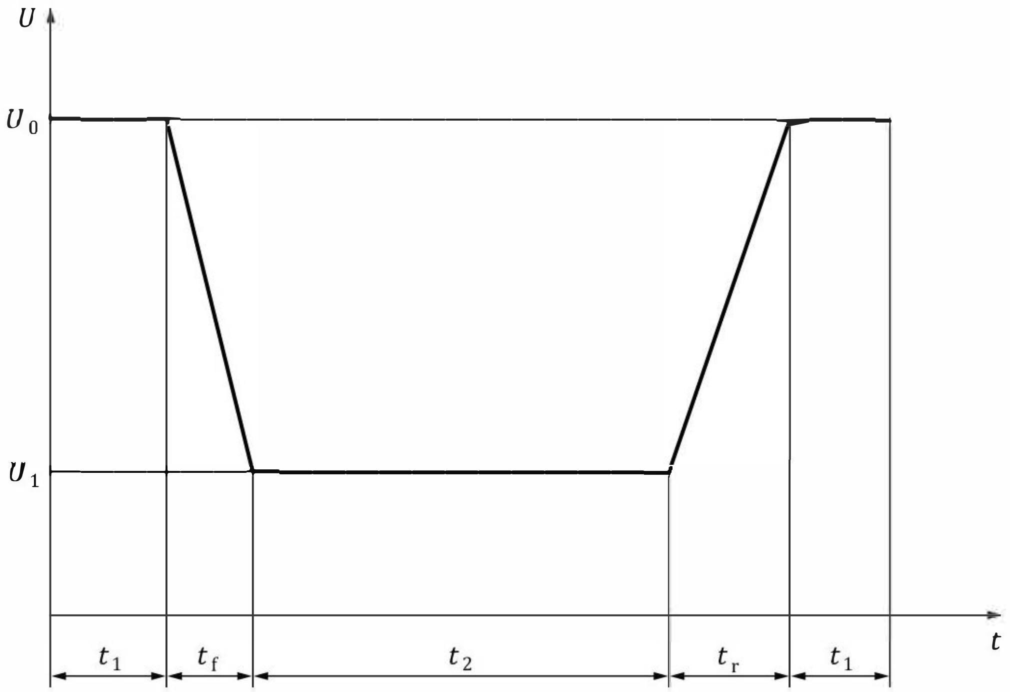
The purpose of this test is to verify the functionality of the component in the upper and lower transitory voltage range.

10.2.2 Test

Set the supply voltage at the relevant inputs of the DUT as defined in test case 1 and test case 2.

10.2.2.1 Test case 1: lower transitory voltage range

Set the supply voltage at the relevant inputs of the DUT as defined in Figure 3 and Table 5.



Key

t time

U test voltage

Figure 3 — Test profile for test-02: lower transitory voltage range (test case 1)

Table 5 — Test parameters for test-02: lower transitory voltage range (test case 1)

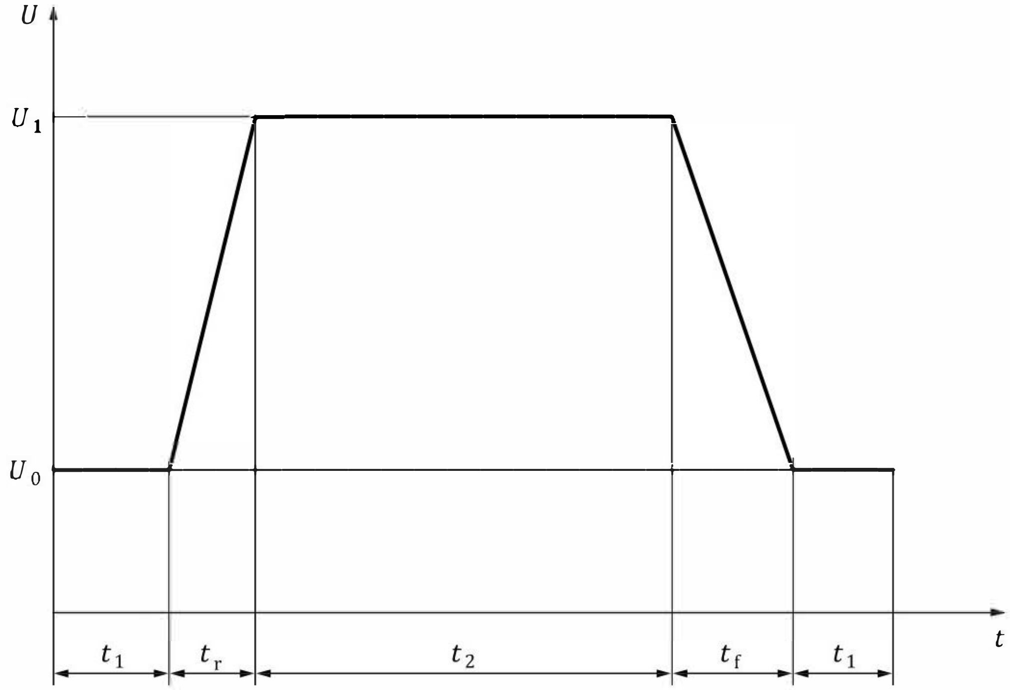
Operating mode	2.4
U_0	36 V
U_1	31 V
t_1	60 s
t_2	2 s
t_r	10 ms (0,5 V/ms)

Table 5 *(continued)*

t_f	10 ms (0,5 V/ms)
Number of cycles	5

10.2.2.2 Test case 2: upper transitory voltage range

Set the supply voltage at the relevant inputs of the DUT as defined in Figure 4 and Table 6.



Key

t time

U test voltage

Figure 4 — Test profile for test-02: upper transitory voltage ranges (test case 2)

Table 6 — Test parameters for test-02: upper transitory voltage ranges (test case 2)

Operating mode	2.4
U_0	52 V
U_1	54 V
t_1	60 s
t_2	120 s
t_r	4 ms (0,5 V/ms)
t_f	4 ms (0,5 V/ms)
Number of cycles	5

10.2.3 Procedure

Continuously monitor the DUT and repeat the profile, without pause, until the required number of test cycles defined in the test parameters table have been completed.

10.2.4 Requirement

All DUT functions shall comply with the definition of the selected functional category defined in Table 2.

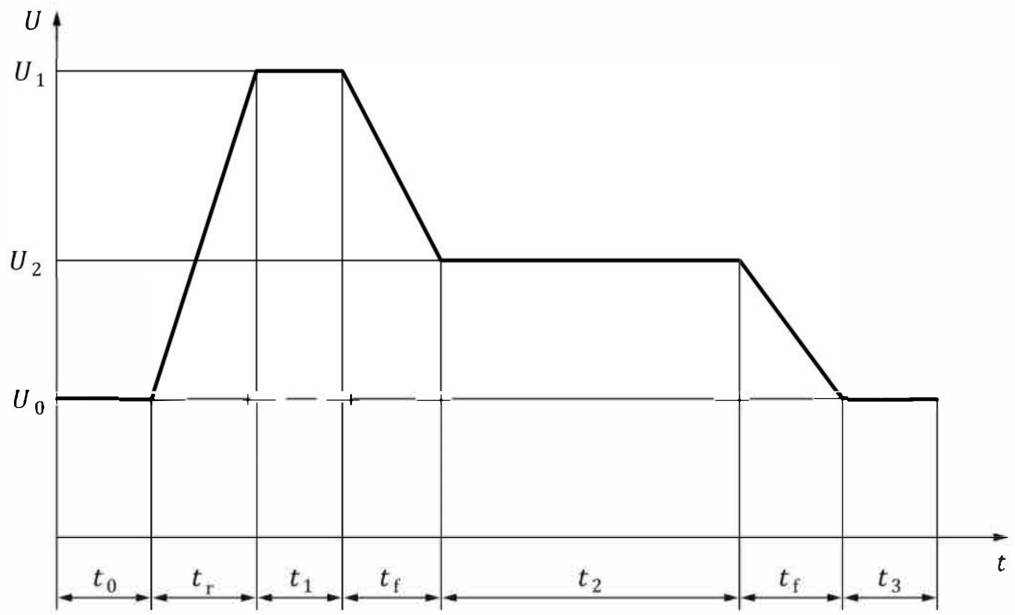
10.3 Test-03: short term overvoltage

10.3.1 Purpose

This test is intended to check the immunity of the component to transient overvoltages.

10.3.2 Test

Set the supply voltage at the relevant inputs of the DUT as defined in Figure 5 and Table 7.



Key

t time

U test voltage

Figure 5 — Test profile for test-03: short term overvoltage

Table 7 — Test parameters for test-03: short term overvoltage

Operating mode	2.4
U_0	52 V
U_1	70 V
U_2	58 V
t_0	≥5 s
t_r	0,7 ms (25,71 V/ms)
t_1	40 ms
t_f	1 ms
t_2	600 ms
t_3	≥5 s
Number of cycles	1 000

10.3.3 Procedure

Continuously monitor the DUT and repeat the profile, without pause, until the required number of test cycles defined in the test parameters table have been completed.

10.3.4 Requirement

All DUT functions shall comply with the definition of the selected functional category defined in Table 2.

10.4 Test-04: supply component load dump control test

10.4.1 Purpose

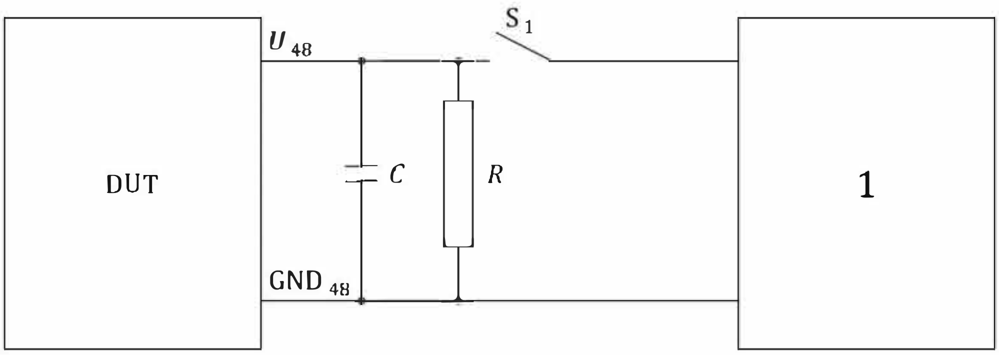
This test is a simulation of a load dump situation where voltage transients occur following a sudden reduction in the load current drawn from a generator, motor-generator or DC/DC converter and whilst the battery is either out of circuit or incapable of absorbing power.

10.4.2 Test

Set up the test, the supply voltage at the relevant inputs of the DUT as defined in Figure 6 and Table 8.

The test set up shall ensure that the DUT can be operated to supply power to the 48 V system and loaded, via a suitable wiring harness and load bank to supply at least 95 % of its rated maximum power to the 48 V system.

Additionally, a switch shall be included which will enable the variable test load applied to the DUT to be reduced to zero within a time period of less than t_{s1} and without damage occurring to the switch. Actual switching time shall be measured during the test or before the test and recorded into the test report.



Key

S_1 switch on 48 V

R resistor simulating vehicle power network resistance

C capacitor simulating vehicle power network capacitance

1 test load

Figure 6 — Test setup for test-04: load dump

Table 8 — Test parameters for test-04: load dump

Operating mode	2.4
U_0	52 V
R	36 Ω
C	0,5 mF
t_{s1}	≤100 µs

Table 8 *(continued)*

Number of cycles	2

NOTE R and C values could be changed to a value agreed between customer and supplier.

10.4.3 Procedure

The switch (S_1) is closed.

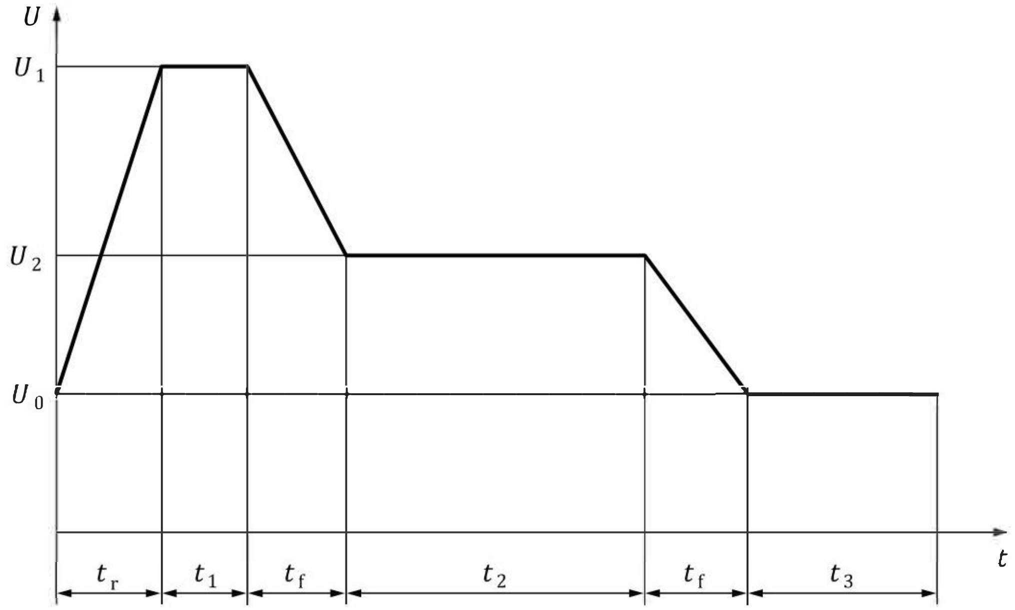
Operate the DUT and variable test load to deliver at least 95 % of its rated maximum output power.

Open switch S_1 to isolate the variable test load.

Continuously monitor the DUT and repeat the profile, without pause, until the required number of test cycles defined in the test parameters table have been completed.

10.4.4 Requirement

Following the switch opening, the output voltage profile from the DUT shall not exceed the profile in Figure 7 and Table 9.



Key

t time

U test voltage

Figure 7 — Requirement profile for test-04: load dump

Table 9 — Requirement parameters for test-04: load dump

Operating mode	2.4
U_1	70 V
U_2	58 V
t_1	40 ms
t_2	600 ms
t_3	9 s
t_r	0,7 ms

Table 9 *(continued)*

t_f	1 ms

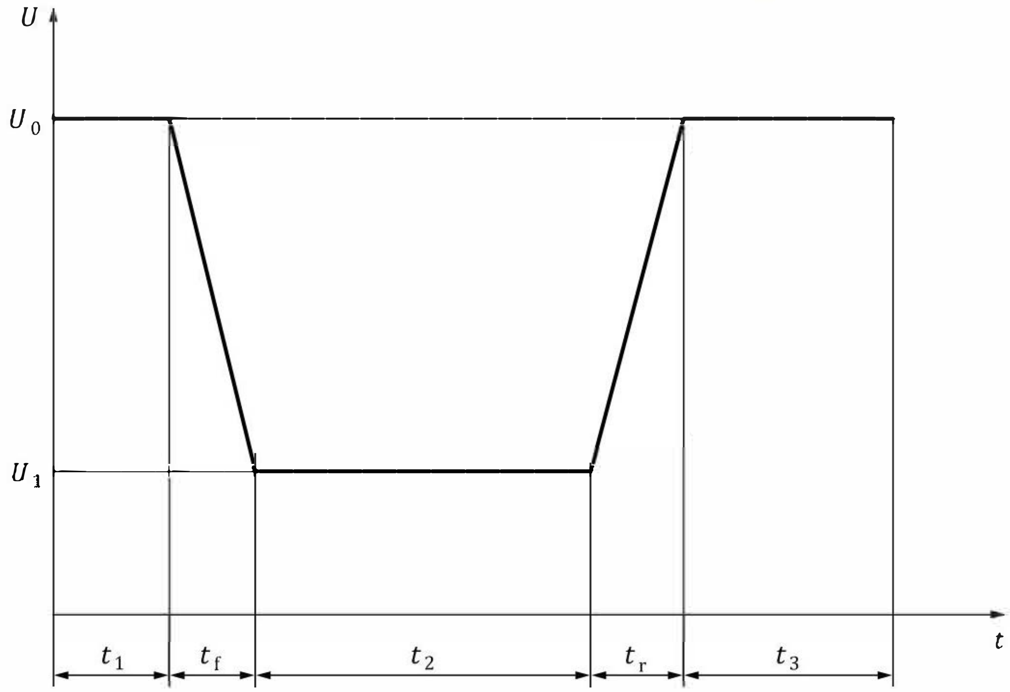
10.5 Test-05: starting profile

10.5.1 Purpose

This test is intended to check the immunity of the component to voltage variations during the cold crank phase.

10.5.2 Test

Set the supply voltage at the relevant inputs of the DUT as defined in Figure 8 and Table 10.



Key

t time

U test voltage

Figure 8 — Test profile for test-05: starting profile

Table 10 — Test parameters for test-05: starting profile

Operating mode	2.4
U_0	36 V
U_1	24 V
t_f	5 ms (2,4 V /ms)
t_2	10 s
t_r	5 ms (2,4 V/ms)
t_1	2 s
t_3	60 s
Number of cycles	10

10.5.3 Procedure

Continuously monitor the DUT and repeat the profile, without pause, until the required number of test cycles defined in the test parameters table have been completed.

10.5.4 Requirement

All DUT functions shall comply with the definition of the selected functional category defined in Table 2.

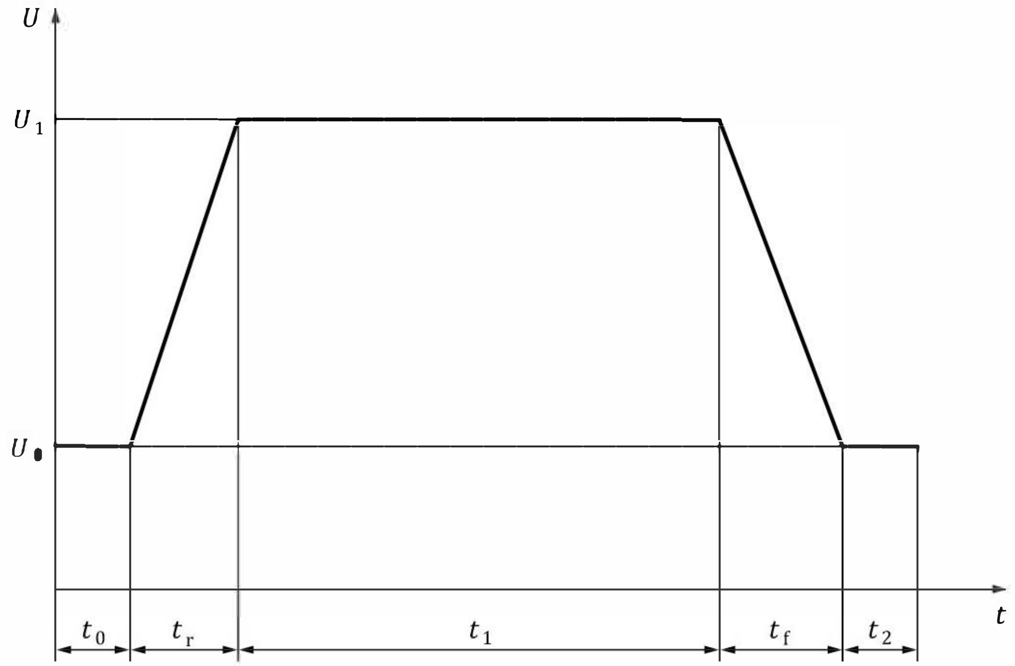
10.6 Test-06: long term overvoltage

10.6.1 Purpose

This test checks the robustness of the component against a long-term overvoltage.

10.6.2 Test

Set the supply voltage at the relevant inputs of the DUT as defined in Figure 9 and Table 11.



Key

t time

U test voltage

Figure 9 — Test profile for test-06: long term overvoltage

Table 11 — Test parameters for test-06: long term overvoltage

Operating mode	2.4
U_1	60 V
U_0	52 V
t_0	≥5 s
t_r	0,1 s (80 V/s)
t_1	60 min
t_f	0,1 s (80 V/s)

Table 11 *(continued)*

t_2	≥5 s
T_{test}	T_{max} – 20 K
Number of cycles	1

During the test, the full load request transmitted to the component shall be maintained.

10.6.3 Requirement

All DUT functions shall comply with the definition of the selected functional category defined in Table 2.

10.7 Test-07: overvoltage with consumer components which may supply electrical energy

10.7.1 Purpose

This test is applicable to all components which not only consume electrical energy but may also supply electrical energy with no possibility of switching off this electrical energy supply without negative effects occurring in the vehicle.

Such components shall either be capable of self-limiting their output supply voltage or systematic countermeasures shall be applied to the vehicle in order to ensure compliance with this specification.

This test does not apply to components that supply electrical energy as a primary function, such as generators. For these components test-04 is applicable.

The purpose of this test is to verify that the component alone complies with the voltage range specified here and is applicable where systematic countermeasures at the vehicle level are not used to ensure compliance.

The test emulates a condition where such a component supplies energy into the vehicle 48 V power supply system which can only be absorbed by the power network simulation and subsequently leads to an undesired increase in system voltage.

10.7.2 Test

10.7.2.1 General

The maximum electrical current which the DUT can draw and the maximum electrical current which the DUT can supply, in addition to the maximum times for which these consumption and supply conditions may occur, shall be defined and agreed with the customer before the test is performed.

10.7.2.2 Test part 1, without sink

An electrical power source which is capable of supplying the agreed maximum electrical current consumption of the DUT at the required voltage for the agreed duration of the test shall be used.

During this test, the electrical source shall not act as a sink when the DUT operates to supply electrical energy.

The DUT shall be operated in such a way that, with the supply voltage set to U_0, it is able to supply its maximum electrical current after t_0. t_0 depends on the characteristics of the component.

Figure 10 gives an example of a possible test setup for part 1, with the power network simulation and without sink.

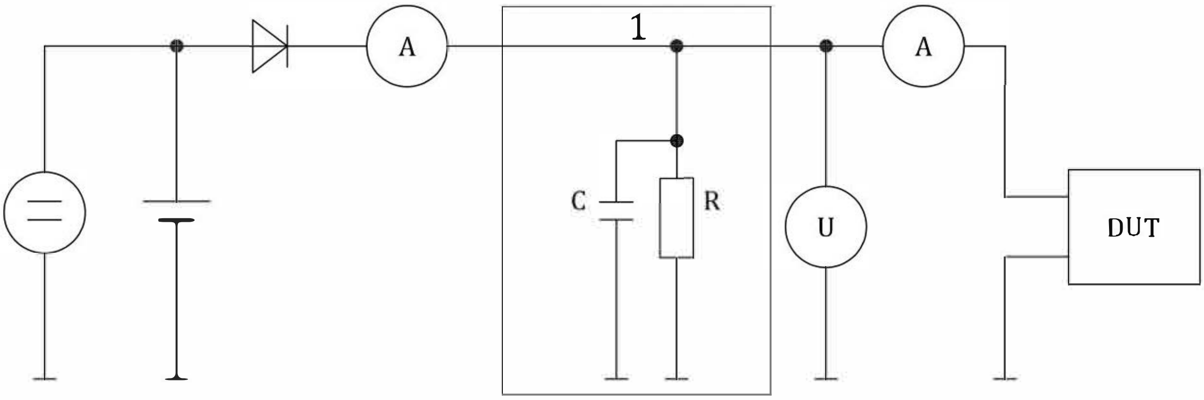
With reference to Table 12 and Figure 12, at the end of t_0, the operation of the DUT shall then be changed such that it immediately supplies electrical energy.

The DUT shall continue to operate in this state (as defined in Table 2) until the voltage at the DUT falls below the level U_2 again, but at least for test duration t_1.

The DUT current and the power supply system current shall be measured and documented during the test.

Following the end of the test cycle, it shall be immediately repeated until the required number of cycles have been completed.

The test shall be performed at each required test temperature.



Key

R resistor simulating vehicle power network resistance

C capacitor simulating vehicle power network capacitance

1 power network simulation

Figure 10 — Example of possible test setup for part 1, with the power network simulation and without sink

Table 12 — Test-07: test parameters for components that return electrical energy, part 1

Operating mode	refer to test procedure
T_{test}	T_{min}, T_{RT} and T_{max}
R	36 Ω
C	0,5 mF
U_0	52 V
t_0	>0 s (depending on the component)
t_1	300 ms
Number of cycles	3 cycles per value of T_{test}

NOTE *R* and *C* values can be changed to a value agreed between customer and supplier.

10.7.2.3 Test part 2, with sink and cut-off at maximum current

An electrical power system which is capable of supplying and absorbing the agreed maximum electrical current consumption of the DUT whilst maintaining the voltage U_0 at the terminals of the DUT for the duration of the test shall be used.

Figure 11 gives an example of a possible test setup for part 2, with the power network simulation and with sink.

With reference to Table 13 and Figure 12, the DUT shall be operated in such a way that, with the supply voltage set to U_0, it is able to supply its maximum electrical current after t_0.

At the end of t_0, the operation of the DUT shall then be changed such that it immediately supplies electrical energy. The DUT shall continue operating in this state (as defined in Table 2) until its maximum agreed supply current is reached.

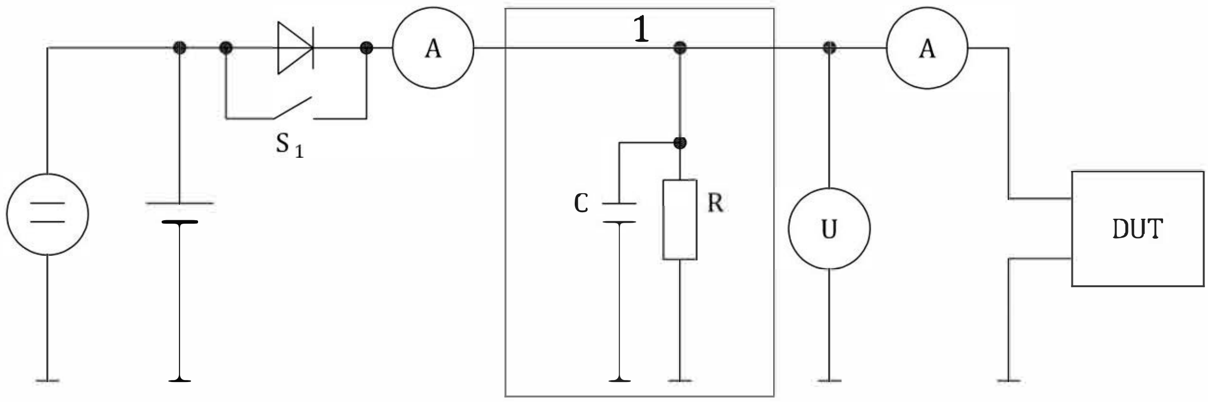
When the current supplied by the DUT reaches its maximum agreed value (during the rising voltage slope of Figure 12), absorption of the returned electrical energy by the power supply system shall be set to zero current within the switching time period t_{off}.

The DUT shall continue operating in this state (as defined in Table 2), until the voltage at the DUT falls below the level U_2 again, but at least for test duration t_1.

The DUT current and the power supply system current shall be measured and documented during the test.

Following the end of the test cycle, it shall be immediately repeated until the required number of cycles have been completed.

The test shall be performed at each required test temperature.



Key

S_1 switch

R resistor simulating vehicle power network resistance

C capacitor simulating vehicle power network capacitance

1 power network simulation

Figure 11 — Example of possible test setup for part 2, with the Power network simulation and sink

The switch shall be capable of breaking, without damage, the maximum current which may be supplied by the DUT.

The battery shall be specified and maintained in a state such that it is capable of absorbing the maximum power which may be supplied by the DUT without the voltage exceeding U_0.

Table 13 — Test parameters for test-07 for overvoltage with components that return electrical energy, part 2

Operating mode	refer to test procedure
T_{test}	T_{min}, T_{RT} and T_{max}
R	36 Ω
C	0,5 mF
t_{off}	≤100 µs
U_0	52 V

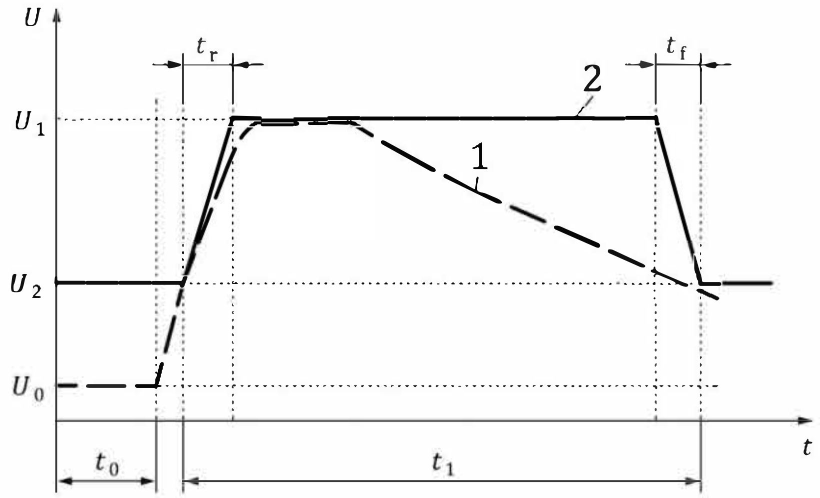
Table 13 *(continued)*

t_0	>0 s (depending on the component)
Number of cycles	3 cycles per value of T_{test}

NOTE *R* and *C* values can be changed to a value agreed between customer and supplier.

10.7.3 Requirements for part 1 and part 2

The maximum voltage level at the DUT shall not exceed U_1 and the time between exceeding the voltage level U_2 and falling below the voltage level U_2 shall be determined and shall not exceed t_1 as shown in Figure 12. Requirement parameters for test-07 part 1 and part 2 are defined in Table 14.



Key

t time

U test voltage

1 example of the test result of the component

2 limit

Figure 12 — Requirements Profile for test-07

Table 14 — Requirement parameters for test-07 components that return electrical energy, part 1 and part 2

U_1	58 V
U_2	54 V
t_r	≥160 µs (25V/ms)
t_f	≥160 µs (25V/ms)
t_1	300 ms

NOTE 1 The times t_r and t_f of the limit curve can be agreed between customer and supplier.

NOTE 2 This limit envelope is illustrated by Figure 12 where an example is also provided of an acceptable response which a DUT could provide when tested to this procedure.

All DUT functions shall comply with the definition of the selected functional category defined in Table 2.

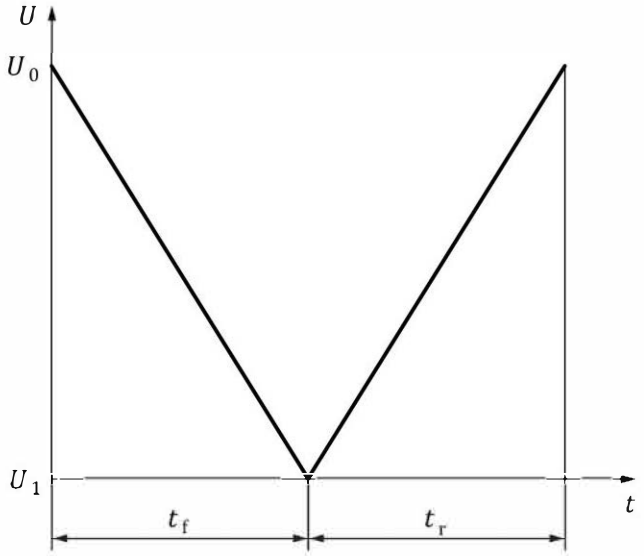
10.8 Test-08: decrease and increase of supply voltage

10.8.1 Purpose

This test is intended to check immunity of a component to decrease and increase of supply voltages.

10.8.2 Test

Set the supply voltage at the relevant inputs of the DUT as defined in Figure 13 and Table 15.



Key

t time

U test voltage

Figure 13 — Test profile for test-08: decrease and increase of supply voltage

Table 15 — Test parameters for test-08: decrease and increase of supply voltage

Operating mode	2.1 and 2.4
U_0	44 V
U_1	0 V
t_f	21 min (≈ 35 mV/s)
t_r	21 min (≈ 35 mV/s)
Number of cycles	1

10.8.3 Requirement

All DUT functions shall comply with the definition of the selected functional category defined in Table 2.

10.9 Test-09: voltage ripples

10.9.1 Purpose

This test is intended to check immunity of a component to ripples in the on-board system, caused, for example by a generator or a DC/DC converter.

It specifies a conducted voltage test method and procedure for determining the immunity of electronic components. The method is applied to each individual DUT on its power supply lines.

10.9.2 Test

10.9.2.1 General

Setup the test with reference to Table 16.

Table 16 — Test parameters for test-09: voltage ripples

Operating mode	2.2
Frequency range	f1: 10 Hz to 1 kHz f2: 1 kHz to 30 kHz f3: 30 kHz to 200 kHz
U_0	≥31 V, ≤54 V
Dwell time	≥2 s
Frequency step	logarithmic 2 %
Voltage ripple limit: U_{pp}	f1: 8 V ± 2 % f2: 6 V ± 2 % f3: 2 V ± 2 %
Current limit: I_{pp}	f1: 80 A f2: 15 A f3: 10 A
Requested test combinations	f1: U_0 = 35 V and U_0 = 50 V f2: U_0 = 34 V and U_0 = 51 V f3: U_0 = 32 V and U_0 = 53 V
Number of cycles	1 test sequence for each test combination

The power source shall be able to produce the requested ripple voltage and/or the currents in the specified frequency range.

Prior to starting this test, measure and record the impedance of the DUT at its 48 V supply terminals.

Connect an AC voltage measurement (e.g. oscilloscope with voltage probe) to the test signal generator output (loaded by the DUT) and an AC current measurement device (e.g. oscilloscope with current probe) and an AC voltage measurement (e.g. oscilloscope with voltage probe) to the DUT input as shown in Figure 14.

10.9.2.2 Reference Test

Before the test is pursued in operating mode 2.2, a reference test is applied in operating mode 2.3. In this operating mode the main input capacitance of the DUT shall be connected to the power supply.

The reference test determines the necessary voltage ripple U_R at the power supply which has to be applied to the DUT in order not to exceed the current limit Ipp for the applied excitation frequency.

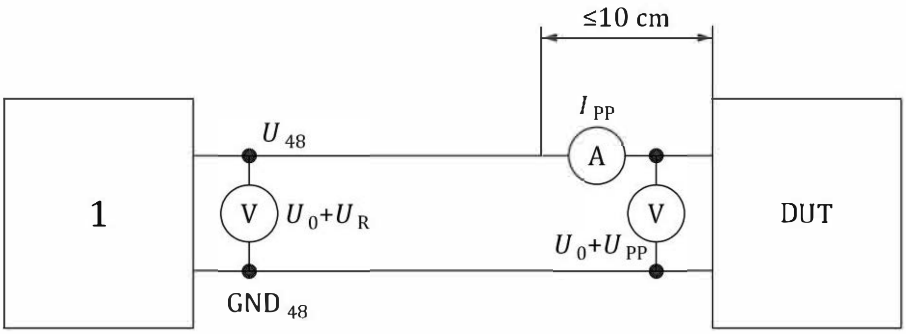
For the reference test, each frequency range is tested at the maximum and minimum voltage values given in Table 16 for U_0.

The power supply shall inject an AC voltage ripple U_R on top of U_0 which shall be progressively increased until either the maximum voltage ripple U_{pp} at the DUT or the maximum current limit I_{pp} is reached. The ascertained ripple voltages of U_R of the power supply for every frequency step shall be documented.

It is necessary to distinguish between U_R and U_{pp} due to the impedance of the cable harness and input impedance of the DUT. Therefore, U_R can be much higher than U_{pp}.

NOTE The input capacitance which is connected in operating mode 2.3 is very important for the reference test, because it mainly determines the current ripple during the reference test. If the architecture of the DUT features any switch which disconnects the input capacitance from the power supply, the reference test would not determine the correct voltage ripple U_R.

If the DUT featured a low pass input filter (e.g. EMC filter), the test may only have to be performed for frequencies where the filter of the DUT has a frequency response of more than -20 dB. An evidence shall be provided showing the frequency response of the input filter. Depending on the impedance of the DUT and the cable harness, too high and unrealistic values of U_R would be tested at higher frequencies. Therefore, performing the test until this threshold is considered sufficient.



Key

U_R AC ripple voltage at power supply

U_{PP} peak-to-peak AC voltage at DUT

I_{PP} peak-to-peak AC current at DUT

1 power supply

Figure 14 — Test setup for test-09 voltage ripple

10.9.2.3 Voltage ripple test

In order to perform the voltage ripple test, the ascertained voltage ripple U_R from the reference test for each frequency step is applied to the DUT in operating mode 2.2. It is not allowed to further reduce the voltage ripple U_R even if the current limit I_{pp} is now exceeded.

The setup of the test has to be the same as in the reference test (type and length of cable).

Record I_{PP} and U_{pp} during the voltage ripple test.

10.9.3 Requirement

All DUT functions shall comply with the definition of the selected functional category defined in Table 2.

The DUT impedance shall be measured before and after the test. In case the impedance deviation is bigger than the defined standard tolerance the test is failed corresponding to FS5.

10.10 Test-10: reinitialisation

10.10.1 Purpose

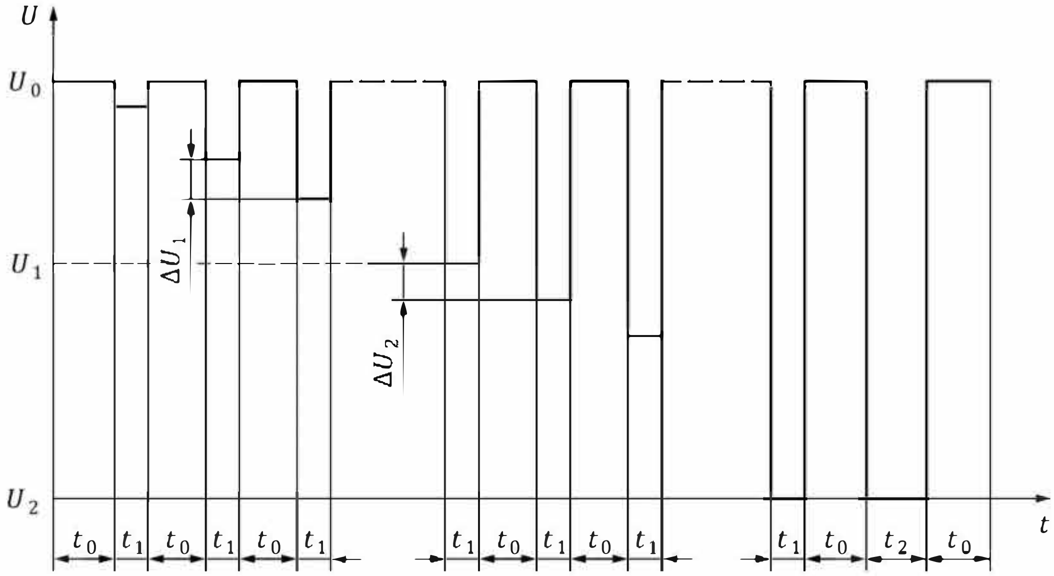
This test is intended to check the correct reinitialisation of the component after interruption of onboard power supply. This test shall only be performed on DUT's whose control logic (or parts thereof) is supplied by 48 V.

10.10.2 Test

Setup the test with reference to Table 17 and Figure 15.

Starting at U_0 with a voltage drop of 0 V and increasing voltage drop in steps of ΔU_1 till U_1.

After reaching U_1, then increasing the voltage drop in steps of ΔU_2 till U_2.



Key

t time

U test voltage

Figure 15 — Test profile for test-10: reinitialisation test

Table 17 — Test parameters for test-10: reinitialisation test

Operating mode	2.4
U_0	36 V
U_1	24 V
U_2	0 V
ΔU_1	2 V
ΔU_2	0,5 V
t_f	<100 ms
t_r	<100 ms
t_1	5 s
t_2	10 s
t_0	≥10 s, until the DUT becomes 100 % operational

NOTE t_f and t_r are not represented on Figure 15 in order to make it easier to understand the figure.

10.10.3 Requirement

At U_0, FS1 is required.

At voltage lower than U_0, the functional status shall be according to Table 2. If the DUT enters FS4, a restart of the DUT is mandatory before the next voltage dip.

10.11 Test-11: discontinuities in supply voltage

10.11.1Purpose

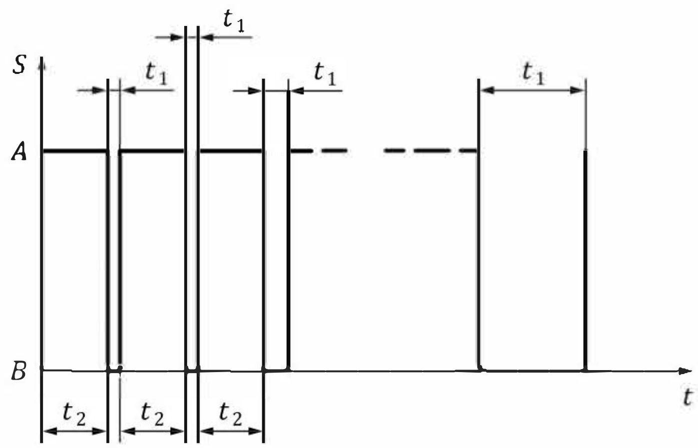
The behaviour of a component when subjected to interruption of supply of varying duration is tested. Examples for this occurrence may be short circuits, switching of loads, disconnecting of batteries and others.

This test applies to power consumers and not to power generators.

10.11.2Test

Setup the test with reference to Table 18 and Figures 16 and 17.

The duration of the voltage interruption increases by the increments given in Table 18. The resulting control signal for S_1 is shown in Figure 16.



Key

t time

S S_1 switch control signal

A switch closed

B switch open

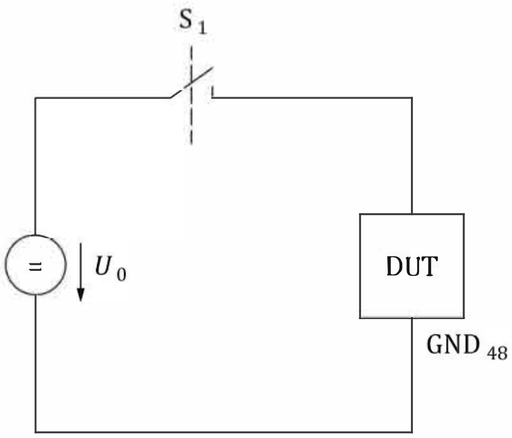
Figure 16 — Test profile for test-11: discontinuities in supply voltage

Table 18 — Test parameters for test-11: discontinuities in supply voltage

<table>
<tr><td>Operating mode</td><td colspan="2">2.3 and 2.4</td></tr>
<tr><td>R_i</td><td colspan="2">≤60 mΩ incl. switch S_1</td></tr>
<tr><td>U_0</td><td colspan="2">48 V</td></tr>
<tr><td rowspan="6">t_1</td><td colspan="2">The supply voltage of U_0 is interrupted for interval t_1, which shall increase during the test in the following sequence:</td></tr>
<tr><td>Range of t_1</td><td>Increment in t_1 following each interruption</td></tr>
<tr><td>100 µs ≤ t_1 < 1 ms</td><td>100 µs</td></tr>
<tr><td>1 ms ≤ t_1 < 10 ms</td><td>1 ms</td></tr>
<tr><td>10 ms ≤ t_1 < 100 ms</td><td>10 ms</td></tr>
<tr><td>100 ms ≤ t_1 < 2 s</td><td>100 ms</td></tr>
</table>

Table 18 *(continued)*

t_2	≥10 s, until the DUT becomes 100 % operational according to specification
switch reaction time	≤10μs



Key

S_1 switch on 48 V supply

Figure 17 — Test setup for test-11: discontinuities in supply voltage

Two reference measurements shall be performed and documented with the test set-up given in Figure 17. One reference measurement with a 1 kΩ (±5 %) resistor and the second with a 10 Ω (±5 %). The resistors are used in place of the DUT. The reference measurements enable the reaction time of the switch to be verified as acceptable before the full test is performed. The resistors used shall, therefore, have low inductance. After the reaction time performance of the switch has been verified, the DUT may then be tested with the full set-up as shown in Figure 17.

10.11.3 Requirements

All DUT functions shall be FS1 for durations t_1 ≤ 100 μs and shall be FS3 for durations t_1 > 100 μs or as agreed between customer and supplier. If the DUT enters FS4, a restart of the DUT is mandatory before the next voltage dip.

The time duration of t_1 after which the DUT departs from FS1 shall be recorded.

10.12 Test-12: ground loss

10.12.1 Purpose

This test simulates a scenario in which a 48 V component has lost its ground connection(s). The ground loss testing is applicable for any 48 V device with interfaces (e.g. CAN/LIN/FlexRay bus or other analogue or digital signal circuits) connected to the 12 V/24 V electrical system. $U_{12/24}$ and $GND_{12/24}$ terminals are optional terminals and as such shown with dashed lines in Figure 18.

The test is divided into several parts in order to cover relevant situations as they may occur in the later vehicle application independently of the concrete DUT implementation. In addition, there is one reference test defined, which is proving the functionality of communication failure detection mechanisms of the test set-up as defined in Figure 18 and in 10.12.2.

In case of a component having a separate $GND_{12/24}$ connector, the risk of losing both ground connections can be managed in two ways:

— Double ground loss test is not needed if there is a protection mechanism in the system to protect it after first ground loss.

— Double ground loss test is mandatory if there is no protection mechanism in the system to protect it after first ground loss.

10.12.1.1 Scope of reference test

This test shall document the effectiveness of the test set-up according to Figure 18 and Table 20 whether communication faults on the bus systems or signal lines in conjunction with TN_1 and TN_2 are properly detected by the test system. Detailed requirements regarding TN_1 and TN_2 are defined in 10.12.1.3.

10.12.1.2 Scope of loss of GND tests

The test cases for the different GND loss conditions are defined in Table 19 and encompass the following relevant vehicle operational cases:

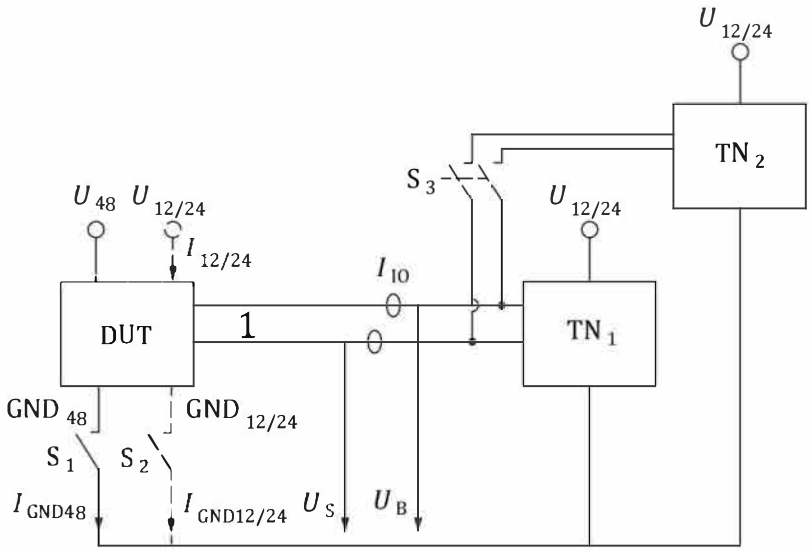
— loss of one GND connection while DUT, TN_1 and TN_2 are communicating. DUT is actively sending (operating mode 2.4), see B.2. An essential element of this test is making sure that there is active communication between DUT, TN_1 and TN_2 from the beginning of the GND disconnect. DUT shall send from the beginning of the GND disconnect with maximum repetition rate. Since a DUT may have two separate GND connections, there are two related tests defined, one with opening GND_{48} and one with opening $GND_{12/24}$;

— loss of one GND connection while the DUT is in a low power/non-operational state, representing vehicle parking situations (operating mode 2.1). In such state a DUT may have disabled major parts of the hardware to save quiescent current. A loss of GND in this phase shall not cause unwanted effects. Since a DUT may have two separate GND connections, there are two related tests defined, one with opening GND_{48} and one with opening $GND_{12/24}$;

— recovery from GND loss situation representing the repair activity starting-up the DUT again with proper GND connections.

Table 19 — Overview of test-12: ground loss

Ref.	Test part	Failure case	Comment
10.12.1.3	Part 1	Reference test, communication failure	Proves effectiveness of communication monitoring in test set-up.
10.12.1.4	Part 2	Loss of GND_{48}	During operating mode 2.4: Impact on vehicle communication (between DUT, TN_1 and TN_2) when loss of GND_{48}. Impact on voltages and currents. During operating mode 2.1: Impact on voltages and currents.
10.12.1.5	Part 3	Loss of $GND_{12/24}$	During operating mode 2.4: Impact on vehicle communication (between DUT, TN_1 and TN_2) when loss of $GND_{12/24}$. Impact on voltages and currents. During operating mode 2.1: Impact on voltages and currents. Applicable only for DUT with $GND_{12/24}$ connector.



Key

U_S	voltage differential between analogue/digital signal and ground
U_B	voltage differential between communication bus signal and ground
U_{48}	48 V supply voltage
$U_{12/24}$	12 V supply voltage
I_{GND48}	current on 48 V ground
$I_{\text{GND12/24}}$	current on 12 V/24 V ground
I_{IO}	current on each bus and input/output line
S_1	switch in 48 V ground
S_2	switch in 12 V/24 V ground
S_3	switch in TN_2 analogue/digital signal and digital bus lines
TN_1	terminal network 1, see description below
TN_2	terminal network 2, see description below
1	bus signal

Figure 18 — Test setup for test-12: ground loss

TN_1 and TN_2 are network components representing the relevant communication bus or signal lines. Their interface components comply with the requirements of the relevant communication standard particularly in terms of impedance at their interface. The complete description of those networks shall be given in the test plan, and as agreed between customer and supplier.

With all switches (S_1, S_2 and S_3) closed there shall be proper communication between the two TN components and the DUT with following requirements:

- bus load of at least 50 % generated by the two TN components, both TN are contributing with at least 25 % each resulting in bidirectional communication;
- a message counter shall be implemented within both TN devices and messages shall be verified using for example CRC (cyclic redundancy check) mechanism;
- any errors in communication between TN_1 and TN_2 are immediately identified, recognized and logged. The effectiveness of monitoring shall be demonstrated and documented by opening S_3.

Table 20 — Test parameters for test-12: ground loss

Operating mode defined for test part separately	2.1 and 2.4
U_0	48 V
Optional supply voltage $U_{12/24}$	U_N
t_1	1 min

10.12.1.3 Test part 1: reference test to confirm communication monitoring

This test is intended to prove that the test, when set-up according to Figure 18, can detect communication problems between TN_1 and TN_2 during the later loss of GND tests. Therefore, a dedicated switch, S_3, allows a communication failure to be intentionally provoked. This reference test shall be executed successfully at least once before the dedicated loss of GND tests are performed.

All switches (S_1, S_2 and S_3) are closed and all the components (DUT, TN_1, TN_2) are running according to 10.12.2 in operating mode 2.4. Communication between DUT, TN_1 and TN_2 is working and monitored as defined in 10.11.2. DUT is sending DUT specific messages as agreed between customer and supplier.

— Open switch S_3 whilst TN_1 and TN_2 are communicating with each other and observe whether the test system detects the missing communication between TN_1 and TN_2.

— After t_1, close S_3 and observe whether the communication between TN_1, TN_2 and the DUT recover to the correct expected operation or not.

The communication between the DUT and TN_1 shall not be affected by the opening of S_3.

10.12.1.4 Test part 2: loss of GND_{48}

This test is intended for testing the impact of GND_{48} ground loss of the DUT during active communication between DUT, TN_1 and TN_2. It is applicable for all devices as defined in 10.12.1.

Apply test as described below in both operating mode 2.4 and operating mode 2.1:

— all switches (S_1, S_2 and S_3) are closed and all the components (DUT, TN_1, TN_2) are running according to chapter 10.12.2 in correct operating mode (2.4 or 2.1);

— if operating mode is 2.4: communication between TN_1 and TN_2 is working and monitored as defined in 10.12.2; DUT is sending DUT specific messages as agreed between customer and supplier;

— if operating mode is 2.1: communication between TN_1 and TN_2 is stopped;

— in case of a separate $GND_{12/24}$ connection the current $I_{GND12/24}$ is monitored;

— in case of a separate $U_{12/24}$ connector the current $I_{12/24}$ is monitored;

— the potential of U_S and U_B and currents in bus and signal lines are monitored;

— open S_1. Monitor U_S and U_B. Also monitor communication[1)] between DUT, TN_1 and TN_2 and the applicable currents. In case of system ground loss protection mechanism, check if the DUT reacts as specified by the customer.

— Additional test in case of a separate $GND_{12/24}$ connector:

  if the system does not include ground loss protection mechanism, open S_2 additionally in order to test a total ground loss and its effect on TN_1, TN_2 and the DUT. S_2 to be opened time t_1 after S_1 was opened;

1) In operating mode 2.1 there is no communication between DUT and TNx.

— if operating mode is 2.1: re-activate and confirm the communication between TN_1 and TN_2 while the switch/switches is/are still opened;

— after the time t_1, close all switches again and observe U_S and U_B as well as the communication between TN_1 and TN_2 and the applicable monitored currents until the DUT operates as specified.

10.12.1.5 Test part 3: loss of $GND_{12/24}$

This test is intended for testing the impact of $GND_{12/24}$ ground loss of the DUT during active communication between DUT, TN_1 and TN_2. It is applicable for devices according to 10.12.1 definition with separate $GND_{12/24}$.

— all switches (S_1, S_2 and S_3) are closed and all the components (DUT, TN_1, TN_2) are running according to 10.12.2 in correct operating mode (2.4 or 2.1);

— if operating mode is 2.4: communication between DUT, TN_1 and TN_2 is working and monitored as defined in 10.12.2; DUT is sending DUT specific messages as agreed between customer and supplier;

— if operating mode is 2.1: communication between TN_1 and TN_2 is stopped;

— in case of a separate $U_{12/24}$ connector the current $I_{12/24}$ is monitored;

— the potential of U_S and U_B and currents in bus and signal lines are monitored;

— open S_2. Monitor U_S and U_B as well as the communication between TN_1 and TN_2 and the applicable currents. In case of system ground loss protection mechanism, check if the DUT reacts as specified by the customer.

— Additional test:

  if the system does not include ground loss protection mechanism, open S_1 additionally in order to test a total ground loss and its effect on TN_1, TN_2 and the DUT. S_1 to be opened time t_1 after S_2 was opened;

— if operating mode is 2.1: reactivate and confirm the communication between TN_1 and TN_2 while the switch/switches is/are still opened;

— after t_1, close all switches again and monitor U_S and U_B as well as the communication between DUT, TN_1 and TN_2 and the applicable currents until the DUT operates as specified.

10.12.2 Requirements

10.12.2.1 Part 1

— The test system shall record, by means of a message counter, how many failed attempts made by TN_2 at signal transmission occurred during the phase when switch S_3 was open. This value shall be documented and reported.

— The test system shall detect that communication between TN_1 and the DUT is still operating correctly while the switch S_3 is open and this shall be documented and reported.

— After closure of S_3 the test system shall verify that the communication between the DUT, TN_1 and TN_2 is fully functional and without any communication errors occurring. This shall be documented and reported.

10.12.2.2 Parts 2 and 3

— Functional status during test: FS3. Functional status before and after test: FS1 (as defined for operating mode 2.4 and 2.1).

— It shall be documented that the DUT was in correct operating mode (2.4 or 2.1) and, if operating mode 2.4, actively sending whilst S_1 or S_2 was opened.

— The voltages U_S and U_B shall stay below the maximum supply voltage of ISO 16750-2 and related voltage limits defined for the applicable bus systems like CAN/LIN/FlexRay at any time.

— The communication between TN_1 and TN_2 shall not be disturbed during and after the test but communication of the DUT may be discontinued while S_1 or S_2 is open.

— The observed current in bus and signal lines shall not exceed at any time the limits given in bus and signal communication specifications, if available, and shall not increase by more than 100 mA (relative to the current measured in reference test) if no specifications are available.

— In case of a separate $GND_{12/24}$ connection the observed $I_{GND12/24}$ current shall not exceed its specified maximum value and shall not increase by more than 200 mA (relative to the current measured in reference test).

— In case of a separate $GND_{12/24}$ connection and a system ground loss protection mechanism, check if the DUT reacts as specified by the customer.

— In case of a separate $U_{12/24}$ connector, the voltage shall stay below the maximum supply voltage of ISO 16750-2. The observed $I_{12/24}$ shall not show any negative current of more than 1 mA.

NOTE 1 Actively sending means the DUT is actively communicating with a maximum repetition rate. For detailed information, see example for CAN in Annex B.

NOTE 2 The reasons for current limits in the requirements for parts 2 and 3 are to limit the risks on the rest of the vehicle.

10.13 Test-13: fault current

10.13.1 Purpose

The fault current resistance of a component with connections to both vehicle power supplies (12 V/24 V and 48 V) is examined.

The test applies if there is no protection mechanism in the system that reacts to protect it after a first ground loss as described in test-12 (ground loss).

This test ensures the robustness required in 9.3 (a single failure shall not cause a short circuit between the 48 V supply and the 12 V/24 V supply).

This test should ensure that no 12 V/24 V component will be damaged by a fault current of a 12 V/24 V/48 V component even in the case of complete (12 V/24 V and 48 V) ground loss.

This test applies only to components with interfaces to a 12 V/24 V system, such as communications, PWM or digital switched circuits. If the DUT has only connections to the 48 V electrical system, this test is not applicable to it.

10.13.2 Test

Setup the test with test parameters as defined in Table 21 for both option 1 and option 2.

Option 1:

The DUT is connected to the test apparatus as shown in Figure 19 but with all 12 V/24 V pins, (communication and I/O), also shorted together. A test voltage U_0 is applied for a duration of t_0 between the 48 V supply and the short-circuited 12 V/24 V pins.

The current flowing through the DUT shall be measured and documented.

If the requirement for test option 1 cannot be met, then test option 2 shall be performed.

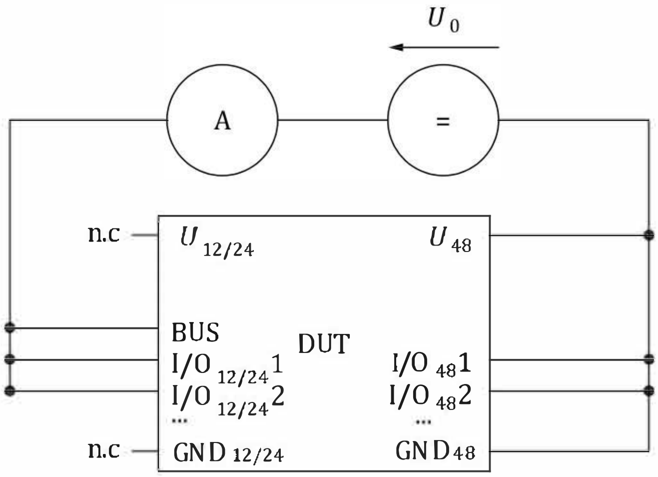


Figure 19 — Test setup for test-13: fault current — Option 1

Option 2:

The DUT is connected to the test apparatus as shown in Figure 20. All 48 V pins (supply and I/O) are connected with each other (short circuited). A test voltage of U_0 is applied for a duration t_0 between the 48 V supply and each pin (communication and I/O) of the 12 V/24 V supply systems.

The current then flowing through the DUT shall be measured and documented.

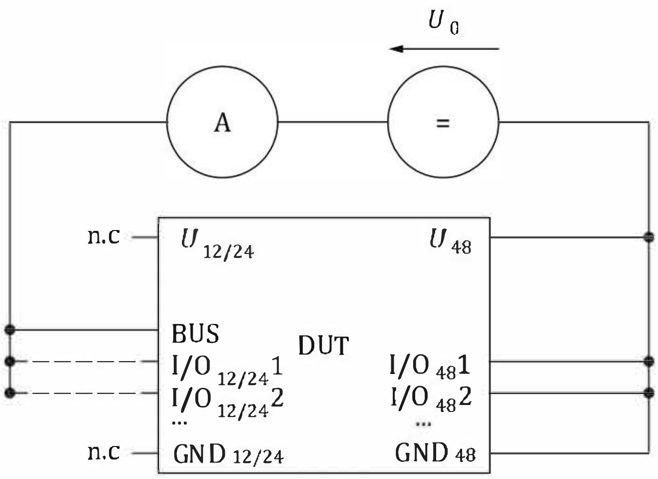


Figure 20 — Test setup for test-13: fault current — Option 2

Table 21 — Test parameters for test-13: fault current

U_0	70 V
t_0	10 min

10.13.3 Requirement

Test option 1:

The combined current drawn by the short-circuited pins (communication and I/O), of the 12 V/24 V and the 48 V pins shall be $|I| \leq 10\ \mu A$.

Test option 2:

The current drawn by each pin (communication and I/O), of the 12 V/24 V and the 48 V pins shall be $|I| \leq 10\ \mu A$.

10.14 Test-14: ground offset

10.14.1 Purpose

For components connected by communication or signal lines, potential differences between the individual supply inputs may occur. It shall be ensured that the functionality of the component and the communication or signal line is not influenced by a potential difference to ground.

The components shown in Figure 21 as "other 12 V/24 V components" are virtual components representing the relevant communication bus.

Their interface components shall comply with the requirements of the component specifications.

10.14.2 Test

If the DUT has several voltage and ground connections for the 48 V electrical system, the test shall be performed individually for each connection point.

Table 22 — Test parameters for test-14: ground offset

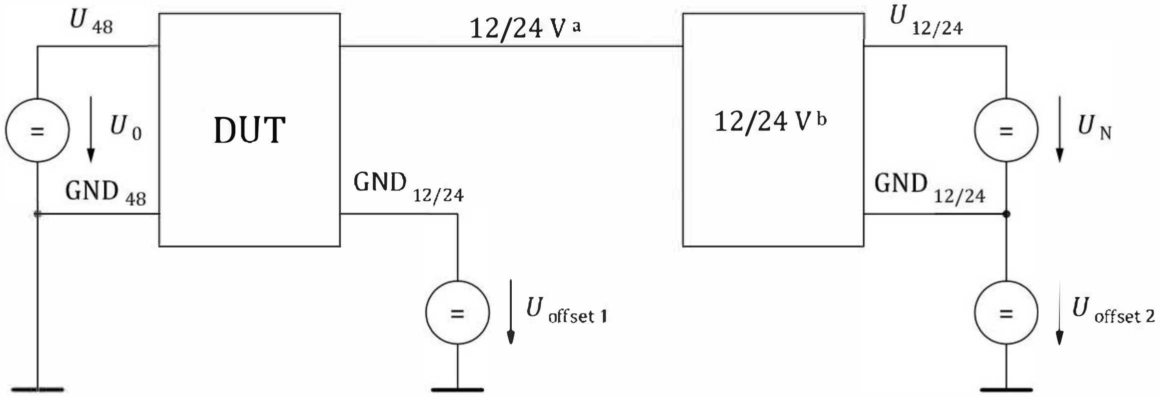
Operating mode	2.4
U_0	36 V and 52 V

Depending on the ground connections of the DUT, either test setup 1 (see Figure 21) or test setup 2 (see Figure 22) shall be chosen.

Use test parameters as defined in Table 22 for both test setup 1 and test setup 2.

Test setup 1:

Setup a test scenario as shown in Figure 21 and follow the test steps in Table 23.



a Communication or signal lines to 12/24 V component.

b Other 12/24 V component.

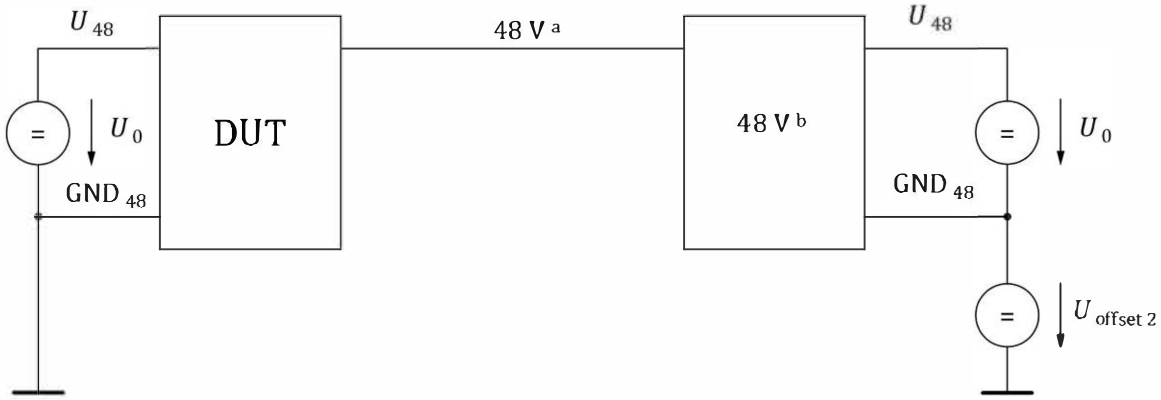
Figure 21 — Test setup for a DUT with a 12 V/24 V ground connection for test-14

Table 23 — Test parameters for test setup 1

Test	U_0	$U_{offset\ 1}$	$U_{offset\ 2}$
1.		0 V	0 V
2.		+1 V	0 V
3.		−1 V	0 V
4.	36 V	+1 V	+1 V
5.		+1 V	−1 V
6.		−1 V	+1 V
7.		−1 V	−1 V
8.		0 V	0 V
9.		+1 V	0 V
10.		−1 V	0 V
11.	52 V	+1 V	+1 V
12.		+1 V	−1 V
13.		−1 V	+1 V
14.		−1 V	−1 V

Test setup 2:

Setup a test scenario as shown in Figure 22 and follow the test steps in Table 24.



a Communication or signal lines to 48 V component.

b Other 48V component.

Figure 22 — Test setup for a DUT without a 12 V/24 V ground connection for test-14

Table 24 — Test parameters for test setup 2

Test	U_0	$U_{offset\ 2}$
1.		0 V
2.	36 V	+1 V
3.		−1 V
4.		0 V
5.	52 V	+1 V
6.		−1 V

10.14.3 Requirement

All DUT functions shall comply with the definition of the selected functional category defined in Table 2.

10.15 Test-15: short circuit in signal line and load circuit

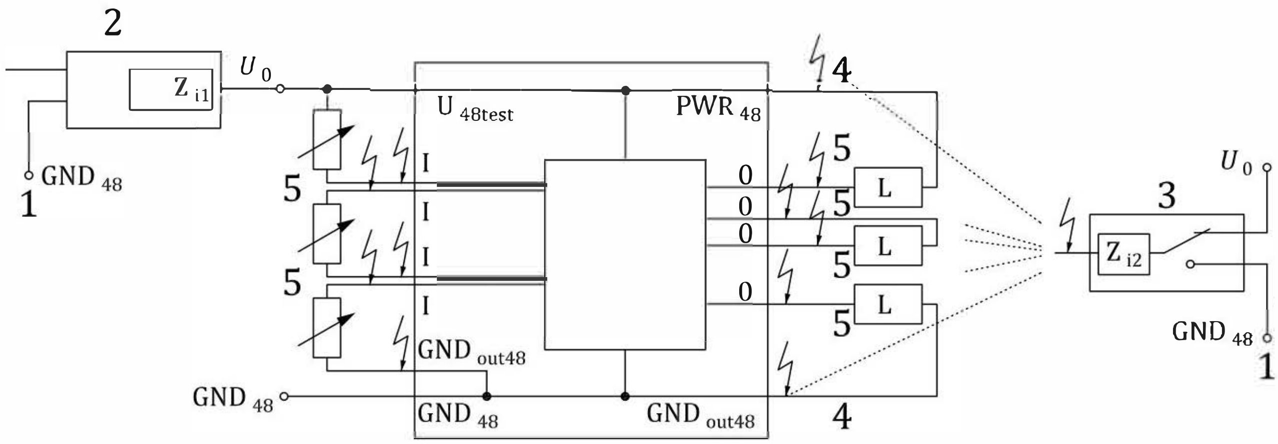
10.15.1 Purpose

This test simulates single failures occurring by short circuits between different 48 V input and 48 V output lines which may be caused for example by wiring harness problems like short circuits of supply lines and ground, for example by screws or sharp edges cutting through the wire insulation.

10.15.2 Test

Setup a test scenario as defined in Figure 23 and Table 25.

The power supply used for the test shall be able to supply the short circuit currents expected from the test.



Key

1 ground

2 power supply

3 short circuit generation

4 non-protected power output or direct ground connection

5 other input/outputs

Figure 23 — Test setup for test-15: short circuit in signal line and load circuit

Table 25 — Test parameters for short circuit in signal line and load circuit

Operating mode	2.3 and 2.4
U_0	36 V and 52 V
t_1	60 s
Source impedance of 48 V supply Z_{i1}	≤0,02 Ω
Short circuit impedance Z_{i2}	≤0,02 Ω

The assumption is made that fuses included in harnesses are generally used to protect the vehicle harness, and not the DUT. Therefore, tests shall be performed on the various lines of the DUT without using any fuse included in the test harness. The power supplies used for the test shall be able to deliver the expected short circuit currents to the component. In case of short circuit on a non-protected power output or direct ground connection (see Figure 23), assumption is made that the DUT will fail before the supply which may limit the current.

10.15.3 Procedure

Test four cases:

U_0 = 36 V, operating mode 2.3

U_0 = 52 V, operating mode 2.3

U_0 = 36 V, operating mode 2.4

U_0 = 52 V, operating mode 2.4

Connect the DUT to the power supply and the short circuit generation device through harnesses. Section of wiring shall be representative of the real use, and length of wiring shorter than 1 m. In order to ensure the safety of the test setup, a fuse could be added between the power and the DUT. Fuse characteristics shall be specified in the test plan before testing and agreed between the supplier and the customer.

Individually short circuit each of the 48 V input or output pins of the DUT to U_0 for time period t_1.

Individually short circuit each of the 48 V input or output pins of the DUT to GND_{48} for time period t_1.

Only accessible input and output connectors are tested.

The tests shall be performed with activated and non-activated outputs.

10.15.4 Requirements

For the purpose of this test, the DUT input/output lines shall be classified into several categories.

Non-protected power output or direct ground connection:

— non-protected power output: output which delivers power for another component, without any electronic power management. Design implies that it may be damaged in case of short circuit;

— ground connection which are directly connected to a ground input. Design implies that it may be damaged in case of short circuit.

Other input/outputs, which include as examples:

— protected power output: output which delivers power for another component, including active electronic components which shall limit and/or stop the current in case of short circuit;

— signal line: input/output line which delivers no significant current (e.g. sensor). Expectation is that electronic serial component ensures enough current limitation in case of short circuit.

The classification for each line shall be specified in the test plan before testing and agreed between the supplier and the customer.

The following functional status shall be achieved for a successful test outcome:

— non-protected power output or direct connection to ground: FS5;

— other input/ outputs: FS3.

10.16 Test-16: quiescent current

10.16.1 Purpose

When operating in quiescent mode (key off mode) the component is expected to minimise its electrical current consumption.

This test does not encompass the measurement of current due to short term, “after-run” functions which, if required by the component, shall be defined as part of the key parameters included within the specification.

This test enables the minimum current that will be drawn by the component and also the current which it will draw if it is required to periodically wake up to perform an operation during the quiescent phase to be measured.

By using these values and also the values of operation time for each current draw, the mean value of the quiescent current which will be drawn by the component will be calculated.

If not otherwise agreed between the supplier and the vehicle manufacturer this test shall apply to all components which are permanently supplied at 48 V.

10.16.2 Test

Setup a test scenario as defined Table 26.

Table 26 — Test parameters for test-16: quiescent current

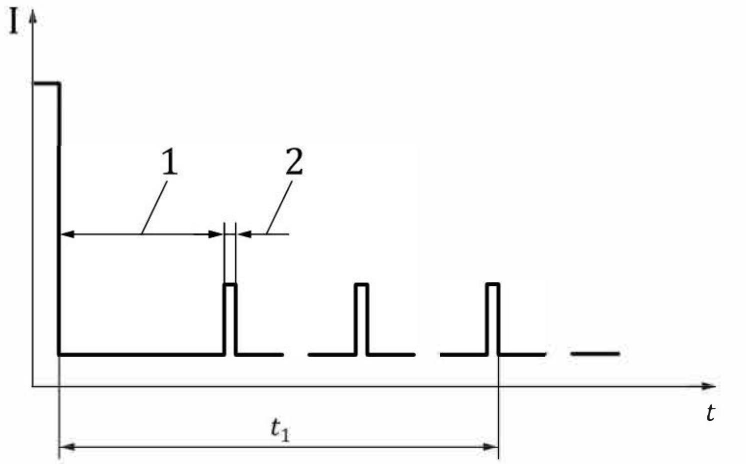
Operating mode	2.1
$U_{[illegible]}$	48 V
T_{test}	T_{min}, 40 °C
t_1	12 h plus the time to reach end of last wake up period

— The component shall first be configured such that it enters and remains in quiescent state.

— If the component is required to periodically wake up and perform defined functions then any external conditions or signals required to ensure this occurs shall be provided.

— The current shall be measured with a frequency of 1 Hz for a minimum of 12 h.

— The measurement period shall include at least one wake state and shall include an equal number of sleep and wake states as illustrated by the example shown in Figure 24.



Key

t_1 time (h)

I current (mA)

1 sleep

2 wake

Figure 24 — Example graph of quiescent test current measurement

— The value of current recorded for this test shall be integrated as shown below to obtain the average value of quiescent current, I_q.

$$I_q = \frac{1}{t}\int_0^t I(t)dt$$

10.16.3Requirements

The target for all DUTs is the lowest possible quiescent current.

The test shall be performed separately for both test temperatures.

At T_{min} and 40 °C, the value of I_q shall be ≤0,1 mA.

Annex A
(informative)

Example of functional status and functional categories

A.1 Example of functional status

For a component, the steps needed to define the functional status of a function that is required to be evaluated using this specification are as follows:

1) define relevant performance index as a function of the controlling parameter;

2) define min. and max. acceptable performance for nominal range;

3) FS1 when component provides a performance in the min./max. range;

4) FS2 when the nominal performance is not assured but component is still working;

5) FS3 component might not be working but can restart automatically;

6) FS4 no automatic restart.

A.2 Examples for functional categories

A.2.1 Example A for different functional categories (FC III to FC I) of a DUT

A Belt Starter Generator (BSG) contains at least four primary functions. A starter function, a boost function, a generator function and communication.

— The starter function is an example of functional category FC III:

One relevant performance index for this function could be the available power.

The nominal performance as agreed between the customer and supplier is expected between 24 V and 52 V (FS1). This nominal performance can include a reduction as a function of engine speed or due to thermal limitations.

When the voltage is in the range of 52 V to 58 V the performance might be further limited to protect the component from damage (FS2).

Finally, when the voltage is above or below these levels the component might enter a self-protection mode and stop. In order to ensure good availability when the overvoltage or the undervoltage is resolved the component will reactivate automatically (FS3).

— The boost function is an example of functional category FC II:

One relevant performance index for this function could be the available power.

The nominal performance as agreed between the customer and supplier is expected between 36 V and 52 V (FS1). This nominal performance can include a reduction as a function of engine speed or due to thermal limitations.

When the voltage is in the range of 36 V to 24 V or 52 V to 58 V the performance might be further limited to protect the component from damage (FS2).

Finally, when the voltage is above or below these levels the component might enter a self-protection mode and stop. In order to ensure good availability when the overvoltage or the undervoltage is resorbed the component will reactivate automatically (FS3).

— The communication is an example of functional category FC I:

The communication shall work between 24 V and 54 V (FS1). For short term overvoltage even up to 70 V (FS1). Below 24 V the communication may stop (FS3).

The generator function is not fully applicable with this document, as it acts as energy source and needs to be tested by other means so that it complies with the voltage range defined in this document.

A.2.2 Example B for functional category FC IV

Heater function of a 48 V PTC heater (example of functional category IV):

One relevant performance index for a PTC heater could be the heating power.

When it is FS1, the heater shall be able to provide at least 1 000 W. Assuming it shall be FS1 throughout the nominal range from 36 V to 52 V, then it might provide 1 000 W at 36 V and provide a higher output at higher voltages, or it could have a controller to give a constant 1 000 W over the entire nominal range.

As the voltage drops into the lower transitory voltage range, the heating power would likely drop to FS2, as it would likely provide an output less than 1 000 W.

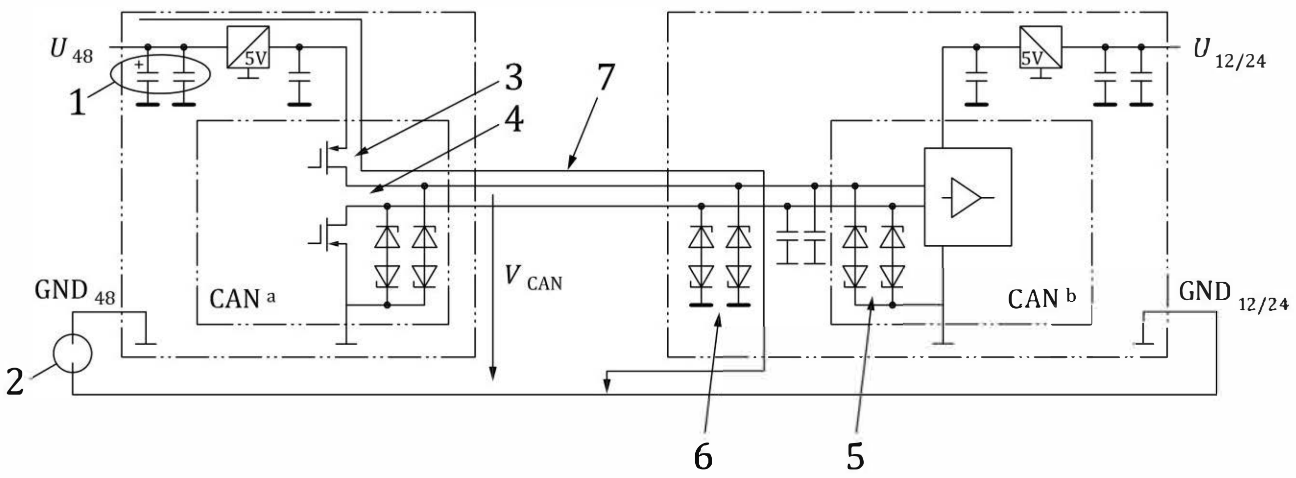
Annex B
(informative)

Loss of GND_{48} using the example CAN communication

B.1 Rationale

After the event of loss of GND_{48} the MCU and CAN transceiver continue to operate as long as the on-board supply voltage is sufficient. Due to the discharge of the internal buffer capacitors increases the internal ground voltage (with reference to $GND_{12/24}$) in the 48 V component. As a result, the voltage on the CAN outputs increases, too.

The loss-of- GND_{48} event is critical while the 48 V component drives CAN dominant, because during CAN dominant output the internal CAN output resistance is low. In the worst case, this scenario could cause a CANH voltage (see V_{CANH} in Figure B.1) close to U_{48} with reference to $GND_{12/24}$. As illustrated in Figure B.2, such voltage level can exceed the maximum rating voltage of a CAN transceiver and possibly trigger the on-chip ESD diodes. Furthermore, if discrete ESD diodes are applied, the typical breakdown and clamping voltage of the ESD diodes can be exceeded.

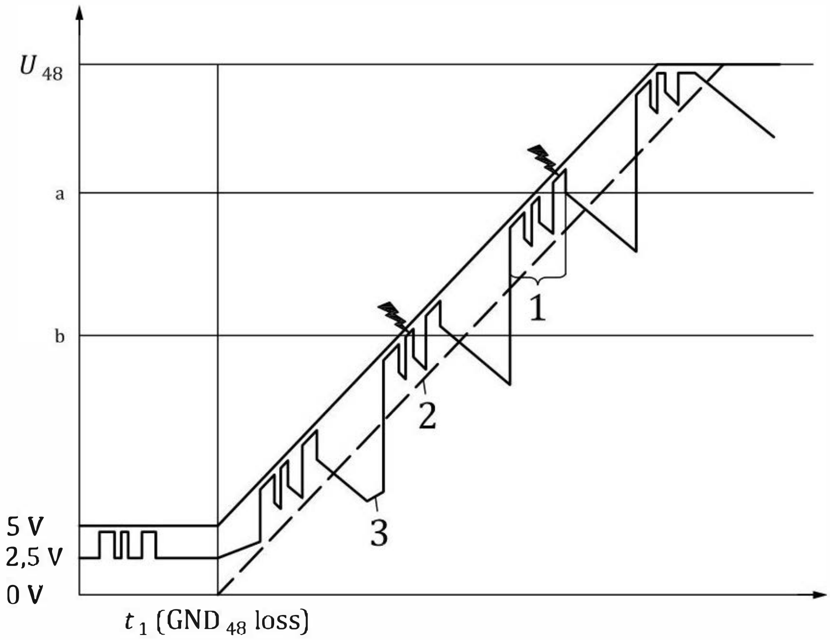


Key

1 stored energy
2 loss of ground
3 low resistance
4 CAN dominant transmission
5 on-chip ESD diodes
6 discrete ESD diodes
7 critical current path in this example
a CAN transceiver -transmitting.
b CAN transceiver -receiving.

Figure B.1 — Loss of GND_{48} example during active CAN sending

Figure B.1 is an illustration of the critical loss of GND_{48} scenario using the example CAN. It is not a test setup for test-12: ground loss. Instead in the test setup TN_1 and TN_2 shall be without any clamping device to measure the resulting voltage on CANH and CANL caused the DUT.



Key

t time

U test voltage

1 CAN frame

2 voltage at GND_{48} pin of DUT

3 voltage at CANH

Figure B.2 — Illustration of voltage at CANH during active CAN sending at the time of GND_{48} loss

B.2 Actively sending

The critical moment, CAN dominant transmission during the event of loss of GND_{48}, can be met when the DUT sends with maximum CAN repetition rate before, during and after the event of loss of GND_{48}. Transmitting with maximum repetition rate is referred to as 'actively sending' in test-12: ground loss.

For CAN interfaces the maximum repetition rate can be achieved when the acknowledge (ACK) for a CAN frame is not sent by the receiving CAN controller of the 12 V/24 V components (TN_1 and TN_2). CAN frames with acknowledge error are retransmitted automatically. For instance, the CAN acknowledge can be prevented by disconnecting the receiving CAN controller (TN_1 and TN_2) or using a receive-only mode within TN_1 and TN_2.

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