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Road Vehicles – Electrical disturbances by conduction and coupling – Part 4: Electrical transient conduction along shielded high voltage supply lines only

Véhicules routiers — Perturbations électriques par conduction et par couplage — Partie 2: Transmission des perturbations électriques par conduction uniquement le long des lignes d'alimentation

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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.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

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.

ISO 7637-4 was prepared by Technical Committee ISO/TC 22, *Road vehicles*, Subcommittee SC 32, *Electrical and electronic equipment*.

ISO 7637 consists of the following parts, under the general title *Road vehicles — Electrical disturbances by conduction and coupling*:

— *Part 1: Definitions and general considerations*

— *Part 2: Electrical transient conduction along supply lines only*

— *Part 3: Electrical transient transmission by capacitive and inductive coupling via lines other than the supply lines.*

— *Part 4: Electrical transient conduction along shielded high voltage supply lines only*

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Road Vehicles – Electrical disturbance by conduction and coupling – Part 4: Electrical transient conduction along shielded high voltage supply lines only

1 Scope

This part of ISO 7637 specifies test methods and procedures to ensure the compatibility to conducted electrical transients of equipment installed on passenger cars and commercial vehicles fitted with electrical systems with voltages higher than 60 V_{DC} and lower than 1.500 V_{DC} and a power-supply isolated from the vehicle-body. It describes bench tests for both, injection and measurement of transients. It is applicable to all types of electrical independent driven, road vehicles (e. g. battery electrical vehicle [BEV] or hybrid electrical vehicle [HEV], plugin hybrid vehicle [PHEV]).

Failure mode severity classification for immunity to transients is given in annex A.

This document describes tests with internal pulses generated by the dc high voltage modules. Internal pulses:

- Voltage ripple (Pulse A);
- Pulsed sinusoidal disturbances (Pulse B);
- Low frequency sinusoidal disturbances (Pulse C).

2 Normative references

The following referenced documents are indispensable for the application 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 7637-1: 2002, *Road vehicles -- Electrical disturbances from conduction and coupling -- Part 1: Definitions and general considerations*

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

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 7637-1 apply.

4 Test procedure

4.1 General

Methods for measuring the transient emission on shielded high voltage supply lines and test methods for the immunity of devices against transients are given. These tests, called "bench tests", are made in the laboratory.

The bench test methods will provide comparable and reproducible results between laboratories. They also give a test basis for the development of devices and systems and may be used during the production phase.

A bench test method for the evaluation of the immunity of a device against supply line transients may be performed by a test pulse generator; this may not cover all types of transients which can occur in a vehicle. Therefore, all described test pulses are typical pulses.

In special cases, it may be necessary to apply additional test pulses. However, some test pulses may be omitted, if a device, depending on its function or its connection is not influenced by comparable transients in the vehicle. It is part of the vehicle manufacturer's responsibility to define the test pulses required for a specific device.

Test pulse A is used to test equipment against transient voltages. The nearly rectangular shaped pulses include different harmonics and fast rise times. Due to the fact that the most energy is stored in the low frequency harmonics, pulse C can be used as a testing alternative for pulse A.
Test pulse B is used for testing high frequency oscillations, f.e. fast switching.

The DUT shall be operated under typical conditions which cause the maximum disturbance and sensitivity during the measurement. This is the worst case mode for every test and frequency step Conditions shall be agreed between vehicle manufacturer and supplier.

For all test setup adequate test equipment (e. g. connectors, cables, housings) shall be used.

4.2 Test temperature and test voltage

The ambient temperature during the test shall be (23 ± 5) °C.

The high voltage supply system can vary in a range from 60 V_{DC} up to 1.500 V_{DC}. The used voltage and its allowed tolerances of battery/generator in operation shall be agreed between vehicle manufacturer and supplier and shall be documented in the test plan.

4.3 Voltage transient emissions test along high voltage supply lines

This subclause defines a test setup to evaluate automotive electrical and electronic high voltage components (DUT) for conducted emissions of transients along battery fed or switched high voltage supply lines. A device under test (DUT) which is considered as a potential source of conducted disturbances shall be tested according to the procedure described in this clause.

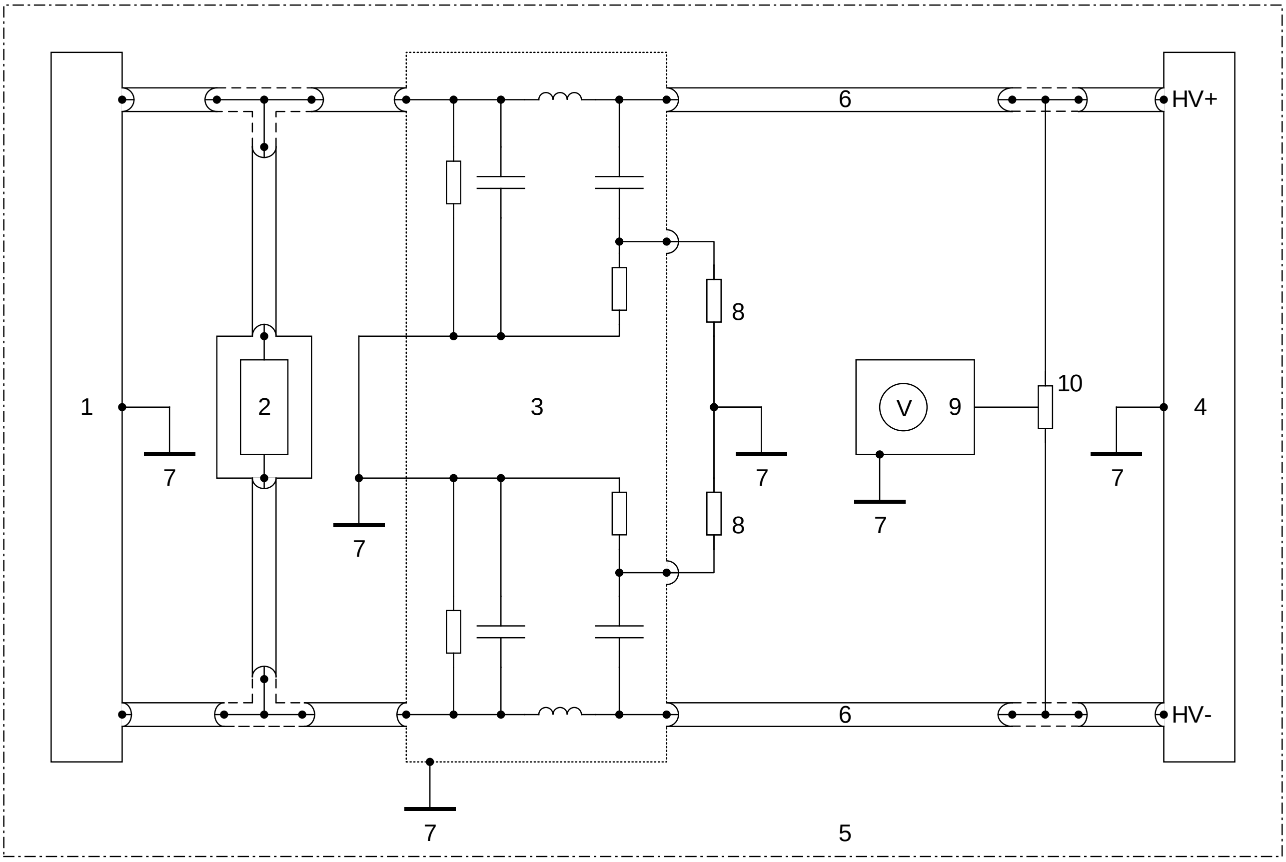
Care shall be taken to ensure that the surrounding electromagnetic environment does not interfere with the measurement set-up.

Voltage transients from the device under test (DUT), are measured using the shielded artificial network (for high voltages) to standardize the impedance loading on the DUT (see 5.1). The DUT is connected via the artificial network to the high voltage power supply (see 5.2) as given in figure 1.

If no other requirements are specified the DUT and all wiring connections between artificial network and DUT shall be spaced with a distance of $\left(50\ {}^{+10}_{\ 0}\right)$ mm above the metal ground plane.

The cable sizes shall be chosen in accordance with the real situation in the vehicle, i. e. the wiring shall be capable of handling the operating current of the device under test, and as agreed between vehicle manufacturer and supplier.

Supply voltage U_A and the disturbance voltage shall be measured close to the DUT-terminals using a voltage probe and oscilloscope or waveform acquisition equipment at the power supply terminals (see figure 1).



Key

1 shielded high voltage power supply
2 load for high voltage battery (if necessary, see subclause 5.4)
3 shielded high voltage artificial network
4 DUT
5 ground plane
6 high voltage supply line (*)
7 ground connection
8 50 Ω termination
9 oscilloscope or waveform acquisition equipment
10 high voltage differential probe

(*) Length of the HV-cable depends from the routing in the vehicle, recommended sizes 200 mm +200/0 mm or 1700 mm + 300/0 mm (standard length) or length of the original HV-harness. The harness length shall be documented in the test plan. Ground connection of DUT shall be connected to ground plane with a cable original length and diameter according to the vehicle application.

Figure 1 – Transient emission test set-up to measure voltage ripple along high voltage supply lines

Figure 1 shows the test setup for the measurement between HV+ and HV-. For measurement between HV+ and ground or HV- and ground the other terminal of the voltage probe has to be connected to ground.

Details to high voltage supply line length, ground connection and wiring shall be agreed between vehicle manufacturer and supplier.

The various operating modes and the conditions of the DUT shall be considered for the measurements and specified in the test plan.

The sampling rate and trigger level of the oscilloscope or waveform acquisition equipment shall be selected to capture a waveform displaying the complete duration of the transient, and with sufficient resolution, to display the highest positive and negative portions of the transient.

Utilising the proper sampling rate and trigger level, the voltage amplitude shall be recorded by actuating the device under test according to the test plan. Other transient parameters, such as rise time, fall time, transient duration, etc. may also be recorded. Unless otherwise specified, ten waveform acquisitions are necessary. It is only necessary to report the waveforms with highest positive and negative amplitude (with their associated parameters). Measurements have to be taken in DUT worst case mode for each test and frequency.

The measured transient shall be evaluated according to Annex B. All pertinent information and test results shall be reported. If required per test plan, include transient evaluation results with respect to the performance objective as specified in the test plan.

4.4 Transient immunity test along high voltage supply lines

Various types of transients appear on the high voltage supply lines, generated by the switching of various loads.

If not otherwise specified, all transient tests shall be performed between HV+ and HV- (line-to-line) and between HV+ respectively HV- and ground (line-to-ground). For voltage ripple, it is recommended to test also simultaneously HV+ and HV- to ground (lines-to-ground).

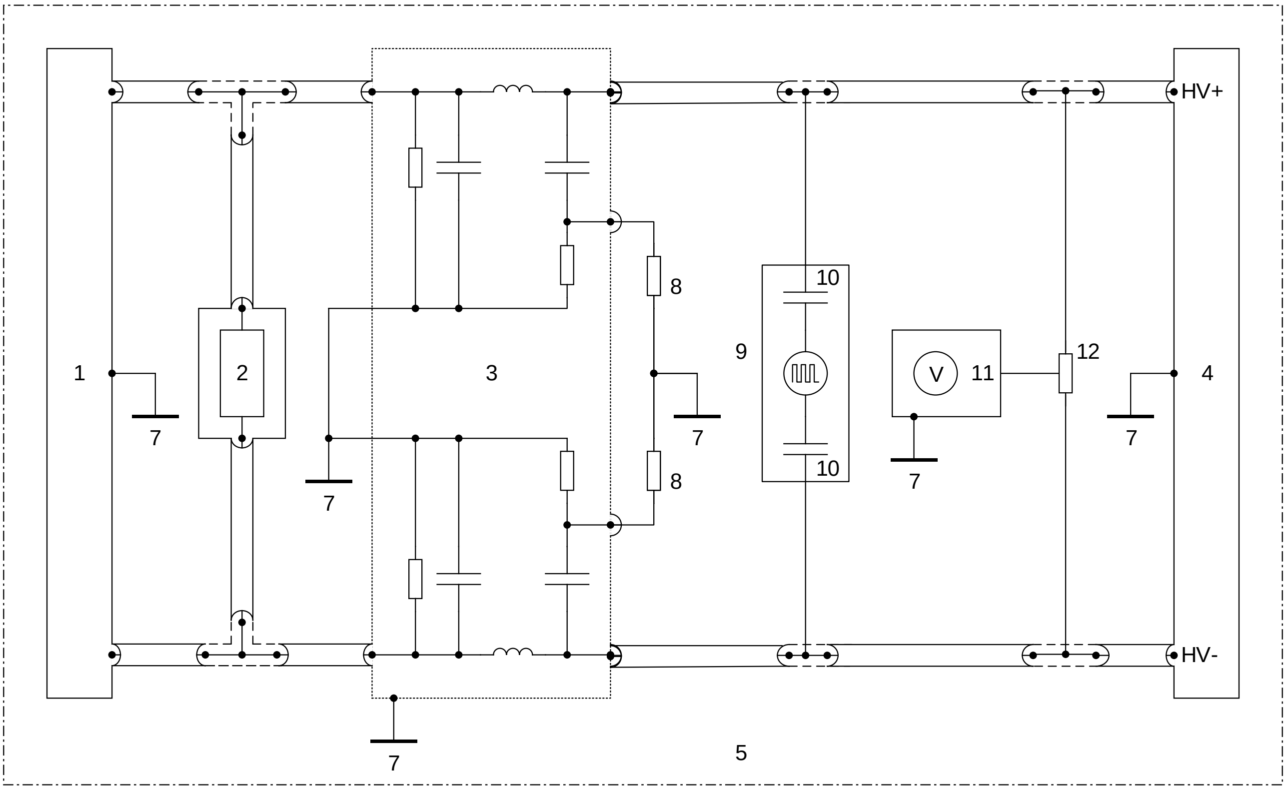
4.4.1 Voltage Ripple (Pulse A)

Figure 2a shows the test setup for coupling between HV+ and HV-.

Figure 2b shows the example of test setup for simultaneous coupling between HV+ and ground and HV- and ground. The lower terminal of generator has to be connected to ground. The upper terminal has to be connected to a specific coupling network described in clause 5.5.1.1 (Figure 10). The output of the network shall be connected to HV+ and HV- (as shown in Figure 2.b).

Ground connection of DUT shall be connected to ground plane with a cable original length and diameter according to the vehicle application.
Details to ground connection and wiring shall be agreed between vehicle manufacturer and supplier.

For square wave generator description/characteristics see 5.5.1.

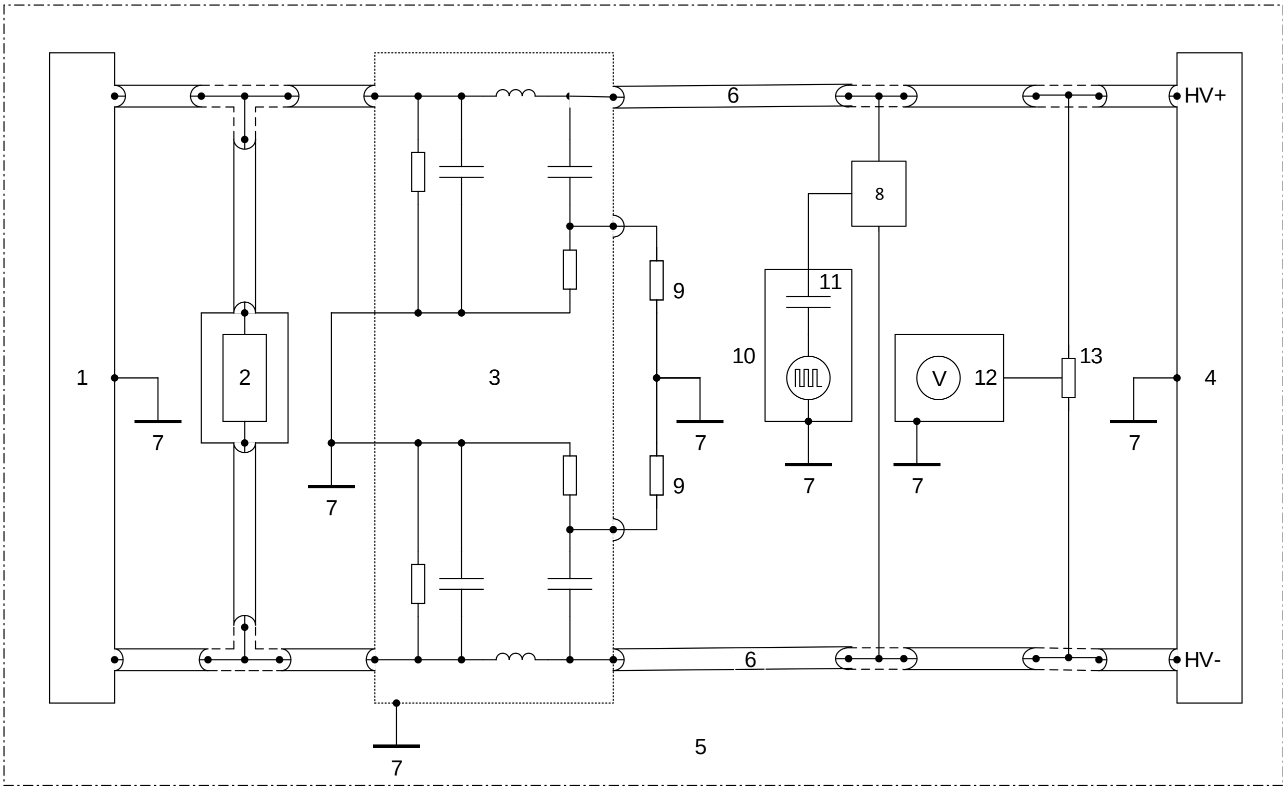


Key

1 shielded high voltage power supply
2 load for high voltage battery (if necessary, see subclause 5.4)
3 shielded high voltage artificial network
4 DUT
5 ground plane
6 high voltage supply line (*)
7 ground connection
8 50 Ω termination
9 square wave generator
10 coupling capacitor
connection between generator output and HV lines as short as possible.
due to test setup a 2nd coupling capacitor at HV- side is optional
11 oscilloscope or equivalent
12 high voltage differential probe

(*) Length of the HV-cable depends from the routing in the vehicle, recommended sizes 200 mm +200/0 mm or 1700 mm + 300/ 0 mm (standard length) or length of the original HV-harness. The harness length shall be documented in the test plan.

Figure 2a – Transient immunity test set-up for voltage ripple pulse A (e. g. “line-to-line”)



Key

1 shielded high voltage power supply
2 load for high voltage battery (if necessary, see subclause 5.4)
3 shielded high voltage artificial network
4 DUT
5 ground plane
6 high voltage supply line (*)
7 ground connection
8 specific coupling network, see Figure 10 in clause 5.5.1.1
9 50 Ω termination
10 square wave generator, both terminals shall be isolated to ground!
11 coupling capacitor
connection between generator output and HV lines as short as possible.
12 oscilloscope or equivalent
13 high voltage probe

(*) Length of the HV-cable depends from the routing in the vehicle, recommended sizes 200 mm +200/0 mm or 1700 mm + 300/ 0 mm (standard length) or length of the original HV-harness. The harness length shall be documented in the test plan.

Figure 2.b – Transient immunity test set-up for voltage ripple pulse A (e. g. “HV+ line-to-ground and HV- line to ground”)

4.4.2 Pulsed sinusoidal disturbances (pulse B)

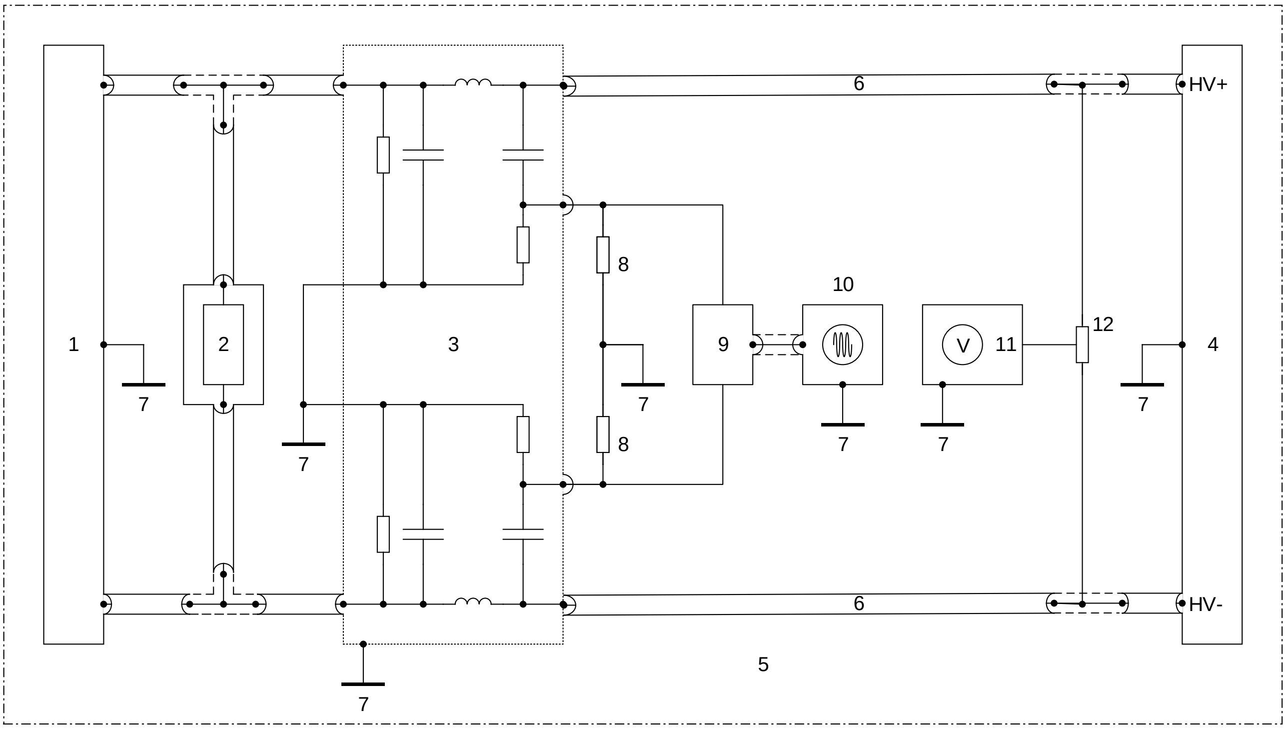
Figure 3a shows the test setup for coupling between HV+ and HV-.

Figure 3b shows the example of test set-up for coupling between HV+ and ground. The lower terminal of generator has to be connected to ground. The upper terminal has to be connected to HV+ (as shown) or to HV-. Corresponding one voltage probe terminal has to be connected to HV+ respectively to HV-; the other voltage probe terminal has to be connected to ground.

The test should be performed for both configurations:

- with generator (key 10), oscilloscope (key 12) and HV probe (Key 13) connected to HV+
- with generator (key 10), oscilloscope (key 12) and HV probe (Key 13) connected to HV-

Ground connection of DUT shall be connected to ground plane with a cable original length and diameter according to the vehicle application.
Details to ground connection and wiring shall be agreed between vehicle manufacturer and supplier.
For sine wave generator description/characteristics see 5.5.2.

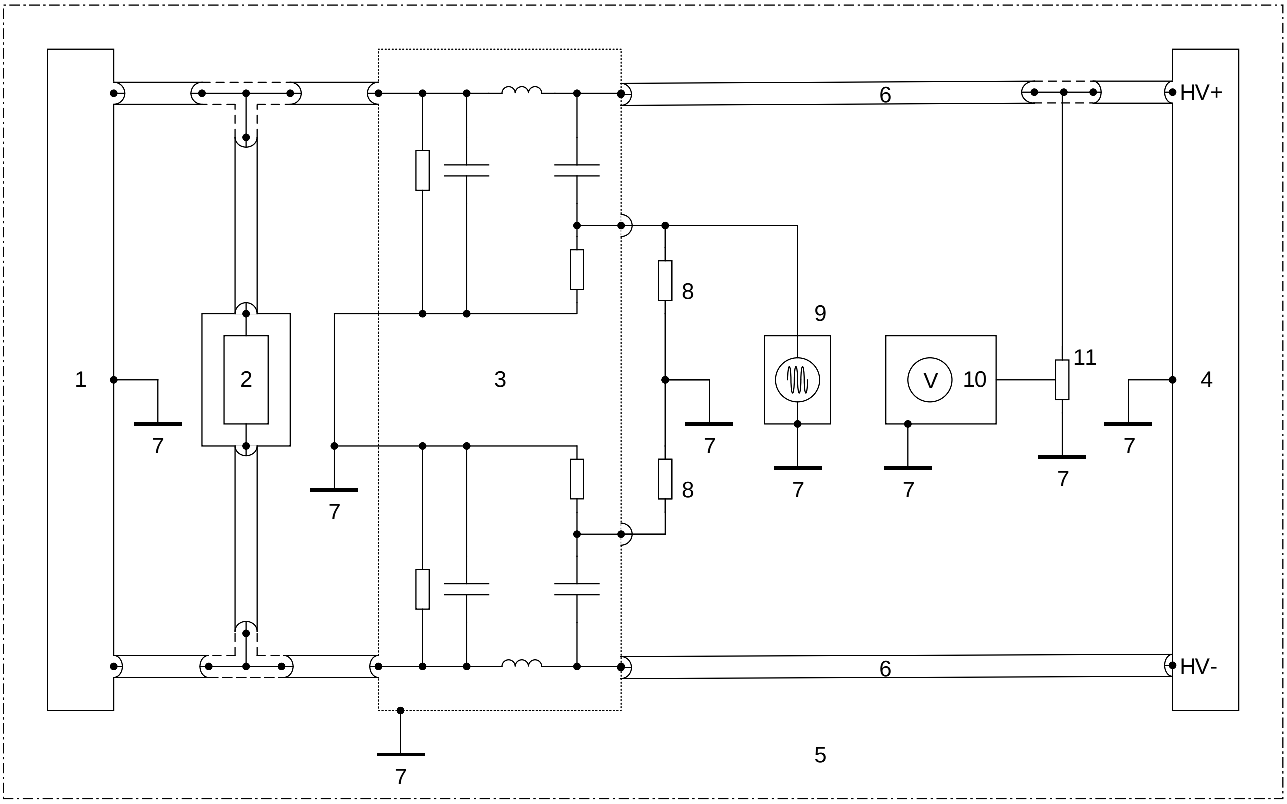


Key

1 shielded high voltage power supply
2 load for high voltage battery (if necessary, see subclause 5.4)
3 shielded high voltage artificial network
4 DUT
5 ground plane
6 High voltage supply line (*)
7 ground connection
8 50 Ω termination
9 balun transformer (see Figure 12)
10 sine wave generator
11 oscilloscope or equivalent
12 high voltage differential probe

(*) Length of the HV-cable depends from the routing in the vehicle, recommended sizes 200 mm +200/0 mm or 1700 mm + 300/ 0 mm (standard length) or length of the original HV-harness. The harness length shall be documented in the test plan.

Figure 3a – Transient immunity test set-up for pulsed sinusoidal disturbances pulse B (e. g. “line-to-line”)



Key

1 shielded high voltage power supply
2 load for high voltage battery (if necessary, see subclause 5.4)
3 shielded high voltage artificial network
4 DUT
5 ground plane
6 high voltage supply line (*)
7 ground connection
8 50 Ω termination
9 sine wave generator
10 oscilloscope or equivalent
11 high voltage probe

(*) Length of the HV-cable depends from the routing in the vehicle, recommended sizes 200 mm +200/0 mm or 1700 mm + 300/ 0 mm (standard length) or length of the original HV-harness. The harness length shall be documented in the test plan.

Figure 3b – Transient immunity test set-up for pulsed sinusoidal disturbances pulse B (e. g. “HV+ line-to-ground”)

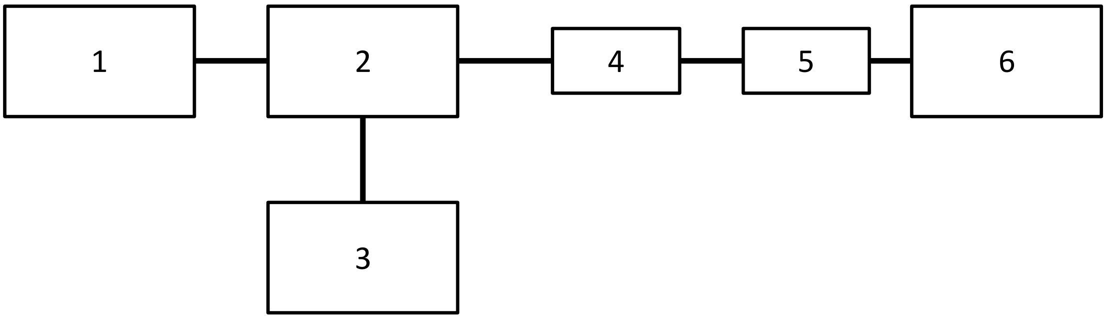
4.4.2.1 Level setting procedure (line to ground)

1. Set pulse frequency

Connect a power meter to the output of the test generator (see Fig. 3c);

NOTE An attenuator may be needed to protect the power meter input.

2. Record the forward power to obtain the desired test level (without modulation) measured at the output of the test generator (see Table A.2.2);
3. Repeat step 1 to 2 for all pulse frequencies.



Key

1 generator
2 directional coupler
3 power meter
4 50 Ω load
5 attenuator (optional)
6 power meter

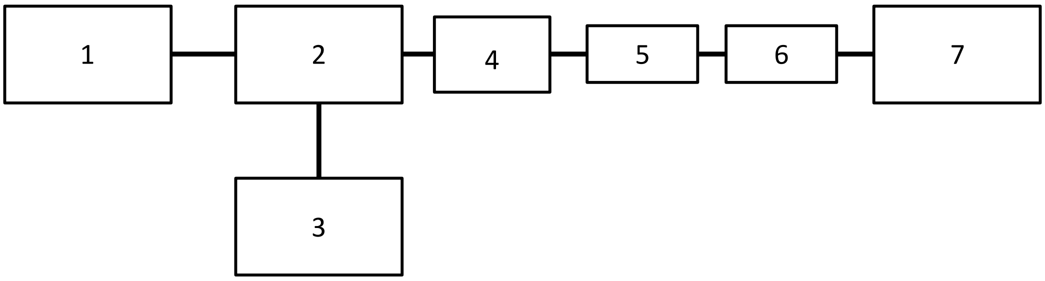
Figure 3c – Test setup for level setting line to ground

4.4.2.2 Level setting procedure (line to line)

1. Set pulse frequency;
2. Connect a power meter to the output of the test generator. The balun shall be terminated with a 50 Ω load (see Figure 3d);

NOTE An attenuator may be needed to protect the power meter input.

3. Record the forward power to obtain the desired test level (without modulation) measured at the output of the test generator (see Table A.2.2);
4. Correct the forward power by adding the correction factor of the balun transformer (see Figure. 3a, item 10) at the current pulse frequency;
5. Repeat step 1 to 4 for all pulse frequencies.



Key

1 generator
2 directional coupler
3 power meter
4 balun
5 50 Ω load
6 attenuator (optional)
7 power meter

Figure 3d – Test setup for level setting line to line

4.4.2.3 Execution of the test

The test shall be performed using the signal levels established during level setting process as described in 4.4.2.1 and 4.4.2.2.

4.4.3 Low frequency sinusoidal disturbances (pulse C)

This test determines whether the equipment will accept superposed sinusoidal frequency components. This document provides the test setup for testing frequency conducted susceptibility.

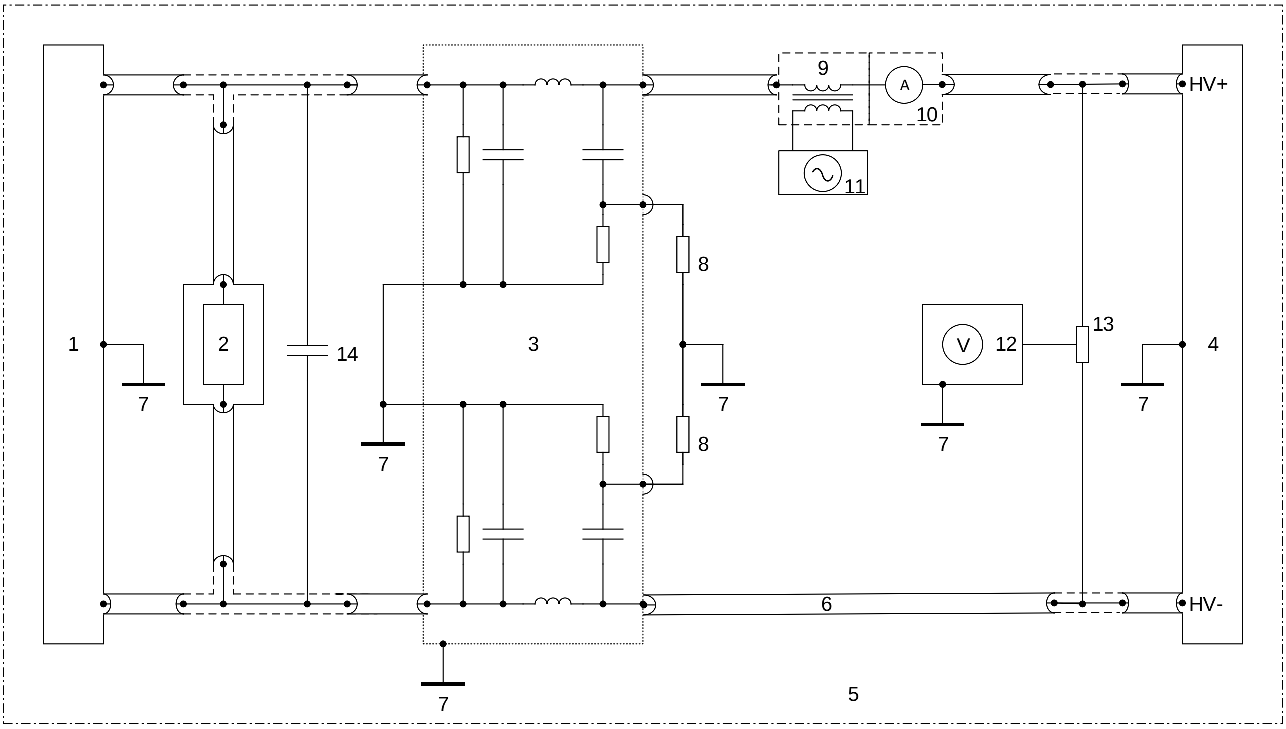
Figure 4a shows the test setup for coupling between HV+ and HV-.

Figure 4b shows the example of test setup for coupling between HV+ and ground. The lower terminal of the coupling transformer has to be connected to ground via capacitor. The upper terminal has to be connected to HV+ (as shown) or to HV-. Corresponding one voltage probe terminal has to be connected to HV+ respectively to HV-; the other voltage probe terminal has to be connected to ground.

The test should be performed for both configurations:

- with generator (key 10), oscilloscope (key 12) and HV probe (Key 13) connected to HV+
- with generator (key 10), oscilloscope (key 12) and HV probe (Key 13) connected to HV-

A capacitor of 100µF or more shall be connected across the high voltage dc power supply.
The optional current monitor is to measure the AC part of the frequency current and not the EUT current.
Ground connection of DUT shall be connected to ground plane with a cable original length and diameter according to the vehicle application.
Details to ground connection and wiring shall be agreed between vehicle manufacturer and supplier.
For the LF sinusoidal generator and coupling transformer description/characteristics see 5.5.3.

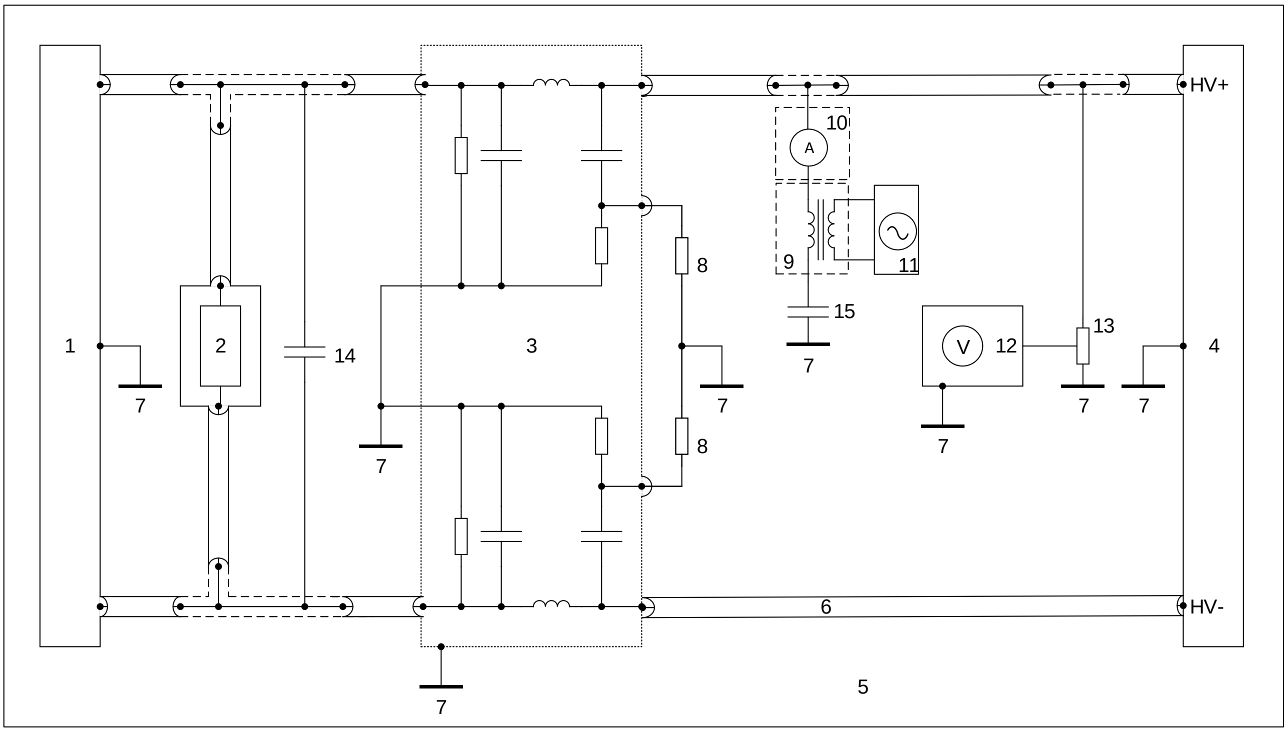


Key

1	shielded high voltage power supply
2	load for high voltage battery (if necessary, see subclause 5.4)
3	shielded high voltage artificial network
4	DUT
5	ground plane
6	high voltage supply line (*)
7	ground connection
8	50 Ω termination
9	coupling transformer
10	current monitoring (optional)
11	Low frequency generator
12	oscilloscope or equivalent
13	high voltage differential probe
14	capacitor >100uF if using high voltage power supply instead a battery

(*) Length of the HV-cable depends from the routing in the vehicle, recommended sizes 200 mm +200/0 mm or 1700 mm + 300/ 0 mm (standard length) or length of the original HV-harness. The harness length shall be documented in the test plan.

Figure 4a – Transient immunity test set-up for low frequency sinusoidal disturbances pulse C (e. g. “line-to-line”)



Key

1 shielded high voltage power supply
2 load for high voltage battery (if necessary, see subclause 5.4)
3 shielded high voltage artificial network
4 DUT
5 ground plane
6 high voltage supply line (*)
7 ground connection
8 50 Ω termination
9 coupling transformer
10 current monitoring (optional)
11 Low frequency generator
12 oscilloscope or equivalent
13 high voltage differential probe
14 capacitor >100uF if using high voltage power supply instead a battery
15 capacitor (value shall be adjusted for the frequency which will be used)

(*) Length of the HV-cable depends from the routing in the vehicle, recommended sizes 200 mm +200/0 mm or 1700 mm + 300/ 0 mm (standard length) or length of the original HV-harness. The harness length shall be documented in the test plan.

Figure 4b – Transient immunity test set-up for low frequency sinusoidal disturbances pulse C (e. g. "HV+ line-to-ground")

5 Test instrument description and specifications

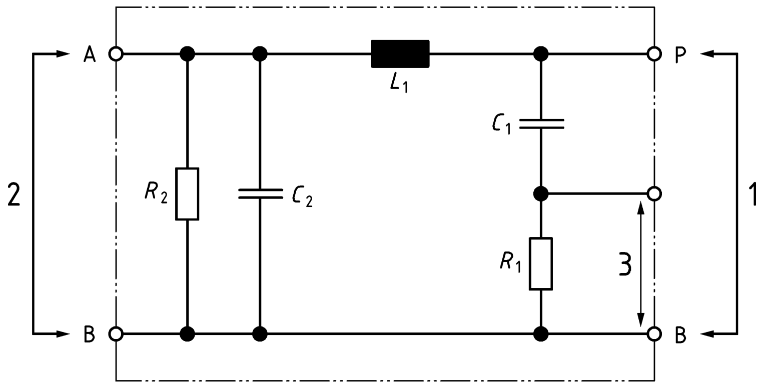
5.1 Shielded artificial network

A 5 µH/50 Ω High Voltage Artificial Network (HV-AN) as defined in Figure 5 shall be used.

The HV-AN(s) shall be mounted directly on the ground plane. The grounding connection of the HV-AN(s) shall be bonded to the ground plane.

Measurement ports of HV-AN(s) shall be terminated with a 50 Ω load.

The HV-AN magnitude impedance ZPB (tolerance ±20 %) in the measurement frequency range of 0,1 MHz to 100 MHz is shown in Figure 6. It is measured between the terminals P and B (of Figure 5) with a 50 Ω load on the measurement port with terminals A and B (of Figure 5) short circuited.



Key

1 port for the DUT

2 power supply port

3 measurement port

L_1 5 µH

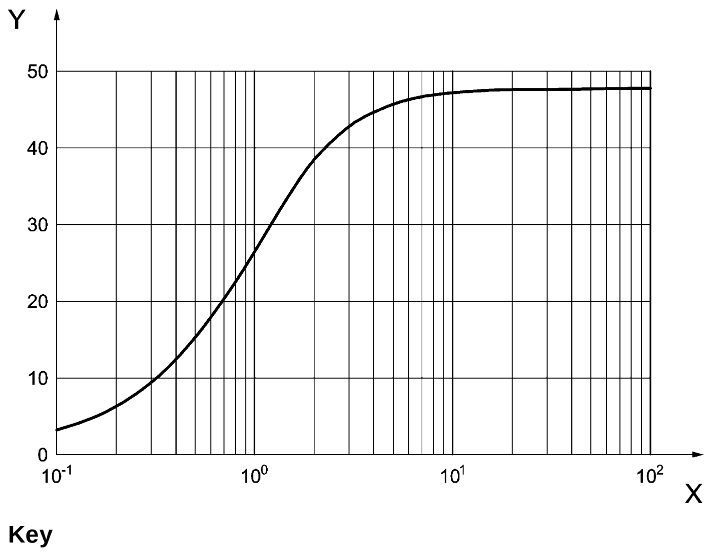
C_1 0,1 µF

C_2 0,1 µF

R_1 1 kΩ

R_2 1 MΩ (discharging C_2 to < 50 V_{dc} within 60 s)

Figure 5 — Example of 5 µH HV-AN schematic



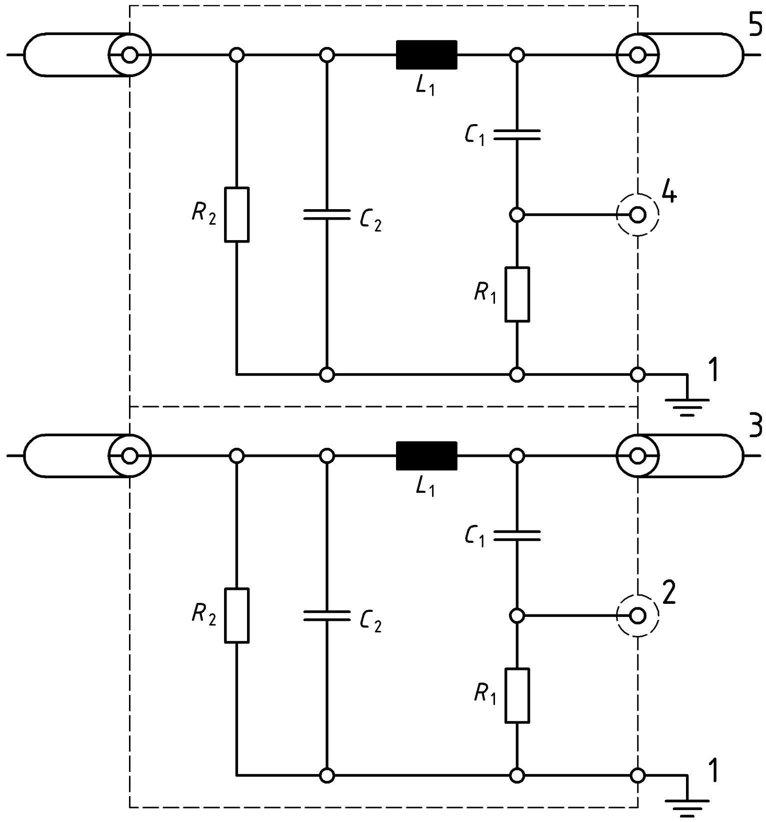
Key

X frequency (MHz)

Y impedance (Ω)

Figure 6 — Characteristics of the HV-AN impedance

If unshielded HV-AN's are used in a single shielded box, then there shall be an inner shield between the HV-AN's as described in Figure 7.



Key

1 ground

2 measuring port HV-

3 supply line HV-

4 measuring port HV+

5 supply line HV+

L_1 5 µH

C_1 0,1 µF

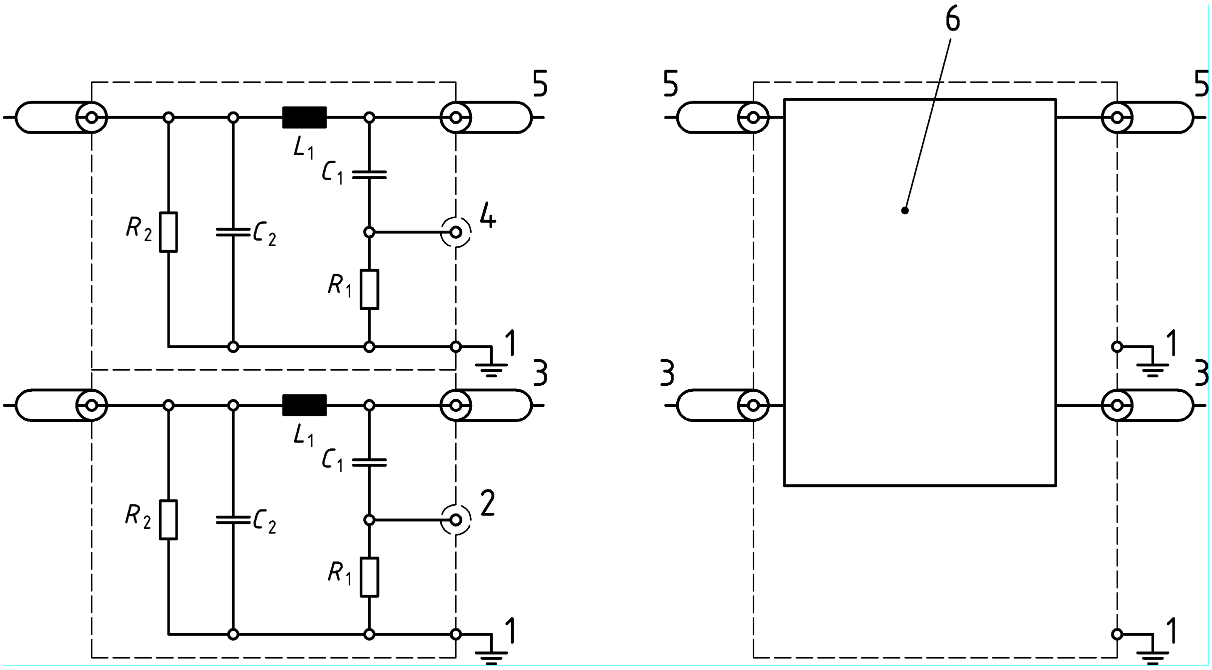
C_2 0,1 µF

R_1 1 kΩ

R_2 1 MΩ (discharging C_2 to < 50 V_{dc} within 60 s)

Figure 7 — Example of 5 µH HV-AN combination in a single shielded box

An optional impedance matching network (see Key 6 in Figure 8) may be used to simulate common mode/differential mode impedance seen by the DUT plugged on HV power supply (see Figure 8). If used, this impedance matching network should be defined in the test plan.



Key

1 ground

2 measuring port HV-

3 supply line HV-

4 measuring port HV+

5 supply line HV+

6 differential & common mode impedance matching network (optional)

L_1 5 µH

C_1 0,1 µF

C_2 0,1 µF

R_1 1 kΩ

R_2 1 MΩ (discharging C_2 to < 50 V_{dc} within 60 s)

Figure 8 — Impedance matching network attached between HV-ANs and DUT

5.2 Shielded high voltage power supply

The continuous source shall be able to supply the DUT with the necessary voltage range and supply current. Maximal noise ripple U_{pp} ≤ 1,5 % of nominal voltage.

5.3 Measurement instrumentation

As measuring equipment an oscilloscope or waveform acquisition equipment with voltage probes and the following parameters shall be used.

- Bandwidth DC to at least 400 MHz;
- Sampling rate: at least 2 Gigasamples per second (single shot mode).

Voltage measurement can be performed either with a differential probe or two matched common mode probes.

Differential mode probe characteristics:

Bandwidth	DC to at least 100 MHz;
Input impedance	Z ≥ 1 MΩ at DC.

Common mode probe, characteristics:

Bandwidth	DC to at least 100 MHz;
Input impedance	Z ≥ 1 MΩ at DC.

5.4 Load for high voltage battery

- Resistor 500 Ω +/- 5 %

in parallel to

- Capacitor 10 µF +/- 10 %
  equivalent series resistance ESR < 5 mΩ at 10 kHz
  minimal current bearing capacity: 50 A_{rms} at 10 kHz
  (current bearing capacity shall be adapted to the test-voltage).

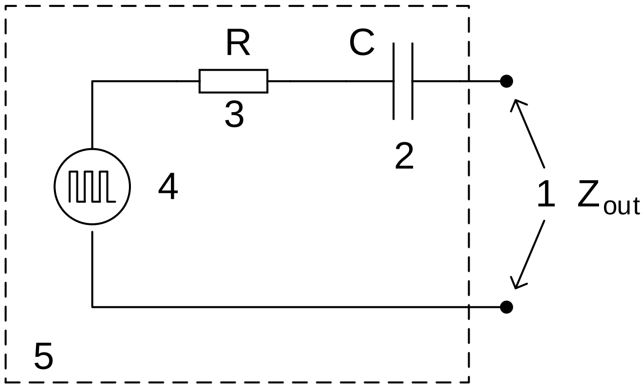
5.5 Test pulse generators for immunity testing

5.5.1 Test generator for Voltage Ripple, Pulse A

Generation of a continuous square-wave test-signal:

- Frequency range 1 kHz up to 300 kHz / 50 % duty-cycle;
- Frequency steps 1 kHz / 10 kHz;
- Z_{out} ≤ 0,5 Ω (Z_{out} = Upp / Ipp, measured at generator output (Figure 9)
- T_{Rise}, T_{Fall} < 1 µs at open circuit voltage (25 V_{pp});
- T_{Rise}, T_{Fall} < 2,5 µs at short circuit current (> 30 A_{pp});
- Current capability ≥ 32 A (rms), ≥ 70 A (peak);
- Coupling capacitor For example: 120 µF +/- 10 %, protected against direct contact “b”, self-healing equivalent series resistance ESR < 5 mΩ at 10 kHz minimal current bearing capacity: 50 A_{rms} at 10 kHz
  (current bearing capacity shall be adapted to the test-voltage).
- Calibration parameters:
- Short circuit Current I_{SC} > 30 A_{pp} at open circuit voltage V_{OC} = 25 $V_{pp;}$
- T_{rise}, T_{fall} < 1,0 µs at V_{OC} = 25 V_{pp} (1 kHz up to 300 kHz);
- T_{rise}, T_{fall} < 2,5 µs at I_{SC} > 30 A_{pp} (1 kHz up to 300 kHz);
- Z_{out}= V_{OC} / I_{SC} ≤ 0,5 Ω at 300 kHz.

Note: Shape of the squarewave under test can depend heavily on the impedance of the DUT.



Key

1 $Z_{out:}$Total output impedance of generator for Voltage Ripple measured at output including coupling capacitor; $Z_{out} \leq 0.5\ \Omega$
2 C: coupling capacitor (here implementation in the generator)
3 R: generator resistance
4 generator
5 generator housing

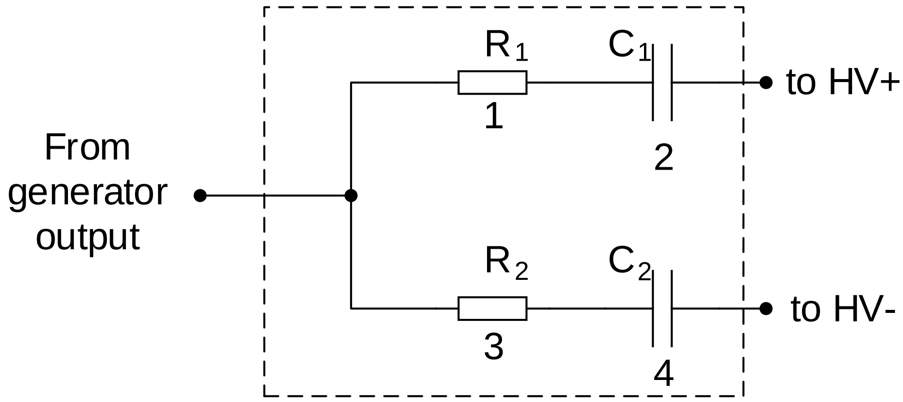
Figure 9 - Implementation of generator for voltage ripple

5.5.1.1 Coupling network for test on HV+ or/and HV- to ground

At given internal impedance of the voltage ripple generator the short circuit current is proportional to the required open circuit voltage. The internal components of a generator have a limited current capability. Therefore it can be necessary, to limit the output current for tests on HV+ to ground respectively on HV- to ground with an external resistor, because some DUTs contain capacitors with high capacity to ground.

Especially for tests on commercial vehicles where higher test levels for HV+ or HV- to ground (up to 250 V_{pp}), are required this external resistor for the generator is essential. For the recommended simultaneously HV+ to ground and HV- to ground test two coupling capacitors are necessary to avoid DC-current through the two external resistors. Figure 10 shows such a coupling network.

The test shall be performed in line-to-line and in line-to-ground mode. The simultaneous HV+ to ground and HV- to ground test (true common mode) requires a specific coupling network that supplies the test pulses symmetrically to the two high voltage lines.



Key

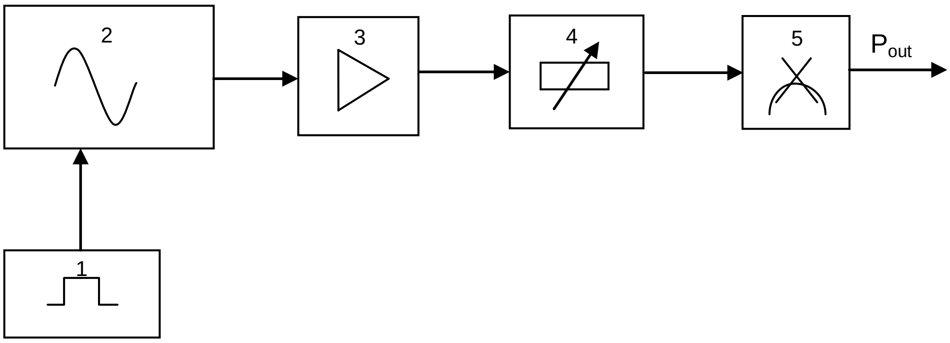
1,3 R_1, R_2: > 10 Ω (high power resistor; limiting of CM-current to protect the generator)
2,4 C_1, C_2: 30 µF (ESR < 5 mΩ at 10 kHz)

Figure 10 - Coupling network for voltage ripple test (line(s)-to-ground)

5.5.2 Test generator for pulsed sinusoidal disturbances, Pulse B

The test generator shall have the following RF properties:

- frequency range: 1-10 MHz;
- impedance: 50 Ω (nominal);
- output power for desired test level (example: Pout 25 W for 100 Vpp / 225 W for 300 Vpp).



Pulse modulator

Key

1 pulse modulator
2 sine wave generator
3 RF-Amplifier
4 variable attenuator
5 directional coupler and forward power measurement: Pout

Figure 11 - Implementation of generator for pulsed sinusoidal disturbances

5.5.3 Test generator for low frequency sinusoidal disturbances, Pulse C

•	Generation of a continuous sinusoidal test-signal:	
•	Frequency range	15 Hz up to 400 kHz;
•	Frequency steps	If no linear or logarithmic sweep is available, the test equipment should be capable of generating several frequencies per decade (see table A.2). The pulse duration at each frequency shall be at least 2s;
•	Voltage capability	15 Hz up to 250 kHz: 30 V (rms); 250 kHz up to 400 kHz: 20 V (rms);
•	Current capability	16 A (rms).

If the induced current required to generate the specific signal voltage level is too high, the test conditions will be satisfied if the peak to peak current is limited to at least 20 amps. This peak to peak current is in addition to the normal DUT current from the high voltage dc power supply.

5.5.3.1 Coupling network for test on HV+ or/and HV- to ground

The coupling transformer is used to couple the required disturbances into the DUT. This transformer also facilitates DC isolation of the LF generator from the DUT. The transformer should be able to handle LF Power frequencies from 15 Hz to 400 kHz

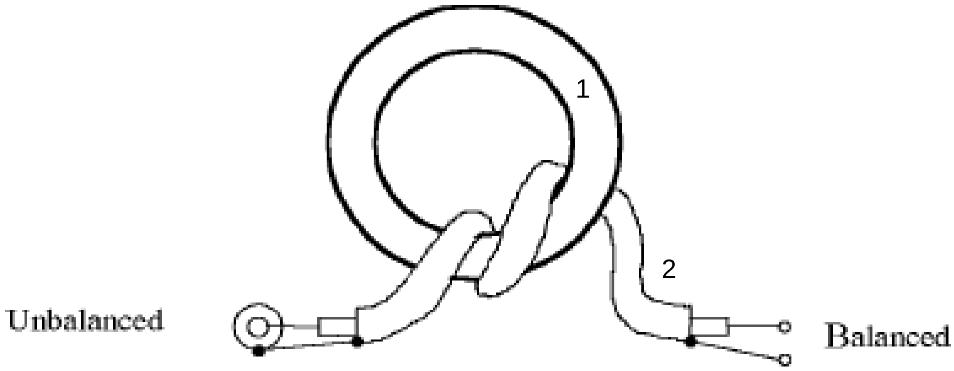
The test shall be performed in line-to-line- and in line-to-ground-mode.

For the LF sinusoidal generator and coupling transformer description/characteristics see 5.5.3.

5.5.3.2 Coupling Balun for line-to-line-coupling (sheath current filter)

For immunity testing against line-to-line coupled fast transients a balun based on ANSI C37.90.1 – annex D – or equivalent may be used.

A simple transmission line transformer providing the unbalanced to balanced mode transformation is shown in Figure 12. Both terminals on the balanced side have to be terminated with 50 Ω to ground.



Key

1 ferrite core toroids (2 pieces, stacked up) A_L = 5400 nH/turn^2, 2x A_{LX} 256 = appr. 2,75 mH)
inner diameter 39 mm, outer diameter 60 mm, core thickness 2x 18 mm

2 16 turns of 50 Ω coaxial cable (recommended: RG402 or similar) wound on the 2 stacked up toroids

Figure 12 – Example of unbalanced / balanced transmission line transformer

Annex A
(normative)

Example of test severity levels associated with functional performance status classification

A.1 General

This annex gives examples of test severity levels which should be used in line with the principle of functional performance status classification (FPSC) described in ISO 7637-1.

A.2 Classification of high voltage test pulse severity level

The suggested minimum and maximum severity levels for high voltage systems are given in tables A.1, A.2 and A.3.

A selected level and test time for testing at or in between these values may be chosen according to the agreement between vehicle manufacturer and supplier. In cases where no specific values are defined, it is recommended to use levels from tables A.1, A.2 and A.3.

~~A.2.1~~

A.2.1 Test pulse A, Voltage Ripple

Table A.1 – Parameters for test pulse A, voltage ripple

Test frequency f_{PWM}	Frequency step	Test voltage U_{pp} (V) (*) severity level				Dwell time per step (s)	Test coupling
		I	II	III	IV		
3 kHz - 30 kHz	1 kHz	5	25	50	(**)	2	HV+ to HV- HV+ to ground HV- to ground optional: HV+ and HV-to ground
30 kHz – 300 kHz	10 kHz	0,5	2,5	5	(**)		

(*) Test voltage shall be aligned without load.

(**) Severity level class for special applications: Details shall be agreed between vehicle manufacturer and supplier

The frequency ranges may be changed to 1 kHz – 20 kHz and 20 kHz – 300 kHz. Since many inverters use 4-12 kHz switching frequency. Details shall be agreed between vehicle manufacturer and supplier.

A.2.2 Test pulse B, Pulsed Sinusoidal Disturbances

Table A.2 – Parameters for test pulse B, pulsed sinusoidal disturbances

Pulse frequency (MHz)	Test voltage U_{pp} (V) (*) severity level				Oscillations per pulse packet	Repetition time (µs)	Test duration (minutes)	Test coupling
	I	II	III	IV				
1	20	50	100	(**)	10	200 / 100 / 50	5 / 5 / 5	HV+ to HV- HV+ to ground HV- to ground
2								
5								
10								

(*) Test voltage shall be aligned at 50 Ω load. The load remains in the test setup Details shall be agreed between vehicle manufacturer and supplier.

(**) Severity level class for special applications: Details shall be agreed between vehicle manufacturer and supplier

A.2.3 Test pulse C, Low Frequency Sinusoidal disturbances

Table A.3 – Parameters for test pulse C, Low Frequency Sinusoidal disturbances

Test frequency f_{PWM}	Frequency step	Test voltage U_{pp} (V) severity level				Dwell time per step (s)	Test coupling
		I	II	III	IV		
Optional: < 3 kHz (*)	(*)	(*)	(*)	(*)	(**)	2	HV+ to HV- HV+ to ground HV- to ground
3 kHz - 30 kHz	f.e. 1 kHz	5	15	25	(**)		
30 kHz - 300 kHz	f.e. 10 kHz	0,5	1,5	2,5	(**)		
Optional: > 300 kHz (***)	(***)	(***)	(***)	(***)	(***)		

(*) Optional test frequencies and severity levels for applications with relevant harmonics < 3 kHz: Details shall be agreed between vehicle manufacturer and supplier

(**) Severity level class for special applications: Details shall be agreed between vehicle manufacturer and supplier

(***) Test frequencies and severity levels for applications with relevant harmonics > 300 kHz: Details shall be agreed between vehicle manufacturer and supplier

A.3 Example of FPSC application, using test pulse severity Levels

An example of severity levels is given in table A.4. This table can be different for each kind of pulse, and for different high voltage electrical vehicle systems (levels from tables A.1 to A.3).

Table A.4- Example of FPSC Levels

	Category 1	**Category 2**	**Category 3**
L_{4i}	Level IV	Level IV	Level IV
L_{3i}	Level III	Level IV	Level IV
L_{2i}	Level III	Level III	Level IV
L_{1i}	Level III	Level III	Level III

Annex B
(normative)

Transient voltage waveform evaluation

B.1 General

The purpose of this annex is to provide a method of evaluation to characterise transient emissions from disturbance sources as tested according to the test conditions specified in clause 4.3 of the main part of this standard.

B.2 Essential elements of transient emission waveform characteristics

The following waveform parameters are to be taken into consideration for the evaluation of waveform characteristics (see ISO 7637 part 1 for definitions).

The emission limits shall be derived from severity levels in Annex A.

Abbreviations have been assigned to the waveform parameters as given in Table B.1

Table B.1 - Terms and abbreviations

Parameter	Definition see part 1, clause	Abbreviation
Peak amplitude	3.12	U_s (U_{S1}, U_{S2})
Pulse duration	3.13.1	t_d
Pulse rise time	3.13.2	t_r
Pulse fall time	3.13.3	t_f
Pulse repetition time	3.14.4	t_1
Burst duration	3.14.1	t_4
Time between bursts	3.14.2	t_5
Burst cycle time	3.14.3	$t_4 + t_5$

B.3 Voltage waveform characteristics and classification of transient emissions

B.3.1 Test pulse A, Voltage Ripple

T_{rise} < 1µs T_{fall} < 1 µs

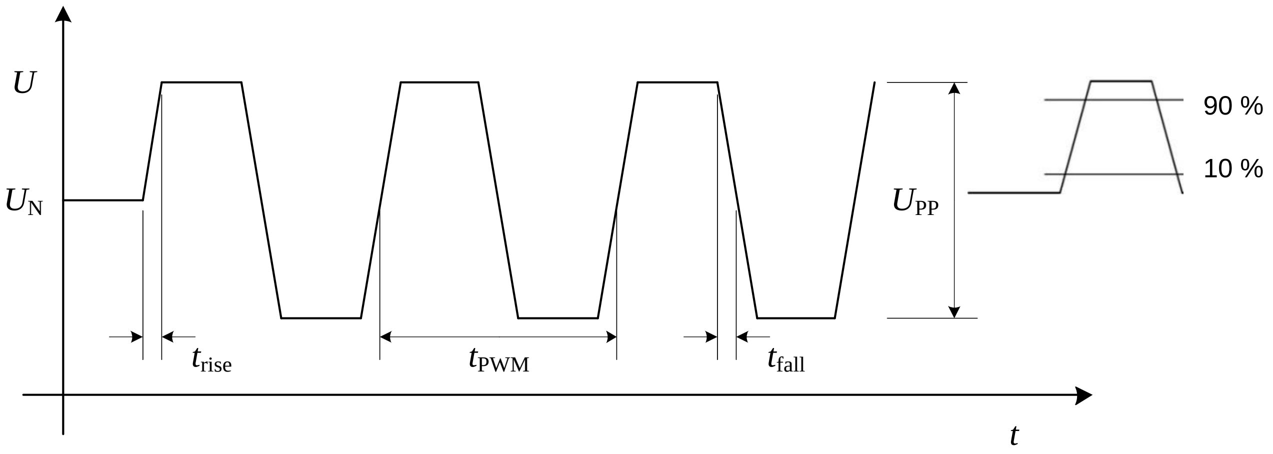


Figure B.1: Test pulse A, Voltage Ripple

Test pulses shall be adjusted without load and without DUT.

B.3.2 Test pulse B, Pulsed Sinusoidal Disturbances

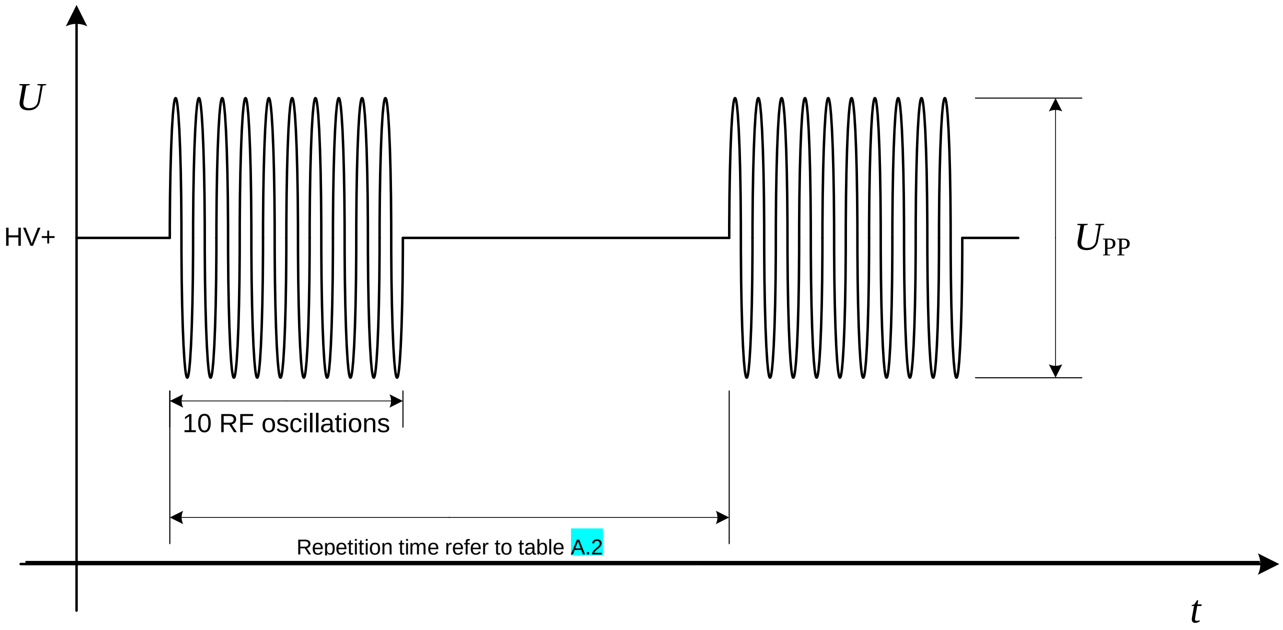


Figure B.2 - Test pulse B, sine wave pulses, e. g. on HV+

Test B shall be adjusted with 50 Ω termination at transmitter output.

B.3.3 Test pulse C, Low Frequency Sinusoidal Disturbances

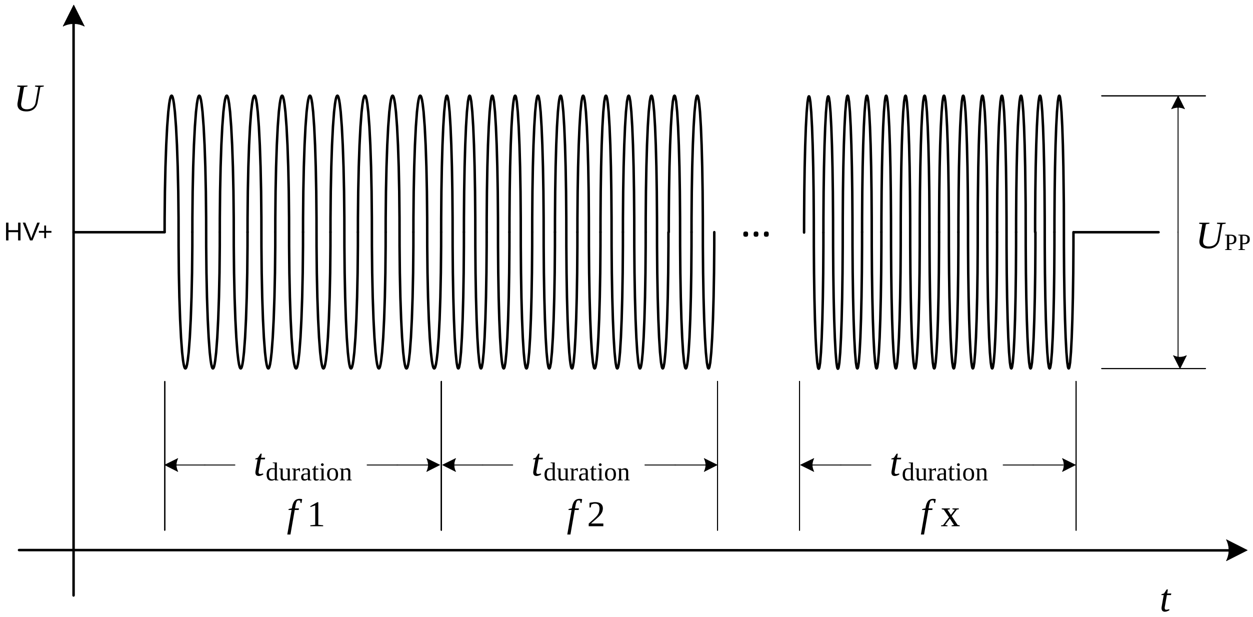


Figure B.3 - Test pulse C, Low Frequency Sinusoidal Disturbances

Annex C
(informative)

Test pulse generator verification procedure

C.1 Scope

The purpose of this annex is to provide a method for the verification of the output characteristics of the test pulse generator.

C.2 Voltage ripple

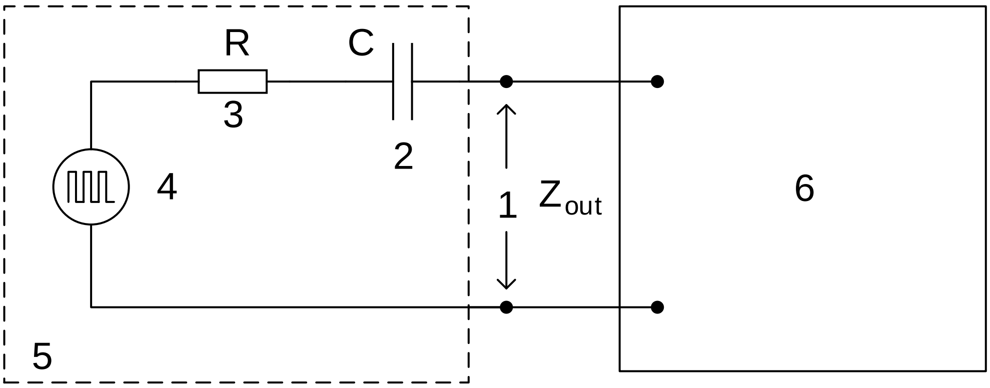
The verification measurements are performed under three different conditions to determine the behaviour of the test pulse generator:

— Under open condition;

— Under short condition;

— With LISN and Load.

Figure C.1 shows the pulse A verification setup for open condition. The output voltage of the generator is measured with an oscilloscope, which input is in high resistance setting.

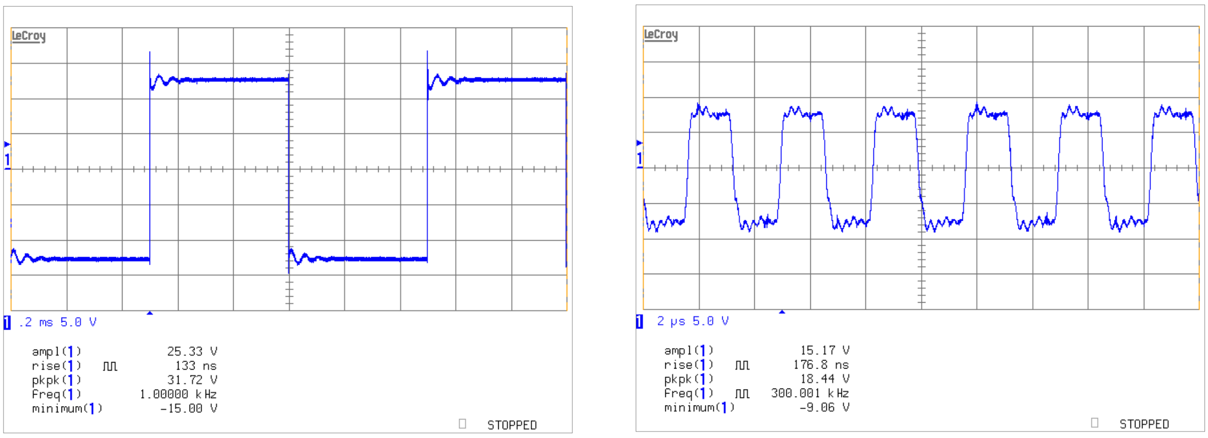


Key

1 Z_{out}:T Total output impedance of generator for Voltage Ripple (including coupling capacitor); $Z_{out} \leq 0.5\ \Omega$
2 C: coupling capacitor (may be integrated in generator housing)
3 R: generator resistance
4 generator
5 generator housing
6 oscilloscope with voltage probe

Figure C.1 Pulse A verification under open condition

For information: Figure C.2 shows some example voltage pulses recorded with the open setup.

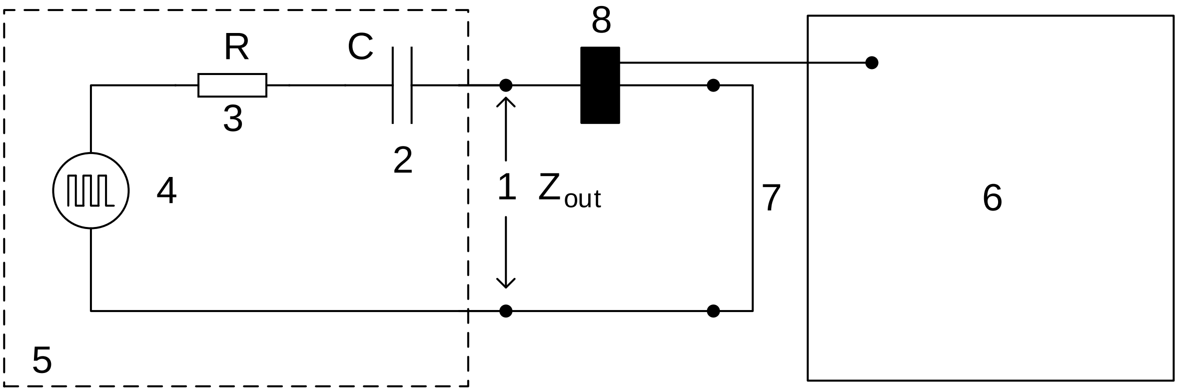


Key

1 Left: Pulse repetition = 1 kHz, $V_{in,pp}$ = 25 V
2 Right: Pulse repetition = 300 kHz, $V_{in,pp}$ = 15 V

Figure C.2 Example of pulse A: Open circuit

Figure C.3 shows pulse A verification setup for short-circuit condition. In this measurement a current probe

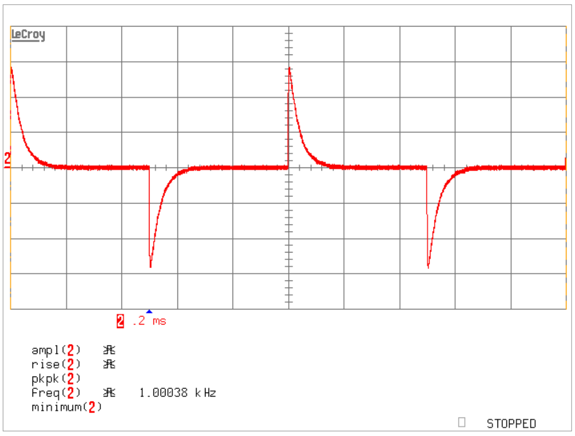


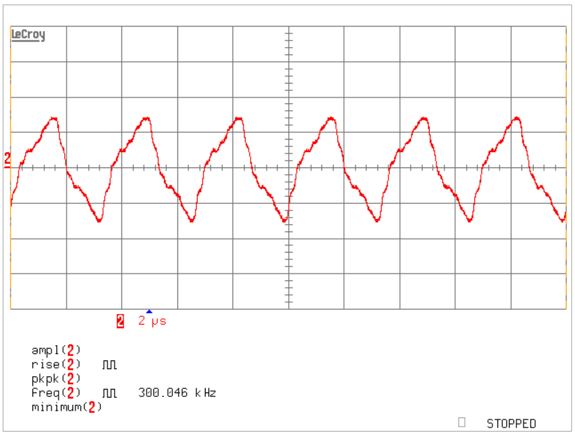
Key

1 Z_{out}:T Total output impedance of generator for Voltage Ripple (including coupling capacitor); $Z_{out} \leq 0.5\ \Omega$
2 C: coupling capacitor (may be integrated in generator housing)
3 R: generator resistance
4 generator
5 generator housing
6 oscilloscope
7 short circuit
8 current probe

Figure C.3 Pulse A verification under short-circuit condition

For information: Figure C.4 shows some example current pulses recorded with the short setup.





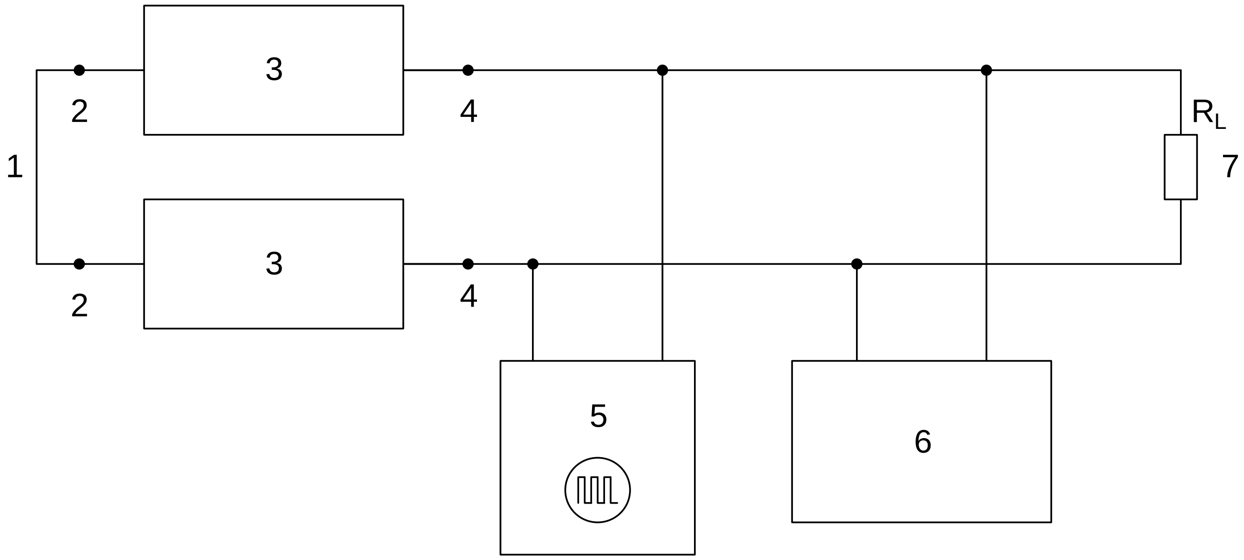
Key

1 Left: Pulse repetition = 1 kHz, $I_{in,pp}$ > 130 A, $V_{in,pp}$ = 25 V, Z_{out} < 0.36 Ω (Figure only for timebase verification)

2 Right: Pulse repetition = 300 kHz, $I_{in,pp}$ > 29 A, $V_{in,pp}$ = 25 V, Z_{out} < 0.53 Ω (Figure only for timebase verification)

Figure C.4 Example pulses: Short circuit condition (only for time base evaluation)

In order to find a better agreement with the vehicle, pulse verification with LISN is recommended. The setup is shown in Figure C.5. The vehicle harness is reproduced by two CISPR 25-LISN (see chapter 5.1).

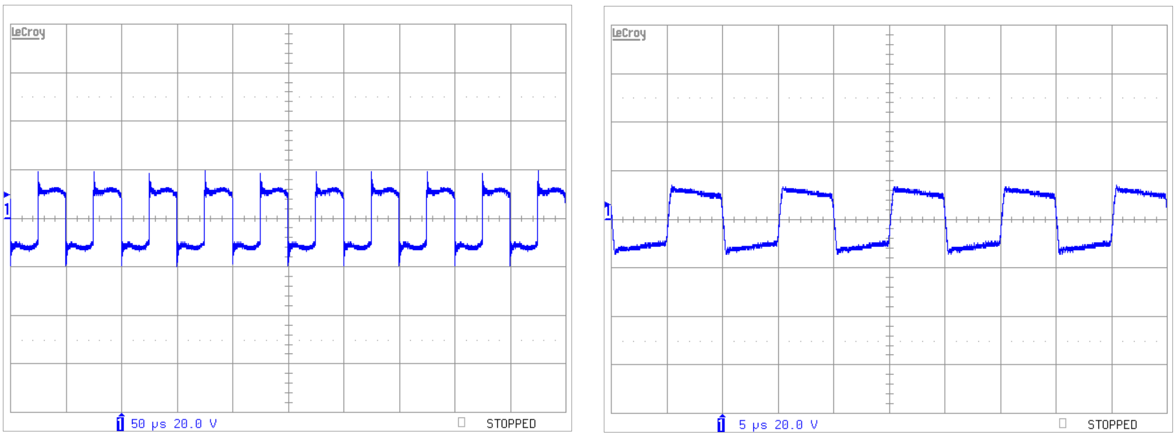


Key

1 short circuit
2 input
3 shielded HV LISN (See chapter 5.1)
4 output
5 pulse generator (See chapter 5.5.1)
6 oscilloscope
7 $R_{L:}$ load resistor (for ripple 100 Ω and for sinusoidal disturbances 50 Ω is recommended)

Figure C.5 - Pulse verification with LISN and load

For information: Figure C.6 shows some example pulses recorded with the LISN and load setup.



Key

1 Left: Pulse repetition = 20 kHz, $V_{in,pp}$ = 25 V
2 Right: Pulse repetition = 100 kHz, $V_{in,pp}$ = 25 V

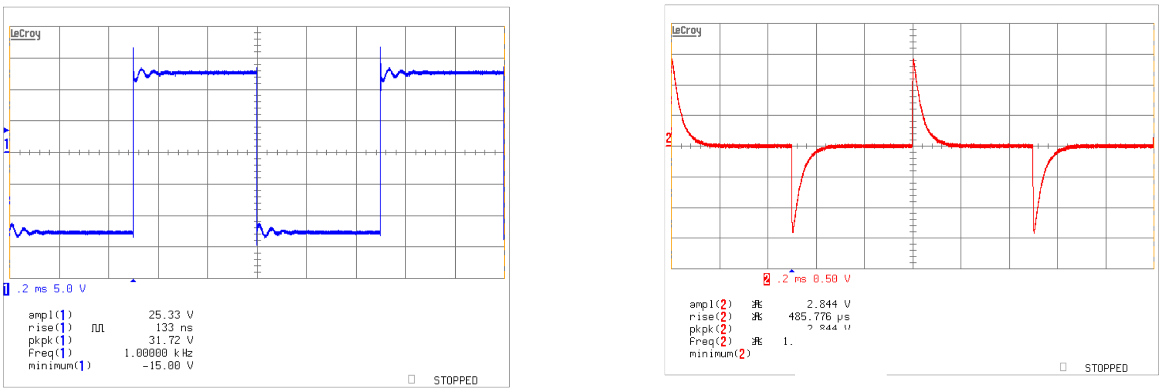
Figure C.6 - Example pulses: LISN and load condition (only for time base evaluation)

C.2.1 Determination of Z_{out} in timebase

In order to determine the relevant Z_{out} it is recommended to use the open and short setup to determine $V_{in,pp}$ and $I_{in,pp}$ (Peak-to-Peak) with the same input voltage $V_{in,pp}$. The coupling capacitor should be included in these measurements to derive most significant results. Z_{out} can be calculated by $Z_{out} = V_{in,pp} / I_{in,pp}$ in which all transducers have been considered and the measurement data is cleared from them.

The important electromagnetic disturbances especially occur in the rising or falling slope of the voltage pulses, where the amplitude reaches its maximum. If Z_{out} is determined after the capacitor by using the Peak-Peak-values, most side effects are considered. In this case Z_{out} is valid for the most threatening phase of the voltage pulses and therefore valid to specify the generator performance.

For information, in figure C.7 an example is given to determine Z_{out}.



Key

1 Left: Pulse repetition = 1 kHz, $V_{in,pp}$ = 25 V
2 Right: Pulse repetition = 1 kHz, $I_{in,pp}$ > 130 A, $V_{in,pp}$ = 25 V (Figure only for timebase verification)

Figure C.7 Example to determine Z_{out}

Figure C.7 shows $V_{in,pp}$ = 25 V and $I_{in,pp}$ > 130 A. Therefore Z_{out} = (25 V/65 A) = 0,38 Ω.