SAE International™

SURFACE VEHICLE STANDARD

J1113-11	REV. JUN2007
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Immunity to Conducted Transients on Power Leads

RATIONALE

The January 2006 version of this standard has been revised to re-insert Pulse 4, Pulse 5a, and Pulse 5b. All corresponding information has also been added to the main body and appendices. These pulses were originally deleted from the March 2002 version of the document (by referencing to ISO 10650-2). Since there is no equivalent SAE version of the ISO 10650-2, these pulses are re-inserted to provide specifications of in a SAE document. Function Performance Status Classifications utilized in Appendix B has also been updated to reflect the latest changes in SAE J1812.

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1. SCOPE

This SAE Standard defines methods and apparatus to evaluate electronic devices for immunity to potential interference from conducted transients along battery feed or switched ignition inputs. Test apparatus specifications outlined in this procedure were developed for components installed in vehicles with 12-V systems (passenger cars and light trucks, 12-V heavy-duty trucks, and vehicles with 24-V systems). Presently, it is not intended for use on other input/output (I/O) lines of the device under test (DUT).

1.1 Measurement Philosophy

Installed electrical equipment is powered from sources which contain, in addition to the desired electrical voltage, transients with peak values many times this value, caused by the release of stored energy during the operation of a relay and/or other loads connected to the source while starting and/or turning off the vehicle. These tests are designed to determine the capability of equipment to withstand such transients. The tests are performed in the laboratory (bench tests). Bench test methods give results, which also allow comparison between laboratories.

These tests may not cover all types of transients, which can occur in a vehicle. The test pulses described in Section 8 are, however, characteristic of typical pulses. To ensure proper operation of a vehicle in the electromagnetic environment, vehicle testing should be performed in addition to bench testing.

2. REFERENCES

General information regarding this document, including definitions, references, and general safety considerations is found in SAE J1113-1.

2.1 Applicable Publications

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

2.1.1 SAE Publication

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

SAE J1113-1 Electromagnetic Compatibility Measurement Procedure and Limits for Components of Vehicles, Boats (Up to 15 m), and Machines (Except Aircraft) (16.6 Hz to 18 GHz)

2.1.2 ISO Publication

Available from ANSI, 25 West 43rd Street, New York, NY 10036-8002, Tel: 212-642-4900, www.ansi.org.

ISO 7637-2.3 (Release date 2004) Road vehicles—Electrical disturbance by conduction and coupling—Part 2.3: Electrical transient conduction along supply lines only

3. TEST EQUIPMENT

3.1 Test Facility

Care shall be taken to ensure that the electromagnetic environment (radiated background noise) is not so high as to interfere with the measurement instrumentation setup.

3.2 Test Instrumentation

The following list defines the equipment needed to perform the test.

3.2.1 Oscilloscope

The use of a digitizing oscilloscope is preferred. If a digitizing oscilloscope is not available, a storage oscilloscope may be used. The oscilloscope used shall meet the following requirements:

a. Digitizing Oscilloscope
   Sampling Rate .... 2 gigasamples/s (min)
   Memory Size .... 1000 samples (min)
   Bandwidth .... DC to 400 MHz (min)
   Input Sensitivity .... 5 mV/div (min)
   High Impedance (input impedance >1 MΩ) oscilloscope shall be used

b. Storage Oscilloscope
   Bandwidth (Single Shot) .... DC to 400 MHz (min)
   Input Sensitivity .... 5 mV/div (min)
   Writing Speed .... 100 cm/µs (min)
   High Impedance (input impedance >1 MΩ) oscilloscope shall be used

3.2.2 Voltage Probe

Attenuation .... Must be compatible with the scope used and with sufficient attenuation to avoid possible damage by the transients
Min. Breakdown Voltage .... 1.5 kV
IProbe Cable Length .... 3 m (max)
Probe Ground Length .... 130 mm (max)
Probe capacitance C .... < 10pf

3.2.3 DC Power Supply

(See J1113-1)

If a standard power supply (with sufficient current capacity) is used to simulate the battery, it is important that the low internal impedance of the battery is also simulated.

When a battery is used, a charging source may be needed to achieve the specified reference levels.

3.2.4 Vehicle Simulator

A vehicle simulator unit shall be provided. This device must be capable of providing the inputs and loads necessary to exercise the DUT such that it operates as if it were installed in the vehicle.

3.2.5 DUT Monitoring Instrumentation

Instrumentation and/or visual observation shall be used to monitor the parameters of the DUT as stated in the Test Plan.

3.2.6 Test Pulse Generator

The test pulse generator shall be capable of producing the open circuit test pulses described in Section 8 at the maximum value of $|V_s|$. V_s shall be adjustable up to its limits.

The peak voltage V_s shall be adjusted to the test levels specified in Appendix B with tolerances of +10% and –0%. The timing (t) tolerances and internal resistance (R_i) tolerance shall be ±20% unless otherwise specified.

A verification procedure for the generator performance and tolerances is described in Appendix A.

Recommended values for the evaluation of immunity of devices can be chosen from Appendix B.

3.3 Test Voltages

The test voltages shall be as shown in Table 1 unless other values are agreed upon by the users of this document, in which case such values shall be documented in the test report.

TABLE 1 - TEST VOLTAGES

Test Voltage	12 V System (Volts)	24 V System (Volts)
V_A	13.5 ± 0.5	27 ± 1
V_B	12 ± 0.2	24 ± 0.4

V_A is the supply voltage when the alternator is operating.
V_B is the supply voltage when the alternator is not operating.

3.4 Test Set-Up Documentation

When testing is performed, all related details of the test shall be documented per Section 7. This includes details on test set-up, wiring harnesses, equipment used, and the DUT.

4. TEST PLAN

Prior to testing, a Test Plan shall be developed by those responsible for the specific DUT. In general, the Test Plan is based on the Product Specification and is agreed upon by the customer and supplier. The Test Plan should include all the details of the tests to be performed, such as: the DUT functions to be monitored; their function performance status classifications and Test Severity Levels as defined in Section 6 and Appendix B; the definitions of DUT performance deviations; and the order, level, repetition rate, and number of applications of the waveforms. Unless otherwise specified by the Test Plan, all tests shall be conducted at room temperature (23 °C ± 5 °C).

NOTE: **Special consideration for time between test pulses and number of test pulses**: Period t_1, the time between test pulses given with each test pulse definition, is a default value, which applies to DUTs without timing or dynamic processes. Consideration should be given in the Test Plan for each DUT function whose susceptibility may vary according to its internal timing or processing functions. Selection of time between pulses and number of pulses should maximize the probability that a test pulse will be applied during times of highest DUT susceptibility. In no case should the time between test pulses be less than the response time of the transient generator.

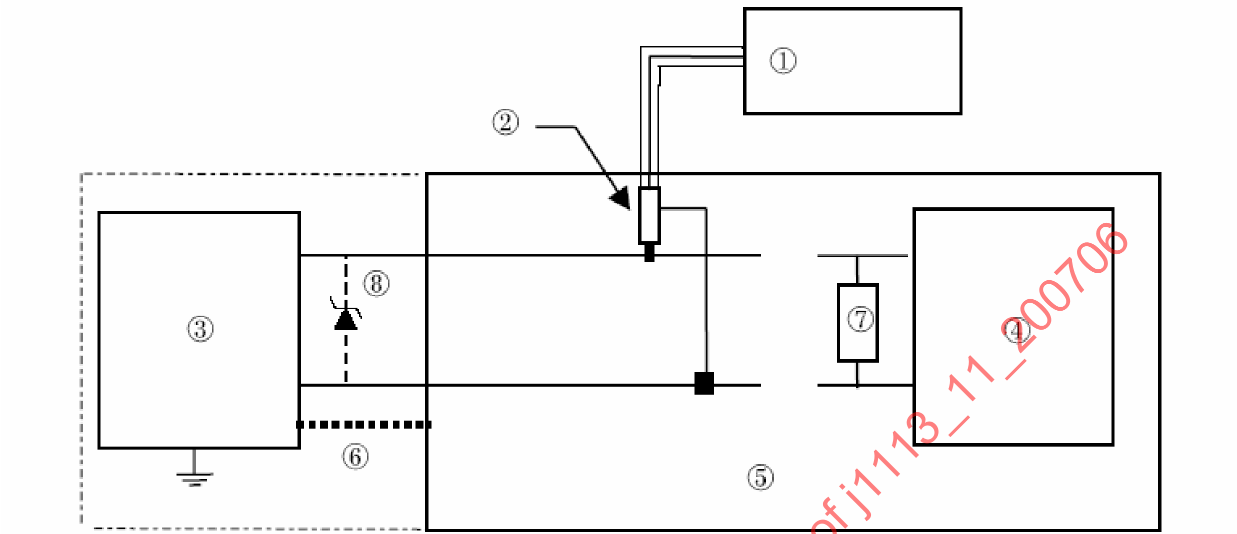
5. TEST PROCEDURE

5.1 The test setup is given in Figures 1A and 1B.

For test pulses 3a and 3b, the leads between the terminals of the test pulse generator and the device under test shall be laid out in a straight parallel line, shall have a height of (50 mm + 10/–0 mm and shall have a length of 0.5 m ± 0.1 m.

The test pulse generator (see 3.2.6) shall be capable of producing the open circuit waveforms shown in Figures 2 through 9 with the parameters given in Tables 2 to 9.

The test pulse generator is verified according to Appendix A and then set up to provide the specific pulse polarity, amplitude, duration, and resistance with the DUT and optional resistance R_v and suppression diode bridge disconnected (see Figure 1A). (The appropriate voltage values are selected from Appendix B).

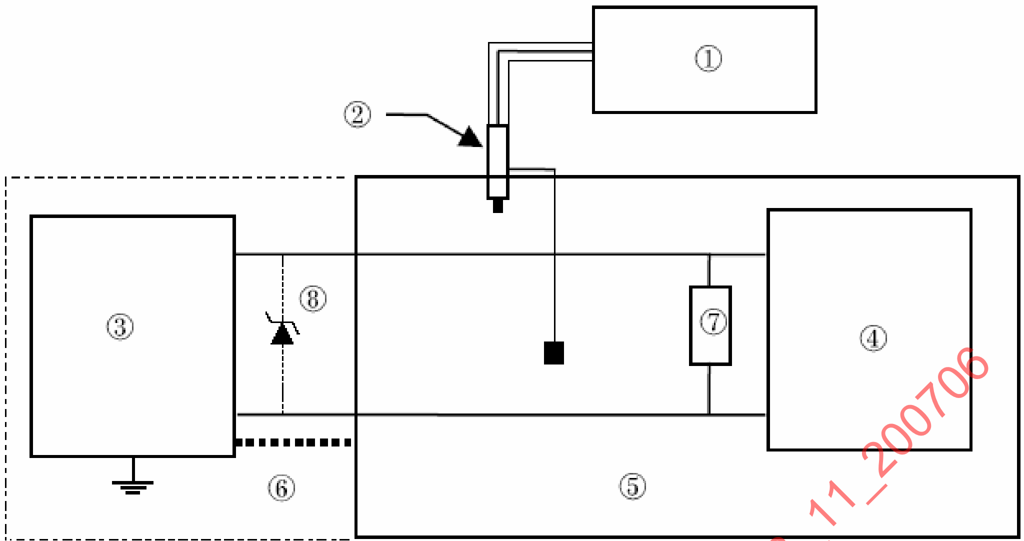


Legends:

1. Oscilloscope or Equivalent
2. Voltage probe
3. Test Pulse Generator with internal power supply resistance R_i
4. Device Under Test (DUT)
5. Ground Plane
6. Ground connection. Maximum length for test pulse 3 is 100 mm
7. Optional resistor (R_v) to simulate vehicle system loading for load dump test pulse 5a and 5b only. If used, the value of () shall be specified in the test plan (typical value 0.7 Ω to 40 Ω)
8. Optional diode bridge for simulation of load dump waveform for alternator with centralized load dump suppression for pulse 5b only (see Figure 1C)

FIGURE 1A - TRANSIENT IMMUNITY TEST SET-UP - PULSE ADJUSTMENT

NOTE: The test pulse generator can be located either on or off the ground plane.



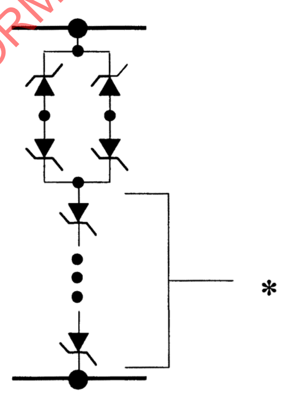
Legends:

1. Oscilloscope or Equivalent
2. Voltage probe
3. Test Pulse Generator with internal power supply resistance R_i
4. Device Under Test (DUT)
5. Ground Plane
6. Ground connection. Maximum length for test pulse 3 is 100 mm
7. Optional resistor (R_v) to simulate vehicle system loading for load dump test pulse 5a and 5b only. If used, the value of () shall be specified in the test plan (typical value 0.7 Ω to 40 Ω)
8. Optional diode bridge for simulation of load dump waveform for alternator with centralized load dump suppression for pulse 5b only (see Figure 1C)

FIGURE 1B - TRANSIENT IMMUNITY TEST SET-UP - PULSE INJECTION

NOTE: The test pulse generator can be located either on or off the ground plane.

NOTE: Osciloscope can be connected to the test apparatus during test to obtain additional information for engineering analysis (optional).



* Add forward biased diodes as required to achieve maximum open-circuit (suppressed) voltage

FIGURE 1C - EXAMPLE OF SUPPRESSION DIODE BRIDGE FOR TEST PULSE 5b ONLY

5.2 Connect the DUT to the generator (see Figure 1B) and disconnect the oscilloscope.

5.3 Apply the transient to the DUT.

5.4 Monitor the DUT's performance during/after transient injection for any deviations.

5.5 Perform the appropriate functional tests, per the test plan, to determine deviations and record the results as outlined in Section 7.

NOTE 1: In determining the susceptibility level, care must be exercised to eliminate the effects of cumulative deterioration such as dielectric "punch through" in semi-conductor devices.

NOTE 2: When testing to a specified level, unnoticed deviations may occur which may be detected only by performing functional tests and comparing the results of tested components against those of untested components.

6. TEST SEVERITY LEVELS AND EVALUATION OF RESULTS

6.1 A full description and discussion of the Function Performance Status Classification including Test Severity Levels are given in SAE J1113-1. It should be reviewed prior to using the Test Severity Levels presented in Appendix B.

6.2 A careful examination of the DUT shall be made during and after the completion of a test to determine proper operation. Any irregularities shall be recorded in the Test Report and shall be evaluated based on the Test Plan, the specifications covering the product being tested, or by agreement between the purchaser and supplier.

7. TEST DOCUMENTATION

The following information shall be recorded, unless otherwise prescribed in the Test Plan covering the product being tested:

7.1 Part number and/or description of the DUT.

7.2 Copy of the original Test Plan.

7.3 Description of the test setup and equipment used.

7.4 Description of the harness used between the injection apparatus and the DUT.

7.5 Test Pulse being applied (by number).

7.6 Order of injection for each of the waveform amplitudes.

7.7 Number (repetitions) of the pulse applied.

7.8 Pulse period (interval between pulses).

7.9 Any deviation from the waveforms prescribed for testing.

7.10 Point of application of pulse (pin number, letter, or name).

7.11 Exact characteristics of any disturbance during injection of the pulse.

8. TEST PULSES

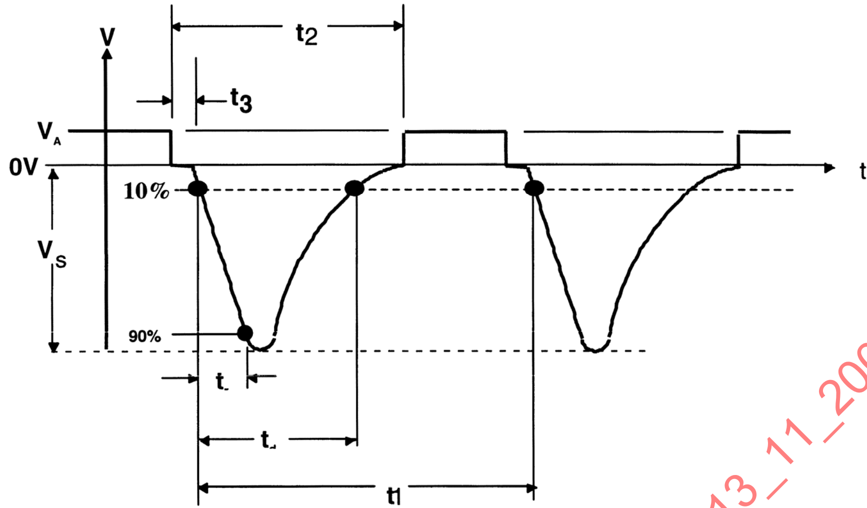


FIGURE 2 - TEST PULSE 1
SUPPLY DISCONNECTION FROM INDUCTIVE LOADS WITH DUT REMAINING CONNECTED DIRECTLY IN PARALLEL WITH THIS INDUCTIVE LOAD

TABLE 2 - TEST PULSE 1 PARAMETERS

Parameters	12 V System Passenger Car and Light-Duty Trucks Pulse 1a	12 V System Heavy-Duty Trucks Pulse 1b	24 V System Pulse 1c
V_s	–75 V to –100 V	–150 V to –600 V	–450 V to –600 V
R_i	10 Ω	20 Ω	50 Ω
t_d	2 ms	1 ms	1 ms
t_r	1 µs +0/–50%	1 µs +0/–50%	3 µs +0/–50%
t_1 (1)	0.5 s to 5 s	0.5 s to 5 s	0.5 s to 5 s
t_2	200 ms	200 ms	200 ms
t_3 (2)	<100 µs	<100 µs	<100 µs

1. t_1 shall be chosen such that the device under test is correctly initialized before the application of the next pulse.
2. t_3 The smallest possible time necessary between the disconnection of the supply source and the application of the pulse.

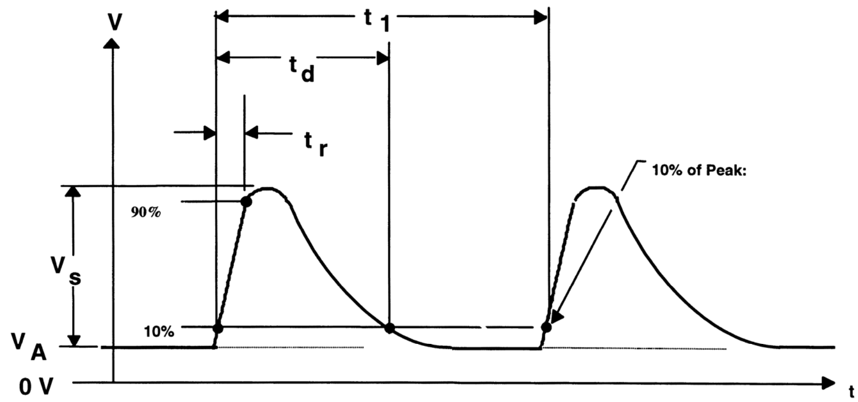


FIGURE 3 - TEST PULSE 2A
SUDDEN INTERRUPTION OF CURRENT IN A DEVICE CONNECTED IN PARALLEL
WITH THE DUT DUE TO THE WIRING HARNESS INDUCTANCE

TABLE 3 - TEST PULSE 2A PARAMETERS

Parameters	12 V System	24 V System
V_s	+37 V to +75 V	+37 V to +75 V
R_i	2 Ω	2 Ω
t_d	0.05 ms	0.05 ms
t_r	1 µs +0/–50%	1 µs +0/–50%
t_1 (1)	0.2 s to 5 s	0.2 s to 5 s

1. t_1 shall be chosen such that the device under test is correctly initialized before the application of the next pulse.

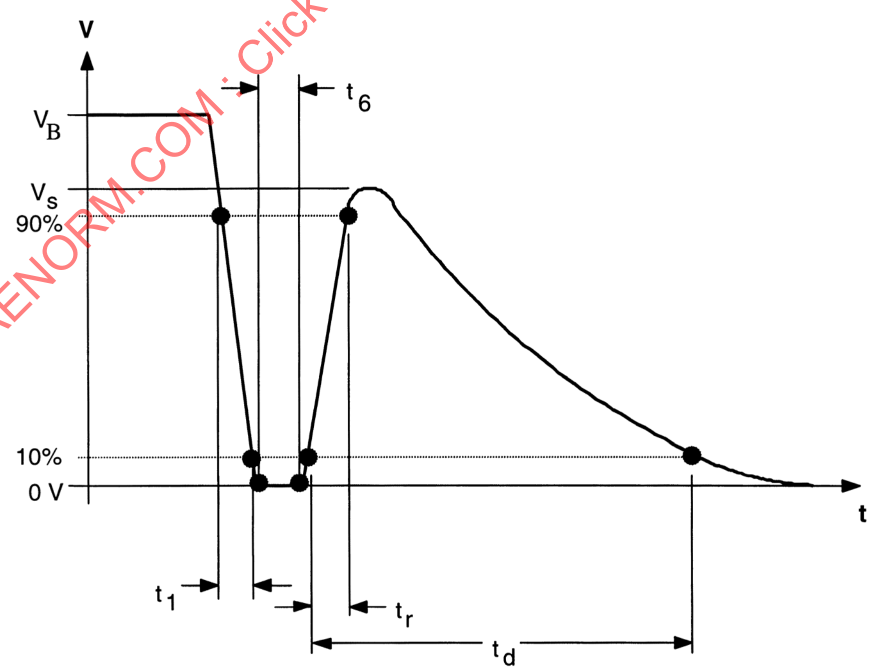


FIGURE 4 - TEST PULSE 2B
TRANSIENT FROM DC MOTORS ACTING AS GENERATORS AFTER IGNITION SWITCH - OFF

TABLE 4 - TEST PULSE 2B PARAMETERS

Parameters	12 V System	24 V System
V_s	10 V	20 V
R_i	≤ 0.05 Ω	≤ 0.05 Ω
t_d	0.2 s to 2 s	0.2 s to 2 s
t_1	1 ms ± 50%	1 ms ± 50%
t_r	1 ms ± 50%	1 ms ± 50%
t_6	1 ms ± 50%	1 ms ± 50%

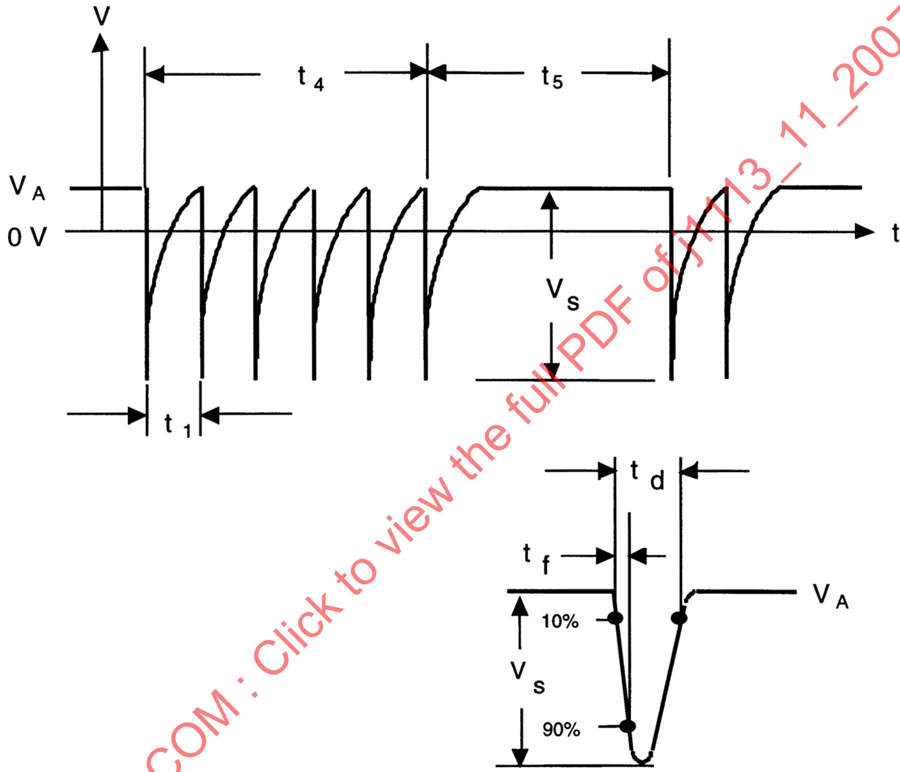


FIGURE 5 - TEST PULSE 3A
SWITCHING SPIKES

TABLE 5 - TEST PULSE 3A PARAMETERS

Parameters	12 V System	24 V System
V_s (from V_A)	–112 V to –150 V	–150 V to –200 V
R_i	50 Ω	50 Ω
t_d	0.1 µs + 100/–0%	0.1 µs + 100/–0%
t_f	5 ns ± 30%	5 ns ± 30%
t_1	100 µs	100 µs
t_4	10 ms	10 ms
t_5	90 ms	90 ms

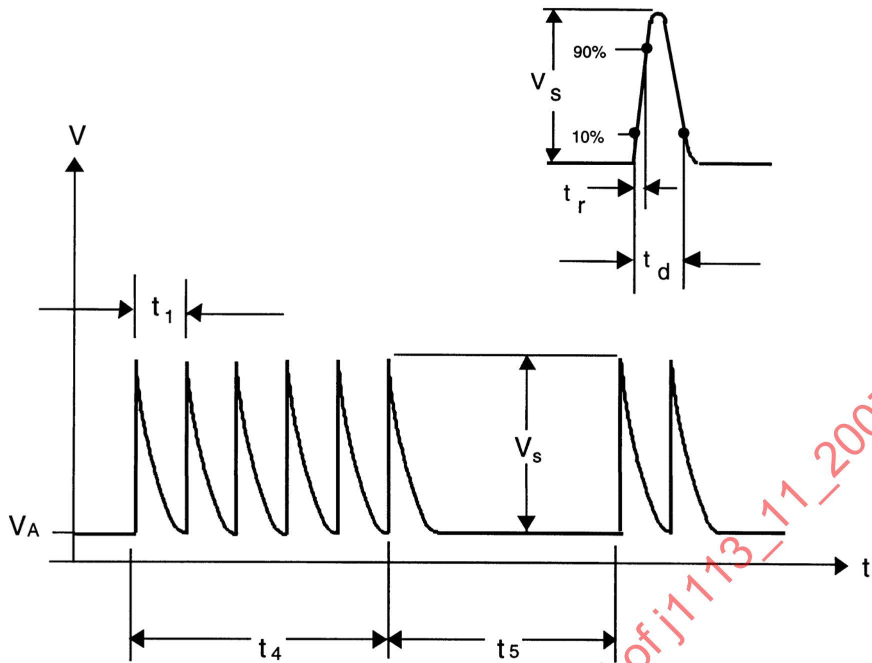


FIGURE 6 - TEST PULSE 3B
SWITCHING SPIKES

TABLE 6 - TEST PULSE 3B PARAMETERS

Parameters	12 V System	24 V System
V_s	+75 V to +100 V	+150 V to +200 V
R_i	50 Ω	50 Ω
t_d	0.1 µs + 100/–0%	0.1 µs + 100/–0%
t_r	5 ns ± 30%	5 ns ± 30%
t_1	100 µs	100 µs
t_4	10 ms	10 ms
t_5	90 ms	90 ms

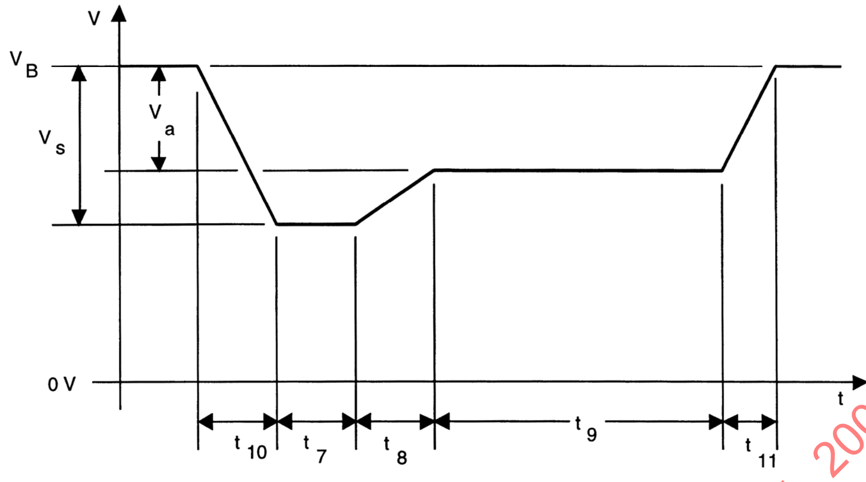


FIGURE 7 - TEST PULSE 4 SINGLE PULSE,
i.e., STARTER MOTOR ENGAGEMENT DISTURBANCE

TABLE 7 - TEST PULSE 4 PARAMETERS

Parameters	12 V System	24 V System
V_s (From V_B)	–4 V to –7 V	–5 V to –16 V
V_a (From V_B)	–2.5 V to –6 V with $\lvert V_a \rvert \leq \lvert V_s \rvert$	–5 V to –12 V with $\lvert V_a \rvert \leq \lvert V_s \rvert$
R_i	0 Ω to 0.02 Ω	0 Ω to 0.02 Ω
t_7	15 ms to 40 ms(1)	50 ms to 100 ms(1)
t_8	≤ 50 ms	≤ 50 ms
t_9	0.5 s to 20 s(1)	0.5 s to 20 s(1)
t_{10}	5 ms	10 ms
t_{11}	5 ms to 100 ms(2)	10 ms to 100 ms(3)

1. The value used should be agreed between the vehicle manufacturer and the equipment supplier to suit the proposed application.
2. t_{11} = 5 ms is typical of the case when engine starts at the end of the cranking period, while t_{11} = 100 ms is typical of the case when the engine does not start.
3. t_{11} = 10 ms is typical of the case when engine starts at the end of the cranking period, while t_{11} = 100 ms is typical of the case when the engine does not start.

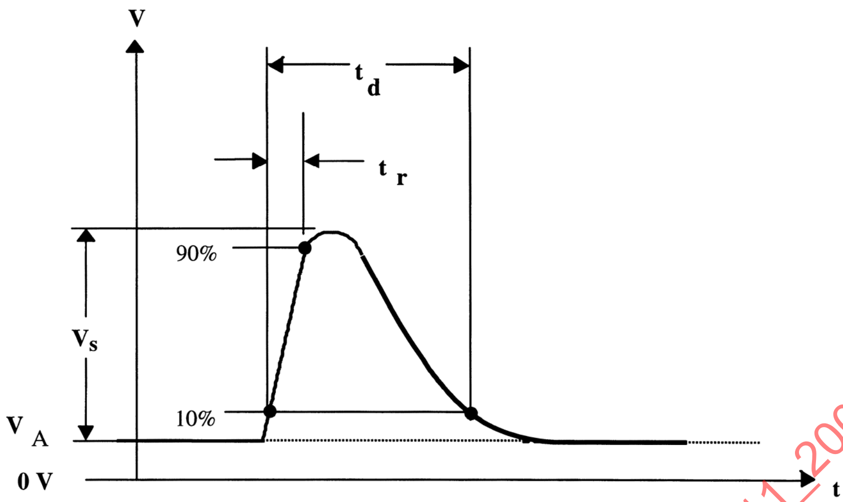
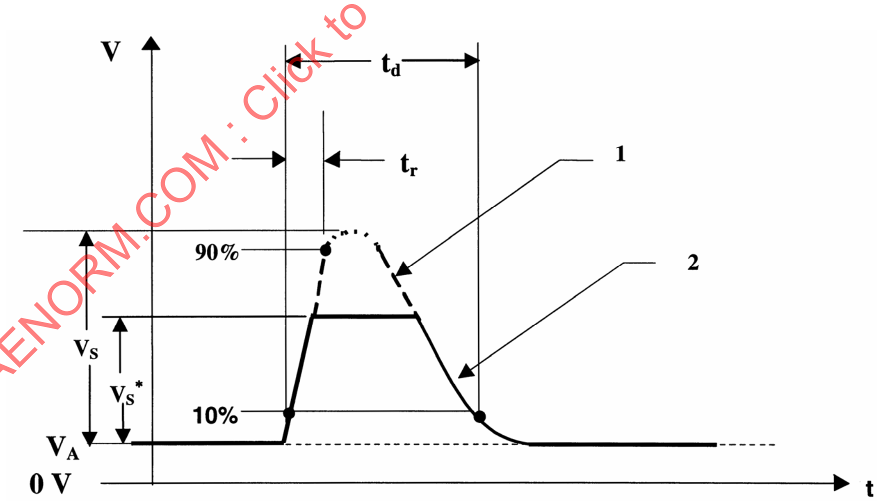


FIGURE 8 - TEST PULSE 5A
LOAD DUMP, SINGLE PULSE - UNSUPPRESSED

TABLE 8 - TEST PULSE 5A PARAMETERS

Parameters	12 V System	24 V System
V_s	22 V to 87 V	44 V to 174 V
R_i	0.5 Ω to 4 Ω	1 Ω to 8 Ω
t_d	40 ms to 400 ms	100 ms to 350 ms
t_r	10 ms +0/–5 ms	10 ms +0/–5 ms



Legend:

1. Unsuppressed
2. Suppressed

FIGURE 9 - TEST PULSE 5B
LOAD DUMP, SINGLE PULSE - WITH CENTRALIZED LOAD DUMP SUPPRESSION

TABLE 9 - TEST PULSE 5B PARAMETERS

Parameter	12 Volt System	24 Volt System
V_s	22 V to 87 V	44 V to 174 V
V_s *	As specified by customer	As specified by customer
t_d	Same as Unsuppressed Value	Same as Unsuppressed Value

The following general considerations of the dynamic behavior of alternators during load dump apply:

a. The internal resistance of an alternator, in the case of load dump, is mainly a function of alternator rotational speed and excitation current.

b. The internal resistance, R_i, of the load dump test pulse generator shall be obtained from the following relationship

$$R_i = \frac{10 \times U_{nom} \times N_{act}}{0.8 \times I_{rated} \times 12\,000\ \text{min}^{-1}} \quad \text{(Eq. 1)}$$

where:

U_{nom} is the specified voltage of the alternator
I_{rated} is the specified current at an alternator speed of 6000 min^{-1} (as given in ISO 8854)
N_{act} is the actual alternator speed, in reciprocal minutes

c. The pulse is determined by the peak voltage V_s, the internal resistance R_i, and the pulse duration t_d; in all cases small values of V_s are correlated with small values of R_i and t_d, and high values of V_s with high values of R_i and t_d.

9. NOTES

9.1 Marginal Indicia

The change bar (l) located in the left margin is for the convenience of the user in locating areas where technical revisions have been made to the previous issue of the report. An (R) symbol to the left of the document title indicates a complete revision of the report.

PREPARED BY THE SAE EMI TASK FORCE
OF THE SAE EMC STANDARDS COMMITTEE

APPENDIX A - (NORMATIVE)
TEST PULSE GENERATOR VERIFICATION PROCEDURE

A.1 SCOPE

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

A.2 GENERAL

See 3.2 for measurement instrumentation requirements

The verification measurements described in Section A.3 shall be conducted under two different load conditions to determine the behavior of the test generator.

a. Under no load conditions

b. Under matched load conditions

The V_A and V_B for this verification procedure are 0 V.

Care shall be taken for the selection of the resistors. They shall have sufficient power dissipation for both pulse and DC supply rating. Additionally they shall be non-inductive. The tolerance of the matching resistor shall be ±1%.

A.3 PULSE VERIFICATION

A.3.1 Test Pulse 1

A.3.1.1 (12 V System)

TABLE A1 - PULSE 1 - 12 V VERIFICATION VALUES

	V_s	t_r	t_d
No load	–100 V ±10%	1.0 µs +0/–50%	2000 µs ± 20%
10 Ω load	–50 V ± 20%		1500 µs ± 20%

A.3.1.2 (24 V System)

TABLE A2 - PULSE 1 - 24 V VERIFICATION VALUES

	V_s	t_r	t_d
No load	–600 V ± 10 %	3.0 µs +0/–50%	1000 µs ± 20 %
50 Ω load	–300 V ± 10 %		1000 µs ± 20 %

A.3.2 Test Pulse 2a (12 V and 24 V System)

TABLE A3 - PULSE 2a - 12 V/24 V VERIFICATION VALUES

	V_s	t_r	t_d
No load	+50 V ± 10%	1 µs +0/–50%	50 µs ± 20%
2 Ω load	+ 25 V ± 20%	1 µs +0/–50%	12 µs ± 20%

A.3.3 Test Pulse 2b (12V and 24V System)

TABLE A4 - PULSE 2b - 12 V/24 V VERIFICATION VALUES

	V_s	t_r, t_1, t_6	t_d
No load and 0.5 Ω load	+10 V ± 10% (12 V system) +20 V ± 10% (24 V system)	1 ms ± 50%	2 s ± 20%

A.3.4 Test Pulse 3a/3b (12 V and 24 V System)

TABLE A5 - PULSE 3a/3b - 12 V/24 V VERIFICATION VALUES

	V_s	t_r	t_d
No load	±200 V ± 10%	5.0 ns ± 30%	150 ns ± 30%
50 Ω load	±100 V ± 20%	5.0 ns ± 30%	150 ns ± 30%

A.3.5 Test Pulse 4 (12 V and 24 V System)

No pulse verification is available.

A.3.6 Test Pulse 5a (12 V and 24 V System)

TABLE A6 - PULSE 5a - 12 V/24 V VERIFICATION VALUES

	V_s	t_r	t_d
No load	+100 V ± 10%	10 ms +0%,–50%	400 ms ± 20%
2 Ω load	+50 V ± 20%	10 ms +0%,–50%	200 ms +0%,–50%

The pulse is calibrated at a test level of 100 V, a pulse width of 400 ms and a source impedance of R_i = 2 Ω into a 2 Ω terminating resistor. A terminating resistor of 2 Ω is regarded as an optimum (no influence of losses due to cables and connectors).

APPENDIX B - (INFORMATIVE)
EXAMPLE OF TEST SEVERITY LEVELS
(SEE PAR. 6.1)

B.1 The test levels in Tables B1 and B2 are example test severity levels for the Performance Objectives.

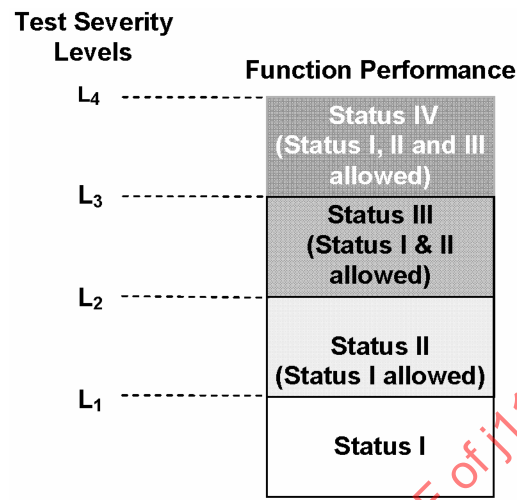


FIGURE B1 - FUNCTION PERFORMANCE STATUS CLASSIFICATION

TABLE B1 - EXAMPLE OF PULSE SEVERITY LEVELS SELECTION TABLE FOR 12-VOLT SYSTEMS (SEE FIGURE B1)

This example illustrates how the function of the device is expected to perform when exposed to the injected transient voltage Vs for a 12 volt system.

Test Severity Levels	Pulse 1	Pulse 2a	Pulse 2b	Pulse 3a	Pulse 3b	Pulse 4	Pulse 5a
L_4	–100 V	+75 V	+10 V	–150 V	+100 V	–7 V	87 V
L_3	–75 V	+50 V	+10 V	–112 V	+75 V	–6 V	NA
L_2	–50 V	+40 V	+10 V	–75 V	+50 V	–5 V	NA
L_1	–25 V	+25 V	+10 V	–35 V	+25 V	–4 V	NA

TABLE B2 - EXAMPLE OF PULSE SEVERITY LEVELS SELECTION TABLE FOR 24-V SYSTEMS (SEE FIGURE B1)

Test Severity Levels	Pulse 1	Pulse 2a	Pulse 2b	Pulse 3a	Pulse 3b	Pulse 4	Pulse 5
L_4	- 600 V	+ 75 V	+ 20 V	- 200 V	+ 200 V	- 16 V	150 V
L_3	- 450 V	+ 50 V	+ 20 V	- 150 V	+ 150 V	- 12 V	NA
L_2	- 300 V	+ 40 V	+ 20 V	- 100 V	+ 100 V	- 8 V	NA
L_1	NA	+ 25 V	+ 20 V	- 50 V	+ 50 V	- 5 V	NA

APPENDIX C - (INFORMATIVE)
DETERMINATION OF PULSE GENERATOR'S ENERGY CAPABILITY

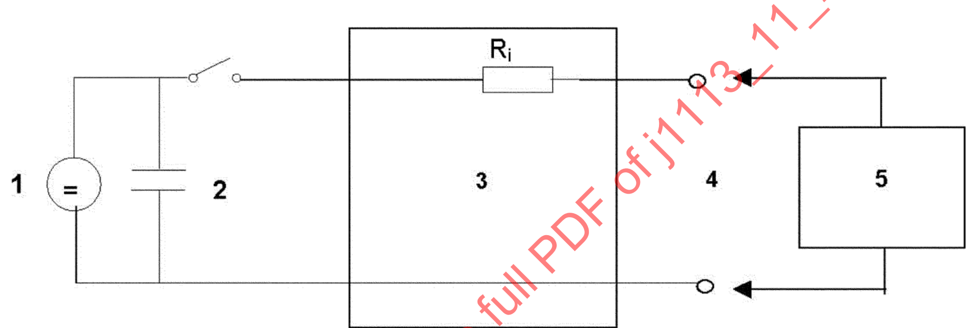
C.1 DETERMINATION AND VERIFICATION OF PULSE GENERATOR MINIMUM ENERGY CAPABILITY

C.2 CALCULATION METHOD FOR DETERMINATION OF MINIMUM ENERGY CAPABILITY SPECIFICATION

This method is to calculate the energy of the pulse as delivered by the generator to the matching resistor (resistive load R_L) utilizing the measured pulse parameters T_d and V_s.

The transient generator used for this document shall generate double exponential transients, which are a result of capacitive discharges into a pulse shaping network. This type of generator is used for the pulses 1(12 V), 1(24 V), 2a, 3a/3b and pulse 5.

Pulse 2b and pulse 4 have to be realized by programmable dc power sources.



Key

1 Power supply

2 Capacitor C_s

3 Pulse shaping network with internal resistance R_i

4 Pulse output

5 Matching load resistor R_L

FIGURE C1 - EXAMPLE OF A SIMPLIFIED CIRCUIT DIAGRAM
OF A TRANSIENT GENERATOR

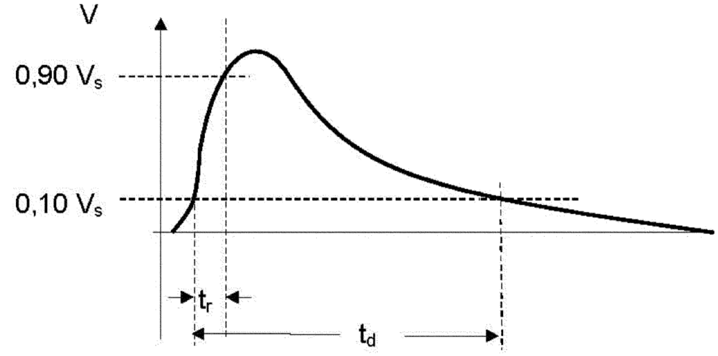


FIGURE C2 - DOUBLE EXPONENTIAL PULSE SHAPE GENERATED BY A TRANSIENT GENERATOR

The influence of the rise time is not taken into account ($t_r << t_d$), which is allowed for all pulses specified in this document.

C.2.1 Voltage Function

$$V(t) = \frac{V_0 \times R_L}{R_i + R_L} \times e^{-\left(\frac{2.3 \times t}{Td}\right)} \quad \text{(Eq. C1)}$$

where:

V_0 is the open circuit output voltage
R_i is the source resistor of the generator
R_L is the load resistor for the generator
t_d is the pulse width 10% to 10% of V_s
V(t) is a function of the voltage wave shape

C.2.2 Current Function

$$I(t) = \frac{1}{R_L} \times \frac{V_0 \times R_L}{R_i + R_L} \times e^{-\left(\frac{2.3 \times t}{Td}\right)} = \frac{V_0}{R_i + R_L} \times e^{-\left(\frac{2.3 \times t}{Td}\right)} \quad \text{(Eq. C2)}$$

where:

V_0 is the open circuit output voltage
R_i is the source resistor of the generator
R_L is the load resistor for the generator
t_d is the pulse width 10% to 10% of V_s
I(t) is a function of the current wave shape

C.2.3 Function of the Pulse Energy

$$P(t) = V(t) \times I(t) = \frac{(V_0)^2 \times R_L}{(R_i + R_L)^2} \times \left(e^{-\left(\frac{2.3 \times t}{Td}\right)} \right)^2 = \frac{(V_0)^2 \times R_L}{(R_i + R_L)^2} \times e^{-\left(\frac{4.6 \times t}{Td}\right)} \quad \text{(Eq. C3)}$$