Conducted Immunity Tests for Automotive Electronics
Automotive EMC Seminar - IEEE HK

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Luterbach, Switzerland

Our competence center for conducted equipment:
- ESD
- Burst
- Surge
- Power Quality
- Automotive

SCS Accredited Calibration Centre
Headquarters
Berlin, Germany

- Our competence center for
  - RF Equipment
  - GTEM Cell, Reverberation Chamber
  - EMC System
  - DKD accredited Calibration Centre
- **Wokingham, UK**
  - Our competence center for
    - Compliance 3 Software
    - EMC System Project
    - Power Amplifier
    - UKAS accredited Calibration Centre
Turnkey Projects

- 3m Anechoic Chamber
- Radiated Emission System
- Radiated Immunity System
- ESD
- Conducted Emission
- Conducted Immunity
Turnkey Projects

- CISPR25 Emission System x2
- 600V/m Radiated Immunity System
- ESD
- BCI System
- Transient Immunity System
- Magnetic Field Immunity
- Stripline, TEM Cell
- Optical EUT Monitoring
Turnkey Projects

- 200V/m Radiated Immunity System
- Automatic EUT monitoring System

Alpine China
Turnkey Projects

- ESD
- BCI System up 400mA
- Transient Immunity
- Magnetic Immunity
- 1kW Power Amplifier – 200V/m

Radiated Immunity System

中国电器科学研究院
Conducted Immunity Testing on Automotive Electronics: From ISO 7637 to Introduction of Manufacturer standards
What is EMC?

Special Considerations for Motor Vehicles

In ISO 7637 and variants, we are considering transients and voltage drops that are coupled over battery lines and signal lines.

Immunity Testing simulates ‘Conducted EMC’ that occurs during normal or error conditions in a motor vehicle.

Emissions testing ensures that the noise created by a device is less than specified levels.

Evaluates the performance of components during simulated real-world EMC events.

These failure conditions are documented and tests defined by International organizations (ISO, SAE) and manufacturers (Ford, VW).
Why EMC is important?

- Causes:
  - Alternators, Converters, Switching Processes
  - Electric Motors, Fuel Pump, Fan Motors
  - Lights, Radio
  - Every kind of electronic device
  - Coupled on Power Lines and Wiring Harnesses
  - Engine Start

- When devices shall be tested:
  - Before production and sampling during production
  - During redesigns or modifications
  - During initial design phases
Electromagnetic Compatibility (EMC) refers to the ability of electronic equipment to function properly in an electromagnetic environment. It covers two main aspects: Immunity and Emission.

**Immunity** includes:
- ESD (Electrostatic Discharge)
- RF (Radio Frequency)
- Magnetic
- Conducted Transient
- Voltage Fluctuation

**Emission** includes:
- Conducted Transient
- Conducted Continuous
- RF

There are many test cases to ensure compliance with EMC standards.
Distinct Characteristics in Automotive Conducted EMC

- DC 12V, 24V, 42V
- Lots of different Transients
  - Positive and Negative Transients
  - Emission and Immunity Tests
- Lots of Voltage Fluctuation
- Extremely detailed in test setup:
  - Harness height and length
  - Separation
- Test Fixture
- Load Simulator
- Very long test time
Automotive Conducted EMC Setup

- EUT is set to be in operation mode(s)
- Test Fixture
- Load simulator

EUT example: Climate Control Console
EMC Standards in Automotive Industry

<table>
<thead>
<tr>
<th>International Bodies</th>
<th>Manufacturers (OEM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISO</td>
<td>BMW</td>
</tr>
<tr>
<td>IEC / CISPR</td>
<td>Daimler Chrysler</td>
</tr>
<tr>
<td></td>
<td>Fiat</td>
</tr>
<tr>
<td></td>
<td>Ford</td>
</tr>
<tr>
<td></td>
<td>General Motors</td>
</tr>
<tr>
<td></td>
<td>Honda</td>
</tr>
<tr>
<td></td>
<td>Hyundai</td>
</tr>
<tr>
<td></td>
<td>Mazda</td>
</tr>
<tr>
<td></td>
<td>Peugeot</td>
</tr>
<tr>
<td></td>
<td>Nissan</td>
</tr>
<tr>
<td></td>
<td>Renault</td>
</tr>
<tr>
<td></td>
<td>Toyota</td>
</tr>
<tr>
<td></td>
<td>Volkswagen</td>
</tr>
<tr>
<td></td>
<td>...More!</td>
</tr>
</tbody>
</table>

Regional Requirement

- 2004/104/EC (e-mark)
- SAE (SAE J1113-11, SAE J1113-12)
- JASO
- GB/T

No so difficult

Much more complicated
ISO Standards on Automotive Electronics

- ISO 7637-2: Conducted Transient on power line
  - 7 tests
- ISO 7637-3: Conducted Transient no non power line
  - 4 tests
- ISO 16750-2: Environmental conditions and testing for electrical and electronic
  - 6 out 10 tests are voltage fluctuation
- ISO 10605: ESD

Lots of the test cases are introduced and modified in OEM Standards

Usually in a more harsh way

All these tests simulate typical electrical environment in a full vehicle
Conducted Transient Immunity & Voltage Fluctuation
OEM standards refer to ISO but different

Different automotive standards require different transient pulses. The requirements are different in:

- Amplitude
- Impulse
- Frequency
- Pulse energy
- Test method, test setup

What are the causes of differences?

- Wiring harness
- Components
- Generators
- etc.
## Conducted Immunity Tests Summary

<table>
<thead>
<tr>
<th>ISO7637-2</th>
<th>Ford</th>
<th>Nissan</th>
<th>Volkswagen</th>
</tr>
</thead>
<tbody>
<tr>
<td>ES-XW7T-1A278-AC</td>
<td>CI 210</td>
<td>EQ/TE 01</td>
<td>Pulse 1</td>
</tr>
<tr>
<td>CI 220</td>
<td>Pulse A1</td>
<td>EQ/TE 02</td>
<td>Pulse 2</td>
</tr>
<tr>
<td>Pulse 3a</td>
<td>CI 220</td>
<td>EQ/TE 03</td>
<td>Pulse 3</td>
</tr>
<tr>
<td>Pulse 3b</td>
<td>Pulse A2</td>
<td>EQ/TE 04</td>
<td>Pulse 4</td>
</tr>
<tr>
<td>Pulse 4</td>
<td>Pulse B1</td>
<td>EQ/TE 05</td>
<td>Pulse 4b</td>
</tr>
<tr>
<td>Pulse 5a</td>
<td>Pulse B2</td>
<td>EQ/IC 01</td>
<td>Pulse 5b</td>
</tr>
<tr>
<td>Pulse 5b</td>
<td>Pulse C</td>
<td>pulse 1</td>
<td>Pulse 6</td>
</tr>
<tr>
<td>Pulse D</td>
<td>pulse 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pulse E</td>
<td>EQ/IC 02</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pulse F</td>
<td>pulse 3a</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pulse G</td>
<td>pulse 3b</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CI 230</td>
<td>EQ/IC 03</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CI 250</td>
<td>EQ/IC 04</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CI 260</td>
<td>EQ/IC 05</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CI 270</td>
<td>EQ/IC 06</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
This test is a simulation of transients due to supply disconnection from inductive loads; it applies to a DUT if as used in the vehicle, it remains connected directly in parallel with an inductive load.\(^{(1)}\)

\[
s (q_k) = \frac{1}{n-1} \sum_{k=1}^{n} (q_k - Q)
\]

---

**Parameter** | **12 V system** | **24 V system**
--- | --- | ---
\(U_s\) | -75 V to -100 V | -450 V to -600 V
\(R_i\) | 10 \(\Omega\) | 50 \(\Omega\)

---

Generator internal resistance \(R_i\): 10 \(\Omega\) (50 \(\Omega\))

---

200 ms

\(\leq 100\mu s\)

0.5 - 5 s

13.5 V (27 V)

0 V

-75 to -100 V

(-450 to -600 V)

\(\leq 1\mu s\) (3 \(\mu s\))

2 ms (1 ms)
Test Purpose of ISO 7637-2
Test Pulse 1 Variant

<table>
<thead>
<tr>
<th>Parameter</th>
<th>12 V system</th>
<th>24 V system</th>
</tr>
</thead>
<tbody>
<tr>
<td>$U_s$</td>
<td>-75 V to -100 V</td>
<td>-450 V to -600 V</td>
</tr>
<tr>
<td>$R_i$</td>
<td>10 $\Omega$</td>
<td>50 $\Omega$</td>
</tr>
<tr>
<td>$t_d$</td>
<td>2 ms</td>
<td>1 ms</td>
</tr>
<tr>
<td>$t_r$</td>
<td>$1_{-05}$ /$\mu$s</td>
<td>$3_{-1,5}$ /$\mu$s</td>
</tr>
<tr>
<td>$t_1$ a</td>
<td>0.5 s to 5 s</td>
<td></td>
</tr>
<tr>
<td>$t_2$</td>
<td>200 ms</td>
<td></td>
</tr>
<tr>
<td>$t_3$ b</td>
<td>&lt; 100 $\mu$s</td>
<td></td>
</tr>
</tbody>
</table>

Ford
ES-XW7T-1A278-AC
Cl220 pulse E (12V only)

Nissan
28401NDS02
EQ/IC 01 Pulse1 (12V only)

Volkswagen
TL 82066

ISO 7637-2
Pulse 2a simulates transients due to sudden interruption of currents in a device connected in parallel with the DUT due to the inductances of the wiring harness.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>12 V system</th>
<th>24 V system</th>
</tr>
</thead>
<tbody>
<tr>
<td>$U_s$</td>
<td>+37 V to +50 V</td>
<td></td>
</tr>
<tr>
<td>$R_i$</td>
<td>2 Ω</td>
<td></td>
</tr>
<tr>
<td>$t_d$</td>
<td>0.05 ms</td>
<td></td>
</tr>
<tr>
<td>$t_r$</td>
<td>$(1 - 0.5) \mu s$</td>
<td></td>
</tr>
<tr>
<td>$t_l^0$</td>
<td>0.2 s to 5 s</td>
<td></td>
</tr>
</tbody>
</table>

![Diagram of Test Pulse 2a](image)
Test Purpose of ISO 7637-2
Test Pulse 2a Variant

<table>
<thead>
<tr>
<th>Parameter</th>
<th>12 V system</th>
<th>24 V system</th>
</tr>
</thead>
<tbody>
<tr>
<td>$U_s$</td>
<td>+37 V to +50 V</td>
<td></td>
</tr>
<tr>
<td>$R_i$</td>
<td>2 Ω</td>
<td></td>
</tr>
<tr>
<td>$t_d$</td>
<td>0.05 ms</td>
<td></td>
</tr>
<tr>
<td>$t_r$</td>
<td>$\left(1 - 0.5\right)$ μs</td>
<td></td>
</tr>
<tr>
<td>$t_1^a$</td>
<td>0.2 s to 5 s</td>
<td></td>
</tr>
</tbody>
</table>

ISO 7637-2

Ford
ES-XW7T-1A278-AC
CI220 pulse F (12V only)

Nissan
28401NDS02
EQ/IC 01 Pulse 2a (12V only)

Volkswagen
TL 82066

<table>
<thead>
<tr>
<th>Pulse</th>
<th>Number</th>
<th>$U_s$ (V)</th>
<th>$t_d$ (μs)</th>
<th>$t_r$ (μs)</th>
<th>Generator $R_i$ (Ω)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>12 V</td>
<td>42 V</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pulse 2</td>
<td>5,000 pulses</td>
<td>+50</td>
<td>50</td>
<td>1</td>
<td>4 10</td>
</tr>
<tr>
<td>Pulse 2</td>
<td>5,000 pulses</td>
<td>+75</td>
<td>200</td>
<td>1</td>
<td>10</td>
</tr>
</tbody>
</table>
Test Purpose of ISO 7637-2
Test Pulse 2b

*Pulse 2b simulates transients from dc motors acting as generators after the ignition is switched off*

It is more like a voltage fluctuation test. Most car manufacturers had withdrawn this because it is covered by other voltage fluctuation tests.
Pulse 3 occurs as the result of switching processes. The characteristics of this pulse are influenced by distributed capacitance and inductance of the wiring harness.

**Parameters for test pulse 3a**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>12 V system</th>
<th>24 V system</th>
</tr>
</thead>
<tbody>
<tr>
<td>$U_s$</td>
<td>$-112 \text{ V to } -150 \text{ V}$</td>
<td>$-150 \text{ V to } -200 \text{ V}$</td>
</tr>
</tbody>
</table>

**Parameters for test pulse 3b**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>12 V system</th>
<th>24 V system</th>
</tr>
</thead>
<tbody>
<tr>
<td>$U_s$</td>
<td>$+75 \text{ V to } +100 \text{ V}$</td>
<td>$+150 \text{ V to } +200 \text{ V}$</td>
</tr>
</tbody>
</table>
Test Purpose of ISO 7637-2
Test Pulse 3a/3b Variant

Most manufacturers bring these tests into their own EMC standards except Ford

<table>
<thead>
<tr>
<th>Test pulse 3a</th>
<th>$t_r$</th>
<th>$t_d$</th>
</tr>
</thead>
<tbody>
<tr>
<td>No load</td>
<td>$-200 \text{ V } \pm 20 \text{ V}$</td>
<td>$5 \text{ ns } \pm 1,5 \text{ ns}$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Test pulse 3b</th>
<th>$U_s$</th>
<th>$t_r$</th>
<th>$t_d$</th>
</tr>
</thead>
<tbody>
<tr>
<td>No load</td>
<td>$+200 \text{ V } \pm 20 \text{ V}$</td>
<td>$5 \text{ ns } \pm 1,5 \text{ ns}$</td>
<td>$150 \text{ ns } \pm 45 \text{ ns}$</td>
</tr>
</tbody>
</table>

General Motor
GMW3097

Nissan
28401NDS02
EQ/IC 02 Pulse 3a/3b

Volkswagen
TL 82066 Pulse 3a/3b

Pulse width
$t_d = 100\text{ns}$
Pulse 4 is the voltage reduction caused by energizing the starter motor circuits of the internal combustion engines.
Test Purpose of ISO 7637-2
Test Pulse 4

- All manufacturers require Starting Profile test but in more complicated way

Volkswagen
TL 82066 Pulse 4/4b
Very Complicated Starting Profile tests

This test is to be done at -40°C or below

Ford
ES-XW7T-1A278-AC CI230
Power Cycling
Pulse 5 is a simulation of a load dump transient occurring in the event of a discharged battery being disconnected while the alternator is generating charging current with other loads remaining on the alternator circuit at this moment.
All manufacturers require Load Dump test but almost all of them are specified in different ways.

This pulse generates high energy and is often destructive.

### Test Pulse 5a/5b Variant

- **Ford**
  - ES-XW7T-1A278-AC
  - CI220 pulse G

- **Nissan**
  - 28401NDS02
  - EQ/IC 03 Pulse 5a/5b

- **Volkswagen**
  - TL 82066 Pulse 5b
  - Only applicable to 42V system
  - $R_l = 3\Omega$

### Test Pulse 5a Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>12 V system</th>
<th>24 V system</th>
</tr>
</thead>
<tbody>
<tr>
<td>$U_s$</td>
<td>85 V to 87 V</td>
<td>123 V to 174 V</td>
</tr>
<tr>
<td>$R$</td>
<td>0.6 Ω to 4 Ω</td>
<td>1 Ω to 8 Ω</td>
</tr>
<tr>
<td>$t_c$</td>
<td>40 ms to 400 ms</td>
<td>100 ms to 350 ms</td>
</tr>
<tr>
<td>$t_e$</td>
<td>$\left\lceil 10 \frac{U_s}{R} \right\rceil$ ms</td>
<td></td>
</tr>
</tbody>
</table>

### Test Pulse 5b Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>12 V system</th>
<th>24 V system</th>
</tr>
</thead>
<tbody>
<tr>
<td>$U_s$</td>
<td>85 V to 87 V</td>
<td>123 V to 174 V</td>
</tr>
<tr>
<td>$U_s'$</td>
<td>As specified by customer</td>
<td></td>
</tr>
<tr>
<td>$t_e$</td>
<td>Same as unsuppressed value</td>
<td></td>
</tr>
</tbody>
</table>
Test Purpose of ISO 7637-2
Test Pulse 5a/5b

Pulse 5a
85V
13.5V
0V

Pulse 1
0V
-100V
-150V

Pulse 3a
13.5V
100μs
10 ms
-112 to -150 V
0 V

Test Pulse 5a/5b
Manufacturer EMC Standards Tests

Ford ES-XW7T-1A278-AC CI220

Pulse A1

Pulse A2

Pulse C

These pulses are caused by actual mechanical relay with defined circuitry.
Nissan
28401NDS02
EQ/IC 04 : Resistance to power supply micro-interruptions
Siemens VDO
Fuel Pump Transient test for IPC
Pulse Generation System
Typical Setup

Photograph Courtesy of CVC
TeSEQ Conducted Immunity System
Automotive Electronics

NSG5500  NSG5600  PA 5840

Transients

Voltage Fluctuation

ISO
SAE
JASO
BMW
Daimler Chrysler
Fiat
Ford
General Motors
Honda
Hyundai
Mazda
Peugeot
Nissan
Renault
Toyota
Volkswagen
Etc..

TeSEQ Pulse Generation System
Conducted Transient Emissions
Automotive EMI
- CISPR12, 25 -> Continuous Interference
- ISO 7637-2 -> Transient due to switching process

ISO 7637-2
- Must do test
- Test procedure is straight forward
- Lots of details in test setup
- Lots of mal-practice in the market
ISO7637-2 Emissions Test Layout

“Slow Pulse” Setup

“Fast Pulse” Setup

Cable lengths, 50 -0/+10 mm above GND plane, disturbance voltage shall be measured as close to the DUT terminals as possible
ISO 7637-2 Emissions Test Layout

For applications where the DUT is far from the switch, the setup should have the AN between the switch (simulating the wiring harness) and the DUT.

“Slow Pulse Setup”
Millisecond range or slower
ISO 7637-2 Emissions Test Layout

For applications where the DUT is near the switch, the setup should have the AN before the switch “Fast Pulse Setup” nanosecond-to-microsecond range.
Emissions Relay or Electronic Switch?

When to use a relay and when the electronic switch:

**Relay**
- Voltages over 400V
- Usually must be approved by OEM
- Poor Repeatability, Slow/Chattering
- Must be replaced
- Should be production relay from the vehicle containing the DUT

**Electronic Switch**
- Less than 400V
- Fast and Repeatable
- Voltage Drop Must be Accounted For $\Delta U \leq 1V$ at 25 A
ISO 7637 and CISPR 25 Artificial Network are **NOT** the same

**Differences Between ISO 7637 and CISPR25 Artificial Networks**
Test procedure is quiet straightforward but has to be done manually.

Search for the worst cases (highest amplitude) by:
- Changing the switch on/off time
- Changing the switching repetition
Typical Measurement Result

Very Heavily Inductive

Mixed R/L Load

Much more severe pulses from DUTs with high inductance
ISO7637-2 Emissions Limits

Ford
ES-XW7T-1A278-AC
CE410 Limits <+100V, >-150V
Only use Fast Pulse setup
Only use Fast Pulse setup

**Table 7 – Maximum permissible transient emission for 12-V and 42-V interference sources**

<table>
<thead>
<tr>
<th>Pulse</th>
<th>( U_s ) (V)</th>
<th>( t_d ) (( \mu )s)</th>
<th>( t_r ) (( \mu )s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pulse 1</td>
<td>( \geq -100 )</td>
<td>( \leq 2,000 )</td>
<td>( \geq 1 )</td>
</tr>
<tr>
<td>Pulse 2</td>
<td>( \leq +50 )</td>
<td>( \leq 50 )</td>
<td>( \geq 1 )</td>
</tr>
<tr>
<td>Pulse 3a</td>
<td>( \geq -150 )</td>
<td>( \leq 0.1 )</td>
<td>( \geq 0.005 )</td>
</tr>
<tr>
<td>Pulse 3b</td>
<td>( \leq +100 )</td>
<td>( \leq 0.1 )</td>
<td>( \geq 0.005 )</td>
</tr>
<tr>
<td>Pulse 4</td>
<td>not applicable</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pulse 5b (only 42 V)</td>
<td>( \leq 16 )</td>
<td>( \leq 300,000 )</td>
<td>10,000</td>
</tr>
</tbody>
</table>

**Table 8 – Maximum permissible transient emission for 24-V interference sources**

<table>
<thead>
<tr>
<th>Pulse</th>
<th>( U_s ) (V)</th>
<th>( t_d ) (( \mu )s)</th>
<th>( t_r ) (( \mu )s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pulse 1</td>
<td>( \geq -150 )</td>
<td>( \leq 2,000 )</td>
<td>( \geq 1 )</td>
</tr>
<tr>
<td>Pulse 2</td>
<td>( \leq +75 )</td>
<td>( \leq 200 )</td>
<td>( \geq 1 )</td>
</tr>
<tr>
<td>Pulse 3a</td>
<td>( \geq -150 )</td>
<td>( \leq 0.1 )</td>
<td>( \geq 0.005 )</td>
</tr>
<tr>
<td>Pulse 3b</td>
<td>( \leq +100 )</td>
<td>( \leq 0.1 )</td>
<td>( \geq 0.005 )</td>
</tr>
<tr>
<td>Pulse 4</td>
<td>not applicable</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pulse 5</td>
<td>not applicable</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Measurement of conducted transient emission
Measurement of conducted transient emission

- Complicated Measurement Setup
Teseq Transient Emission System

Detectable switch

Control unit

Artificial Network

AES 5500

Photograph Courtesy of HKPC