IEC Transient Immunity

IEC 61000-4-4 Ed3: 2012  Electrical fast transient / Burst immunity test
IEC 61000-4-5 Ed3: 2014  Surge immunity test and Inventory of last revision
IEC 61000-4-6 Ed4: 2013  Conducted disturbances inducted by radio frequency fields

EMC & Wireless Technical Seminar @ CETECOM Milpitas  November 11, 2015
IEC 61000-4-4

Electrical fast transient / Burst immunity test
Phenomenon open a contact

Equivalent diagram of a switching circuit

Typical voltage waveform across an opening switch

230V Power relays
EMC Model for fast transients

**Source of interference**
- Circuit breaker in electric circuits
- High voltage switchgears
- 110/230V power supply systems
- 24V control lines

**Characteristics**
- Impulse with rise time in nanoseconds
- Broadband interference spectrum up to 400 MHz
- Amplitudes up to some kV

**Coupling**
- Capacitive (du/dt) to parallel lines
- Inductive by magnetic fields (di/dt) to earth leads
- Radiation in the near field by arcs

**Migration**
- Conducted in the cable system
- Asymmetrical resp. Line to Earth
### Test level IEC 61000-4-4: Ed3.0 (2012-4)

<table>
<thead>
<tr>
<th>Level</th>
<th>Power line</th>
<th>I/O line</th>
<th>Peak voltage [kV]</th>
<th>Repetition rate [kHz]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0,5</td>
<td>0,25</td>
<td>5 or 100</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>0,5</td>
<td>5 or 100</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>1</td>
<td>5 or 100</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>2</td>
<td>5 or 100</td>
<td></td>
</tr>
<tr>
<td>X (1)</td>
<td>special</td>
<td>special</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 1 - Test levels

The use of 5 kHz repetition frequency is traditional, however, **100 kHz** is closer to reality. Product committees should determine which frequencies are relevant for specific products or product types. In Annex B1 you will find representative values from real installations for your assistance.
Test equipment simplified circuit diagram of EFT / burst generator

Components

- **U**: High-voltage source
- **Rc**: Charging resistor
- **Cc**: Energy storage capacitor
- **Rs**: Impulse duration shaping resistor
- **Rm**: Impedance matching resistor
- **Cd**: DC blocking capacitor
- **Switch**: High-voltage switch (electronic switch)

**NOTE:** The characteristics of the switch together with stray elements (inductance and capacitance) of the layout shape the required rise time.
**Characteristic waveform**

Output voltage range with 1000 Ω load: 
min. 0.24 kV up to 3.8 kV; 
min. 0.125 kV up to 2 kV;

Output voltage range with 50 Ω load:

Pulse repetition frequency: 
5 kHz and 100 kHz ± 20 %

Burst duration (see 6.1.2 and fig. 2): 
(15 ± 3) ms at 5 kHz 
(0.75 ± 0.15) ms at 100 kHz 
(300 ± 60) ms

Burst period

**Pulse shape:**
Termination at coaxial output 
(with 50 Ω load)

Rise time $t_r = (5 \pm 1.5)$ ns 
Pulse duration (50 %-value) $t_d = (50 \pm 15)$ns 
Peak value of voltage; Table 2 ± 10 %

Termination at coaxial output 
(with 1000 Ω load)

Rise time $t_r = (5 \pm 1.5)$ ns 
Pulse duration (50 %-value) $t_d = 50$ ns 
with a tolerance of − 15 ns to + 100 ns 
Peak value of voltage; Table 2 ± 20 %

New in Edition 3
Parameter of the actual interferences

**Single pulse**
Rise time $tr = 5\text{ns}$
Pulse duration $td = 50\text{ns}$

**Pulse packet (Burst)**
Repetition time: $Tr = 300\text{ms}$
As formerly:
Duration burst packet $Td = 15\text{ms}$
At spike frequency $f = 5\text{kHz}$
Duration burst packet $Td = 0.75\text{ms}$
At spike frequency $f = 100\text{kHz}$
Mathematical modeling of Burst waveforms

Figure 3 shows the ideal waveform of a signal pulse into a 50 Ω load with nominal parameters

\( t_r = 5 \text{ ns} \) and 
\( t_w = 50 \text{ ns} \)

Formula of the ideal waveform per Figure 3, \( v_{EFT}(t) \)

\[
v_{EFT}(t) = k_v \cdot \frac{\left( \frac{t}{\tau_1} \right)^{n_{EFT}} - \frac{t}{\tau_2}}{1 + \left( \frac{t}{\tau_1} \right)^{n_{EFT}}} \cdot e^{\frac{t}{\tau_2}}
\]

where

\[
k_{EFT} = e^{-\frac{t}{\tau_2} \left( \frac{n_{EFT} \cdot \tau_2}{\tau_1} \right)^{n_{EFT}}}
\]

\( k_v \) is max. or peak value of the open-circuit voltage

\( (k_v = 1 \text{ means normalized voltage}) \)

\( n_{EFT} = 1,8 \)

\( v_1 = 0,92 \quad \tau_1 = 3,5 \text{ ns} \quad \tau_2 = 51 \text{ ns} \)

Figure 3
Characteristics - output voltage peak -

New peak voltages for 1000Ω load with respect to the voltage divider Ratio with Ri = 50 Ω in table 2

<table>
<thead>
<tr>
<th>Set voltage</th>
<th>( V_p ) (open circuit)</th>
<th>( V_p ) (1000 Ω)</th>
<th>( V_p ) (50 Ω)</th>
<th>Repetition frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>kV</td>
<td>kV</td>
<td>kV</td>
<td>kV</td>
<td>kHz</td>
</tr>
<tr>
<td>0.25</td>
<td>0.25</td>
<td>0.24</td>
<td>0.125</td>
<td>5 or 100</td>
</tr>
<tr>
<td>0.5</td>
<td>0.5</td>
<td>0.48</td>
<td>0.25</td>
<td>5 or 100</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>0.95</td>
<td>0.5</td>
<td>5 or 100</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>1.9</td>
<td>1</td>
<td>5 or 100</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>3.8</td>
<td>2</td>
<td>5 or 100</td>
</tr>
</tbody>
</table>

Measures should be taken to ensure that stray capacitance is kept to a minimum.

NOTE 1 Use of a 1000 Ω load resistor will automatically result in a voltage reading that is 5% lower than the set voltage, as shown in column \( V_p \) (1000 Ω). The reading \( V_p \) at 1000 Ω = \( V_p \) (open circuit) multiplied times 1000/1050 (the ratio of the test load to the total circuit impedance of 1000 Ω plus 50 Ω).

NOTE 2 With the 50 Ω load, the measured output voltage is 0.5 times the value of the unloaded voltage as reflected in the table above.
Calibration at the coaxial output

In order to provide a common supply basis for all test simulators, the characteristics of the test simulators have to be proved.

The verification at **coaxial output** has to be carried out as follows:

1. The demanded test voltage is set at the simulator.

2. The curve progression is measured at the coaxial output of the simulator. The Peak value of the voltage has to be 50\% of the set voltage at the simulator.

3. The curve progression is measured at constant simulator settings at 1000 Ω The peak value of the voltage has to be Up (open circuit) corresponding (±20\%).
Calibration routine no.: 1

Calibration at coaxial 50 Ohm output of the simulator with a 50 Ohm load

Ratio with KW50 -> 1:400
Example: 2000V Burst = 5V on scope
Calibration routine no.: 2

Calibration at coaxial 50 Ohm output of the simulator with a 1000 Ohm load

Ratio with KW1000 → 1:1000
Example: 2000V Burst = 2V on scope
Coupling/Decoupling network for mains connectors (IEC 61000-4-4:2012)

Coupling capacitors: 33 nF
Insertion loss: asymmetric (all lines against reference earth)
**Calibration of the CDN for mains supply**

new in Edition 3

Proof of characteristics of coupling/decoupling network:

The pulse shape has to be proved at each output/path of coupling-/decoupling network

- Therefore all coupling paths are set simultaneously (Common Mode)
- The output of the coupling network is terminated with a coaxial load of 50 Ω

The calibration has to be provided with a voltage setting of 4kV as follows:

<table>
<thead>
<tr>
<th></th>
<th>since EN 61000-4-4:2004</th>
<th>New: EN 61000-4-4:2012</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rise time $t_r$</td>
<td>5 ns ± 30%</td>
<td>5.5 ns ± 1.5ns</td>
</tr>
<tr>
<td>Pulse duration $t_d$</td>
<td>50 ns ± 30%</td>
<td>45ns ± 15ns</td>
</tr>
<tr>
<td>peak value of voltage</td>
<td>± 10% of the voltage according to table</td>
<td></td>
</tr>
</tbody>
</table>
Calibration routine no.: 3

- The EFT transients are coupled to all CDN lines simultaneously (CM).
- The output of the CDN shall not be short circuited.
- The EFT transients shall be measured at each individual output of the CDN with 50Ω load, while the other outputs are open.
- Each individual output must show the transients within the tolerances as specified.

![Diagram showing calibration routine steps]

1. The EFT transients are coupled to all CDN lines simultaneously (CM).
2. The output of the CDN shall not be short circuited.
3. The EFT transients shall be measured at each individual output of the CDN with 50Ω load, while the other outputs are open.
4. Each individual output must show the transients within the tolerances as specified.

U_{meas} = 50 \, \Omega
Capacitive Coupling Clamp

Dimensions have now tolerances
Lower coupling plate height: (100 ± 5) mm
Lower coupling plate width: (140 ± 7) mm
Lower coupling plate length: (1 000 ± 50) mm
Calibration of capacitive coupling clamp

In a new chapter the edition 3 describes the calibration method of the capacitive coupling clamp with a transducer plate.

The transducer plate consists in a metallic sheet of 120 mm x 1050 mm of max 0.5 mm thickness, isolated on top and bottom by a dielectric foil of 0.5 mm. Isolation for 2.5 kV on all sides must be guaranteed in order to avoid the clamp to contact the transducer plate.
Calibration setup of capacitive coupling clamp

- The transducer plate is to be inserted into the coupling clamp and must be terminated at the opposite end of the generator connection with a coaxial load of 50 Ω.

- The calibration is performed with the generator output voltage set to **2 kV**. The calibration have to meet the following requirements:

  Rise time $t_r$  5ns ± 1,5ns
  Pulse duration $t_d$  50ns ± 15ns
  peak value of voltage  1kV ± 200V
Test setup and test execution

Coupling mode: „all lines against ground reference“
So, the coupling mode is a pure „Common Mode testing“. This means that the testing of single lines, line after line, is not demanded any more, but only all lines simultaneously have to be supplied with burst pulses.

Components
PE protective earth
N neutral
L phase
Z1 decoupling inductive
Cc coupling capacitor
General tests set-up acc. to EN 61000-4-4:2012

Figure 11: Example of a test setup for laboratory type tests (new marked new in Ed3)
Test setup coupling on lines

Coupling mode: Common mode “all lines to reference ground”
The coupling network has to be connected with the reference ground in low impedance manner!
Test setup: Coupling on supply lines

Burst to AC supply lines EUT on insulated support distance generator to EUT = 0.5m
Test setup: Coupling on supply lines (floor standing device)
Test setup: signal lines with capacitive coupling clamp

Example: Floor standing system of two EUTs
Test setup: capacitive coupling clamp

EUT must be placed on the same side as the burst simulator is connected.

Decoupling network to the AE port if required.
Test setup: capacitive coupling clamp

Figure 13 Example of a test setup for equipment with elevated cable entries
Example for in situ test on a.c./d.c. power ports and PE

Figure 13 Example of a test setup for equipment with elevated cable entries

Grounding connection according to the manufacturer’s specification. Length to be specified in the test plan.

* AC power port

Test point PE terminal on the cabinet

EFT/B test generator

Ground reference plane

AC mains supply

Protective earth

* DC terminals shall be treated in a similar way

** Coupling capacitor(s)
Alternative method for coupling to signal lines without a CCC

The capacitive coupling clamp is the preferred method for coupling the test voltage into signal and control ports. If the clamp cannot be used due to mechanical reasons (e.g. size, cable routing) in the cabling, it shall be replaced by,

a. a tape or a conductive foil enveloping the lines under test.
   or alternatively
b. via discrete (100 ± 20) pF capacitors
### Table C.1 – Example of uncertainty budget for voltage rise time ($t_r$)

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Estimate</th>
<th>Unit</th>
<th>Error bound</th>
<th>Unit</th>
<th>PDF $^a$</th>
<th>Divisor</th>
<th>$u(x_i)$</th>
<th>$c_i$</th>
<th>Unit</th>
<th>$u_i(y)$</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_{10%}$</td>
<td>0.85</td>
<td>ns</td>
<td>0.10</td>
<td>ns</td>
<td>triangular</td>
<td>2.45</td>
<td>0.041</td>
<td>-1.02</td>
<td>1</td>
<td>0.041</td>
<td>ns</td>
</tr>
<tr>
<td>$T_{90%}$</td>
<td>6.1</td>
<td>ns</td>
<td>0.10</td>
<td>ns</td>
<td>triangular</td>
<td>2.45</td>
<td>0.041</td>
<td>1.02</td>
<td>1</td>
<td>0.041</td>
<td>ns</td>
</tr>
<tr>
<td>$\Delta R$</td>
<td>0</td>
<td>ns</td>
<td>0.15</td>
<td>ns</td>
<td>normal ($k = 1$)</td>
<td>1.00</td>
<td>0.150</td>
<td>1.02</td>
<td>1</td>
<td>0.152</td>
<td>ns</td>
</tr>
<tr>
<td>$A$</td>
<td>360</td>
<td>ns·MHz</td>
<td>40</td>
<td>ns·MHz</td>
<td>rectangular</td>
<td>1.73</td>
<td>23.09</td>
<td>-44·10$^{-5}$</td>
<td>1/MHz</td>
<td>0.010</td>
<td>ns</td>
</tr>
<tr>
<td>$B$</td>
<td>400</td>
<td>MHz</td>
<td>30</td>
<td>MHz</td>
<td>rectangular</td>
<td>1.73</td>
<td>17.32</td>
<td>39·10$^{-5}$</td>
<td>ns/MHz</td>
<td>6.78·10$^{-3}$</td>
<td>ns</td>
</tr>
</tbody>
</table>

$^a$ Probability Density Function

\[
u_c(y) = \sqrt{\sum u_i(y)^2}
\]

\[
U(y) = 2 \cdot u_c(y)
\]

\[
\gamma = \frac{U(y)}{T}
\]

Expressed in % of 5.33 ns: 6.2 %
Table C.2 – Example of uncertainty budget for EFT/B peak voltage value (VP)

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Estimate</th>
<th>Unit</th>
<th>Error bound</th>
<th>Unit</th>
<th>PDF (^a)</th>
<th>Divisor</th>
<th>(u(x_i))</th>
<th>(c_i)</th>
<th>Unit</th>
<th>(u_i(y))</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>(V_{PR})</td>
<td>3.75</td>
<td>V</td>
<td>0.0073</td>
<td>V</td>
<td>triangular</td>
<td>2.45</td>
<td>0.0030</td>
<td>1.000</td>
<td>1</td>
<td>2.99</td>
<td>V</td>
</tr>
<tr>
<td>(\delta)</td>
<td>1000</td>
<td>1</td>
<td>50</td>
<td>1</td>
<td>rectangular</td>
<td>1.73</td>
<td>28.9</td>
<td>3.75</td>
<td>V</td>
<td>108</td>
<td>V</td>
</tr>
<tr>
<td>(\delta R)</td>
<td>0</td>
<td>1</td>
<td>0.03</td>
<td>1</td>
<td>normal ((k = 1))</td>
<td>1.00</td>
<td>0.030</td>
<td>3.751</td>
<td>V</td>
<td>112.5</td>
<td>V</td>
</tr>
<tr>
<td>(\delta V)</td>
<td>0</td>
<td>1</td>
<td>0.02</td>
<td>1</td>
<td>rectangular</td>
<td>1.73</td>
<td>0.012</td>
<td>3.751</td>
<td>V</td>
<td>43.3</td>
<td>V</td>
</tr>
<tr>
<td>(\beta)</td>
<td>7.0</td>
<td>MHz</td>
<td>0.8</td>
<td>MHz</td>
<td>rectangular</td>
<td>1.73</td>
<td>0.462</td>
<td>0.328</td>
<td>V/MHz</td>
<td>0.152</td>
<td>V</td>
</tr>
<tr>
<td>(B)</td>
<td>400</td>
<td>MHz</td>
<td>30</td>
<td>MHz</td>
<td>rectangular</td>
<td>1.73</td>
<td>17.32</td>
<td>-0.0058</td>
<td>V/MHz</td>
<td>0.0995</td>
<td>V</td>
</tr>
</tbody>
</table>

\(^a\) Probability Density Function

\[ u_c(y) = \sqrt{\sum u_i(y)^2} \]
\[ U(y) = 2 u_c(y) \]
\[ y = 3.75 \text{ kV} \]

Expressed in % of 3.75 kV: 8.8 %

New in edition 3
Table C.3 – Example of uncertainty budget for EFT/B voltage pulse width (tw)

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Estimate</th>
<th>Unit</th>
<th>Error bound</th>
<th>Unit</th>
<th>PDF $^a$</th>
<th>Divisor</th>
<th>$u(x_i)$</th>
<th>$c_i$</th>
<th>Unit</th>
<th>$u_r(y)$</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_{50% R}$</td>
<td>3,5</td>
<td>ns</td>
<td>0,10</td>
<td>ns</td>
<td>triangular</td>
<td>2,45</td>
<td>0,041</td>
<td>-1,00</td>
<td>ns</td>
<td>0,040 8</td>
<td>ns</td>
</tr>
<tr>
<td>$T_{50% f}$</td>
<td>54,5</td>
<td>ns</td>
<td>0,10</td>
<td>ns</td>
<td>triangular</td>
<td>2,45</td>
<td>0,041</td>
<td>1,00</td>
<td>ns</td>
<td>0,040 8</td>
<td>ns</td>
</tr>
<tr>
<td>$\delta R$</td>
<td>0</td>
<td>ns</td>
<td>1,50</td>
<td>ns</td>
<td>normal ($\nu = 1$)</td>
<td>1,00</td>
<td>1,50</td>
<td>1,00</td>
<td>ns</td>
<td>1,50</td>
<td>ns</td>
</tr>
<tr>
<td>$\beta$</td>
<td>7,0</td>
<td>MHz</td>
<td>0,8</td>
<td>MHz</td>
<td>rectangular</td>
<td>1,73</td>
<td>0,462</td>
<td>-0,004 5</td>
<td>ns/MHz</td>
<td>0,002 1</td>
<td>ns</td>
</tr>
<tr>
<td>$B$</td>
<td>400</td>
<td>MHz</td>
<td>30</td>
<td>MHz</td>
<td>rectangular</td>
<td>1,73</td>
<td>17,32</td>
<td>8,0 \times 10^{-5}</td>
<td>ns/MHz</td>
<td>0,001 4</td>
<td>ns</td>
</tr>
</tbody>
</table>

$^a$ Probability Density Function

\[
u_r(y) = \sqrt{\sum u_i(y)^2}
\]

\[U(y) = 2 \nu_r(y)\]

\[Y = 51,0\ \text{ns}\]

Expressed in % of 51,0 ns: 5,9 %

New in edition 3
EFT Burst generators

Current EFT Burst generators from the AMETEK CTS product lines

- Compact NX5
- UCS 500N7
- EFT 500N8
- NSG 3040
- NSG 3060
IEC 61000-4-5 Ed.3: (2014)
Surge immunity test and
Inventory of last revision of IEC 61000-4-5 Ed.3 (2014)
IEC 61000-4-5 PHENOMENON

- **Atmospheric discharges**
  - Max current peak value
  - Rise of the current \( \frac{di}{dt} \),
  - Rise of \( \frac{dU}{dt} \) caused the tripping of arrestors in the primary loop who are transformed to the secondary part.

- **Switching events** electromechanical events
  - Switching of capacitive loads in high voltage circuits. Cables, capacitor banks etc.
  - Switching of loads in low voltage systems.
  - Switching of resonance circuits with thyristors.
  - Short circuits and flash-overs in installations.
  - Tripping of protection devices as varistors and fuses.
IEC 61000-4-5  STANDARD LIGHTNING IMPULSE

5% standard lightning means, parameters exceeds in 5% of all events per Prof. Prinz

<table>
<thead>
<tr>
<th>Parameter</th>
<th>5 % - value</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\dot{i}$</td>
<td>100 kA</td>
<td>Increase the potential on Earth devices, footstep voltage</td>
</tr>
<tr>
<td>$\frac{di}{dt}$</td>
<td>100 kA / ms</td>
<td>Induction of voltages, inductive voltage drops</td>
</tr>
<tr>
<td>$\int i^2 dt$</td>
<td>5 kA²s</td>
<td>Thermal and dynamic effects</td>
</tr>
<tr>
<td>$\int i , dt$</td>
<td>100 As</td>
<td>Charge, melting on point of impact</td>
</tr>
</tbody>
</table>

![Graph showing the current waveform](image)

IC

$10^9$ J (Ws)

Faktor $10^{16}$
EMC Model Surge

- **Coupling**
  - Capacitive to parallel lines (du/dt)
  - Induction in loops (di/dt)
  - Radiation in the near field
  - Direct coupling in case of direct impact

- **Propagation**
  - Conducted to supply-, signal-, data- and control lines
  - Symmetrical (line to line) or unsymmetrical to PE
IEC 61000-4-5 Edition 3 (2014)

No Change of:
- Test levels
- Generator specifications
- Phase angle
- Separation of pulse 1.2/50 and 10/700

Fazit: The user can still use his surge generator

Changes to Ed 3 :2014 :
- Impulsform definition (only one definition)
- Add mathematical formula for wave shape
- Calibration for CDN and generator with a capacitor of 15 µF
- New definition for CDN up to 200A / phase with calibration
- New specification for CDN for signal and data-lines with calibration
- New specification for high speed communication CDN
- Move of 10/700 µs generator to Annex and Harmonization with ITU-TK series
- Measurement Uncertainty MU in annex D
One Waveshape definition in the IEC 61000-4-5 Edition 3 (2014)

Previous edition 2 offers two methods for waveshape measurement

Table 2 – Definitions of the waveform parameters 1,2/50 μs – 8/20 μs

<table>
<thead>
<tr>
<th>Definitions</th>
<th>In accordance with IEC 60060-1</th>
<th>In accordance with IEC 60469-1</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Front time μs</td>
<td>Time to half value μs</td>
</tr>
<tr>
<td>Open circuit voltage</td>
<td>1,2 ± 30 %</td>
<td>50 ± 20 %</td>
</tr>
<tr>
<td>Short-circuit current</td>
<td>8 ± 20 %</td>
<td>20 ± 20 %</td>
</tr>
</tbody>
</table>

NOTE: In existing IEC publications, the waveforms 1,2/50 μs and 8/20 μs are generally defined according to IEC 60060-1 as shown in Figures 2 and 3. Other IEC recommendations are based on waveform definitions according to IEC 60469-1 as shown in Table 2.

Both definitions are valid for this part of IEC 61000 and defining just one single generator.
IEC 61000-4-5  IMPULSE DEFINITION

- **Open circuit voltage**: 1.2/50µs
  
  Front Time: \( T_f \) = 1.67 x T = 1.2µs ± 30%
  
  Duration: \( T_d \) = Tw = 50µs ± 20%

  NOTE: The open circuit voltage waveform at the output of the coupling/decoupling network may have a considerable undershoot, in principle as the curve shown in Figure

- **Short circuit current**: 8/20µs
  
  Front Time: \( T_f \) = 1.25 x Tr = 8µs ± 20%
  
  Duration: \( T_d \) = 1.18 x Tw = 20µs ± 20%

  NOTE: The 30% undershoot specification applies only at the generator output. At the output of the coupling/decoupling network there is no limitation on undershoot or overshoot.

The calculation as per IEC 60469-1 (10% - 90%) is deleted
Test Levels

Table 1 specifies in detail the test levels for the open circuit voltages for testing Line to Line and Line to ground.

Table 1 Test Levels

<table>
<thead>
<tr>
<th>Level</th>
<th>Open circuit test voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Line to Line</td>
</tr>
<tr>
<td>1</td>
<td>---</td>
</tr>
<tr>
<td>2</td>
<td>0,5</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>X&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Special</td>
</tr>
</tbody>
</table>

<sup>a</sup> "X" can be any level, above, below or in between the others. The level shall be specified in the dedicated equipment specification.

- All voltages of the lower test levels shall be satisfied.
- For selection of the test levels for the different interfaces, refer to Annex A.
Generator Source Impedance

The characteristics of the test generator shall simulate the phenomena as closely as possible. Depending on the different arise and coupling mechanism of the sources, the standard defines different source impedance's for surge testing.

If the source of interference is in the **same circuit**, for example in the power supply network (direct coupling), the generator may simulate a low impedance source.

If the source of interference is **in other circuit** as the victim equipment (indirect coupling) as the ports of the victim equipment, then the generator may simulate a higher impedance source.

<table>
<thead>
<tr>
<th>2 Ohm</th>
<th>12 Ohm (2 Ohm + 10 Ohm)</th>
<th>42 Ohm (2 Ohm + 40 Ohm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power lines (acc. to IEC61000-4-5: low-voltage power supply)</td>
<td>All other Lines</td>
<td></td>
</tr>
<tr>
<td>symmetrical (L-N, L-L)</td>
<td>unsymmetrical (L-PE, N-PE)</td>
<td>Unsymmetrical</td>
</tr>
<tr>
<td>Source in the same circuit</td>
<td>Source in the other circuit</td>
<td>(symmetrical)</td>
</tr>
<tr>
<td>unsymmetrical Switching</td>
<td>indirect lightning</td>
<td>only indirect influences</td>
</tr>
<tr>
<td>direct lightning</td>
<td>indirect lightning</td>
<td></td>
</tr>
</tbody>
</table>

IEC 61000-4-5 Edition 3 (2014)

Characteristics and performance of the generator:
The output impedance is controlled with the relationship between the open circuit peak voltage and the short circuit current.
New values for the 12 Ω output (10Ω + 2 Ω) impedance have been defined.

NOTE The time parameters are valid for the short circuit current at the generator output without 10Ω resistor.  (New additional note)

<table>
<thead>
<tr>
<th>Open-circuit peak voltage ± 10 % at EUT port of the CDN</th>
<th>Short-circuit peak current ± 10 % at EUT port of the CDN (18 μF)</th>
<th>Short-circuit peak current ± 10 % at EUT port of the CDN (9 μF + 10 Ω)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0,5 kV</td>
<td>0,25 kA</td>
<td>41,7 A</td>
</tr>
<tr>
<td>1,0 kV</td>
<td>0,5 kA</td>
<td>83,3 A</td>
</tr>
<tr>
<td>2,0 kV</td>
<td>1,0 kA</td>
<td>166,7 A</td>
</tr>
<tr>
<td>4,0 kV</td>
<td>2,0 kA</td>
<td>333,3 A</td>
</tr>
</tbody>
</table>
Calibration of CDNs for a.c./d.c. mains supply rated up to 200 A per line (6.4.2)

The characteristics of the CDN shall be measured under *open-circuit* conditions (load greater than or equal to 10 kΩ) and under *short-circuit* conditions at the same set voltage.

All performance characteristics stated in 6.3.2 Tables 4 and 5 shall be met at the CDN output.

<table>
<thead>
<tr>
<th>Surge voltage parameters under open-circuit conditions</th>
<th>Coupling impedance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load &gt; 10kΩ</td>
<td></td>
</tr>
<tr>
<td></td>
<td>18 µF</td>
</tr>
<tr>
<td></td>
<td>(Line to Line)</td>
</tr>
<tr>
<td>Peak voltage</td>
<td></td>
</tr>
<tr>
<td>Current rating ≤ 16 A</td>
<td>Set voltage +10 %/-10 %</td>
</tr>
<tr>
<td>16 A &lt; Current rating ≤ 32 A</td>
<td>Set voltage +10 %/-10 %</td>
</tr>
<tr>
<td>32 A &lt; Current rating ≤ 63 A</td>
<td>Set voltage +10 %/-10 %</td>
</tr>
<tr>
<td>63 A &lt; Current rating ≤ 125 A</td>
<td>Set voltage +10 %/-10 %</td>
</tr>
<tr>
<td>125 A &lt; Current rating ≤ 200 A</td>
<td>Set voltage +10 %/-10 %</td>
</tr>
<tr>
<td>Front time</td>
<td>1.2 µs ± 30 %</td>
</tr>
<tr>
<td>Duration</td>
<td></td>
</tr>
<tr>
<td>Current rating ≤ 16 A</td>
<td>50 µs +10 µs/-10 µs</td>
</tr>
<tr>
<td>16 A &lt; Current rating ≤ 32 A</td>
<td>50 µs +10 µs/-15 µs</td>
</tr>
<tr>
<td>32 A &lt; Current rating ≤ 63 A</td>
<td>50 µs +10 µs/-20 µs</td>
</tr>
<tr>
<td>63 A &lt; Current rating ≤ 125 A</td>
<td>50 µs +10 µs/-25 µs</td>
</tr>
<tr>
<td>125 A &lt; Current rating ≤ 200 A</td>
<td>50 µs +10 µs/-30 µs</td>
</tr>
</tbody>
</table>

**New in Ed. 3**
- Waveshape defined for common mode coupling to PE
- Tolerances are *increased* at higher current in the coupling network.

**Decoupling inductivity:**
- Maximum 1.5 mH
- Voltage Drop CDN < 10%
TOPICS FOR EDITION 3

The residual surge voltage measured between surged lines and ground on the a.c./d.c. mains supply port of the CDN with EUT and mains supply not connected shall not exceed 15% of the maximum applied test voltage or twice the rated peak voltage of the CDN, whichever is higher.

The unwanted surge voltage measured between non-surged lines and ground shall not exceed 15% of the maximum applied test voltage without EUT and mains supply connected (open circuit).

Table 5 – Current waveform specification at the EUT port of the coupling/decoupling network

<table>
<thead>
<tr>
<th>Surge current parameters under short-circuit conditions a</th>
<th>Coupling impedance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>18 μF (line-to-line)</td>
</tr>
<tr>
<td>Front time</td>
<td>( T_f = 1,25 \times T_r = 8 , \mu s \pm 20% )</td>
</tr>
<tr>
<td>Duration</td>
<td>( T_d = 1,18 \times T_w = 20 , \mu s \pm 20% )</td>
</tr>
</tbody>
</table>

\( a \) The measurement of the surge current parameters shall be performed with the a.c./d.c. power port of the CDN open-circuit.

\( b \) The value 1,04 is derived from empirical data.
Measurements shall be performed with the impulse applied to one coupling path at a time. The peak amplitude, the front time and impulse duration shall be measured for the CDN rated impulse voltage under open-circuit conditions.

The inputs of the DN at the auxiliary equipment (AE) side shall be short circuited to PE for the impulse voltage and impulse current measurement at the EUT output port.

The residual voltage value depends on the protection requirements of the AE. Therefore no limits are given in this standard.

<table>
<thead>
<tr>
<th>Calibration process for unsymmetrical interconnection lines</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coupling</td>
</tr>
<tr>
<td>----------</td>
</tr>
<tr>
<td>Surge voltage at EUT side</td>
</tr>
<tr>
<td>Surge Current at EUT side</td>
</tr>
<tr>
<td>Surge voltage at EUT side</td>
</tr>
<tr>
<td>Surge Current at EUT side</td>
</tr>
<tr>
<td>Residual voltage on AE Side (with protection)</td>
</tr>
</tbody>
</table>

Changes to Ed 3 :2014
Waveform specification for unsymmetrical interconnection lines

Table 8: Surge waveform specs. at the EUT port of the CDN

<table>
<thead>
<tr>
<th>Coupling method</th>
<th>CWG Output voltage (1-3)</th>
<th>Voc at CDN EUT output ± 10 %</th>
<th>Voltage Front time $T_f$</th>
<th>Voltage Duration $T_d$</th>
<th>$I_{sc}$ at CDN EUT output ± 20 %</th>
<th>Current Front Time $T_f$</th>
<th>Current Duration $T_d$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line to PE R = 40 Ω CD = 0.5 μF</td>
<td>4 kV</td>
<td>4 kV</td>
<td>1.2 μs</td>
<td>38 μs</td>
<td>87 A</td>
<td>1.3 μs</td>
<td>13 μs</td>
</tr>
<tr>
<td>Line to PE R = 40 Ω CD = GDT</td>
<td>4 kV</td>
<td>4 kV</td>
<td>1.2 μs</td>
<td>42 μs</td>
<td>95 A</td>
<td>1.5 μs</td>
<td>48 μs</td>
</tr>
<tr>
<td>Line to Line R = 40 Ω CD = 0.5 μF</td>
<td>4 kV</td>
<td>4 kV</td>
<td>1.2 μs</td>
<td>42 μs</td>
<td>87 A</td>
<td>1.3 μs</td>
<td>13 μs</td>
</tr>
<tr>
<td>Line to Line R = 40 Ω CD = GDT</td>
<td>4 kV</td>
<td>4 kV</td>
<td>1.2 μs</td>
<td>47 μs</td>
<td>95 A</td>
<td>1.5 μs</td>
<td>48 μs</td>
</tr>
</tbody>
</table>

1) It is recommended to calibrate the CDN at the highest rated pulse voltage, as this will minimise the effects of the switching noise generated by CLDs and GDTs. The value shown in the table is for a generator setting of 4 kV. In case the CDN is rated for another maximum pulse voltage, the calibration shall be done at this maximum rated pulse voltage. The short circuit peak current specification shall be adapted accordingly. e.g. If the Maximum voltage is 1 kV the short circuit current value shown in this table shall be multiplied by 1/4.

2) Coupling via gas arrestors, clamping or avalanche devices will show some switching noise on the pulse waveform. Working with the highest possible pulse voltage will minimise their impact on measurements; it is recommended to neglect the switching noise for the front times and duration values measurements.

3) The values shown in this table are for a CWG with ideal values. In case the CWG generates parameter values close to the tolerances, the additional tolerances of the CDN may generate values out of tolerances for the CWG-CDN combination.
Calibration process for symmetrical interconnection lines (6.4.3.3)

Measurements shall be performed with the impulse applied to one coupling path at a time. The peak amplitude, the front time and impulse duration shall be measured for the CDN rated impulse voltage under open-circuit conditions.

The inputs of the CDN at the auxiliary equipment (AE) side shall be short circuited to PE for the impulse voltage and impulse current measurement at the EUT output port.

The maximum allowed residual voltage value depends on application specific elements, which are not specified in this standard.

<table>
<thead>
<tr>
<th>Coupling method</th>
<th>CWG Output voltage ( V_{oc} )</th>
<th>Voltage at CDN EUT output ( V_{oc} ) %</th>
<th>Voltage Front time ( T_F ) µs</th>
<th>Voltage Duration ( T_d ) μs</th>
<th>Current at CDN EUT output ( I_{oc} ) A</th>
<th>Current Front Time ( T_F ) µs</th>
<th>Current Duration ( T_d ) μs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Common mode CD, 40 Ω path</td>
<td>2 kV</td>
<td>2 kV</td>
<td>1.2 µs</td>
<td>42 µs</td>
<td>48 A</td>
<td>1.5 µs</td>
<td>45 µs</td>
</tr>
</tbody>
</table>
Calibration coupling network

It is the intention of this standard that the output waveforms meet specifications at the point where they are to be applied to the EUT. The characteristics of the generator shall be measured under:

- **Open circuit voltage with HV-Probe**
  - each:
    - DM: L-N
    - CM: L-PE
    - CM: N-PE

- **Short circuit current with current probe**
  - each:
    - DM: L-N
    - CM: L-PE
    - CM: N-PE
Selecting the coupling/decoupling network method

- **Mains**
  - Yes
  - No
  - **shielded cable?**
    - No
    - Yes
      - **shield connected?**
        - one end
        - Yes
        - No

- **Line to line**
- **Line to GND**

**Grounded each end**
- Fig 12

**Coupling 40 Ω**
- Coupling via arrestors, capacitor or clamping device
- Fig 9

**Coupling arresters or clamping devices**
- capacitors or direct
- Fig. 10 or Fig. 11

Changes to Ed 3 :2014
Example of test setup for capacitive coupling on a.c./d.c. lines

New measurements method is defined including residual voltages at AE ports of data lines CDN. The inductance values for the decoupling inductance is removed from each figure.

Fig. 5: Coupling Line to Neutral
Decoupling: \( L = 1.5\, \text{mH} \)

Fig. 6: Coupling \( L \)-PE and N – PE
Decoupling: \( L = 1.5\, \text{mH} \)
Example of test setup for capacitive coupling on 3-phase a.c. lines.

Fig. 7: Coupling Line to Line / Neutral

Fig. 8: Coupling Line - PE and Neutral - PE
Coupling to unshielded unsymmetrical interconnections lines

Switch S1:
- Line to Earth: Position 0
- Line to Line: Position 1 to 4

Switch S2:
- during the test: Positions 1 to 4 but not in same position as switch S1

Switch S3:
- Position coupling with gas arrester to symmetrical I/O lines
- Position capacitive coupling 0.5uF asymmetrical I/O lines
- Position capacitive coupling 3.0uF Ringwave

Alternative coupling via clamping circuit
Coupling on I/O lines via CNV508N1

Example

- Earth connector EUT
- Lines between the coupling network and the EUT must not exceed 2 m of length
- Generator connector
  - red -> HV
  - black -> COM
- Example: Coupling line 1 to earth (PE)
- Grounding of the CDN
Unshielded symmetrical interconnection lines

Line to Ground coupling

IEC 61000-4-5 Ed2, Figure 14

1.2/50us Generator
\[ R_{m2} = n \times 40 \, \Omega, \text{ max.} \ 250 \, \Omega \]

10/700us Generator
\[ R_{m2} = n \times 25 \, \Omega, \text{ max.} \ 250 \, \Omega \]

IEC 61000-4-5 Ed3, Figure 10 and Figure A4

1.2/50us Generator
\[ R_C = n \times 40 \, \Omega \]

10/700us Generator
\[ R_C = 25 \, \Omega \]

Other coupling devices than gas arrestors (GDT) are allowed.

Changes to Ed 3 :2014
CDN for unshielded symmetrical interconnection lines

CNV 504/508 T-Series

1.2/50us Generator

4 lines $\Rightarrow R_c = 160 \, \Omega$ (4 lines x $40 \, \Omega$)

2 lines $\Rightarrow R_c = 80 \, \Omega$ (2 lines x $40 \, \Omega$)
CDN for unshielded symmetrical interconnection lines

CNV 504/508 T-Series

10/700µs Generator

4 lines ⇒ $R_c = 25\,\Omega$, (135 Ω is short-circuited)

2 lines ⇒ $R_c = 25\,\Omega$

Note:
- 135 Ω resistor is short circuited by a bridge
- Gas arrestor is disabled (bridge) and replaced by an alternative coupling device
Test set-up for shielded lines ground at both sides

NOTE 1 It is permissible for the power to the EUT and/or the AE to be provided via a decoupling network, rather than via the isolating transformer shown. In this case, the EUT's protective earth connection should not be connected to the decoupling network.

NOTE 2 D.C. supplied EUT and/or AE should be powered through the decoupling networks.
The EUT is isolated from ground and the surge ($2\Omega$) is applied to its metallic enclosure; the termination (or auxiliary equipment) at the port(s) under test is grounded.

Cable length:
- 20 m (preferred length) or
- the shortest length over 10 m, where the manufacturer provides pre-assembled cables used in actual installations

No test shall be required for cables which according to the manufacturer’s specification are $\leq 10$ m.
Test set-up for shielded cables

- **High voltage connector,** To be connected at the central earthing point of EUT 1
- **20m shielded signal line laid in meandering manner**
- **Insulating transformer**
- **Auxiliary Equipment or EUT2**
- **EUT1**
- **Reference earth of high voltage source, that has to be connected as return conductor to reference earth.**
- **Grounding of EUT 2 to the reference earth.**
Test set-up for shielded lines grounded only at both and one end

Rules for application of the surge to shielded lines:

a) Shields grounded at both ends:
   – the test shall be carried out according to Figure 12.

   The test level is applied on shields with a 2 Ω generator source impedance and with the 18 μF capacitor

b) Shields grounded at one end:
   – the test shall be carried out according to 7.4 or 7.5 (see Figure 4) because the shield does not provide any protection against surges induced by magnetic fields.

NOTE 2:
*In this case, surge testing is not applied to the shield.*

Changes to Ed 3 :2014

Figure 4
Coupling on fast symmetrically operated I/O lines

Surge tests to high speed data-lines
Coupling as per figure 11 of IEC 61000-4-5 Ed. 3 :2014

Changes to Ed 3 :2014
Coupling on fast symmetrically operated I/O lines

Example for coupling as per figure 11 of IEC 61000-4-5 Ed. 3.0:2012

Coupling to unshielded lines

Coupling to shield with additional AE protection with SPN 508N1
Test procedure for Surge with 1-phase EUT

The test procedure includes:
- the verification of the test instrumentation according to 7.2.
- the establishment of the laboratory reference conditions;
- the confirmation of the correct operation of the EUT;
- the execution of the test;
- the evaluation of the test results (see Clause 9; Criteria A,B,C,D)

- 5 test-pulses for every setting (Level, Coupling, Angle, Polarity).
- Time between successive pulses: 1 min or less.
Selection of the test levels (depending on the installation conditions)

The surges (and generators) related to the different classes are as in the following:

Classes 1 to 5: **1.2/50μs** (8/20μs) for ports of power lines, short-distance signal circuits/lines and local area networks (e.g. Ethernet, Token Ring, etc.) and similar networks

Classes 4 to 5: **10/700μs** (5/320μs) for symmetrical communication lines intended to interconnect widely dispersed systems via such means as direct connection to multi-user telecommunications networks lines typically >300 m in length.
### Annexes

Changes in Annex are marked in red color

<table>
<thead>
<tr>
<th>Annex</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Annex A</strong> (normative)</td>
<td>Surge testing for unshielded outdoor symmetrical communication lines intended to interconnect to widely dispersed systems <strong>10/700 μs combination wave generator</strong></td>
</tr>
<tr>
<td><strong>Annex B</strong> (informative)</td>
<td>Selection of generators and test levels</td>
</tr>
<tr>
<td><strong>Annex C</strong> (informative)</td>
<td>Explanatory notes</td>
</tr>
<tr>
<td><strong>Annex D</strong> (informative)</td>
<td>Considerations for achieving immunity for equipment connected to low voltage power distribution systems</td>
</tr>
<tr>
<td><strong>Annex E</strong> (informative)</td>
<td><strong>Mathematical modelling</strong> of surge waveforms</td>
</tr>
<tr>
<td><strong>Annex F</strong> (informative)</td>
<td><strong>Measurement uncertainty (MU)</strong> considerations</td>
</tr>
<tr>
<td><strong>Annex G</strong> (informative)</td>
<td>Method of calibration of impulse measuring systems</td>
</tr>
</tbody>
</table>

Changes to Ed 3 :2014
Annex A (Telecom Surge)

The surge testing for outdoor communication lines (telecom part) is moved to Annex A. The waveform definition is seen in the table below.

Table A.1 – Definitions of the waveform parameters
10/700 µs – 5/320 µs

<table>
<thead>
<tr>
<th></th>
<th>Front time µs</th>
<th>Duration µs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open-circuit voltage</td>
<td>10 ± 30 %</td>
<td>700 ± 20 %</td>
</tr>
<tr>
<td>Short-circuit current</td>
<td>5 ± 20 %</td>
<td>320 ± 20 %</td>
</tr>
</tbody>
</table>

Source impedance 40 Ohm

Table A.2 – Relationship between peak open-circuit voltage and peak short-circuit current

<table>
<thead>
<tr>
<th>Open-circuit peak voltage ± 10 % at generator output</th>
<th>Short-circuit peak current ± 10 % at generator output</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5 kV</td>
<td>12.5 A</td>
</tr>
<tr>
<td>1.0 kV</td>
<td>25.0 A</td>
</tr>
<tr>
<td>2.0 kV</td>
<td>50.0 A</td>
</tr>
<tr>
<td>4.0 kV</td>
<td>100.0 A</td>
</tr>
</tbody>
</table>
Annex E (informative)  Mathematical modeling of surge waveforms

New in Ed 3: 2014

This annex offers a numerical model for mathematical calculation the surge wave shape for voltage and current.

\[ V_{SURGE}(t) = k_V \cdot \left( \frac{V_1}{k_{SURGE}} \cdot \frac{\left( \frac{t}{\tau_1} \right)^{\eta_{SURGE}}}{1 + \left( \frac{t}{\tau_1} \right)^{\eta_{SURGE}}} \cdot e^{-\frac{t}{\tau_2}} \right) \]

Figure E. 1: Voltage surge (1.2/50μs): Late time response

Figure E. 2: Voltage surge (1.2/50μs): Early time response
## Annex F (informative) Measurement uncertainty (MU) considerations

**New in Ed 3:2014**

### Table F.1 – Example of uncertainty budget for surge open circuit voltage front time \( (TfV) \)

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Estimate</th>
<th>Unit</th>
<th>Error Bound</th>
<th>Unit</th>
<th>PDF*</th>
<th>Divisor</th>
<th>( u_x(y) )</th>
<th>( c_I )</th>
<th>Unit</th>
<th>( u_y(y) )</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>( T_{fV} )</td>
<td>0.25</td>
<td>ms</td>
<td>0.0050</td>
<td>µs</td>
<td>triangular</td>
<td>2.45</td>
<td>0.0020</td>
<td>-2.08</td>
<td>1</td>
<td>0.0043</td>
<td>µs</td>
</tr>
<tr>
<td>( T_{fV} )</td>
<td>1.15</td>
<td>ms</td>
<td>0.0050</td>
<td>µs</td>
<td>triangular</td>
<td>2.45</td>
<td>0.0020</td>
<td>2.08</td>
<td>1</td>
<td>0.0043</td>
<td>µs</td>
</tr>
<tr>
<td>( 6\sigma )</td>
<td>0</td>
<td>ms</td>
<td>0.025</td>
<td>µs</td>
<td>normal ((k=1))</td>
<td>1.00</td>
<td>0.025</td>
<td>2.08</td>
<td>1</td>
<td>0.052</td>
<td>µs</td>
</tr>
<tr>
<td>( \sigma )</td>
<td>360</td>
<td>µs/kHz</td>
<td>40</td>
<td>µs/kHz</td>
<td>rectangular</td>
<td>1.73</td>
<td>23.1</td>
<td>-0.0019</td>
<td>1/KHz</td>
<td>0.043</td>
<td>µs</td>
</tr>
<tr>
<td>( R )</td>
<td>500</td>
<td>kHz</td>
<td>50</td>
<td>kHz</td>
<td>rectangular</td>
<td>1.73</td>
<td>28.9</td>
<td>0.0014</td>
<td>µs/kHz</td>
<td>0.019</td>
<td>µs</td>
</tr>
</tbody>
</table>

\( u_y(y) = 2u_x(y) \)  
\( (V) = 2 \sigma(V) \)  
\( y = 1.38 \)  

* Probability Density Function

### Table F.2 – Example of uncertainty budget for surge open circuit voltage peak value \( (V_P) \)

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Estimate</th>
<th>Unit</th>
<th>Error Bound</th>
<th>Unit</th>
<th>PDF*</th>
<th>Divisor</th>
<th>( u_x(V) )</th>
<th>( c_I )</th>
<th>Unit</th>
<th>( u_y(V) )</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>( V_{ref} )</td>
<td>3.84</td>
<td>V</td>
<td>0.0075</td>
<td>V</td>
<td>triangular</td>
<td>2.45</td>
<td>0.0031</td>
<td>1001</td>
<td>1</td>
<td>3.06</td>
<td>V</td>
</tr>
<tr>
<td>( \alpha )</td>
<td>1000</td>
<td>1</td>
<td>50</td>
<td>1</td>
<td>rectangular</td>
<td>1.73</td>
<td>28.9</td>
<td>3.84</td>
<td>V</td>
<td>111</td>
<td>V</td>
</tr>
<tr>
<td>( \delta )</td>
<td>0</td>
<td>1</td>
<td>0.03</td>
<td>1</td>
<td>normal ((k=1))</td>
<td>1.00</td>
<td>0.03</td>
<td>3.84 \times 10^{-2}</td>
<td>V</td>
<td>115</td>
<td>V</td>
</tr>
<tr>
<td>( \delta )</td>
<td>0</td>
<td>1</td>
<td>0.02</td>
<td>1</td>
<td>rectangular</td>
<td>1.73</td>
<td>0.012</td>
<td>3.84 \times 10^{-2}</td>
<td>V</td>
<td>44.4</td>
<td>V</td>
</tr>
<tr>
<td>( \beta )</td>
<td>12.7</td>
<td>kHz</td>
<td>1.4</td>
<td>kHz</td>
<td>rectangular</td>
<td>1.73</td>
<td>0.81</td>
<td>0.38</td>
<td>V/kHz</td>
<td>0.32</td>
<td>V</td>
</tr>
<tr>
<td>( \Gamma )</td>
<td>500</td>
<td>kHz</td>
<td>50</td>
<td>kHz</td>
<td>rectangular</td>
<td>1.73</td>
<td>28.9</td>
<td>-0.0009</td>
<td>V/kHz</td>
<td>0.29</td>
<td>V</td>
</tr>
</tbody>
</table>

\( u_y(V) = 2k u_x(V) \)  
\( (V) = 2 \sigma(V) \)  
\( y = 3.84 \)  

Expressed in % of 3.84 kV: 8.6 %

* Probability Density Function

### Table F.3 – Example of uncertainty budget for surge open circuit voltage duration \( (T_d) \)

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Estimate</th>
<th>Unit</th>
<th>Error Bound</th>
<th>Unit</th>
<th>PDF*</th>
<th>Divisor</th>
<th>( u_x(T) )</th>
<th>( c_I )</th>
<th>Unit</th>
<th>( u_y(T) )</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>( T_{d,R} )</td>
<td>0.5</td>
<td>µs</td>
<td>0.0050</td>
<td>µs</td>
<td>triangular</td>
<td>2.45</td>
<td>0.0020</td>
<td>-1.00</td>
<td>µs</td>
<td>0.020</td>
<td>µs</td>
</tr>
<tr>
<td>( T_{d,R} )</td>
<td>51.2</td>
<td>µs</td>
<td>0.0050</td>
<td>µs</td>
<td>triangular</td>
<td>2.45</td>
<td>0.0020</td>
<td>1.00</td>
<td>µs</td>
<td>0.020</td>
<td>µs</td>
</tr>
<tr>
<td>( 6\sigma )</td>
<td>0</td>
<td>µs</td>
<td>0.15</td>
<td>µs</td>
<td>normal ((k=1))</td>
<td>1.00</td>
<td>0.15</td>
<td>1.00</td>
<td>µs</td>
<td>0.15</td>
<td>µs</td>
</tr>
<tr>
<td>( \beta )</td>
<td>12.7</td>
<td>kHz</td>
<td>1.4</td>
<td>kHz</td>
<td>rectangular</td>
<td>1.73</td>
<td>0.81</td>
<td>-0.0002</td>
<td>µs/kHz</td>
<td>0.0042</td>
<td>µs</td>
</tr>
<tr>
<td>( \Gamma )</td>
<td>500</td>
<td>kHz</td>
<td>50</td>
<td>kHz</td>
<td>rectangular</td>
<td>1.73</td>
<td>28.9</td>
<td>0.00013</td>
<td>µs/kHz</td>
<td>0.0038</td>
<td>µs</td>
</tr>
</tbody>
</table>

\( u_y(T) = 2u_x(T) \)  
\( (T) = 2 \sigma(T) \)  
\( y = 50.7 \)  

* Probability Density Function
Surge generators

Current Surge generators from the AMETEK CTS product lines

- Compact NX5
- UCS 500N7
- VCS 500Nx 8
- VCS 500N12 + CDN 100 A
- NSG 3040
- NSG 3060 + coupler
IEC 61000-4-6 Ed 4: (2013)
Conducted disturbances inducted by radio frequency fields
Overview of immunity against sinusoidal disturbance

**EN61000-4-16**
Conducted, asymmetrical disturbances in the range from 0Hz up to 150kHz (DC, 16.67Hz, 50Hz, 60Hz, 15Hz-150kHz) typically without modulation.

**EN61000-4-6**
Conducted disturbances, induced by electromagnetic fields in the range from 150kHz – 80MHz (230MHz). Typically with 1kHz, 80%, AM.

**EN61000-4-3**
High-frequency electromagnetic fields in the range from 80MHz – 6GHz. Typically with 1kHz, 80%, AM.
Phenomenon conducted disturbances inducted by RF fields

- Radio transmitter
- TV transmitter
- Radio / mobile radio
- Radio-relay systems
- Navigation and Radar
- Wireless networks
- Industrial facilities
- Digital wireless phones
Interference signal

Unmodulated RF Signal (CW)
U_{pp} = 2.82V, U_{rms} = 1.00V

Modulated RF Signal, 80% AM
U_{pp} = 5.09V, U_{rms} = 1.12V
U_{max. rms} = 1.80 V

Figure 4 – Open circuit waveform at the EUT port of a coupling device for test level 1
# Test severity level

<table>
<thead>
<tr>
<th>Level</th>
<th>Test voltage V</th>
<th>Frequency range</th>
<th>Ampl. Modulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>3.0</td>
<td>150 kHz – 80 MHz</td>
<td>80% AM with 1kHz</td>
</tr>
<tr>
<td>3</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>X</td>
<td>special</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Level 1**: Environment with low electromagn. fields, radio station more than 1 km away

**Level 2**: Environment with moderate electromagnetic fields, commerce- and business area, portable transceivers with power less than 1 W

**Level 3**: Environment with strong electromagn. fields, industrial area, powerful radio stations in the neighborhood, portable transceivers with power of 2 W and more

**Level x**: Open test severity level, defined in the corresponding product standard
Principle of operation

Current and field distribution during common-mode testing on the lines:
Test simulator

Basic configuration of test simulator

The fixed attenuator T2 ($\geq 6\,\text{dB}$) reduces the mismatching between PA and the CDNs.

T2 can be integrated into the CDNs or even dropped, if the output impedance of PA at all loads keep within the defined values (50 Ohm, previously additional VSWR < 1,2)
CDN-Types

CDN = Coupling-/Decoupling-Network
Different types are specified in the standard

- CDN-M1/2/3/4/5 \((M = \text{Mains})\)
- CDN-S9/15/25/38 \((S = \text{Shielded})\)
- CDN-T2/4 \((T = \text{Telecom, symmetrical})\)
- CDN-AF2/3/4/8 \((AF = \text{General, asymmetrical})\)

- EM clamp
- BCI-clamp (Bulk Current Injection)
Example of a simplified Diagram of a CDN-M3

CDN-M1 /-M2/-M3 /-M4 /-M5 are used for unscreened supply (mains) lines.

The internal setup is in detail specified in the standard, as an example.

**CDN-M3:** \( C_1 = 10 \text{ nF}, C_2 = 47 \text{ nF}, R = 300 \text{ Ohm}, L > 280 \mu\text{H} \text{ at } 150 \text{ kHz} \)

**CDN-M2:** \( C_1 = 10 \text{ nF}, C_2 = 47 \text{ nF}, R = 200 \text{ Ohm}, L > 280 \mu\text{H} \text{ at } 150 \text{ kHz} \)

**CDN-M1:** \( C_1 = 22 \text{ nF}, C_2 = 47 \text{ nF}, R = 100 \text{ Ohm}, L > 280 \mu\text{H} \text{ at } 150 \text{ kHz} \)
Requirements for coupling equipment

Coupling- and decoupling equipment can be made up of one or more housings, however, the basic parameter is the asymmetrical impedance $|Z_{CE}|$ (from the view of EUT-port).

Condition:

- 0.15 – 26 (24) MHz: 150 Ohm +/- 20 Ohm
- 26 (24) MHz - 80 MHz: 150 Ohm +60/- 45 Ohm
- 80 – 230MHz: 150 Ohm +/- 60 Ohm

Informative according Annex B for tests >80MHz.

The wanted signal may not be essentially influenced by the coupling networks. Coupling networks for mains must have an earth connection in all test conditions. High leakage current may occur and safety connections from GND to reference ground plane is mandatory.

New in IEC 61000-4-6 Ed.4

The frequency band was changed from 26 MHz to 24 MHz because of some issues related to high-power CDNs.
Setup for level setting at the EUT Port of CDN's

Note: The 150 Ω load at AE-port is only used at unscreened lines, (at screened lines the port is connected with the reference ground surface).
Level setting at the EUT Port of CDN´s

New in IEC 61000-4-6 Ed.4

\[ U_{mr} = U_0 / 6 \left(\pm 19\% \right) \], in linear quantities, or

\[ U_{mr} = U_0 - 15.6 \text{ dB} \pm 1.5 \text{ dB} \], in logarithmic quantities

IEC 61000-4-6 Ed.3

\[ U_{mr} = (U_0/6) \pm 25 \% \text{ (linear Scale)} \]

\[ U_{mr} = U_0 - 15.6 \text{ dB} \pm 2 \text{ dB} \text{ (logarithmic Scale)} \]

Set-up for level setting:

for the CDN:

for the Clamp EM101:
Different Setups for setting the output level?

Up to now and still valid:

- Use the RF generator $P_{gen}$ for leveling
- Using the recorded level to create the required voltage at the EUT Port of coupling device.

Additional proposal new in IEC61000-4-6 Ed.4:

- Record the forward power $P_{for}$ at the output of the power amplifier
- Using the recorded levels $P_{gen}$, $P_{for}$ and $U_{mr}$ to calculate the used values to create the required voltage at the EUT Port of coupling device.
Level setting

Apply a forward power to the CDN so that the voltage obtained equals $U_{\text{mr}}$ at the output port of the 150Ω to 50Ω adapter.

Record the level of the RF generator $P_{\text{gen}}$ and/or the forward power at the output of the power amplifier $P_{\text{for}}$ and the voltage $U_{\text{mr}}$ at the output port of the 150 Ω to 50 Ω adapter;

Increase the frequency by a maximum of 1 % of the present frequency;

Repeat until last frequency has reached

Calibration file
Amplifier saturation check – record measurement

New in IEC 61000-4-6 Ed. 4  
checks the saturation of the amplifier

Calibration file  

\( \frac{(P_{\text{gen}})}{P_{\text{for}}} \)  

5.1 dB

Apply the new Level

Record the new output power delivered to the CDN \( P_{\text{for,inc}} \) or the voltage at the output port of the 150 Ω to 50 Ω adapter \( U_{mr,inc} \)

Calculate the difference \( P_{\text{for,inc}} - P_{\text{for}} \) or \( U_{mr,inc} - U_{mr} \) (log. scale)
Amplifier saturation check – evaluate measurement data

Is the difference between 3.1dB and 7.1dB?

- **YES**
  - The amplifier is in tolerance and the test system is sufficient for testing at the selected test level.

- **NO**
  - The amplifier is non-linear and is not suitable for testing.

IEC61000-4-6 Ed. 4
check the saturation of the amplifier
New geometry for 150Ω to 50Ω adaptor

The center position of the connector to the CDN is fixed on 30mm distance from the GRP. The ground plate is recommended to be 30mm long.

The reference plane has a dimension of 100mm x 100mm

New in IEC61000-4-6 Ed.4

The reference plane area depends on the parameter h.

h = 30mm  dimension of the reference plane has to be 100mm x 100mm.

h > 30mm  dimension of the reference plane has to be 150mm x 150mm.
Test Jig for EM-Clamp characterization

New in IEC 61000-4-6 Ed.4

Annex A is completed dedicated to the EM and decoupling clamps now. Beside the guideline for setup, measuring the S-parameters and the calculation of the impedance, decoupling and coupling factor, it include also a new calibration jig for the clamps. The construction details of the jig are illustrated hereafter.
Test Jig applications for EM-Clamp

Position of the rod

Center of the clamp: Impedance and Decoupling factor

Bottom position: Coupling factor, EM TEST propose this position for calibration

New in IEC 61000-4-6 Ed.4
Schematic test setup with CDNs

- Each, the EUT and the AE are **10 cm isolated** above the reference ground surface.
- All outgoing lines have to be **decoupled via CDN**.
- The CDNs have to be inserted in a distance of **0.1 m up to 0.3 m** from the EUT.
- The CDNs must be connected well **with the reference ground plane** in a RF-accordant manner.
Test setup for single-unit EUTs

IEC 61000-4-6 Ed.4 : correct

IEC61000-4-6 Ed.3/Ed.2: wrong

- Edition 4 shows the correct setup with **one terminated CDN with 50Ω**
- The standard versions Ed. 2 and Ed.3 show in the setups for single-unit EUTs wrong setups. The **termination of one other non tested CDN is missed**.
New test setup specifications IEC 61000-4-6 Ed.4

Throughout the standard, cable height of at least 30 mm will be used. This is driven largely by practical reasons in actual test setups.

All dimensional values are now clearly limited with ≥, ≤ signs

The CDN in- and output signals are no longer drawn as connected to the GRP.
Procedure for CDN injection application

Procedure since IEC/EN 61000-4-6:2007:

- The port intended to be tested shall be connected with the simulator via the corresponding CDN.
- Only **one other CDN, terminated with 50Ω**, shall be connected with a second port.
- All further ports are only decoupled.

- The CDN to be terminated with 50Ω shall be chosen according to the following priority:
  
  **IEC 61000-4-6 Ed.4 : modifications are blue marked**
  1. CDN-M1 (used for connection of the earth terminal)
  2. CDN-M3, CDN-M4, CDN-M4 (used for mains – class I equipment)
  3. CDN-Sn (n=1,2,..), which is closest (geometrical) to the injection point
  4. CDN-M2 (used for mains – class II equipment)
  5. Other CDN, which is closest (geometrical) to the injection point
Test setup for **multi-unit** EUTs

- The EUT clearance from any metallic objects shall be at least **0.5 m**.
- The **reference ground** plane has to exceed the test set-up itself on all sides by at least **0.2 m**.
- Equipment from several units will only be considered as **one unit** when the **interconnection cables between them is <1m**.
Enhanced injection method flow chart

The flow chart for selecting appropriate injection method has been enhanced by a new decision. Now it is clear that injection method “direct injection” is only applicable to shielded cables.

**New in IEC61000-4-6 Ed.4**

- **Selecting injection method**
  - Are CDN's applicable?  
    - YES: Use CDN injection subclause 7.5  
    - NO:  
      - Is EM clamp or current clamp injection applicable?  
        - YES:  
          - Screened Cable?  
            - YES: Shielded cable?  
              - NO: Use direct injection subclause 7.9  
              - YES: Check the following requirements:  
                1. 150.0 AE impedance  
                2. Test setup can meet Figure 5  
                3. AE sufficiently immune  
            - NO: Use IEM clamp or current clamp injection subclause 7.6  
        - NO: Use IEM clamp or current clamp injection subclause 7.7
  - NO: Check the following requirements:
    1. 150.0 AE impedance
    2. Test setup can meet Figure 5
    3. AE sufficiently immune

**IEC61000-4-6 Ed. 3**

- **Selecting injection method**
  - Are CDN's applicable?  
    - YES: Use CDN injection subclause 7.2  
    - NO:  
      - Is clamp injection applicable?  
        - YES: Check the following requirements:  
          1. 150.0 AE impedance  
          2. Cable 50 mm to 50 mm above J/F  
          3. AE sufficiently immune
        - NO: Use direct injection subclause 7.5  
    - NO: Use clamp or current clamp injection subclause 7.3

1) See Table 4

Figure 12 – Rules for selecting the injection method
Distinctions when testing with injection clamps

In case of too low directivity or better said insufficient decoupling it might be that the asymmetrical impedance with 150Ω at EUT port and the AE port is not given. At the EUT port an accidentally overcurrent could be applied.

The current can be monitored by the means of current probes between the coupling point and the EUT port. If the current $I_{\text{max}}$, defined by

$$I_{\text{max}} = \frac{U_o}{150 \text{ Ohm}}$$

is exceeded, the test voltage can be reduced until achieving $I_{\text{max}}$.

The achieved test voltage has to be reported.
Distinctions when testing with injection clamps

Two different kinds of injection clamps are mentioned:

1. **EM-clamp**
   The EM clamp has a directivity of \(\geq 10\text{dB}\) above 10MHz. The directivity can be enlarged by further ferrites, therefore usually ferrite clamps are used. **Attention: Not to confuse with the coupling clamp according to EN61000-4-4 for coupling burst disturbances!**

2. **Current clamp,**
   in the automotive field better known as **BCI clamp,** has no decoupling function. The RF current induced into a line flows according the impedance ratio of the line.
Test set-up with CDN and EM-clamp

- The \textbf{CDN}-side has no special requirements for the connected \textit{AE}. The \textit{AE} must only be placed 10cm above the reference ground plane.

- The other side of the \textbf{EM-clamp} needs an asymmetric impedance with 150\,$\Omega$. The \textit{AE} 2 is once to terminate with a 50\,$\Omega$ loaded CDN (see CDN 2). Other lines of the \textit{AE} must be decoupled.
Test set-up with CDN and EM-clamp

$L_2 \geq 0.3 \text{ m}$

$0.1 \text{ m} \leq L \leq 0.3 \text{ m}$
Test set-up with CDN and injection clamp as well as monitor probe

$L_2 \geq 0.3\, \text{m}$

$0.1\, \text{m} \leq L \leq 0.3\, \text{m}$
• The test signal shall be injected directly on to the shield of the screened cable through a 100 Ω resistor.

• The decoupling to AE side has to be sufficiently large, L＞280µH !!

Remark: Often the decoupling is not sufficient, so that a part of the disturbance get lost on the AE-side. In this case, the AE could be connected with further ports via an CDN, similar as used for coupling via current clamps.
Test set-up direct coupling via 100 Ohm
Avoid error sources already in the test plan!
Prior to testing it should be thought twice, if the below listed parameter are sufficiently dimensioned:

- **test level**  Is the legal minimum requirement enough, or should be tested considering QA-aspects?
- **step size**  Maximum step size 1% log. (1% from previous frequency)
- **dwell time**  The dwell time per frequency step may not be <0.5s, and has to be selected as long until the operating function and a thereof resulting reaction of the EUT might be possible.
- **Additional** frequencies shall be analyzed in addition to the stepped frequencies (clock rate etc.)
The elevated reference plane shall be electrically connected to earth for safety reasons. It is not significant from an RF point of view.

Annex F (informative): Test set-up for large EUTs
Annex F (informative): Test set-up for large EUTs

Important: Each deviation from the standardized test procedure has to be recorded in the test report.
Measuring uncertainty (informative Annex G)

- Description of the influences to the measuring method.
- Definition of the individual uncertainties.
- Examples of calculating the combined and expanded uncertainty.
- The MU can be determined by the laboratory. The test disturbance is not corrected by the amount of uncertainty!

<table>
<thead>
<tr>
<th>Application:</th>
<th>Example calibration enhanced uncertainty (k=2)</th>
<th>Example test method enhanced uncertainty (k=2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Koppel-/decoupling-network (CDN)</td>
<td>1,27dB</td>
<td>1,36dB</td>
</tr>
<tr>
<td>EM-coupling clamp</td>
<td>1,27dB</td>
<td>3,19dB</td>
</tr>
<tr>
<td>EM-coupling clamp</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Current clamp (BCI)</td>
<td>1,46dB</td>
<td>3,27dB</td>
</tr>
<tr>
<td>Current clamp (BCI)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Direct coupling</td>
<td>1,46dB</td>
<td>3,07dB</td>
</tr>
</tbody>
</table>

The biggest uncertainty is the termination at the AE side (Uxi=2,5).
Generators

Current generators for testing conducted immunity from the AMETEK CTS product lines

- NSG 4070
- CWS 500N1.3
- CWS 500N2.2
Any questions? We are at your disposal!

EM TEST GmbH
Lünener Str. 211
59174 Kamen, Germany
info.emtest@ametek.de

EM TEST (Switzerland) GmbH
Sternenhofstr. 15
4153 Reinach BL, Switzerland
sales.emtest@ametek.com

Phone: +49 (0) 2307 / 260 70-0
Fax: +49 (0) 2307 / 170 50

Phone: +41 (0) 61 / 717 91 91
Fax: +49 (0) 61 / 717 91 99

Thank you for your attention!