

Transient Immunity Testing

a handy guide



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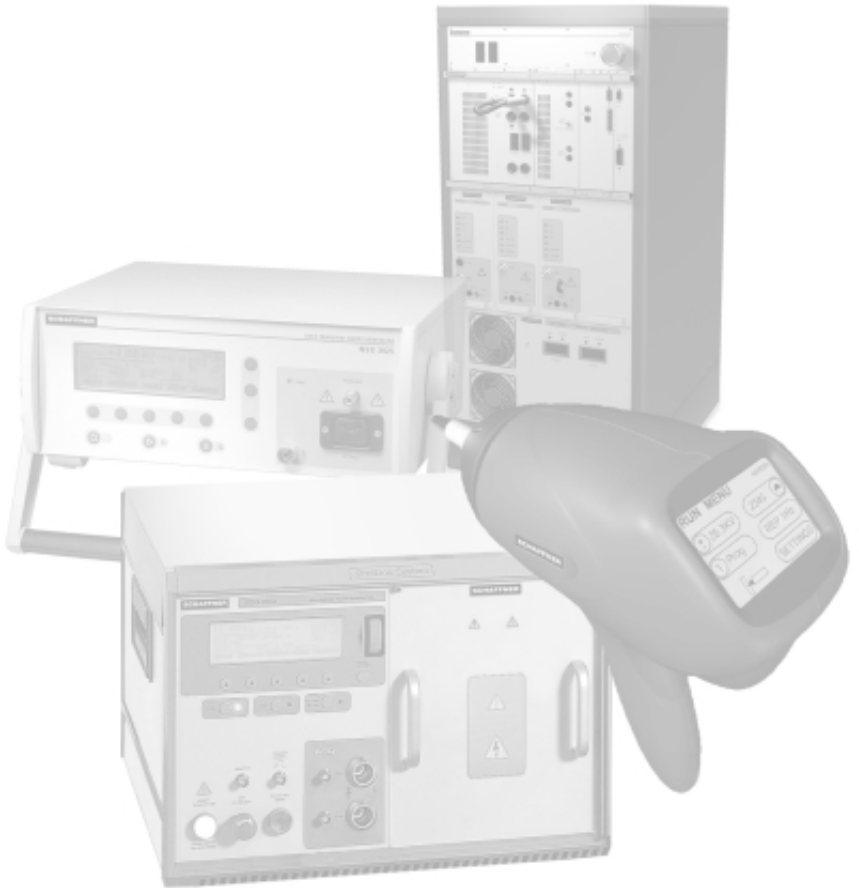
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Transient Immunity Testing

a handy guide



The handy guide to transient tests

Introduction

As well as covering continuous radio frequency phenomena, EMC means ensuring product immunity from several sources of transient phenomena that are present in the electromagnetic environment. These phenomena can be natural, such as electrostatic discharge (ESD) and lightning surge, or man-made such as switching transients and fault surges. They involve short-duration (nanosecond or microsecond) events that have high enough amplitudes to disrupt the operation of electronic circuits and, in some cases, have enough energy to destroy or damage components.

Except for ESD, the source of a transient is not normally near to the victim equipment, and its energy is almost entirely coupled into the circuits via cable connections. Therefore, immunity testing involves applying a repeatable pulse of a defined waveform and level into each relevant cable port, in a specified and reproducible manner. Apart from the rarely-used pulsed magnetic field and damped oscillatory wave tests of IEC 61000-4-9 and -10, there are no commercial tests which apply radiated transients. ESD is the special case which is the exception to this rule: it is applied from a simulator which attempts to mimic the real-world event, and includes both radiated and conducted components.

Application of a series of transients is accompanied by monitoring the function of the EUT to determine whether it has been disrupted and, if so, whether the disruption is acceptable or not.

This guide discusses the mechanisms involved in generating each type of transient, the standard tests that have been devised to deal with them, and some of the practical issues that arise in performing these tests. Some reference material on the standards is given at the end of the guide.

Electrostatic discharge

The discharge event

Charging mechanism

All conductive objects have self-capacitance with respect to ground and mutual capacitance with respect to other bodies. This capacitance can maintain a DC charge with respect to ground, if the object is insulated from ground.

Movement or separation of insulating surfaces causes charge transfer through the triboelectric mechanism, and this leaves a net deficit or surplus of free electrons on the conductive objects that are coupled to these surfaces. Alternatively, proximity to other electrostatically charged objects results in inductive charging.

With perfectly insulating materials, this charge would remain on the object indefinitely, but in reality there is some surface and volume conductivity and the free electrons drift so that the charge differential is gradually neutralised. This occurs more rapidly with greater conductivity. Static dissipative materials and higher relative humidity are two ways to increase the conductivity.

The charge Q is related to the voltage differential by the capacitance of the object:

$$Q = C \cdot V$$

For parallel plates, capacitance is determined by surface area A and separation distance d , as well as by the permittivity ϵ of the dielectric material within the separation gap:

$$C = \epsilon_0 \cdot \epsilon_r \cdot (A/d)$$

For irregular objects, the capacitance can be approximated by applying the above equation to elemental regions of the objects and summing the capacitance due to each element:

$$C = \sum_i \{ \epsilon_0 \cdot \epsilon_r \cdot (A_i/d_i) \}$$

where A_i is the surface area of each element and d_i is the distance between surfaces for each element.

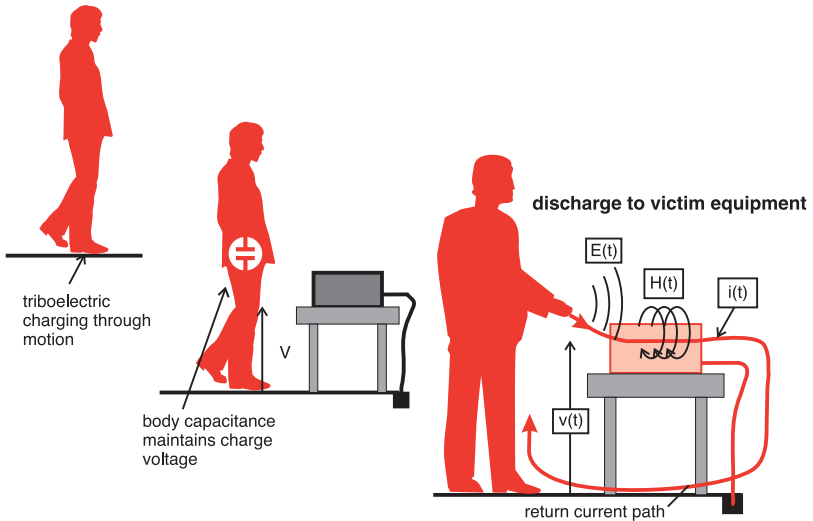
Human body capacitance depends on the size of the person and on their activity, i.e. whether they are sitting, standing or walking. In a moving person, all these factors come together to give a continuously varying voltage on that person. In the worst case – highly insulating materials, low relative humidity and vigorous movement –

the voltage may reach as high as 25kV. Charge potentials higher than this tend to be limited by corona effects. In more typical situations, voltages vary between 2-8kV.

The effect on electronics

When a charged object contacts another object at a different potential (this second object may be at ground potential but is not necessarily so), the charge is equalised between the two objects, and there is both a voltage $v(t)$ and current $i(t)$ transient as this occurs (Figure 1). The amplitude and waveform of the transient depends on the voltage difference and the total impedance in the equalisation current path.

Figure 1 The typical personnel discharge scenario 4



Associated with the $v(t)$ and $i(t)$ are electric and magnetic field transients $E(t)$ and $H(t)$. All four of these aspects of the event will couple with electronic circuits that happen to be in the path of the current or near to the source of the field. This coupling creates induced transient voltages within the signal circuits themselves. Digital circuits in particular may respond to these induced pulses as if they were intentional signals, and their operation is consequently corrupted.

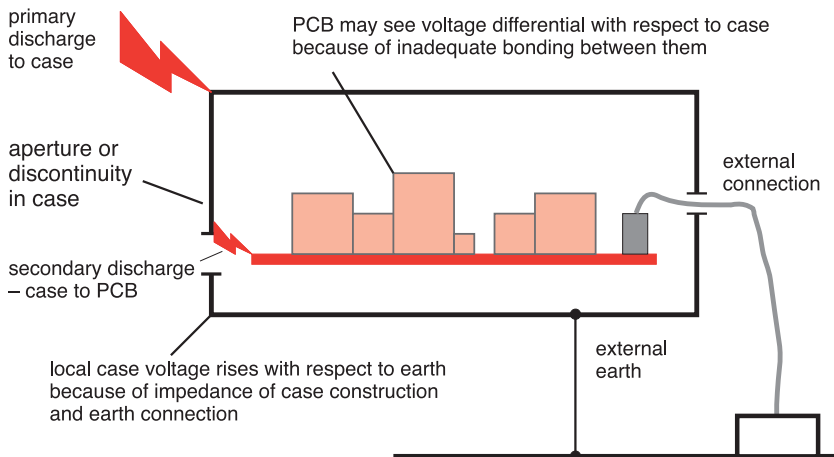
Design to avoid ESD problems includes:

- choose circuit configurations that are unresponsive to short transients
- lay out the PCB to minimise induced voltages at critical nodes
- prevent unavoidable discharge transients from coupling into circuits and cables
- design enclosures as far as possible to prevent discharges from occurring

Secondary discharge

A secondary discharge can occur within equipment if the discharge current through the product attempts to take a path which includes an air gap. The voltage across the gap increases until the gap breaks down, and this secondary breakdown can be more stressful for the circuits than the initial event, because it is closer to them and probably involves a lower path impedance. The breakdown occurs simultaneously with the applied primary discharge. Secondary discharge is best dealt with by ensuring that no sneak air gaps exist, or by making them large enough not to break down, or by bonding across them, and by avoiding sharp edges which encourage high field gradients.

Figure 2 Mechanism of secondary discharge



The IEC 61000-4-2 standard test method and generator

IEC 61000-4-2 and its EN equivalent is the principal basic standard for testing electrostatic discharge immunity. It applies a defined current waveform at a specified voltage level from a hand-held generator (Figure 3), which is essentially a capacitor supplied from a high voltage supply whose charge voltage is discharged via a series impedance through the point of contact to ground. Two methods are given: contact discharge and air discharge.



Figure 3
The Schaffner NSG 435 ESD generator

Contact discharge

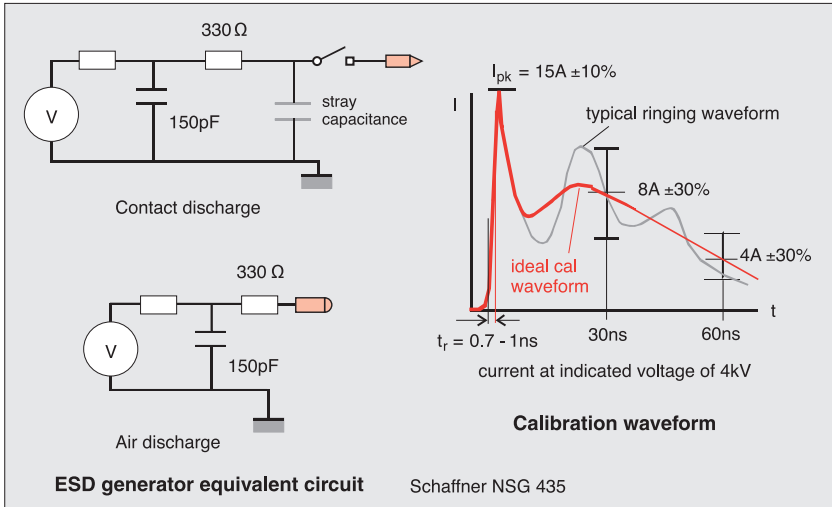
In the contact discharge method, the stress may be applied directly to the EUT or to a coupling plane adjacent to the EUT. Before each test pulse, the capacitor is charged to the desired level but its voltage is held off the generator's probe by a vacuum relay. The probe is applied to a suitably chosen point on the EUT or the coupling plane. The generator is then triggered, so that the relay contacts close and the capacitor voltage is applied through the probe to the EUT. This creates a pulse of current (with associated field and voltage transients) as the voltage discharges through the combined series impedance of the generator, the EUT and the ground plane. This action is repeated the desired number of times, at each location, with the appropriate polarities and levels.

Air Discharge

The same generator is used for the air discharge method, but with a rounded rather than a pointed probe tip. The capacitor is charged to the desired level as before, but the voltage is now continuously applied to the probe, which is held away from the EUT. For each test pulse, the tip is brought up to the chosen point on the EUT, smartly, until it touches. Just before this, the air gap between the tip and the EUT will break down and a discharge current will flow,

limited as before by the combined series impedance of the generator, the air gap, the EUT and the return path. Again, the action is repeated the desired number of times, at each location, with the appropriate polarities and levels.

Figure 4 The ESD generator circuit and waveform

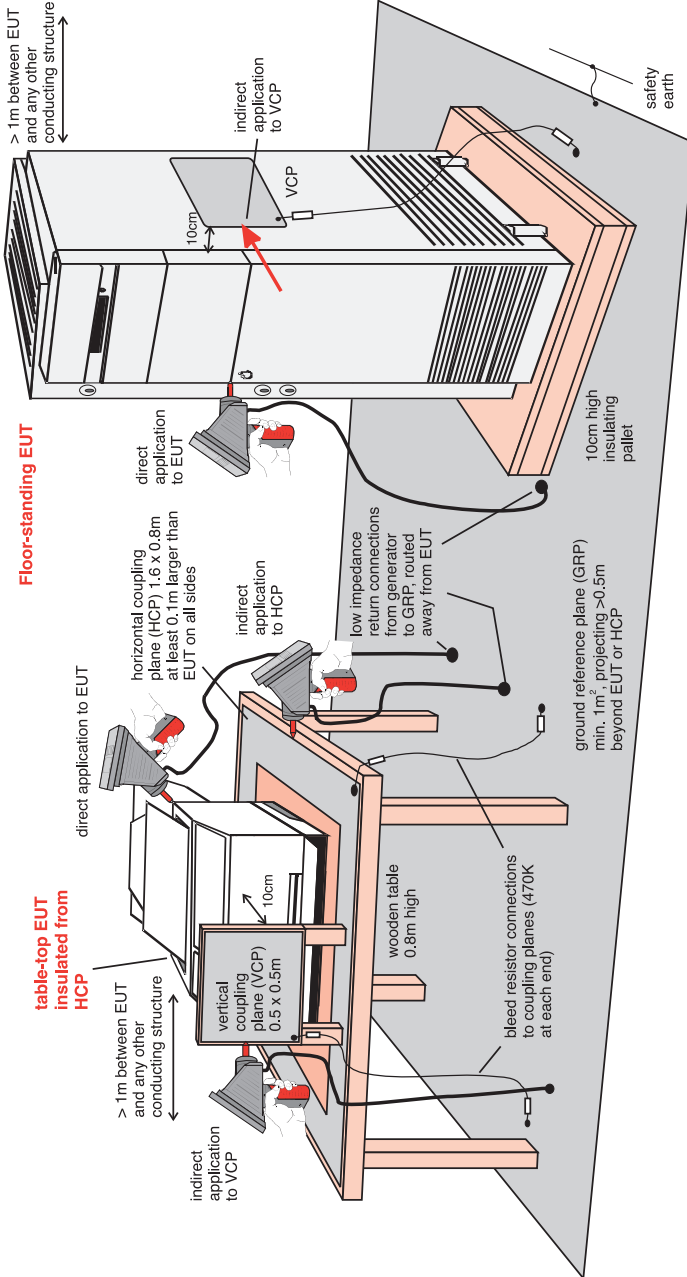


Practical aspects of testing

The test layout

The recommended test layout is shown in Figure 5. The ESD pulse has a subnanosecond risetime and so radio frequency layout precautions are vital. The test must re-create the fast risetime found in reality, since this is an important parameter in deciding both the path the discharge takes through the EUT and the response of the EUT itself. The ground reference plane (GRP) is an integral part of the setup and the generator's return lead must be well bonded to it, since this connection forms part of the current return path.

Figure 5 ESD test layout



The indirect discharge part of the test uses two other planes, different from the GRP, known as the horizontal coupling plane (HCP) and the vertical coupling plane (VCP). Discharges to these planes simulate the stress caused by the radiated field from real-life discharges to nearby objects. Each coupling plane is connected to the GRP by a resistor lead, to ensure that any charge bleeds off within a few microseconds. The construction of these leads is critical: there should be a resistor close to each end, so that the length of lead between them is isolated from the connections and stray coupling to it is neutralised. Although power rating is unimportant, the resistors themselves should withstand a high pulse dV/dt without breaking down, for which carbon composition types are best suited.

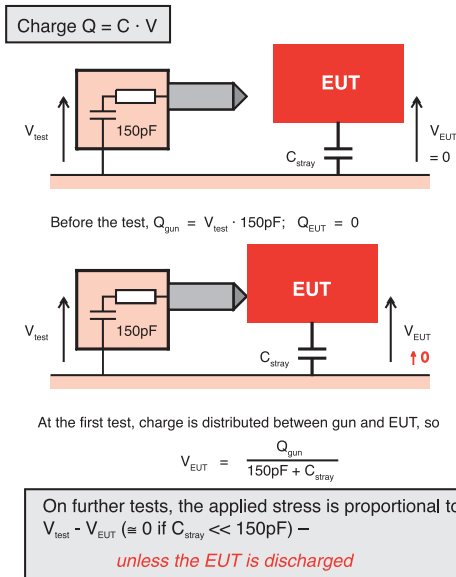
For the few tens of nanoseconds of the ESD event, the plane carries the full stress voltage, which is capacitively coupled to the EUT. Any stray capacitance from the plane to objects other than the EUT modifies the plane's voltage and current waveforms and hence the applied stress. Therefore, it is important to maintain at least 1m clear space around the EUT, which implies some separation of the tabletop setup from walls or other objects. Equally, the separation from the VCP to the EUT is specified as 10cm; even small variations in this distance can cause large changes in coupling to the EUT, so a convenient means of controlling it, such as plastic 10cm spacers on the surface of the plane, is helpful.

Floating EUTs

If the EUT has a ground connection, the charge that is applied by each test pulse will quickly dissipate, leaving the EUT ready for the next application. But this is not true for those EUTs which are isolated from ground such as hand-held stand-alone devices, or safety Class II mains powered units. When a discharge is applied to these, charge moves from the 150pF capacitor of the discharge generator to the self-capacitance of the EUT, leaving it floating at some voltage above ground, the actual value depending on the ratio of capacitances (see Figure 6). This is fine on first application, but it means that the applied stress is progressively reduced on subsequent pulses of the same polarity and level, since the voltage difference between the generator and the EUT is diminishing.

Or, if the polarity is reversed, the EUT suffers a much greater applied stress than intended. Small EUTs may have only a few pF self-capacitance, meaning that they instantly reach nearly the full applied voltage, and subsequent pulses are worthless.

Figure 6 Charging of ungrounded EUTs



You should, therefore, bleed off the charge between each pulse application.

Amendment 2 to the standard, recently published, achieves this by allowing a bleed resistor cable between the EUT and HCP during the test. As long as the resistors are mounted very near to the ends of the cable (within 2cm), the cable can remain in place during the test, since its presence probably won't affect the outcome – although in cases of dispute, the cable should not be connected. As with the bleed resistors for the coupling planes,

you should take some care to ensure that the resistors are capable of withstanding the full pulse voltage without breakdown.

Alternatives to a permanently connected bleed cable are a bleed resistor brush, applied in between discharges for the same purpose – the resistor must still be at the top end of the cable to ground, otherwise the discharge induced by the bleed could be worse than that applied by the ESD gun, leading to a failure of the wrong test; or the use of an air ioniser, to speed the natural discharge of the EUT.

Number, location and level of discharges

The standard tells you to do 10 discharges in the most sensitive polarity “at preselected points”. Lower levels than the specification must also be satisfied – so if for the typical compliance test you are doing 4kV contact and 8kV air, you must also do 2kV contact and both 2kV and 4kV air tests. The test stress is not necessarily linear, so that a product might fail at, say, 4kV and yet pass at 8kV, and this would be an overall failure. But the difficult question is, how do you preselect the appropriate points?

Only points which are accessible during normal use are to be tested, but this is often not much of a limitation. Amendment 2 defines what is meant by accessible parts in more detail. Clause A.5 of the standard gives some guidance. Also, product standards such as EN 55024 may be more explicit than the basic standard. But the difficulty usually lies in establishing the most sensitive locations around the EUT. Exploratory testing using a high pulse repetition rate or higher level is sometimes helpful, if the EUT’s immunity is only slightly greater than the specification, but this doesn’t work if the design gives a good margin of immunity. It also exposes the EUT to greater stress than the compliance test calls for, which may not be acceptable in some cases.

A prototype design may be weaker than the final product, and the weaknesses may be most marked at certain points, which are then prime candidates for the compliance test. But in the end, this question can only be resolved through the skill, experience and perseverance of the test engineer.

Handling the ESD gun

The stress applied to the EUT is not confined just to the voltage and current pulse appearing at the tip. There is a stray field around the front of the gun, and also around the ground return lead as it falls away from the gun. Both of these can couple to the EUT and modify the stress, so it is necessary to control them. You need to ensure that the ground lead does not drape over the EUT but is always held away from it; the standard advises that it is kept at least 20cm away from the EUT and any conductive parts other than its connection to the GRP. Equally, you should always hold the generator such that its probe is perpendicular to the EUT surface that is being tested, and not handle the generator near the probe. This will reduce the variability of coupling of the stray field around the front of the generator.

When the discharge is applied to the coupling planes, the gun should be held edge-on to the plane and opposite the centre of the EUT, for the HCP, or at the centre of one edge of the VCP. This is made explicit in Amendment 1: 1999 to the standard.

As well as angle of incidence, for the air discharge test the speed of approach is important, since this affects the breakdown of the air gap. The standard says “the discharge tip shall be approached as fast as possible (without causing mechanical damage) to touch the EUT”. In the case of contact discharge, contact pressure is relevant; even a thin film of oxide can cause a high contact resistance, which can give dramatic variations in the applied waveform, so the tip must be pressed as hard as possible against the EUT surface.

Figure 7 NSG 438 - Schaffner’s 30kV ESD Gun
for automotive and other stringent safety-critical testing



Electrical fast transient bursts

Source and effect of transients

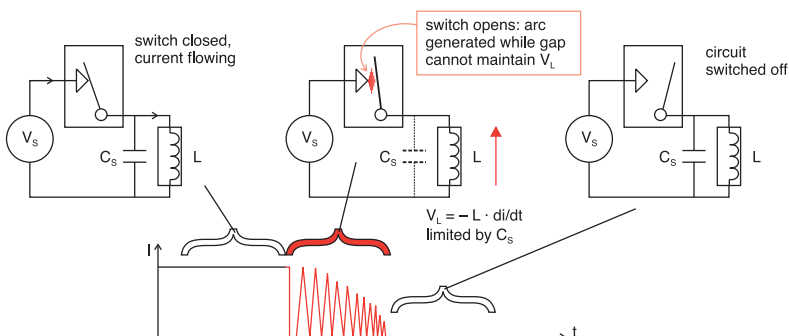
When a circuit is switched off, the current flowing through the switch is interrupted instantaneously. Put another way, at the moment of switching there is an infinite di/dt . All circuits have some stray inductance associated with the wiring; some types of load, such as motors or solenoids, have considerably more inductance in the load itself. The voltage developed across an inductance L by a changing current i is

$$V = -L \cdot di/dt$$

If di/dt is infinite, then this implies an infinitely high voltage. Of course, this doesn't happen in practice since the rate of rise of voltage is limited by stray or intentional circuit capacitance. Even so, a high instantaneous voltage, added to the circuit operating voltage, does appear across the opening switch contacts.

This causes the tiny but increasing air gap across the contacts to break down, and a current flows again, which collapses the voltage spike, so that the briefly formed arc extinguishes. But this re-interrupts the current, so another voltage spike appears, creating a further arc. This process repeats itself until the air gap is large enough to sustain the applied voltage without breakdown, at which point the circuit can be said to be properly switched off. The visible effect is a brief spark between the contacts, which actually consists of a whole series of microsparks, the so-called "showering arc", whose repetition rate and amplitude depend on the circuit and switch parameters.

Figure 8 Transient burst generation



The $i(t)$ and $v(t)$ inherent in each spark event propagate along the circuit wiring. If this is a mains circuit, this burst of noise can appear at other points of connection to the mains distribution ring. Also since the pulses are very fast – of the order of nanoseconds – they couple effectively to other wiring in close proximity to the circuit wiring. Voltage peaks, typically of hundreds but occasionally thousands of volts, appear on any such coupled circuits.

Burst characteristics

The actual occurrence of these bursts, seen from the point of view of victim equipment which is unrelated to the source, is usually random – although some automatic switching events can occur at regular intervals. Noise from brushed motors and arc welding, two special cases of the above mechanism, usually has a strong periodic content. The amplitude of the bursts decays with distance due to the lossy transmission-line characteristics of the wiring, and so it is usually only sources within a few metres of the victim that are significant. The burst waveforms are also random, although research has found that the repetition frequency tends to fall within the range 100kHz–1MHz, and the dv/dt of the rising edge is roughly proportional to the square root of the amplitude.

Effect on electronics

It is rare, though not impossible, for the transients to be coupled into a nearby victim by inductive coupling but, generally, they enter the product via the cable connections. On signal ports, the spikes are almost invariably in common mode, i.e. on all wires (or on the screen) at the same amplitude with respect to external earth. On the mains port, they may appear either in common mode or differentially between phases. Common mode coupling includes the protective earth wire.

Poor filtering or inadequate screen termination on each interface then lets these transients pass into the electronic circuits where they appear as interfering signals at sensitive nodes. As with other types of transient, digital circuits tend to be more susceptible, since each short pulse can appear as a valid digital signal. Occurring in bursts, there is a higher probability that one or more pulses will coincide with a critical timing edge. However, analogue circuits can also be affected, typically by saturation of sensitive amplifiers. Pulse counting circuits are also susceptible if the burst masquerades as a real input.

Good design practice takes two forms:

- the internal circuit design is bandwidth limited wherever possible, and the PCB layout prevents large interference voltages from appearing within the circuit;
- all interfaces must be filtered or screened to a structural low impedance earth so that common mode pulses are prevented from entering the circuit.

The IEC 61000-4-4 standard test method and generator

IEC 61000-4-4 and its EN equivalent is the principal basic standard for testing fast transient immunity. It applies a specified burst waveform via a defined coupling network to the mains connection and via a defined clamp device to any signal connection. Only conducted coupling is used; there is no specification for radiated transient immunity. Choice of ports for the application of the burst depends on the instructions in the product standard being used, but it is generally applied to AC and DC power ports and to signal and control ports that may be connected to cables longer than 3m.

Figure 9 Test setup for mains port

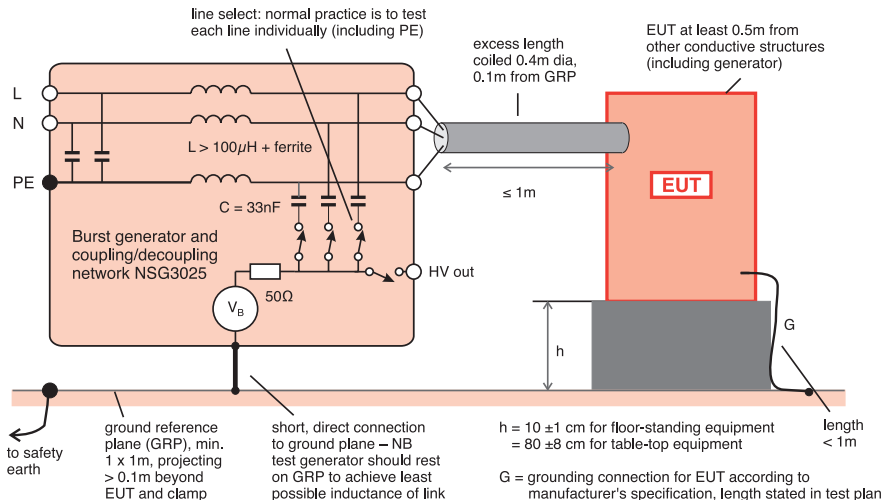
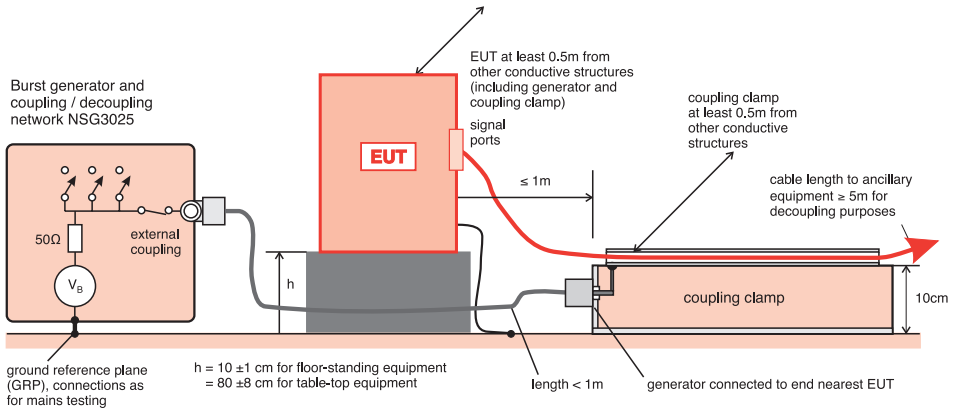


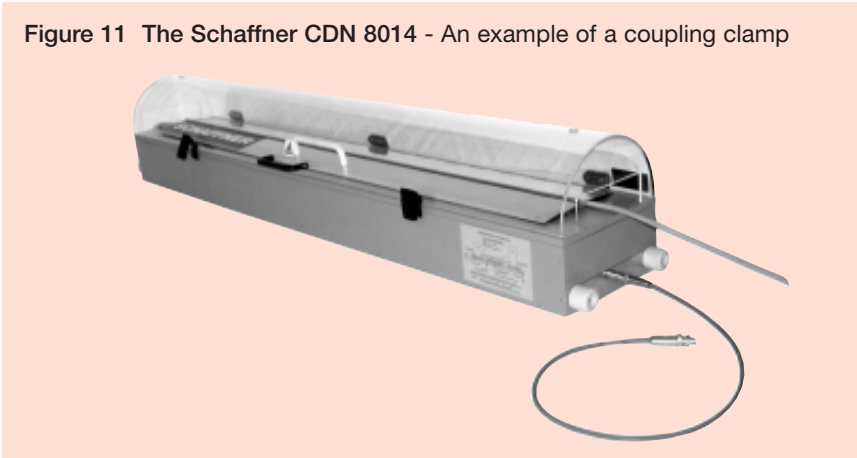
Figure 10 Test setup for signal ports



The power port CDN is essentially an inductor in series with the lines to isolate the burst application from the supply input, in combination with a capacitor feeding the burst voltage onto the chosen line(s). All lines may have the burst applied, including the protective earth, which must, therefore, also include a decoupling inductor.

The capacitive clamp is a pair of metal plates, connected together and hinged down one edge so that they can sandwich the cable under test between them. It is expected that the cable under test will be insulated and, therefore, there is no direct connection, only a capacitive one – if the cable insulation is weak or nonexistent this should be anticipated and some extra insulation provided. Because of the length of the clamp, the capacitive coupling is distributed, which improves repeatability for the higher frequency components of the transients. The clamp must also be located a defined distance above the ground plane, and the burst voltage is applied with respect to this ground plane.

Figure 11 The Schaffner CDN 8014 - An example of a coupling clamp

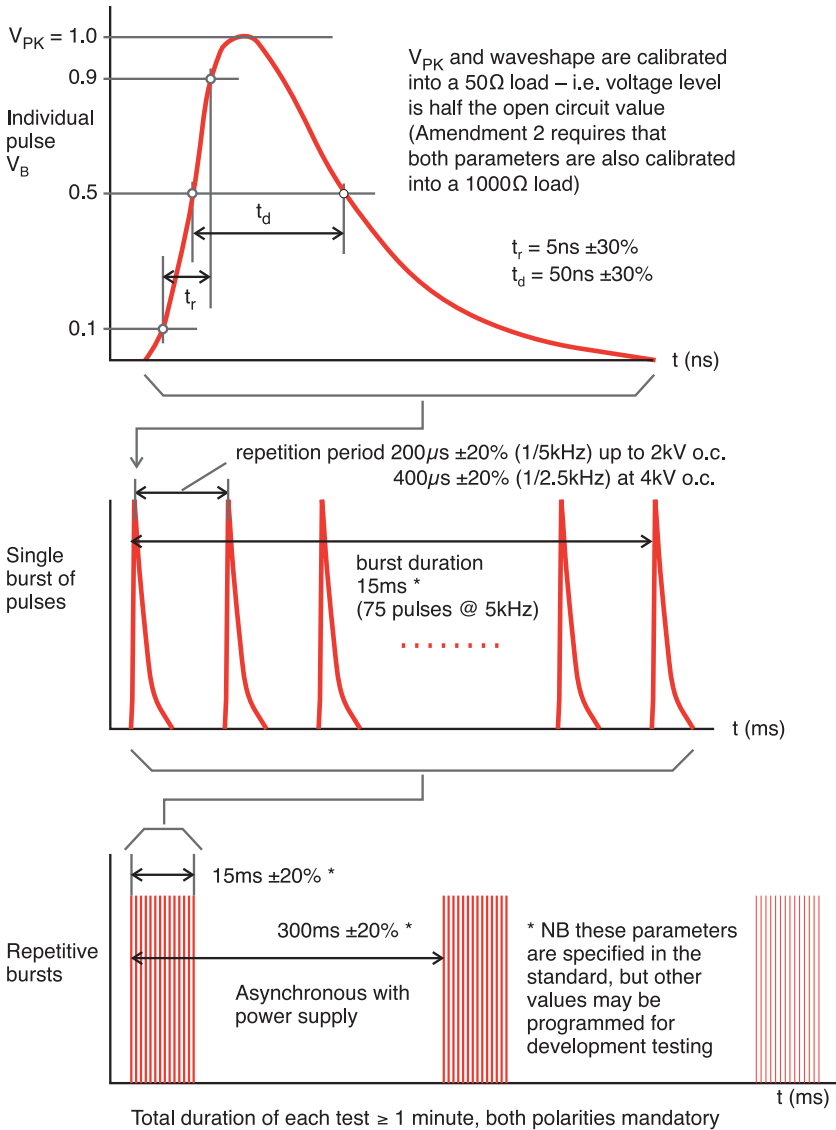


Waveforms

The burst waveform definitions are shown in Figure 12. To standardise the test, the waveshape, number of pulses, their frequency and the burst length and repetition frequency are all specified. It should be understood that these specifications are explicitly not representative of real life which, as mentioned earlier, sees pulse repetition rates in the hundreds of kHz. Instead, they represent the lowest common denominator of what is achievable and repeatable in test generators. It is possible to program most generators for other values and this may be helpful when you are testing your products for their immunity to real (variable) bursts.

The source impedance of the generator is required to be 50Ω and the waveform is calibrated into a 50Ω load and, in the future, according to a new amendment, also into 1000Ω . The load impedance presented by the EUT is unknown and may be anything from a near short circuit, for a screened cable port on an EUT that is well earthed, to a near open circuit for an unscreened port with a series common-mode choke at the interface. Therefore, the actual voltage that appears between the EUT port and the ground plane is similarly unpredictable. The aim of the new amendment is that the waveform of the burst pulse should not change between different generators and different EUTs.

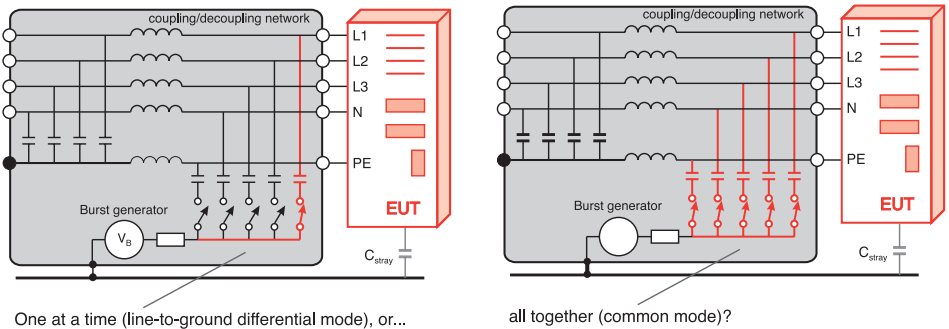
Figure 12 The burst specification



Practical aspects of testing

The transient burst voltage is applied to the power port(s) of the EUT via a coupling/decoupling network (CDN), and to other ports via a capacitive coupling clamp. The voltage is referenced to the ground plane connection point on the test generator. The basic standard is not entirely clear about how the burst should be applied through the CDN (Figure 13). The standard shows it being applied separately to live, neutral and earth lines, but some product standards which call up this test have referred to it as “common mode”, that is on all three lines simultaneously. Schaffner generators such as the NSG 3025 allow you to select any mode of coupling. The result of the test could well be different depending on which type of coupling you choose.

Figure 13 Coupling the burst through the CDN



In practice, the choice is a matter of interpretation and either interpretation could be justified. If you are using the test to check the real-life immunity of your product, it would be best to apply all different modes of coupling, but if you need to stick closely to the letter of a product standard, a restricted interpretation may be reasonable.

The question does not arise with the capacitive clamp, which inherently applies the burst in common mode.

The test layout

This is a high frequency test – the spectrum of the burst extends to hundreds of MHz – and a ground reference plane (GRP) is essential. Trying to do a development test without a ground plane will lead to unrepeatability and lack of correlation to the compliance test. Stray impedances are controlled by the following restrictions:

- The EUT should be 10cm above the GRP (80cm for table-top equipment);
- The GRP should extend at least 10cm beyond the EUT on all sides;
- The EUT and the capacitive coupling clamp should be at least 0.5m from all other conducting structures, including the test generator and the walls of the room;
- The length of the cable between the coupling device (clamp or CDN) and the EUT must be 1m or less, with any excess in the mains cable coiled (not bundled) in a 0.4m diameter loop – it is best to use a standard 1m test cable for all EUTs, regardless of what they are supplied with;
- The test generator must be bonded to the GRP with a low-inductance connection, such as a short bracket or braid. Any inductance at this point will “lift” the generator output waveform off the GRP and introduce ringing on the signal that appears at the EUT. This also applies to the earth plate of the capacitive clamp, which terminates the high voltage coax cable that comes from the generator. This lead must be connected to the end of the clamp nearest the EUT – although clamps are provided with connectors at either end, you have no choice as to which to use in the actual setup.

The test layout needs some thought to achieve all these requirements together. Any deviation will affect the stray inductance or capacitance in the coupling path, which in turn will cause variations in the applied stress. But, for instance, it can be difficult to ensure a distance of less than 1m for the signal cable between the coupling clamp which must be mounted on the GRP, and a tabletop EUT which must be 80cm above it, if the cable port is on the top of a tall EUT. Such difficulties require a departure from the letter of the standard which must be carefully assessed and recorded.

Burst application

The basic standard specifies that the bursts should be applied for at least one minute in each polarity. Some product standards modify this, for instance to two minutes. The main concern is that bursts should be applied for long enough that any coincidence with sensitive states of the EUT has been explored. The product standards also define to what ports the test must be applied. A common qualification is that ports which are connected to cables that are limited to less than 3m in length, are excluded from the test. There is nothing magic about the 3m figure, but the intention is to acknowledge that short cables are unlikely to couple significant amounts of burst interference in real life. Nevertheless, this puts some responsibility on the manufacturer to decide which ports can sensibly be included in this restriction. Annex A of IEC 61000-4-4 gives some information in this respect.

Figure 14 NSG 3025 - Burst Generator

For on-site use, a handy test generator with autonomous functions is required. And for laboratory use, the generator needs to offer extended functionality for product investigation and automated operation for certification work.

The NSG 3025 satisfies all these requirements from one compact unit.



Surge

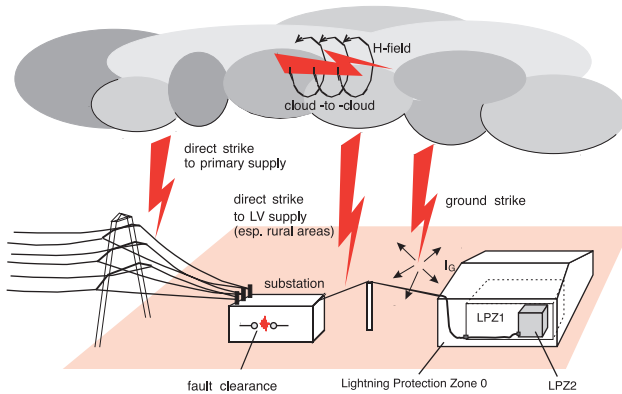
The causes and effects of surges

High energy transients appearing at the ports of electronic equipment are generally a result either of nearby lightning strikes, or are due to major power system disturbances such as fault clearance or capacitor bank switching. Lightning can produce surges with energies of several joules by the following mechanisms (Figure 15):

- direct strike to primary or secondary circuits: the latter can be expected to destroy protective devices and connected equipment; the former will pass through the service transformers either by capacitive or transformer coupling
- indirect cloud-to-ground or cloud-to-cloud strikes create fields which induce voltages in all conductors
- ground current flow I_G from nearby cloud-to-ground discharges couples into the grounding network via common impedance paths, and causes substantial potential differences between different ground points
- primary surge arrester operation or flashover in the internal building wiring causes voltage transients

Lightning protection of buildings and their installations is covered by various standards, including IEC 61024-1:1993, IEC 61312-1:1995 and BS 6651:1992. These standards define hierarchical protection zones within installations, but they admit some level of surges even in the deepest zone, so there is still a need to ensure that individual products can show a degree of immunity from lightning-induced surges.

Figure 15 Surge generation



Fault clearance upstream in the mains supply distribution network produces transients with energy proportional to $0.5 \cdot L \cdot I^2$ trapped in the power system inductance. The energy will depend on the let-through current of the clearance device (fuse or circuit breaker) which can be hundreds of amps in residential or commercial circuits, and higher for some industrial supplies. Power factor correction capacitor switching operations generate damped oscillations at very low frequency (typically kHz) lasting for several hundred microseconds.

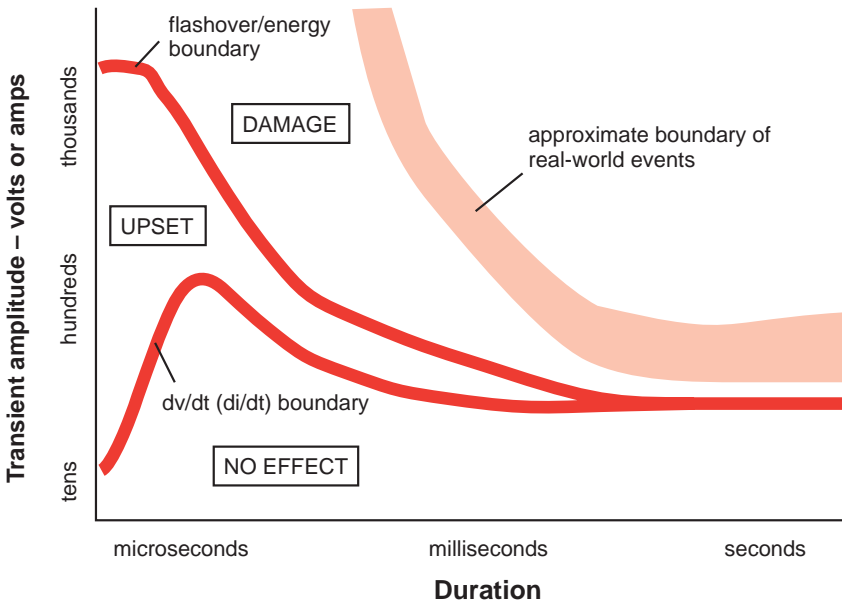
Effect on equipment

Surges impinging on electronic equipment may cause hardware damage and complete failure, or in lesser cases, operational upset. Figure 13 gives an indication of the relationship between surge parameters and these effects.

Below some level dependent on equipment design, no effect is observed. Above this level, a surge may cause the operation of the equipment to change state, without any long-term effect on the circuit components. But at a higher level, there may be enough energy to cause breakdown in critical components. The maximum voltage that is likely to occur is limited by flashover considerations, for instance in a typical domestic mains supply no more than about 6kV can be withstood by the wiring components. The designer has to know what surge voltage can be sustained by the product's interfaces without protection, and what voltage is expected in the protection zone in which the product will be used, in order to decide whether any of these interfaces need additional protection.

Typically, protection involves adding parallel surge suppression devices such as clamping diodes, varistors or spark gaps. The purpose of these devices is to break down in a controlled manner at a voltage lower than can be sustained by the circuit, and dissipate the surge energy within themselves. They must therefore, be sized to withstand the maximum surge energy to be expected in a particular application. The rate-of-change of applied voltage and current also has a bearing on both the susceptibility of a particular interface to upset and on the ability of protection devices to cope with the surge.

Figure 16 Relationships between surge parameters and equipment effects



Standard test waveforms

IEC 61000-4-5 defines the 1.2/50µs V – 8/20µs I combination wave. It also refers to the CCITT (ITU K.17) 10/700µs wave to be applied to telecom ports. IEC 61000-4-12 defines the waveform for the ring wave.

Combination wave

The surge generator called up in the test to IEC 61000-4-5 has a combination of current and voltage waveforms specified, since protective devices in the EUT (or if they are absent, flashover or component breakdown) will inherently switch from high to low impedance as they operate. Thus part of the surge will be delivered into a high impedance and part into a low impedance. The values of the generator's circuit elements are defined so that the generator delivers a 1.2/50µs voltage surge across a high-resistance load (more than 100Ω) and an 8/20µs current surge into a short circuit (Figure 18).

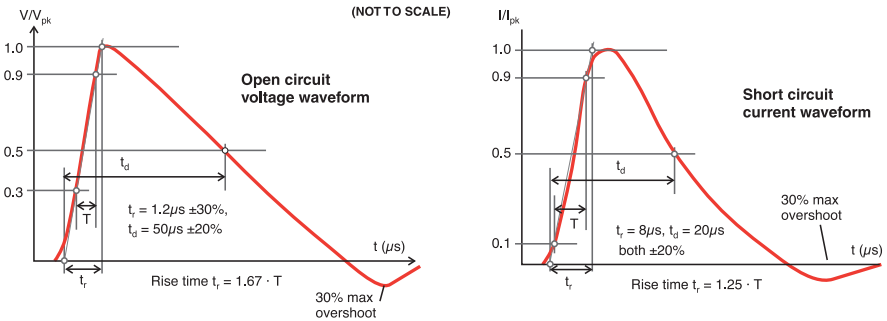
These waveforms must be maintained with a coupling/decoupling network in place, but are not specified with the EUT itself connected, and for coupling devices for signal lines this requirement is waived. Since the surge waveform is specified as both a voltage and current, it has to be calibrated into both an open circuit and a short circuit.

Figure 17 The Schaffner Best Compact Test System

for Burst, ESD, Surge and Transient benchtop compliance testing



Figure 18 The combination surge waveform



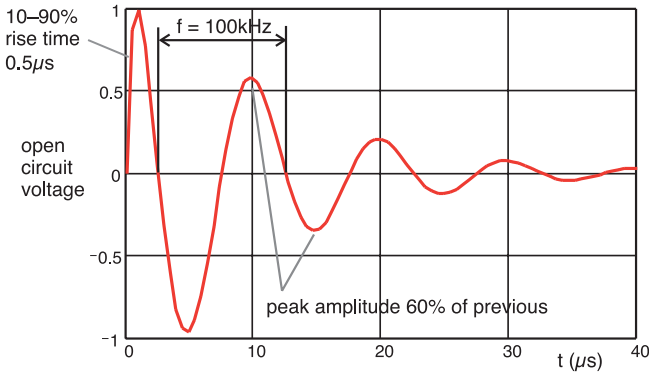
Ring wave

Measurements have shown that most surge voltages in indoor supply systems have oscillatory waveforms. Even if it is unidirectional to start with, an incoming surge excites the natural resonances of the system. The frequency of oscillation can vary between 1–500 kHz and can have different amplitudes and waveforms at various places in the system.

IEC 61000-4-12 defines a "ring wave" with the characteristics shown in Figure 19. It is said to be representative of a wide range of electromagnetic environments of residential and industrial installations. Despite this, it has not found favour with product committees who are responsible for choosing basic standard tests and, as a result, it is not widely applied in product testing.

| Generator output impedance Z | Minimum repetition period | Application |
|------------------------------|---------------------------|--|
| 12Ω | 10s | EUT supply ports connected to major feeders; application between communication ports on cabinets interconnected with 10m long screened data comms cables |
| 30Ω | 6s | EUT supply ports connected to outlets |
| 200Ω | 1s | I/O ports, unless the test involves protection devices or filters, in which case 12Ω or 30Ω is applicable |

Figure 19 The ring wave



Telecom waveforms

For ports connected to telecommunications lines, a further 10/700µs surge is required. The voltage waveform is specified in the same way as for the combination wave above, with a front time of 10µs ±30% and a time to half value of 700µs ±20%.

No current waveform is shown, instead the component values of the waveform generator are provided. The generator has an output resistance of 25Ω which may be provided either internally or by external coupling resistors (see top diagram of Figure 21).

Practical aspects of surge application

Because of the lower frequency spectrum content of the surge waveforms, surge testing is more tolerant of layout variations, and the standards are fairly relaxed in this respect. The cable between the EUT and the coupling/decoupling network should be 2m or less in length (1m for the ring wave). For the combination wave and telecom wave there are no other explicit restrictions on the layout. The ring wave test is best carried out over a ground plane, but even this can be waived for table-top equipment if the earthing connections are well controlled.

Safety

However, you should remember that the surge has a high energy content. The peak voltage that can be applied is 4kV, and the peak current is 2kA. This means that some protective safety measures are at the least advisable and in some cases, essential. If there is any likelihood that the surge voltage could appear on external conductive parts, for instance because the integrity of the earth connection is not assured – or because, as in the test on screened line interfaces, you are applying the surge directly to the enclosure – then personnel must be kept away from the EUT during the test. In any case, the EUT should be disconnected from other equipment where possible and the whole setup should be well insulated to prevent flashover.

Also, high resistances in the path of the surge current will be subject to high dissipation and could overheat with a consequent fire risk. The same applies to surge suppressors within the EUT, which despite the mandatory one-minute cooling-off period may fail catastrophically. Make sure all appropriate connections are tight and capable of taking the expected current, and keep a fire extinguisher handy.

Coupling

For coupling to the mains supply of the combination wave, the generator is connected directly via a 18 μ F capacitor across each phase, but through a 10 ohm resistor and 9 μ F capacitor for phase-to-earth application (Figure 16). This means that the highest energy available from the generator's effective source impedance of 2 ohms is actually only applied between phases. The signal line coupling networks include a 40 ohm series resistor, which reduces the energy in the applied surge substantially.

Coupling to signal lines (Figure 21) has to be invasive; no clamp-type devices are available for this test. It is permissible to use gas discharge tube coupling for signal lines to maintain bandwidth. A separate method is used for shielded lines, in which the surge is effectively applied longitudinally along the shield, by coupling it directly to the EUT at one end of a non-inductively bundled 20m length of cable, with the further end grounded.

Figure 20 Surge coupling to supply lines

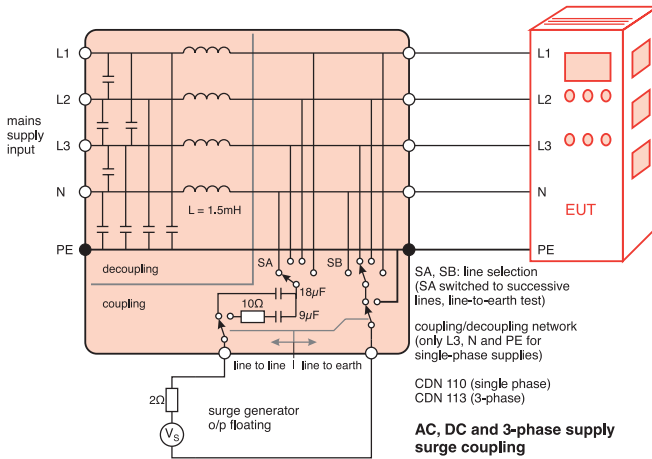
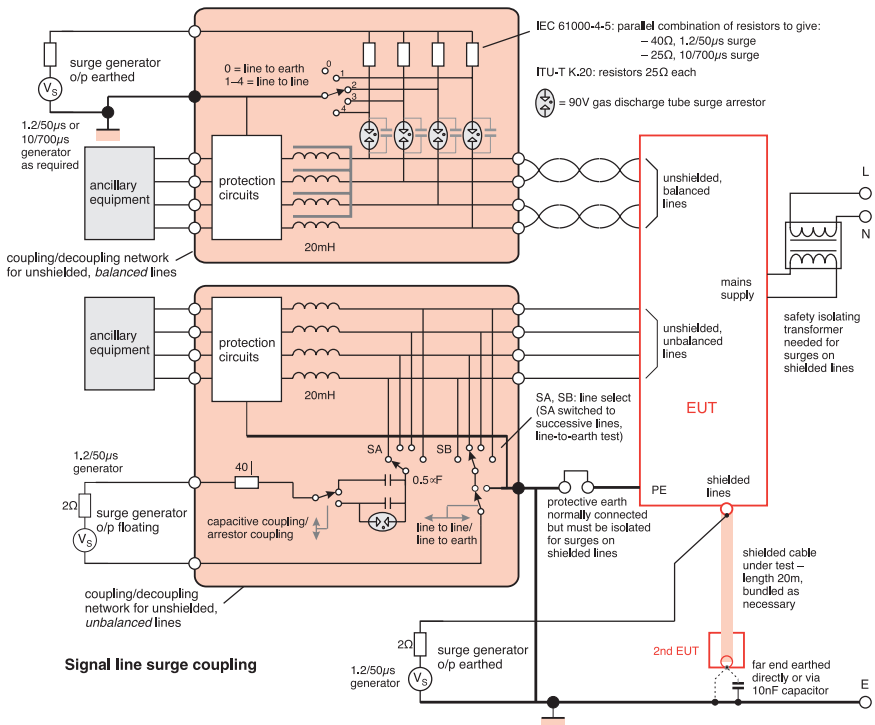


Figure 21 Surge coupling to signal lines

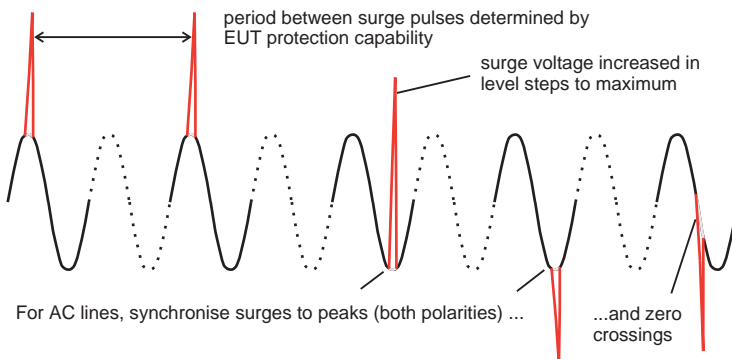


Procedure

The test procedure requires the following steps, bearing in mind that an agreed test plan may modify them:

- Apply at least five positive and five negative surges at each coupling point, but preferably a sufficient number of pulses to find all critical points of the duty cycle of the equipment
- Wait for at least a minute between applying each surge, to allow time for any protection devices to recover
- Apply the surges line to line (three combinations for 3-phase delta, six for 3-phase star, one for single phase) and line to earth (two combinations for single phase, three for 3-phase delta, four for 3-phase star)
- Synchronise the surges to the zero crossings and the positive and negative peaks of the mains supply (four phase values)
- Increase the test voltage in steps up to the specified maximum level, so that all lower test levels are satisfied – the step size being generally interpreted as a level at a time, rather than a fixed voltage step such as 500V

Figure 22 Surge application



A worst case interpretation of the requirements on a three-phase star supply being tested up to level 4 would imply that a single complete test would take nearly 27 hours, not allowing for setup and test sequencing time.

The rationale for “all lower levels must be satisfied” is that the behaviour of many types of surge suppression is likely to vary between low and high values of surge voltage. A suppressor that would break down and limit the applied voltage when faced with a high level, may not do so at lower voltages, or may at least behave differently. The worst case could well be at just below the breakdown voltage of an installed suppression device. Equally, the EUT response can change either because of circuit operation or because of suppressor behaviour when the surge occurs at varying times during the mains cycle. For example, an unfiltered circuit that looks for zero crossings will have an undesired response when a negative-going surge occurs at the positive peak of the cycle. Unless you are very confident of your EUT’s performance in these various conditions, pre-compliance testing over as wide a range of variables as possible is advisable.

Figure 23 The Schaffner System 2050 - A complete conducted immunity test system

System 2050 is a highly versatile, modular, multi-role EMC test facility adaptable to meet a wide variety of test specifications. System 2050 offers a complete set of plug-in networks for full compliance testing to basic, generic and product standards, for single-phase and three-phase power lines as well as data and telecom lines. As needs grow and change, System 2050 can be extended accordingly, thereby protecting investment.

FCC pt 68 upgrade

A single plug-in unit generates all five surge pulses required by FCC pt 68.

For more detailed product characterization, settings can be modified via the front panel keypad and display or via WIN 2050 software.



Reference Material - Generic & Product Standard Requirements



| Standard | Scope | | DOW* | ESD | EFT | Surges |
|----------------------------|---|---------------------|----------------|--|---|---|
| EN 50082-1: 1992 | Residential, commercial & light industrial generic | | N/A | 8kV air discharge, to IEC 801-2: 1984 | 1kV AC power, 0.5kV DC power, signal and control > 3m to IEC 801-4: 1988 | Not required (informative annex only) |
| EN 50082-1: 1997 | | | 1st July 2001 | 4kV contact, 8kV air to EN 61000-4-2 | 1kV AC power, 0.5kV DC power > 10m, signal and functional earth > 3m to EN 61000-4-4 | 1kV L-L, 2kV L-E on AC power input; 0.5kV L-L & LE DC power > 10m, to EN 61000-4-5 |
| EN 50082-2: 1995 | Industrial generic | | N/A | 4kV contact, 8kV air to EN 61000-4-2 | 2kV AC & DC power and PMC, 1kV other signal >3m to EN 61000-4-4 | Not required (informative annex only) |
| EN 61000-6-2: 1999 | | | 1st April 2002 | 4kV contact, 8kV air to IEC 61000-4-2 | 2kV AC & DC power, 1kV signal and functional earth >3m to IEC 61000-4-4 | 1kV L-L, 2kV L-E on AC power; 0.5kV L-L & L-E DC power > 10m; 1kV L-E signal > 30m, to IEC 61000-4-5 |
| EN 55014-2: 1997 | Household appliances etc. | | 1st Jan 2001 | 4kV contact, 8kV air to EN 61000-4-2 | 1kV AC power, 0.5kV DC power, signal and control > 3m to EN 61000-4-4 | 1kV L-L, 2kV L-E on AC mains, to EN 61000-4-5 |
| EN 55020: 1994 + A12: 1999 | Broadcast receivers etc. | | 1st Aug 2002 | 4kV contact, 8kV air to EN 61000-4-2 | 1kV AC power to EN 61000-4-4 | Not required |
| EN 55024: 1998 | Information technology equipment | | 1st July 2001 | 4kV contact, 8kV air to IEC 61000-4-2 | 1kV AC power, 0.5kV DC power, signal and telecom > 3m to IEC 61000-4-4 | 1kV L-L, 2kV L-E on AC mains, 0.5kV L-E on DC power with outdoor cables, to IEC 61000-4-5; 1.5kV 10/700µs on signal/telecom ports with outdoor cables, to ITU-T K recs. |
| EN 50130-4: 1995 | Fire, intruder and social alarm systems | | 1st Jan 2001 | 6kV contact, 8kV air to IEC 801-2:1991 | 2kV AC mains supply, 1kV other supply/signal lines to IEC 61000-4-4 | 1kV L-L, 2kV L-E on AC mains supply; 1kV L-E other supply/signal lines, to IEC 61000-4-5 |
| EN 61326: 1997 | Measurement, control and lab equipment, min. requirements | | 1st July 2001 | 4kV contact, 4kV air to IEC 61000-4-2 | 1kV AC & DC power, 0.5kV I/O signal/control >3m to IEC 61000-4-4 | 0.5kV power L-L, 1kV power & long distance I/O signal/control L-E to IEC 61000-4-5 |
| EN 61547: 1995 | General lighting equipment | | 1st July 1996 | 4kV contact, 8kV air to IEC 61000-4-2 | 1kV AC power, 0.5kV DC power, signal and control > 3m to IEC 61000-4-4 | 0.5kV L-L, 1kV L-E on AC power, to IEC 61000-4-5 |
| EN 300386-2: 1997 | Telecom network equipment, immunity only | Telecom centres | 30th Sept 2001 | 4kV contact, 4kV air to EN 61000-4-2 | 1kV AC power, 0.5kV DC power, outdoor signal and indoor signal > 3m to EN 61000-4-4 | 0.5kV L-L, 1kV L-E on AC power; 0.5kV L-E indoor signal > 10m, to EN 61000-4-5; 1kV 10/700µs on outdoor signal lines, to EN 61000-4-5 |
| | | Not telecom centres | | 6kV contact, 8kV air to EN 61000-4-2 | 1kV AC power and DC power > 3m, 0.5kV outdoor signal and indoor signal > 3m to EN 61000-4-4 | 1kV L-L, 2kV L-E on AC power; 0.5kV L-E indoor signal > 10m, to EN 61000-4-5; 1kV 10/700µs on outdoor signal lines, to EN 61000-4-5 |

* DOW = date of withdrawal (or, "date of cessation of presumption of conformity") of the superseded standard
L-L = line to line; L-E = line to earth; PMC = process, measurement and control ports
Always check the appropriate standard for detailed applicability

Equations

Except for ESD, these equations for the waveshape of the quoted transient waveforms are derived from IEEE C62.41:1991.

ESD current waveform (4kV indicated voltage, t in ns)

$$I(t) = 25.5 \cdot \left[\left(\exp\left(\frac{-t}{3.5}\right) - \exp\left(\frac{-t}{0.7}\right) \right) + 156 \cdot \left(\exp\left(\frac{-t}{28}\right) - \exp\left(\frac{-t}{15.5}\right) \right) \right]$$

Surge voltage 1.2/50µs waveform (t in µs)

$$V(t) = 1037 \cdot V_p \cdot \left(1 - \exp\left(\frac{-t}{0.407}\right) \right) \cdot \exp\left(\frac{-t}{68.22}\right)$$

EFT 5/50ns waveform (t in ns)

$$V(t) = 127 \cdot V_p \cdot \left(1 - \exp\left(\frac{-t}{3.5}\right) \right) \cdot \exp\left(\frac{-t}{55.6}\right)$$

0.5µs/100kHz ring waveform (t in µs, $\omega = 2\pi \cdot 10^5$ rad/s)

$$V(t) = 159 \cdot V_p \cdot \left(1 - \exp\left(\frac{-t}{0.533}\right) \right) \cdot \exp\left(\frac{-t}{9.788}\right) \cdot \cos(\omega t)$$

Surge and transient energy

The energy content of transients and surges is not simple to define. Not all the actual energy stored in the test generator is dissipated in the load. That proportion which is, depends on the ratio of the load and generator impedances. In general, a load such as a surge suppressor will be non-linear and will also have a time or frequency dependence.

The "energy measure" of a given waveform can be described by

$$S = \int_0^T V^2(t) dt$$

which gives the energy that would be delivered by that voltage waveform into a 1Ω resistor, whether or not the generator is capable of this (i.e., assuming zero output impedance). These figures are shown in the right-hand graph of Figure 24.

Alternatively, the actual energy delivered by the generator into a defined resistive load can be calculated. For the ESD and EFT waveforms, these can be the calibration loads of 2Ω and 50Ω respectively. For the surge and ring waves, a load which matches the output impedance can be chosen, and the voltage or current waveform is delivered into this resistance with half the open circuit (or short circuit, for current) amplitude – although this simplifying assumption does not occur in practice as the current and voltage waveforms vary depending on the load impedance.

In these cases, the energy in Joules (watt seconds) is shown in the left-hand graph of Figure 24 and is given by

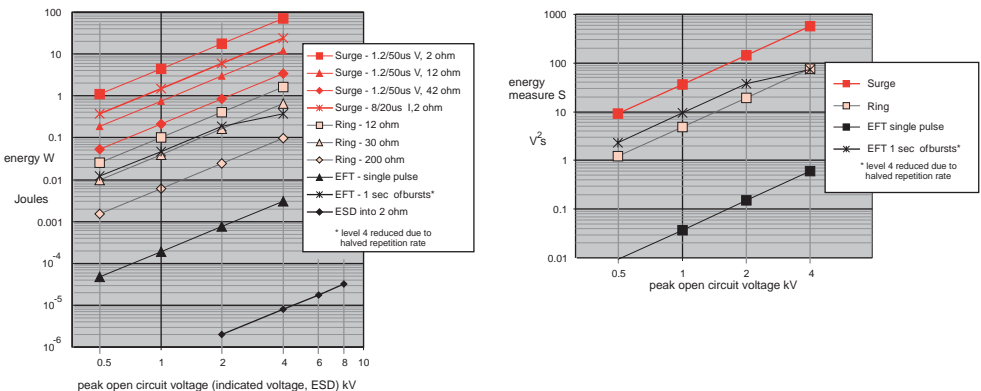
$$W = \frac{1}{R} \cdot \int_0^T \left(\frac{V(t)}{2} \right)^2 dt \qquad W = R \cdot \int_0^T \left(\frac{I(t)}{2} \right)^2 dt$$

where $V(t)$ and $I(t)$ are the open circuit voltage and short circuit current waveforms, respectively.

These graphs are for comparative purposes only – the real energy delivered to a particular EUT can only be calculated if the load impedance and characteristics, and the actual waveshape applied to this load, are known accurately.

The symbols on the graphs represent test levels 1 to 4 as defined in each standard.

Figure 24 Transient energy content



References

IEC 61000-4-2 Ed. 1 + A1 + A2: Electromagnetic compatibility (EMC) - Part 4: Testing and measurement techniques - Section 2: Electrostatic discharge immunity test. Basic EMC Publication

IEC 61000-4-4 Ed. 1.0: Electromagnetic compatibility (EMC) - Part 4: Testing and measurement techniques - Section 4: Electrical fast transient/burst immunity test. Basic EMC Publication

IEC 61000-4-5 Ed. 1.0: Electromagnetic compatibility (EMC) - Part 4: Testing and measurement techniques - Section 5: Surge immunity test

IEC 61000-4-12 Ed. 1.0: Electromagnetic compatibility (EMC) - Part 4: Testing and measurement techniques - Section 12: Oscillatory waves immunity test. Basic EMC Publication

IEEE C62.41-1991: IEEE Recommended Practice on Surge Voltages in Low-Voltage AC Power Circuits

ITU-T Recommendation K.17 (1993): Tests on Power-Fed Repeaters using Solid-State Devices in order to check the Arrangements for Protection from External Interference

Index

| Section headings | Page Number |
|--|-------------|
| Introduction | 1 |
| Electrostatic discharge | 3 |
| The discharge event | 3 |
| The IEC 61000-4-2 standard test method and generator | 6 |
| Practical aspects of testing | 7 |
| Electrical fast transient bursts | 13 |
| Source and effect of transients | 13 |
| The IEC 61000-4-4 standard test method and generator | 15 |
| Practical aspects of testing | 19 |
| Surge | 22 |
| The causes and effects of surges | 22 |
| Standard test waveforms | 25 |
| Practical aspects of surge application | 27 |
| Reference material | 32 |
| Generic and product standard requirements | 32 |
| Equations | 33 |
| Surge and transient energy | 33 |
| References | 35 |
| Index | 37 |

Index

| Figures & Tables | Page Number |
|--|--------------------|
| Figure 1 The typical personnel discharge scenario | 4 |
| Figure 2 Mechanism of secondary discharge | 5 |
| Figure 3 The Schaffner NSG 435 ESD generator | 6 |
| Figure 4 The ESD generator circuit and waveform | 7 |
| Figure 5 ESD test layout | 8 |
| Figure 6 Charging of ungrounded EUTs | 10 |
| Figure 7 The Schaffner NSG 438 30kV ESD Gun | 12 |
| Figure 8 Transient burst generation | 13 |
| Figure 9 Test setup for mains port | 15 |
| Figure 10 Test setup for signal ports | 16 |
| Figure 11 The Schaffner CDN 8014 Coupling Clamp | 17 |
| Figure 12 The burst specification | 18 |
| Figure 13 Coupling the burst through the CDN | 19 |
| Figure 14 The Schaffner NSG 3025 Burst Generator | 21 |
| Figure 15 Surge generation | 23 |
| Figure 16 Relationships between surge parameters and equipment effects | 24 |
| Figure 17 The Schaffner BEST Compact Test System | 25 |
| Figure 18 The combination surge waveform | 26 |
| Figure 19 The ring wave | 27 |
| Figure 20 Surge coupling to supply lines | 29 |
| Figure 21 Surge coupling to signal lines | 29 |
| Figure 22 Surge application | 30 |
| Figure 23 The Schaffner System 2050 Immunity Test System | 31 |
| Figure 24 Transient energy content | 34 |

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