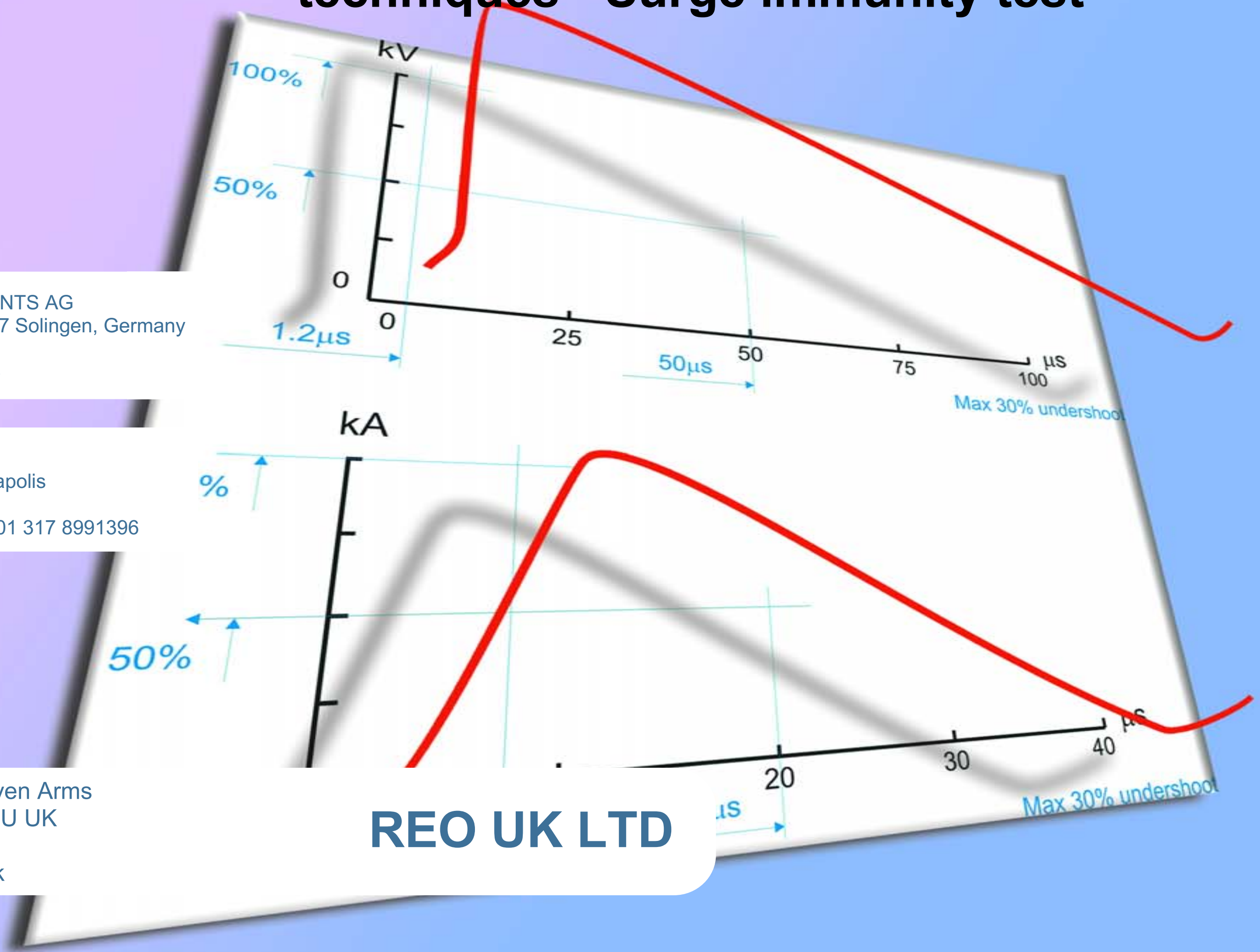
Handbook on EN 61000-4-5

Testing and measurement techniques - Surge immunity test



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Contents

Surges and compliance with the EMC Directive

The basic immunity test method for 'surges' is IEC 61000-4-5:1995 [1]. This has been adopted as the harmonised European standard EN 61000-4-5:1995 [2], which is often called up as a basic test method by immunity standards listed under the Electromagnetic Compatibility (EMC) Directive [3].

Unlike many EMC tests, 'do-it-yourself' surge testing is easy and low cost; because it uses low frequencies and does not need a special test environment. But please note that safety precautions are *always* required with this test.

Since surges in the mains supply voltage are commonplace, and since they can interfere with every kind of electrical and electronic device, equipment or systems (called products in the rest of this handbook) that operates from the electrical mains supply or is connected to long cables or to other equipment, it makes good sense to test products to ensure they will work as intended in their intended operating environment. This is especially important in safety-related, high-reliability, mission-critical, or legal metrology electronic applications.

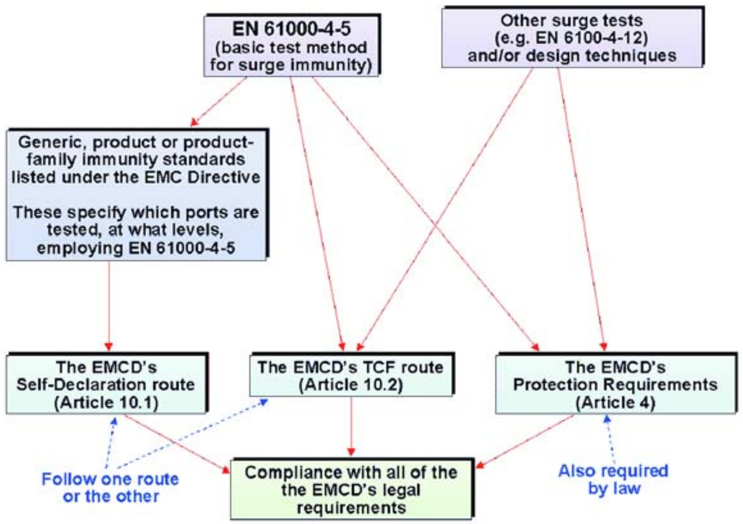
EN 61000-4-5 is a basic test standard, so when following the self-declaration to standards route to conformity (Article 10.1 in [3]), EN 61000-4-5 should *not* be listed on the EMC Declaration of Conformity. Only the relevant generic or product-family harmonised EMC standards should be listed. These will usually call-up EN/IEC 61000-4-5 as a test *method*, but it is always the generic or product-family standard that sets the minimum surge test *levels* which allow conformity to be claimed.

When using the Technical Construction File route to conformity with the EMC directive (Article 10.2 in [3]) it is possible to use EN/IEC 61000-4-5 directly, in which case it *should* be listed on the product's EMC Declaration of Conformity. In such cases the product manufacturer should assess the electromagnetic environment of the product and ensure that it is designed and/or tested accordingly, so as to comply with the EMC Directive's essential 'Protection Requirements' (Article 4 of [3]).

The surge tests required by the immunity standards listed under the EMC Directive are usually just a subset of the surge tests described in EN 61000-4-5 itself. But there may be significant financial benefits in going beyond simple compliance with the *minimum* requirements for Self-Declaration to the EMC Directive – applying all of the surge tests in EN 61000-4-5 can help comply with the EMC Directive's Protection Requirements. Compliance with the EMC Protection Requirements is a legal requirement that applies *in addition* to the requirement to follow one of the conformity assessment routes (Self-Declaration, Article 10.1 or TCF, Article 10.2). Products that pass tests to all relevant immunity standards listed under the EMC Directive, but nevertheless fail in normal use because they are not immune enough, do not comply with the EMC Directives Protection Requirements and are therefore illegally CE marked.

Applying *all* of the tests in EN 61000-4-5 can also be a way to help make products more reliable, reduce warranty costs, improve customer satisfaction and reduce exposure to product liability claims – for more on this refer to the section on "Surge testing and real-life reliability" later on.

Relationship between EN 61000-4-5 and the EMC Directive (EMCD)



This series of handbooks is concerned with testing to the EN standards for typical domestic, commercial, light industrial and industrial environments. But other kinds of immunity tests may be required by the EMC standards for automotive, aerospace, rail, marine and military environments. In particular, the conducted transients and surges in an automotive environment (internal combustion engine with spark ignition, driving an alternator which charges a battery) are very different indeed from those typical of a building connected to a 230/400V mains power supply, as shown by ISO 7637 [4], for example. These industries have developed their own test standards based on their own particular kinds of disturbances, to improve reliability.

This handbook describes how to apply EN 61000-4-5:1995, and applies equally well to IEC 61000-4-5:1995. 2001 versions of these two standards exist, but the only changes from the 1995 versions concern the requirements for test reports and climatic conditions. Since many national tests outside the EU are based on IEC standards, this handbook may be of use where non-EU EMC specifications apply.

Where an electronic product has a safety-related or legal metrology function, requires high reliability, or is mission-critical – mere compliance with the EMC Directive is often insufficient for ensuring that it has been designed correctly – additional and/or tougher immunity requirements may need to be applied. Refer to the IEE's guide [5] and the on-line article [6] for more on this topic.

Important Safety Note: Surge tests are dangerous, and all appropriate safety precautions must be taken. If you aren't *sure* what safety precautions are needed, ask an expert.

What are surges?

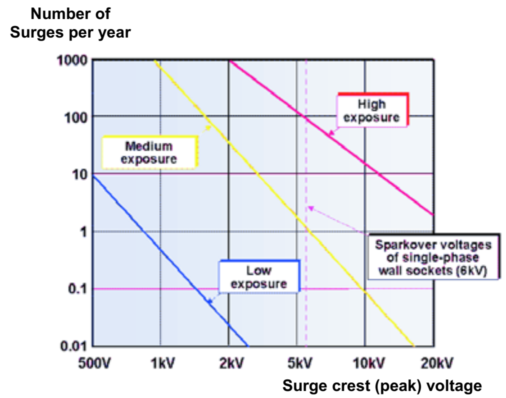
The word 'surge' is often used by power generation and distribution engineers to mean a temporary increase in the AC mains supply voltage, but this is not its meaning in the EMC community. Here, it means a transient overvoltage with a rise time measured in µs (microseconds) or ns (nanoseconds) and a duration lasting for up to several hundred µs. Surges are often measured in kV (kilovolts).

In EMC terms, a surge is a 'slow transient' with a frequency spectrum that usually has little content above 10MHz. Because surges are so slow, their coupling is usually considered to occur due to stray mutual inductances (e.g. as 'crosstalk') or common-impedances.

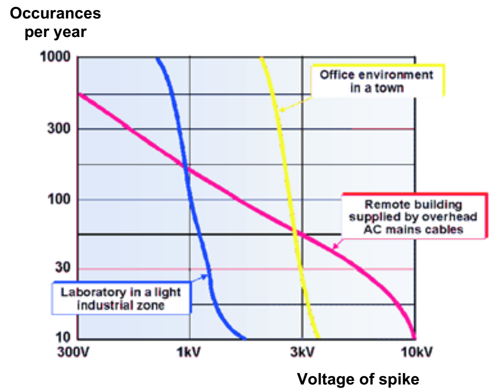
('Fast transient bursts' and 'electrostatic discharge' (ESD) are also typically measured in kV, but are faster transient overvoltages with higher frequency content. These are assumed to couple by both stray capacitance and inductance crosstalk, common-impedances and radiated electromagnetic fields.)

Surges obey a statistical distribution, with low level surges occurring much more frequently than high-level ones.

Power line surge exposure chart (from IEEE C62-41:1991)



"How many times will the mains attack your data" **from "A Hostile World for Computers", by Diane Palframan Manufacturing Systems magazine, August 1989**



How are surges caused?

Surges are created by switching events and insulation faults in AC power distribution networks (LV, MV and HV) and also by the switching of reactive loads such as electric motors or power factor capacitor banks. These surges are essentially caused by the sudden release of the energy stored in the system, and in the case of power distribution this energy is stored in the self-inductance of its long supply lines.

When an insulation fault occurs, for a short time the current in the power distribution network is much higher than usual. So when a protective device such as a fuse or circuit breaker opens, the flyback due to the network's inductance can be quite large.

Surges are also created by lighting. EN 61000-4-5 (and EN 61000-4-12, see later) only address the indirect effects of lightning – due to the induction of voltages and currents or 'earth-lift' (ground lift) due to finite impedance in the protective earthing (grounding) structure that is carrying lightning-related currents. Induction can be directly from the lighting 'bolt' itself, or from cables and other metallic structures carrying lightning-related currents.

Superconducting magnets, such as used in MRI scanners, store a great deal of energy which is released as a very large surge (comparable to, or even greater than a direct lightning strike) if/when their field collapses suddenly due to a loss of superconductivity.

Some sources of surges

What problems are caused by surges?

Surges are high voltage and contain a significant amount of energy, so the main problems caused by surges are electrical, and/or thermal, and/or energy overstress. These overstresses can cause actual damage to electronic devices and their interconnecting cables, connectors and printed circuit board (PCB) traces. Clearly, a surge of some kV can damage a component that is only rated for 100V (e.g. a capacitor or rectifier), and some modern ICs can be destroyed by as little as 10V on any of their pins.

And although in the EMC community we think of surges as slow events, they are fast enough to vaporise the iron wire in a high-power wirewound resistor before the heat in the wire has time to dissipate in its ceramic body. The author has seen wirewound resistors in the popular aluminium clad style with their terminals blown out due to the internal pressure of the iron gas during a surge test. Surge-rated resistors are available, and for the best surge-withstanding performance they don't use resistance wire.

Damage caused by surges is often visible as a scorch mark, or by a visible flash or spark during the test. Thin PCB traces can be burnt or blown right off the board, as can semiconductors and ICs. Burnt insulation (e.g. PCB substrate) can 'leak' and can cause subtle functional problems.

It is possible for low voltage surges to cause more damage than ones with a higher voltage. Gas-discharge type surge protection devices (and the spark gaps created naturally by proximity to earthed metalwork) only 'spark-over' when the voltage exceeds the breakdown voltage of the gas in the tube (or the air). Once they have sparked-over the low-impedance of their arc channel attenuates the surge so that the following circuitry sees a reduced surge voltage level. Surges which are below the trigger voltage are not clamped by the arc-channel so are applied to the electronic circuitry un-attenuated, possibly causing more damage than higher voltage surges.

Insulation can be damaged by repetitive surges, so that it breaks down over time. This is why all the insulation used for AC power conductors, connectors, transformers and PCB traces must satisfy specified overvoltage tests for a product to comply with electrical safety requirements under the LVD, Machinery, or other safety directives.

It is possible for surges to cause an upset in a digital signal, leading to erroneous data bits or lost data, and they can also cause errors in analogue signals. But the fast transients and ESD events cause much greater problems because their higher frequency content means that they couple more strongly, and products that pass tests to these types of EM disturbances usually have no problems with signal upsets due to surges.

Important Safety Note: If you must watch or be in the same room as a surge test you *must* be protected from the possibility of exploding pieces of metal, plastic or ceramic, some of which can be red hot. Acrylic or polycarbonate sheet of suitable thickness is usually recommended as a protection where visibility is required. EN 61000-4-5 does not specify safety requirements, so obtain appropriate safety guidance.

Surge testing and real-life reliability

The basic surge test methods do not necessarily simulate real-world EM disturbances very well. To ensure repeatability they use very carefully specified waveforms, but these might simply reflect what it is possible to generate in a cost-effective laboratory instrument rather than be a true representation of the surge waveforms that could occur in real life.

It is true to say that a product that meets these surge standards will generally be more reliable (all things being equal) than one which has been designed with little or no thought to surviving their tests. But meeting these surge standards cannot *guarantee* freedom from errors or failure in the field due to surges.

For example, surge testing using EN 61000-4-5 is called up by the generic standards and most of the other immunity standards listed under the EMC Directive, usually at the level of ±1kV for line-to-line surges and ±2kV for line-to-ground on the AC power supply. But it is well known (and recognised by lightning protection standards) that in Europe and the USA (at least) the AC mains supplies in typical urban buildings will suffer from surges of about 6kV about three times per year. This is caused by normal thunderstorm activity in the local area, not direct strikes, and applies to buildings which do not have lightning protection systems designed to protect electronics (e.g. BS 6651 Appendix C).

Buildings whose AC power supply is carried by overhead wires can reckon on experiencing many tens or even hundreds of 6kV surges every year, depending on the length of their overhead power line and the local geography, tree cover, climate and other factors.

The figure of 6kV arises because the typical domestic-style mains sockets flash-over at their rear connections at around this voltage and so act like spark-gap suppressers. In industrial premises mains distribution using three-phase supplies fitted only with the larger three-phase mains sockets might suffer from line-to-ground surges of well over 6kV due to the increased flash-over voltage of these sockets. It is ironic that in buildings whose mains wiring has poor quality insulation, the maximum surge voltages can be much smaller – due to the accidental spark-gaps (which are also fire hazards) created by the poor quality wiring.

The author knows of a power supply module widely used in Europe that suffered from an excessive failure rate. This was due to the fact that the creepage and clearance distances between the track to the gate of a switching power FET and the earthed chassis were inadequate at over 5kV (when testing with the EN 61000-4-5 waveshape). These modules would clearly pass all the immunity standards listed under the EMC directive, but were almost certain to fail at least once per year in typical indoor urban environments in Europe and the USA.

There are many kinds of surges – such as those caused by fuse-blowing, the direct effects of lightning, or field collapse in very large inductive loads or superconducting magnets – that are not covered by any of the immunity standards listed under the EMC Directive, or by any of the basic standards they call up.

Where large reactive loads are switched, the stored energy they contain can transfer large amounts of surge energy to their AC or DC power supplies during the arcing of their switches, relays, or contactors as they open. This is another example where the standard surge tests and their generators might not represent the surges that a product is exposed to in real life.

Surges due to inductive load collapse may be a lot faster than lightning induced surges, and may also have more energy in them. Where such loads may be connected to the same branch of the mains distribution and no special surge protection is applied by the installation, testing with a representative surge generator may help improve reliability in the field and reduce warranty claims. In the case of a motor, the rotational inertia of its load may be important where the motor is capable of significant generation efficiency when not energised from its normal supply.

An extreme example of a problem load is the superconducting magnets used in MRI scanners. These can take several weeks to charge up from kA rated power supplies, and when their field collapses they can put surges of around 1MJ back into their supplies, and any other conductors they can arc across to, in just a few microseconds. This is approximately 10,000 times larger than the energy in an EN 61000-4-5 mains surge test at 1kV, and capable of destroying structural metalwork rather like a direct lightning strike. MRI scanner manufacturers almost certainly take whatever steps are necessary to absorb these surges, if only to protect the electronics in their own product.

Standards which test for more extreme surge events than are covered by EN standards do exist in the telecommunication, aerospace, military and some other industries. They can be called upon when it is required to demonstrate that a product's design protects it from such surges. Designing for protection from real-life surges is very helpful in reducing warranty claims and field service.

The financial rewards of producing reliable products can be very great indeed, as one UK manufacturer discovered when they spent £100,000 on redesigning their products to comply with the improved immunity standards required for many products by the EMC Directive from mid-2001, and as a direct result their warranty costs fell by £2.7 million per year.

Another surge standard: IEC 61000-4-12

IEC 61000-4-5 describes how to test with what is known as a uni-directional surge. But IEC 61000-4-12 describes testing with bi-directional surges, called 'ring wave' and 'damped oscillatory wave'. IEC 61000-4-12 states:

"The ring wave is a typical oscillatory transient, induced in low-voltage cables due to the switching of electrical networks and reactive loads, faults and insulation breakdown of power supply circuits or lightning. It is, in fact, the most diffused phenomenon occurring in power supply (HV, MV, LV) networks as well as in control and signal lines."

"The ring wave is representative of a wide range of electromagnetic environments of residential, as well as industrial installations; it is suitable for checking the immunity of equipment in respect of the above-mentioned phenomena which give rise to pulses characterised by sharp front-waves that, in the absence of filtering actions, are in the order of 10ns to a fraction of µs; the duration may range from 10µs to 100µs."

"The resultant phenomenon at the equipment ports, representative of most actual situations, as the result of investigations in different types of installations, is an oscillatory transient with a defined 0.5µs rise time and 100kHz oscillation frequency."

"The test with the ring wave simulates single-shot transients with a low occurrence and repetition rate; this test has, therefore, the capability to verify the performances of the interfaces of the EUT ports with the environment, but limited capability to detect interference of the equipment."

The ring wave test is considered to apply more stress to the product being tested than the same level of test using EN 61000-4-5. For the damped oscillatory wave, IEC 61000-4-12 states:

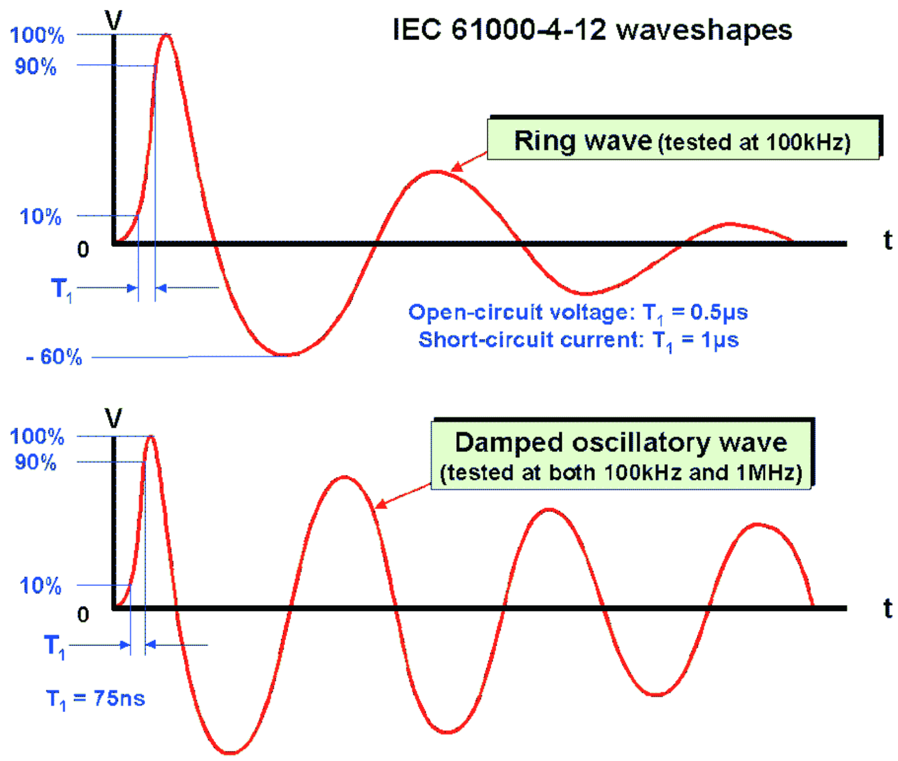
"This phenomenon is representative of switching of isolators in HV/MV open-air stations, and is particularly related to the switching of HV busbars, as well as of background disturbance in industrial plants."

"In industrial plants, repetitive oscillatory transients may be generated by switching transients and the injection of impulsive currents in power systems (networks and electrical equipment)."

"The test with the damped oscillatory wave simulates, with a high margin for the industrial environment, repetitive oscillatory transients; it makes easier the detection of interference of the EUT in different and specific operating conditions. This test should therefore be preferred in appropriate cases (equipment of HV plants), or whenever high priority is given to the reliability of the equipment concerned."

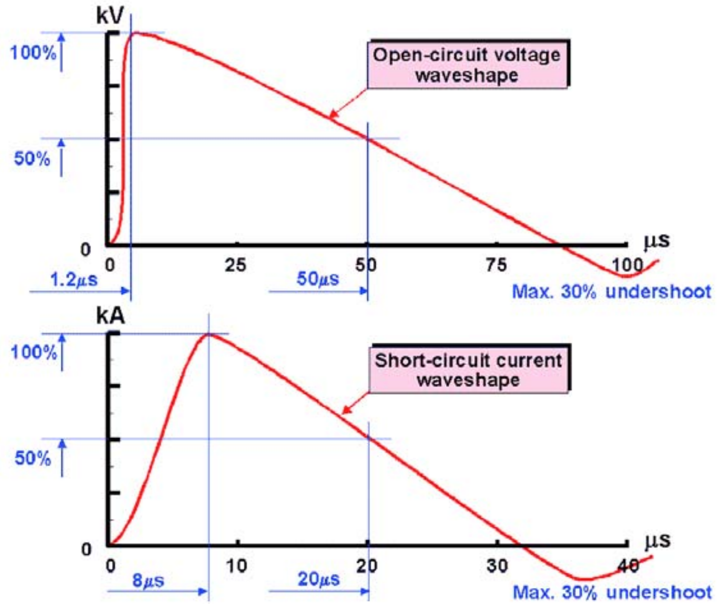
Despite the above, IEC 61000-4-12 is not (as far as the author is aware) yet called up by any of the immunity standards that have been listed (notified) under the EMC Directive. As a result, few manufacturers bother to test their products with the ring wave and/or the damped oscillatory wave.

This lack might leave them exposed to non-compliance with the EMC Directive's Protection Requirements, but – much worse than this – it might leave them exposed to the high costs of an unreliable product (warranty costs plus loss of customer confidence), or even product liability claims.



This section of the handbook is based upon Chapter 4 of [7].

EN 61000-4-5 surge waveshapes: V and I



The standard waveform for the EN 61000-4-5 surge test is a single uni-directional impulse specified by two waveforms at the same time: as a 1.2/50µs voltage impulse into an open-circuit, and as a 8/20µs impulse into a short-circuit – leading to its common name: the 'combination wave'.

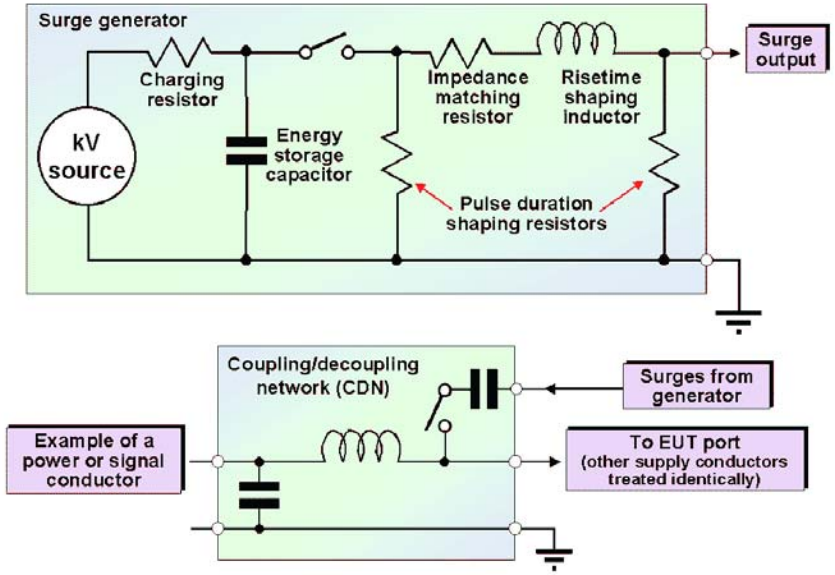
The standard surge waveform for testing telecommunication cables (that exit a building) has a broadly similar shape, with a 10µs rise time and 700µs fall time. When testing AC mains ports the surges are applied (as a positive or negative voltages) at all the zero-crossings and the peaks in a cycle of mains waveform. Time is allowed between each impulse to avoid overheating surge protection devices (SPDs).

The standard describes the basic scheme of a surge waveform generator and the standard test set-up.

Anyone wishing to perform a surge test should have a copy of the relevant issue of the basic test standard EN 61000-4-5, and follow it as closely as they need to for the test accuracy they require.

The frequency spectrum of the surge test is much lower than that in the FTB or ESD tests, and so the test set-up does not need a reference *plane* (of course it requires an earth, but ordinary wired earth connections will do.) But be aware that the surge current can reach kilo-amps, so the wiring between the generator and the equipment under test must be robust.

Basic schemes: EN 61000-4-5 generator and coupling network

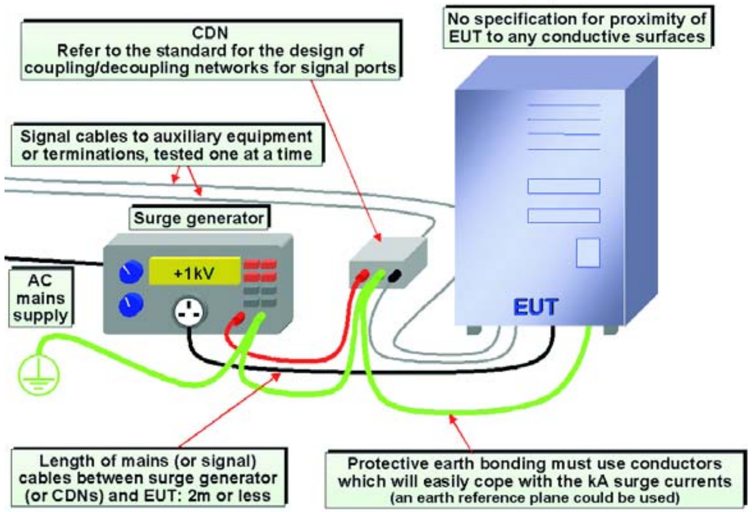


Important Safety Note: The instantaneous power and total energy in an EN 61000-4-5 surge test can be quite large – enough to cause electronic devices to explode and eject burning fragments with considerable violence. For this reason surge tests should only be carried out where third parties are positively excluded, and the entire bodies of all operators and others witnessing the tests should be protected at least by a substantial acrylic or other plastic sheet. Fire extinguishers suitable for electrical fires should also be kept charged and handy, and the location of the mains isolator for the whole test area and EUT should be known and it should be readily accessible.

Because of the lower frequency spectrum content of the surge waveform, surge testing is more tolerant of layout variations than the other tests discussed in this article, and the standard is fairly relaxed in this respect. The cable between the EUT and the coupling/decoupling network should be 2m or less in length. Otherwise there are no restrictions on the layout.

The specified surge waveforms should appear at the output of a compliant generator when it is calibrated with an open circuit, and with a short circuit load. The waveform through the mains coupling/decoupling network must also be calibrated and be unaffected by the network, but for coupling devices for signal lines this requirement is waived.

The basic EN 61000-4-5 test set-up



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

Coupling to signal lines can be problematic since it has to be invasive; no clamp-type devices are available for this test. However for signal lines that would be affected by a 0.5μF capacitor connected to them, it is permissible to use a surge coupling scheme which employs a gas discharge tube (surge arrestor) to isolate the signal from the 0.5μF capacitor.

The standard describes another method for shielded (screened) cables, in which the surge is effectively applied longitudinally along the shield, by coupling it directly to the EUT as an 'earth-lift' surge at one end of a non-inductively bundled 20m length of cable, with the further end grounded. This test is carried out with no series resistor, so that the surge current down the cable shield will be several hundred amps, and is described in Figure 13 of EN 61000-4-5.

EN 61000-4-5 also describes an earth-lift type of surge test that can be applied to ports connected to any cables, shielded or not, in Figure 14. Although it is not mentioned in the standard, this is an effective alternative method for when a coupling/decoupling network is not available, and of course it does not affect signal lines so can be used to test high-speed data ports, RF transmitter and receiver ports, etc.

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

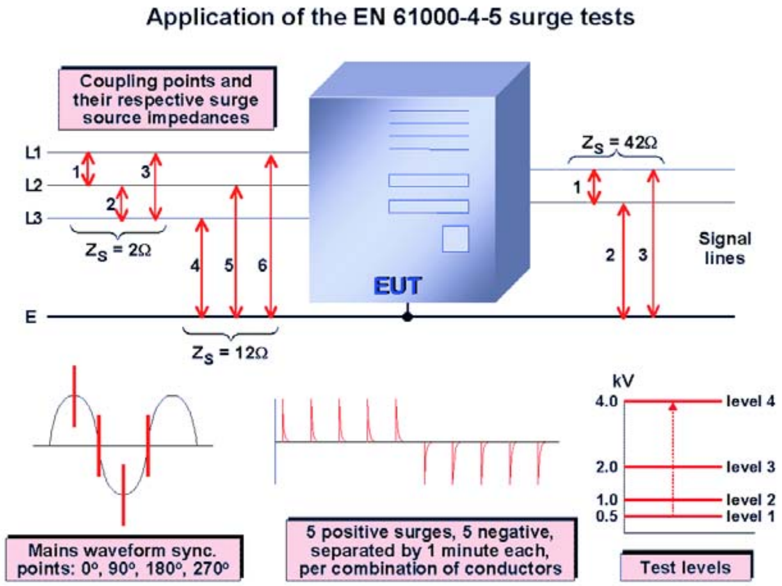
- Apply at least five positive and five negative surges at each coupling point
- Wait for at least a minute between applying each surge, to allow time for any protection devices to recover
- For AC power ports: apply the surges line-to-line (three combinations for 3-phase, one for single phase) and line-to-ground (two combinations for single phase, three for 3-phase)
- For AC power ports: synchronise the surges to the zero crossings and the positive and negative peaks of the mains supply (four possibilities)
- Increase the test voltage in steps up to the specified maximum level, so that all lower test levels are satisfied
- Apply a sufficient number of pulses to find all critical points of the duty cycle of the equipment.

Ignoring the last, which doesn't give any specific guidance for how many pulses would be sufficient, a worst case interpretation of the requirements on a 3-phase AC supply being tested up to 4kV would imply that a single complete test would take 16 hours, not allowing for set-up and test sequencing time. Modern surge test equipment is fully programmable, so can be left to test the product without needing the involvement of a test engineer. But test labs know that their customers would be uncomfortable with such a lengthy test, and usually some shortcuts are taken so that not all these steps are followed rigorously. This means that the various interpretations that the standard encourages can lead to different degrees of stringency in testing.

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 suppresser 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 suppresser 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, it makes sense to apply testing over as wide a range of variables as possible. This is the merit of pre-compliance testing: to inform the test plan for the full compliance test so that confidence can be had in a restricted set of tests which takes a reasonable length of time.

Of course, the EUT must be set-up and operated as it will be in its normal operation. Where it drives any loads (electrical, pneumatic, hydraulic, mechanical, etc.) it is important that these are provided or simulated in a reasonably accurate manner.



REO can create custom loads to meet any requirements

Purchasing or hiring a surge generator

Before purchasing equipment for surge testing, always discover which version of the standard (and its amendments) you need to apply, and ensure that the test equipment meets their requirements. Test equipment that does not comply with the specifications in the latest version of the standard might be able to be made compliant with software upgrades from their manufacturers.

If the test equipment is not fully compliant it may still be acceptable if it is being used for development, 'pre-compliance' or QA purposes.

Calibration of the surge generator is required, of course, for confidence and/or traceability of test results, so it is a good idea to ensure that the equipment you purchase or hire has recently been calibrated. This will at least ensure that it *can* be calibrated, and is not damaged or deficient in some way.

A number of manufacturers supply surge generators as modular options for their combination immunity test instruments. It is quite common to find that such instruments can be fitted with modules that permit testing to IEC 61000-4-5 (surges), IEC 61000-4-4 (fast transient bursts), IEC 61000-4-2 (electrostatic discharge), IEC 61000-4-11 (supply dips and dropouts), and sometimes even IEC 61000-4-8 as well (power frequency magnetic field), with a total cost of typically £15,000 for full compliance.

As a means of saving space, weight, and cost, these combination instruments are an excellent way to achieve compliant testing on your own premises. If you find you are hiring test gear frequently or for long periods, it is a good idea to do a financial analysis based on a two-year break-even to see if it is worth buying the test gear outright.

Filtering, shielding, and isolating transformers

Of course, the product being tested must operate properly in the first place, and if you are testing on a site that suffers from high levels of electromagnetic 'noise' it may be necessary to use filtering and shielding techniques to perform an accurate test. If this is the case, there are a number of issues that will need to be taken into account to suppress the interfering frequencies effectively. Suitable filtering and shielding techniques are described in [8] and [9].

If working on exposed live equipment an isolating transformer may be able to be used to help reduce electric shock hazards. Isolating transformers are a *requirement* of EN 61000-4-5 when doing 'earth-lift' type surge tests on shielded or unshielded cable ports (Figures 13 and 14 in the standard).

It is best to choose special 'high isolation' types of transformers, which have a very low value of primary-to-secondary capacitance, plus choose transformers that are rated for a continuous isolation voltage which considerably exceeds the surge test levels, to maximise safety.

Important Safety Note: Always take all safety precautions when working with hazardous voltages, such as 230V or 400V (3-phase) electricity. If you are not quite certain about all of these precautions – obtain and follow the guidance of an electrical “health and safety at work” expert. When constructing equipment that employs hazardous voltages, always fully apply the latest versions of the relevant parts of EN 61010-1, at least.

REO multistage filter for screened rooms

REO isolating transformer with low primary to secondary capacitances

Low-cost and/or non-compliant testing

Because of the very definitely lethal voltages, stored charge, and energy involved in a surge test generator, we do not encourage anyone to build their own (unless they are very experienced with designing high-voltage equipment for safety and will be applying a safety standard such as EN 61010-1 in full). So no do-it-yourself circuits for surge generators are given here.

Testing with an alternative test generator that has different open-circuit or closed-circuit waveforms from those in EN 61000-4-5 cannot give any confidence that tests using full-compliant test gear would be passed. But such non-compliant tests may be valuable for improving the reliability of a product, especially if they simulate the surges that could be present in its electromagnetic environments.

Many equipment rental companies have stocks of the calibrated test gear needed to do surge tests properly, and will rent them out for daily, weekly, or monthly periods. So the easiest way to perform these tests with reasonable accuracy and lowest cost is often to hire the equipment and do the tests yourself.

The test set-ups for surge tests are not difficult to achieve in a typical manufacturing company, as they don't need special test chambers or open area sites. EMC test laboratories often do their surge tests inside metal shipping containers or low-cost shielded rooms, but this is to help prevent the tests from interfering with other EMC tests that might be going on nearby. Where nothing very sensitive is nearby, such precautions are not needed.

With skill and attention to detail, hired test gear can readily be used to do fully compliant surge testing on your own site.

Buying second-hand test gear

Some rental companies sell off their rental equipment after a few years, and second-hand test gear is also available from a number of other sources. An un-expired calibration certificate on a second-hand purchase is well worth having, if only because it makes the possibility of expensive repairs to achieve your first calibration less likely.

When buying second-hand immunity test gear it is very important indeed to check that it is capable of testing the versions of the standards that you need to use. Some of the test gear is only available second-hand because it is not capable of performing compliant tests to the latest versions of the relevant immunity standards. Such equipment should cost less than compliant test gear, and may still be useful for preliminary investigations where money is tight.

Which ports to test?

Most of the generic, product, or product-family immunity standards that call up EN 61000-4-5 only require surge testing at a product's AC power ports (the mains connections), or at its DC power ports when the DC is provided from an external AC-DC converter or via very long cables. The generic industrial immunity standard EN/IEC 61000-6-2 (which has replaced EN 50082-2) also requires surge tests for signal ports which might be connected to cables longer than 30m.

But EN 61000-4-5 itself recommends testing *all* signal ports, regardless of the length of cable that might be connected to them. As far as the author is aware, the only generic or product standard that requires all signal ports to be tested for surges is the immunity standard for Alarm Systems, EN 50130-4.

The idea that short cables (e.g. less than 30m) cannot suffer from surges is erroneous. Horizontal cables in free space tend to suffer induced surges of about 1kV for every 10 metres of length due to cloud-to-cloud lightning (which are approximately 10 times more frequent than cloud-to-ground strokes) within a radius of about 5km, but the metal plumbing and other metal structures in buildings tend to reduce this coupling for cables within those buildings.

But very few signal cables are floating in free space – they are usually attached to an item of equipment at each of their two ends. At least one of these items is usually powered from the AC (mains) supply (even if via an external AC-DC converter such as a 'plug-top' power supply). If the AC supply input is fitted with surge protection devices that connect to its chassis or earth, or if the AC supply conductors spark-over to the metal chassis, then during a line-to-ground surge event the majority of the surge current will be diverted into the equipment's protective earth conductor. The passage of the large surge current through the large inductance of its protective earth conductor causes an 'earth-lift' (also known as 'ground lift'), when the earthed chassis of the equipment surges to a much higher potential than the 'true earth'.

For example, a not untypical 1kV line-to-ground surge could create a 100A (peak) current with a rise-time of 1µs. When this is diverted through 10m of typical green/yellow earth wire it would give rise to approximately 1kV (peak) between its ends, simply due to the wire's self-inductance. So for a microsecond or two the chassis of the equipment suffers an earth-lift that is roughly equivalent to the voltage of the surge event itself.

When an equipment suffers an earth-lift, the earth-lift voltage applies to *all* of its power and signal ports, not just the AC port. If the equipment at the other end of the cable attached to a signal port is 'floating' – completely isolated from earth/ground (including all its power and signal cables and the equipment attached to them) – then the earth-lift voltage can cause no harm. Of course, the isolation of the other equipment would need to be able to withstand the earth-lift voltage without sparking-over.

But if the equipment at the other end is not completely isolated from earth/ground for example if one of the items of equipment that it, in turn, is connected to is powered from an earthed/grounded power supply – then the earth-lift surge voltage on the original item of equipment could damage either its signal ports or the signal ports of the equipment it connects to (or the equipment that it is, in turn, connected to).

There are many other causes of earth-lifts, including insulation failures and lighting strokes to a building's lightning protection system, both of which can cause very large currents to flow in the metal structure and protective bonding conductors in buildings, vehicles, or other installations.

So we can see that unless *every* detail of *every specific* application of a product is analysed from a surge perspective, it is impossible to be sure whether its signal ports will suffer from surge voltages.

Consequently, to meet the Protection Requirements of the EMC Directive – and/or to help achieve reliable products to reduce warranty costs and keep customers happily returning to buy more of your products – it may be best to test *all* signal ports with the types and levels of surges appropriate to their likely applications, regardless of the lengths of cables which might be connected to them, and regardless of what the generic, product, or product-family immunity standard listed under the EMC Directive requires.

On-site surge testing

On-site surge testing to EN 61000-4-5 is very easy to do, because of the relatively simple test set-ups required, the portability of the test gear, and the fact that no reference plane or shielded room is required.

Annex B of EN 61000-4-5 describes what it calls 'system level testing', which it recommends to demonstrate reliability in an installation rather than compliance with any regulations. However, it may be possible to get an EMC Competent Body to agree to accept on-site testing when following the Technical Construction File (TCF) route to EMC compliance, especially for custom equipment intended for a specific site.

Important Safety Note: Don't forget that all surge tests are dangerous, and all appropriate safety precautions must be taken whether testing in a special test area or on-site. If you aren't *sure* what safety precautions are needed, ask an expert.

References

[1] IEC 61000-4-5 March 1995 plus Corrigendum October 1995, *Electromagnetic Compatibility (EMC). Part 4: Testing and measurement techniques. Section 5: Surge immunity test (includes corrigendum: 1995).*

[2] EN 61000-4-5:1995 incorporating Amendment No. 1, *Electromagnetic Compatibility (EMC). Part 4: Testing and measurement techniques. Section 5: Surge immunity test.*

[3] European Union Directive 89/336/EEC (as amended) on Electromagnetic Compatibility. The Directive's official EU homepage includes a downloadable version of the EMC Directive; a table of all the EN standards listed under the Directive; a guidance document on how to apply the Directive; lists of appointed EMC Competent Bodies; and progress on the 2nd Edition EMC Directive; all at: http://europa.eu.int/comm/ enterprise/ elect_equipment/emc/index.htm.

[4] ISO 7637-0:1990 "*Road Vehicles – Electrical Disturbance by Conduction and Coupling*" parts 0 to 3. Published by British Standards as BS AU 243:1991.

[5] The IEE's 2000 guide: *"EMC & Functional Safety",* can be downloaded as a '*Core'* document plus nine '*Industry Annexes'* from http://www.iee.org/Policy/ Areas/Emc/index.cfm. It is recommended that everyone downloads the Core document and at least reads its first few pages. Complying with this IEE guide could reduce exposure to liability claims.

[6] "EMC-related Functional Safety – An Update", Keith Armstrong, EMC & Compliance Journal, Issue No. 44, January 2003, pp 24-30, on-line at: http://www.compliance-club.com/ KeithArmstrongPortfolio.

[7] *"EMC for Product Designers, 3rd Edition"* Tim Williams, Newnes 2001, ISBN 0-7506-4930-5.

[8] *"EMC for Systems and Installations – Part 4 – Filtering and shielding"*, Keith Armstrong, EMC & Compliance Journal, August 2000, pages 17-26, www.compliance-club.com/Keith ArmstrongPortfolio.

[9] "*EMC for Systems and Installations*", Tim Williams and Keith Armstrong, Newnes 2000, ISBN 0-7506-4167-3

EN and IEC standards may be purchased from the British Standards Institution (BSI) at: orders@bsi-global.com. To enquire about a product or service call BSI Customer Services on +44 (0)20 8996 9001 or e-mail them at cservices@bsi-global.com. IEC standards may be purchased with a credit card from the on-line bookstore at www.iec.ch, and many of them can be delivered by email within the hour.

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This guide is one of a series. You can request all published and future guides by sending an email to **main@reo.co.uk** or from our website at **www.reo.co.uk**

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