Handbook on EN 61000-4-2

Personnel Electrostatic Discharge (ESD)

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Contents

Personnel electrostatic discharge (ESD) and compliance with the EMC Directive

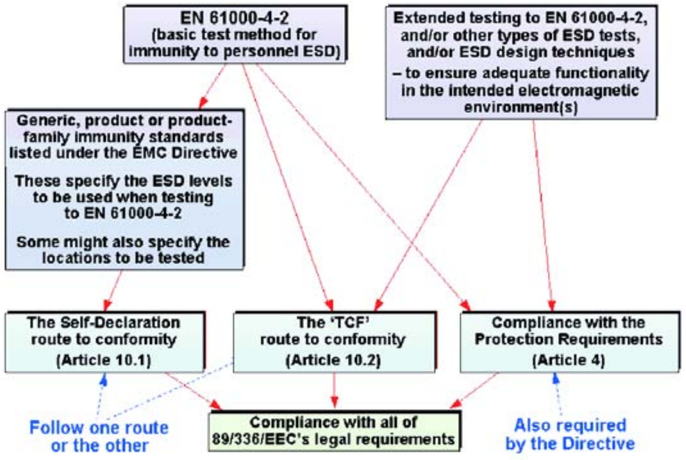
The basic immunity test method for personnel ESD is IEC 61000-4-2 [1]. This has been adopted as the harmonised European standard EN 61000-4-2 [2], which is often called up as a basic test method by immunity standards listed under the Electromagnetic Compatibility (EMC) Directive [3].

All people can carry static charges measured in kiloVolts (kV), which are capable of damaging almost all types of semiconductors. The discharge of these personnel static charges gives rise to transient currents and electromagnetic fields that can interfere with almost every kind of electronic device, equipment or system (called products in the rest of this handbook). So it makes good sense to test products for 'personnel ESD' to ensure they will work reliably despite the static charges on the people in their intended operating environment. This is especially important in safety-related, high-reliability, mission-critical, or legal metrology electronic applications.

EN 61000-4-2 is a basic test standard, so when following the self-declaration to standards route to conformity (Article 10.1 in [3]), EN 61000-4-2 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 or IEC 61000-4-2 as a test *method*, but it is always the generic or product-family standard that sets the minimum test *levels* which allow conformity to be claimed.

When using the Technical Construction File (TCF) route to conformity with the EMC directive (Article 10.2 in [3]) it is possible to use EN/IEC 61000-4-2 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 relationship between EN 61000-4-2 and the first edition of the EMC Directive (89/336/EEC)



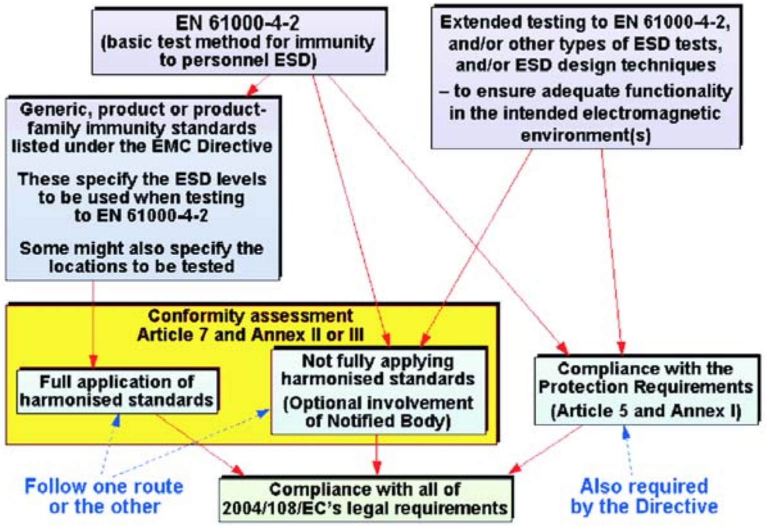
The second edition of the EMC Directive, 2004/108/EC [4], replaces 89/336/EEC on 20th July 2007. Products that are already being supplied in conformity with 89/336/EEC will be allowed to be supplied until 20th July 2009, by which date they too must comply with 2004/108/EC. Whereas 89/336/EEC requires the involvement of a Competent Body with all TCFs, 2004/108/EC effectively allows the TCF route to be used with the *optional* involvement of a Notified Body (the new term for Competent Bodies).

Under 2004/108/EC, equipment manufactured specifically for use at a named 'fixed installation' may not have to comply with any EMC requirements when it is supplied. But testing to EN 61000-4-2 at specified levels will generally be a requirement by the customer to help ensure that his fixed installation complies with the EMC Directive's Protection Requirements.

Important Safety Note: People whose health depends on the correct operation of pacemakers or other body-worn or implanted electro-medical devices should never go near any EMC immunity tests or their associated test equipment, including ESD tests or test equipment.

There may be significant financial or compliance benefits in performing ESD immunity tests that go beyond simply complying with the *minimum* requirements for Self-Declaration to the EMC Directive. This is especially true where products may be used in dry environments (relative humidity less than 25%), or where sources of ESD other than personnel are significant (see the later section on 'Other types of ESD').

The relationship between EN 61000-4-2
and the second edition of the EMC Directive (2004/108/EEC)



These situations are specifically *not* covered by the generic, product or product-family immunity standards listed under the EMC Directive, meaning that it is up to the manufacturer to assess the electromagnetic (EM) environment that his/her product will be used in and test it accordingly, to 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 are unreliable or fail in normal use because they are not immune enough for their real-life EM environment, do not comply with the EMC Directive's Protection Requirements and are therefore illegally CE marked.

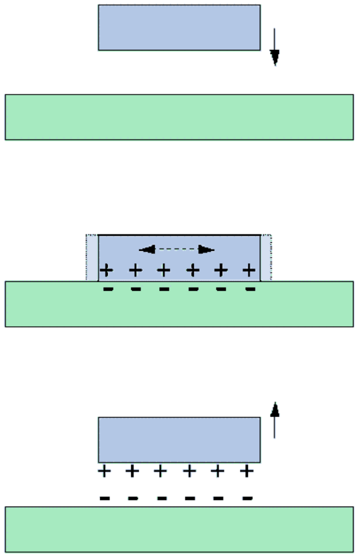
Applying EN 61000-4-2 (or similar) ESD tests which go beyond the minimum requirements of the EMC Directive's listed standards can also be a way to help make products more reliable, reduce warranty costs, improve customer satisfaction and reduce exposure to product liability claims – for more on this refer to the section on “Personnel ESD testing and real-life reliability” later.

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. Some of these industries have developed their own ESD test standards based on their own particular kinds of EM environments. For instance, automotive manufacturers employ ISO10605 for ESD testing, and often test up to 15kV.

This handbook describes how to apply the version of EN 61000-4-2 that is current at the time of writing and applies equally well to the latest version (2001) of IEC 61000-4-2. Despite being marked as '1995', the current version of EN 61000-4-2 incorporates amendments A1 (1998) and A2 (2000) to IEC 61000-4-2:1995. The 2001 version of IEC 61000-4-2 is simply a consolidation of the previous amendments. It is always best to use the latest version of the test standard, except where regulatory requirements for the EU or elsewhere specify the exact version to be used. 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 section “Personnel ESD testing and real-life reliability” later, plus the IEE's guide [5] and the on-line article [6] for more on this, and also read the section below on real-life reliability.

Example of tribocharging (or 'triboelectrification')



Two different materials are brought together (e.g. sole of shoe and carpet)

Assume they have no net charge difference initially

Contact between the two allows electrons to move from one material to the other (tribocharging)

Any friction (rubbing) between the two increases the charge transferred (Q)

The two materials are separated, and the charge imbalance between them remains

The voltage (V) between them rises as the capacitance (C) between them decreases due to increased spacing (Q=CV)

Electrostatic charging (and subsequent discharging) is the first electrical phenomenon ever investigated by humankind – by the ancient Greeks with their cat fur and ebony rods. Many children have enjoyed watching sparks fly as they comb their hair in the dark. We are all used to receiving electric shocks from ESD, usually from our fingers as we go to open a door or cabinet with a metal handle, usually when the air is very dry. Sometimes these shocks can be quite painful. Interestingly, most people will not notice that a spark has flown from their fingers unless the discharge voltage is at least 3kV.

Personnel ESD immunity simply refers to a product's immunity to the static electrical voltages and their discharges from people's fingers, or from keys or other metal objects held in their hands.

Static charges accumulate on an object or a person through a process known as tribocharging. Basically this means that where dissimilar materials are in rubbing or sliding contact, one of them will 'steal' electrons from the other, creating a separation of electrical charge between the two materials. If the materials are then separated, so that the capacitance (C) between them decreases, the charge (Q) on each (positive charge on one, negative on the other) remains the same but the voltage (V) associated with the charge separation increases, according to Q = CV.

Tribocharging is mostly seen when at least one of the materials is an insulator. It happens with dissimilar metals too, but the charges equalise by conduction again unless the rate of separation of the metal pieces is very fast (e.g. blowing metal dust over a metal surface). Where the voltage is sufficient to break down the air between the two materials (by ionising the air and making it highly conductive) a spark occurs as the separated charges attempt to equalise themselves. Such sparking is known as an air discharge. Discharges can also happen in vacuum, and in any insulating gasses, liquids, or solids when their breakdown field strength (in Volts/meter) is exceeded and their atoms or molecules ionise and so become conducting. Detectable sparks occur much more readily between metal surfaces – insulators (such as plastics) cannot discharge more than a small area of their surface, so the energies in their sparks are much less.

Some typical personnel ESD potentials, from [6]

Generation method	The electrostatic voltage generated (in kV)	
	10-20% Relative Humidity (RH)	65-90% Relative Humidity (RH)
Walking across carpet	35	1.5
Walking on vinyl floor	12	0.25
Worker moving at non-metal bench	6	0.1
Opening a vinyl envelope	7	0.6
Picking up a polyurethane bag	20	1.2
Sitting on a polyurethane foam padded chair	18	1.5

Aircraft (fixed-wing and rotorcraft) become tribocharged by their movement through the air, especially in rain or hail, and this is a serious hazard for in-flight refuelling. Closer to the ground, there are many possibilities for tribocharging in the modern world, where natural materials are constantly being replaced by plastic materials that are more insulating. ESD from people, so-called personnel ESD, is a significant EMC threat that is present whenever there are people around. As a person walks over a carpet, or other flooring material he/she becomes tribocharged with respect to the floor material. This might be because the flooring is insulating, or because the person's footwear is insulating (or both).

Humidity reduces the resistance of air, so separated static charges equalise more quickly as relative humidity (RH) increases. High ESD voltages and more intense sparks are more likely when the RH is low, as it can be in heated buildings in winter, or in desert or frozen conditions. Typically, personnel ESD problems get much worse as the relative humidity falls below 25%.

It is very difficult to predict how static voltages will build up, and to understand how the charges created by insulators can create sparks to (or between) metal objects. For a very great deal more on tribocharging and static electricity, read the 'Mr Static' articles by Niels Jonassen [8], especially the Jan/Feb 2001 article.

Personnel ESD is a problem wherever there are people. They move around, generating static charges and they come close enough to products and other metal objects for their static charges to dissipate in a spark. Immunity to this common type of ESD event is what is tested by EN 61000-4-2.

However, tribocharging occurs whenever solids are touched together and then separated, especially if there is any rubbing between them. Furniture ESD is one example. Charged metal chairs, tables, and carts (especially those with insulating wheels) have much lower resistance in their structures than people do, so their discharges can have faster risetimes. Furniture ESD testing was required by the European Computer Manufacturers Association's (ECMA's) TR/40 standard (1987), and also by ANSI C63.16. Keytek have a section in the User Manual for their 'Minizap MZ15 ESD' guns that described how to use them to simulate furniture ESD [9].

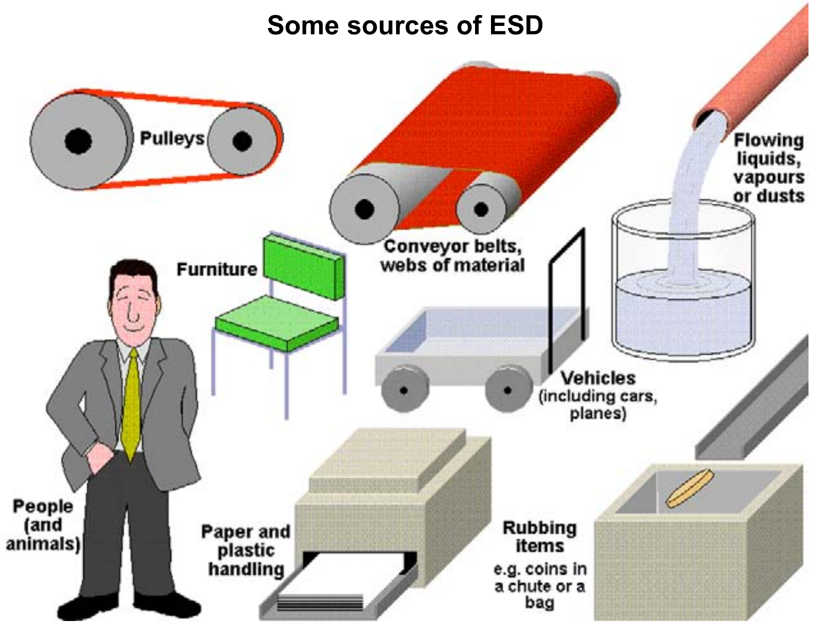
'Cable charging' is another type of ESD event. Moving an insulated cable, especially dragging it across a vinyl floor or carpet, can cause a static charge to build up on the cable's conductors. During the connection of a connector on the end of the cable to a product, the charge sparks across into the connector body and/or into its pins. Cable charging is generally considered less onerous in terms of peak voltage than testing to EN 61000-4-2, but it can injects sparks into connector pins and terminals that would not be tested by EN 61000-4-2. Because the resistance of the conductors in a cable is much less than that of a human body, the risetime of the discharge might be much less, maybe 200ps or less.

Doug Smith reports two unusual forms of ESD in [10] – ESD events inside chairs, and from jingling coins. When a person rises from a chair, charges are generated on both the surface of the chair seat and internally that can cause ESD events to occur inside the chair. These discharges are between metal parts of the chair that are not electrically connected to each other, causing intense electromagnetic fields to be radiated from the metal parts of the chair, usually the legs. This radiation is capable of disrupting the operation of nearby electronic equipment.

Most chairs Doug has observed with this effect produce about a dozen discharges over the first 10 to 15 seconds after a person rises from the chair. However, some office chairs are capable of producing several hundreds of discharges over as much as a minute. Just purchasing "ESD safe" chairs alone will not eliminate the problem. Since 1993, many types of equipment have been affected by this phenomenon, including communications equipment, computer equipment, and even critical aviation equipment.

When small pieces of metal, such as pocket change, move around inside an insulating pouch such a pocket or plastic bag, they generate different charges. When they touch, small ESD events are generated, for the most part too small to cause a visible spark. Doug has measured risetimes of less than 100 picoseconds, with sub-nanosecond pulse widths, corresponding to an upper frequency that exceeds 3GHz. The decreasing silicon feature sizes in semiconductor devices increases their susceptibility to such high frequencies. Doug has caused interference by shaking a plastic sandwich bag containing a handful of coins near communications equipment; a 100MHz PC; and some consumer electronics. In one case, shaking the bag 3 feet from a rack of equipment caused dozens of red LEDs to light.

Some sources of ESD



Tribocharging of the coins in vending and change machines, as coins slide down plastic chutes, can eventually charge the coins in a plastic bin to a very high voltage, giving maintenance personnel unpleasant shocks. If such charges are not encouraged to discharge slowly, they can discharge quickly in a spark to a nearby piece of metalwork, possibly interfering with the microprocessors that control the machine. Polystyrene cups can be a wonderful source of ESD, and are used by Doug Smith in a number of his articles at [11] – a good source of information on real-life ESD and related issues.

AC motors with nylon bearings have been known to charge up their rotors through tribocharging against the bearings, with the rotor then sparking regularly across the bearing to the motor frame and crashing a microprocessor in the same product. Products using insulating belts, pulleys or rollers – either for conveying or for power transfer – can generate high levels of static charge with consequent sparking. Printers and copiers can suffer from internal ESD due to dry paper being fed through rubber rollers and sliding across plastic panels.

'Machine ESD' can be a very big problem in processing industries and vehicles, where liquids, particles or dusts (e.g. flour), plastic, paper, rubber, etc. are processed or sloshed around. Large metal items with large capacitance can become charged up to very high voltages, and in some of the industries the materials being processed are flammable and can be ignited by an ESD spark (this is what is officially claimed to have brought down TWA-800). Liquids don't cause charge separation by tribocharging, but by a different mechanism. However, the result is a charge separation with the possibility of a spark discharge as a result.

It is not uncommon for an 'earthing strap' in a processing plant to be damaged or wear out through corrosion or vibration, with the result that large ESD events can interfere with (or damage) electronic equipment. The sound of the sparks is usually drowned out by the noise from the plant, but running the plant with the lights out (where this can be done safely) can help identify such problems by making the flashes of light associated with the sparks more visible. One of the problems with machine ESD is that the risetimes are often much faster than personnel ESD, due to the low resistances of the metal parts that are charged up, so their frequency spectrum can be much higher than that of EN 61000-4-2 tests. The energy in these discharges can also be much greater than personnel ESD, due to the higher capacitance of large metal objects.

The EM phenomena associated with ESD events

1) Static electric fields caused by the existence of charged bodies or objects

The word 'static' is misleading – it would be more accurate to say slowly varying electric fields. These can have magnitudes high enough to charge-up sensitive circuits (especially high-impedance circuits) and make them to malfunction, maybe even enough to damage associated semiconductor devices.

2) High currents during a discharge

These high currents are what causes damage to the silicon features in semiconductors. There is generally insufficient energy in a personnel ESD event to damage other parts of devices or circuits – but this may not be true for other kinds of ESD, especially machinery ESD, where large items of metalwork can become charged to very high voltages, causing ESD events with much larger energies. After all, lightning is created by the tribocharging of clouds, so could be considered an ESD event.

The high currents associated with a discharge (which can be of the order of 30A during an EN 61000-4-2 test) flow around shields and through conductors, creating voltage drops that can interfere with circuit operation. The response of circuits to such transient currents is non-linear, so it can be possible for significant interference to occur at low ESD voltages but not at high voltages, or with one ESD polarity but not the other. This helps explain some of the test requirements in EN 61000-4-2.

3) Strong transient electric and magnetic fields during a discharge

These can couple to circuits and interfere with their operation. The field strengths created by a 5kV test using EN 61000-4-2 can be as high as 10kV/m at 100mm from the spark, and 1kV/m at a 1 metre distance. This is why EN 61000-4-2 includes some indirect discharge tests – even a totally insulated product that cannot be 'sparked to' during an ESD test can be vulnerable to the fields created by a nearby spark to a different object.

Unfortunately, the fields created by a personnel ESD test are not specified in EN 61000-4-2, so as a result the fields created by different models of ESD guns can differ from each other, and can also differ from the fields created by real personnel ESD events.

4) Secondary field generation and secondary sparking

As the currents from a spark discharge travel around the shields and other conductors in a product, they give rise to secondary magnetic fields, and the voltages they create as they flow through impedances create secondary electric fields. Sometimes the voltages are so high as to cause secondary sparking.

This is especially a problem for joints in shielded enclosures. For example, with a current of (say) 30 Amps and a risetime of (say) 1ns, a current in a shield that would have to divert from its ideal (minimum impedance) path by 50mm to pass through a metal fixing to cross a gap of 0.25mm, would generate (very approximately) 1500V across the gap, enough to cause ionisation of the air in the gap and cause a secondary spark to occur. If the gap was wider, so that secondary sparkling did not occur, it would create very intense secondary magnetic and electric fields near the gap.

One of the problems for these secondary fields and sparks is that they can occur far away from the point of application of the main ESD event, at locations that can be hard to predict. They can interfere with circuits and/or damage devices that were thought to be well protected by segregation, insulation, or other ESD design techniques.

A good technique for testing for (and locating) secondary sparking is to do ESD tests in the near-dark (very carefully – ESD to parts of your body can be painful!). The light they emit reveals the secondary sparks. The author knows of a couple of troublesome ESD problems that were eventually solved when the lights were accidentally turned off during ESD testing, revealing secondary sparking that had not previously been noticed.

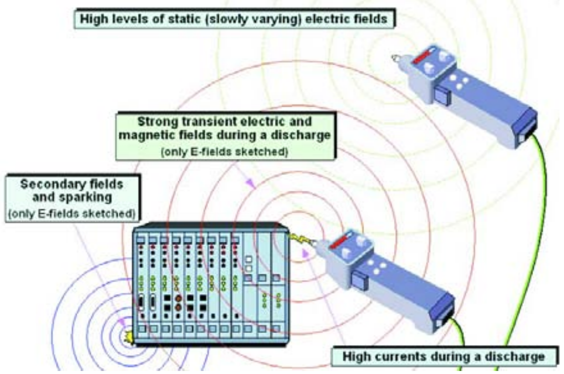
5) Real-life ESD waveforms

This is not another EM phenomenon, but a comment on items 2) – 4) above. The personnel ESD waveform defined by EN 61000-4-2 is measured when the ESD test generator is discharged into a specified 2Ω load. The construction of the load is specified in EN 61000-4-2 and it maintains its 2Ω impedance up to much higher frequencies than are present in a Fourier analysis of the desired ESD waveform.

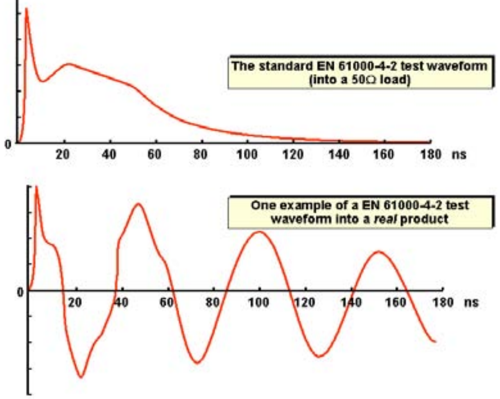
However, in real life the ESD generator will be discharged into conductors that are very far from being such an ideal load, or conductors inside a resonant cavity. As a result, they resonate and the waveforms of the real-life ESD currents, electric and magnetic fields are often broadly similar to a damped sinusoid.

Since ESD generators are only specified by their waveform into a broadband 2Ω load, and not by their circuits or constructional details, different generators from different manufacturers will give unpredictably different waveforms when testing different loads. Also, the

The various EM phenomena associated with an ESD event



Variations in actual test waveforms



different circuits used inside the guns, and their different constructions, results in widely different fields being radiated from the bodies of different models of guns even though they all comply with EN or IEC 61000-4-2.

[12] found a ratio of 5:1 between the voltages which would cause an example equipment to fail, when testing a variety of ESD guns. So there is an uncontrolled range of possible variations between tests carried out with different ESD generators. A product tested successfully with one EN 61000-4-2 compliant 'ESD gun' may fail miserably when tested in the same way with a different model of gun.

One conclusion of [12] was that IEC 61000-4-2 did not specify the design of the ESD gun well enough to ensure that different makes of gun created the same EM stresses on the equipment being tested. It also concluded that IEC 61000-4-2 did not simulate typical personnel ESD events were not simulated very well, so that equipment that passed tests to that standard would not necessarily be reliable when exposed to ESD in real life.

What problems can be caused by ESD?

All semiconductors and many other electronic devices can be permanently damaged by ESD. Some can even be damaged by the slowly varying electric fields associated with charged bodies even without any discharges occurring. The internal silicon features (transistors, conductors, etc) are so small, and have such a low thermal inertia, that even the low energies in typical personnel discharges (for example) can cause actual physical damage. Also, the spacings between conductors (metallisation) in a typical integrated circuit are so small that ESD damage can occur at levels of only a few tens of volts.

Because of this, most semiconductors incorporate static discharge protection devices at all of their inputs and outputs. These internal protection devices cannot use a large amount of silicon area, for cost reasons, so they are limited in the energies they can handle without being damaged themselves. Very few ICs will survive an EN 61000-4-2 test applied directly to their pins, so additional ESD protection is required from their circuits and enclosures.

There is a large body of work and standards concerned with protecting electronic devices during their fabrication or assembly onto a printed circuit board (PCB). This is not the subject of this booklet, but it is worth noting – to help avoid confusion – that some of the names applied to the types of ESD and their tests are similar to those used elsewhere in this booklet (e.g. human body model; personnel ESD; machine ESD; etc.), However, they do not relate to what is being discussed here – final product testing using EN 61000-4-2.

Examples of ESD damage levels for devices

(ignoring any protection provided by their circuits and enclosures)

These figures are based on testing unassembled devices with semiconductor industry's 'human body model', which discharges a 100pf capacitor through a 1.5kΩ resistor, peak current 2A, risetime 5-20ns

Compare this test with EN 61000-4-2, used for testing finished products, which uses 150pF discharged through 330Ω, peak current 30A, risetime 0.7-1ns

Type of Device (typical 2002 technology)	Typical sensitivity (kV)
MR heads, RF FETs	0.01 - 0.1
Power MOSFET transistors	0.1 - 0.3
VLSI	1 - 3
Film resistor	1 - 5
HC and similar CMOS glue logic	1.5 - 5
Small-signal bipolar transistor	2 - 8
Power bipolar transistor	7 - 25

The signals used in circuits can suffer interference from the various EM phenomena associated with ESD events. DC and low-frequency analogue signals experience ESD as a momentary 'glitch' that might not be very important (depending on the circuit and its application). ESD interference with high-speed and high-frequency analogue circuits are more likely to cause malfunctions, for instance interference with the gate drive signals in switch-mode power converters can cause cross-conduction leading to explosive disassembly of the power switching devices (i.e. they can blow up, and large power converters can explode with as much energy and shrapnel as a grenade).

Digital signals can often easily suffer interference from ESD, because even where the signals themselves might have a very low rate the digital devices they are connected to are usually permitted to respond very quickly indeed, registering ESD events as false signals. High-speed digital signals can be using the same (or faster) risetimes than personnel ESD events, so are very susceptible to ESD interference, even a few hundred millivolts can be enough to create erroneous data.

Some examples of real-life interference due to ESD are included in [13].

A big problem with warranty claims and field service is the 'no-fault-found' customer return. Many manufacturers spend considerable amounts of money to try to keep their customers happy, despite not knowing what the cause of the problem is. Many no-fault-found problems appear to be caused by inadequate immunity performance, but EMC and ESD events are often hard to repeat (and few service personnel or customers are EMC/ESD experts or have any EMC/ESD testing gear).

The financial rewards of producing products with adequate immunity can be very great indeed, as one UK manufacturer discovered when they spent £100,000 on redesigning their products to comply with the new issues of the EMC Directives immunity standards around mid-2001, and found to their complete surprise that their new products designs saved them £2.7 million in warranty costs *per year*.

As you can see from the above sections, EN 61000-4-2 only covers a small range of possible ESD events, and various different models of (EN 61000-4-2 compliant) ESD gun can give wildly different results when testing the same equipment [12]. Personnel ESD is certainly an important issue for almost all products, but is often not the *only* ESD issue, and other ESD events may involve faster risetimes and so not be addressed by the waveform used in EN 61000-4-2 testing.

At least one manufacturer [9] makes an ESD gun that has much faster risetimes than the 0.7-1ns required for EN/IEC 61000-4-2 compliant generators – but it still uses the human body model and has a 150Ω series resistance, not the 0Ω resistance of some types of ESD event. For details of an ESD generator that claims to simulate ESD events such as those described in [10], visit [14].

There are military and automotive industry EMC immunity standards which test personnel ESD using different 'human body models' to that used in EN 61000-4-2 (hence different test waveforms), and sometimes they test with higher voltage levels too. Using such standards, or extending and toughening tests under EN 61000-4-2, and/or using test generators that simulate the anticipated real-life ESD events (see above), can help produce more reliable products.

But complying with any immunity test standards (even the ones used for flight control computers on civil airliners) does not necessarily ensure sufficient real-world reliability. This can be a problem for safety-related equipment and systems, or for equipment and systems that require very high reliability (such as speed cameras). This issue is too large to be discussed here, for more on this refer to [15] and the IEE's training course on EMC for Functional safety, high reliability and legal metrology [16].

If it is suspected that ESD is a cause of failures in the field, there are a number of instruments that can be used to perform a site survey to see what ESD events are occurring where the equipment is located. ESD instruments intended for monitoring electronic assembly workstations may also be used, such as [17].

Example of an ESD event detector
(courtesy of Credence Technologies, Inc.)

Introduction

This basic ESD test standard aims to simulate the effects of electrostatic discharges from the fingers of personnel, either directly or via keys or other metal objects held in their hands. Personnel are assumed to have become charged to a high voltage by tribocharging, usually due to rubbing contacts between their shoes or clothing, and dissimilar materials used for flooring, storage, etc.

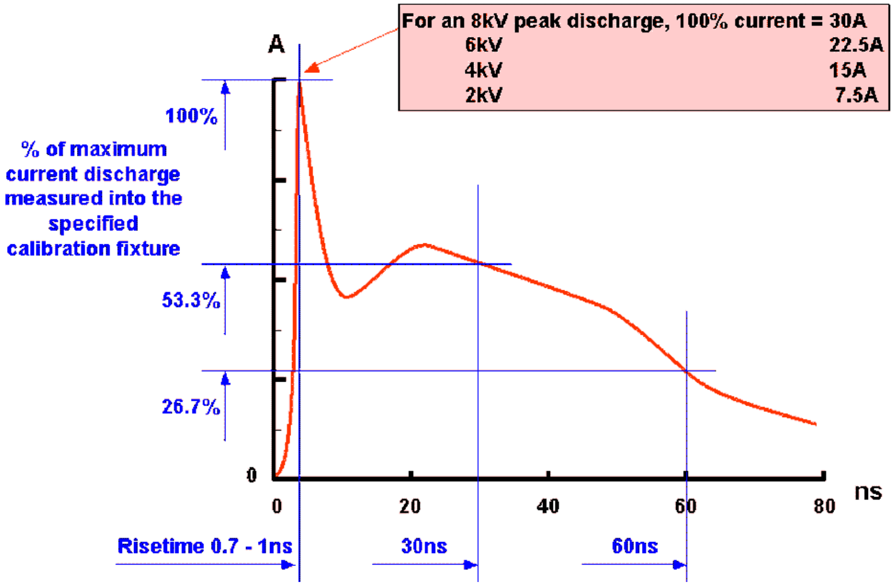
This booklet is not a complete recital of everything that is in EN 61000-4-2, only a general guide. Anyone performing tests to this standard must have a copy of its relevant version (including any amendments), and follow it exactly.

ESD guns compliant to the latest version of EN/IEC 61000-4-2 are easy to buy or hire, and relatively straightforward to use, and no special test facilities are required (but see the section on preventing interference).

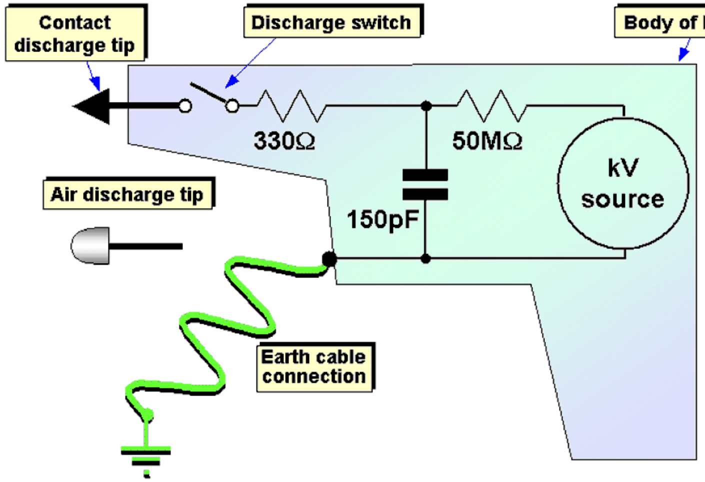
The standard 'human body model' waveform for the EN 61000-4-2 ESD test is a single unidirectional impulse, given in its Figure 3. Figure 1 of EN 61000-4-2 gives the basic scheme of an ESD generator or 'gun'.

EN 61000-4-2 testing done fully in accordance with the standard is not very well controlled. Much depends on the skill and experience of the test engineer, particularly in selecting the test points and in actually applying the discharges to the product.

The standard EN 61000-4-2 current waveshape
(from Figure 3 of EN 61000-4-2)



The basic human body circuit model
(from Figure 1 of EN 61000-4-2)



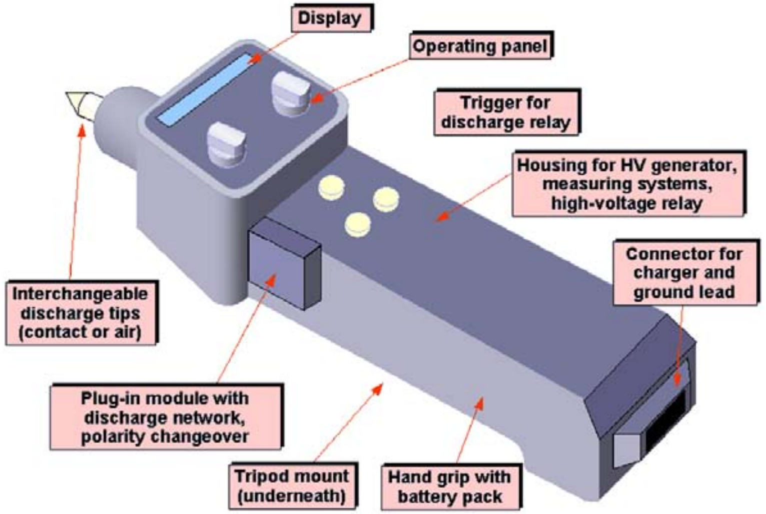
The test set-up

The basic set-up is straightforward. The EUT is placed over a ground reference plane (GRP) to which the ground lead from the ESD gun is directly connected. The GRP must be larger than the EUT – and any horizontal and vertical coupling planes (HCP and VCP) that are used – by at least 0.5m all around, and be connected to the site's protective grounding system. The EUT must be grounded in accordance with its manufacturer's installation instructions.

The gun's ground lead is calibrated with the generator, and the lead that is used for calibration must be the same lead that is used for the testing. Different leads will have different inductances, and this could modify the discharge waveform, particularly its trailing edge. The lead should always be kept away from the EUT and other structures (by at least 200mm), and the test engineer's body. The separation distance between the EUT and the GRP is 100mm for floor standing and 800mm for table-top products. (The distance of 100mm is helpfully the same as the thickness of a fork lift truck pallet.) There should also be at least a 1m clear area around the EUT (apart from the tester and ESD gun).

The VCP is 500mm square, and held 100mm away from the side of the EUT during testing by an insulating fixing. It is connected to the GRP by a special 'bleed lead' that isolates the HCP during the actual discharge but allows charge to slowly conduct away (bleed) afterwards. The bleed lead is constructed with 470kΩ high-voltage resistors located at each of its ends, so that its stray inductance and capacitance are isolated from both the HCP and the ground plane at high frequencies. Carbon composition resistors are usually used (not film types).

Example of an EN 61000-4-2 compliant ESD gun
Courtesy of Thermo Electron Corporation: the KeyTek MiniSap®

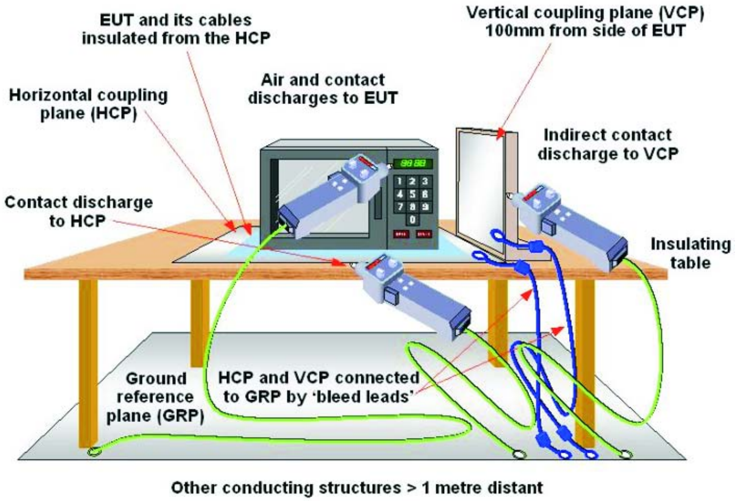


Products that are classed as 'table-top' are tested on an 800mm high wooden table. A secondary metal plane, the HCP, is placed on the top of the table, then a 0.5mm thick sheet of plastic is placed on top of it, then the EUT is placed on the plastic. The HCP is connected to the GRP by another bleed lead. The HCP must be 1.6 by 0.8m and it is normal to make the table so that its top is just this size, then completely cover it with the 0.5mm thick insulation leaving only the edges of the HCP exposed.

The EUT is placed with its front face 100mm from the front edge of the HCP. Where the EUT is so large that the edge of the HCP is not 100mm or more away around all of its sides, two or more isolated HCPs should be used to cover sufficient area, each 300mm away from the other and each connected to the GRP through its own bleed lead.

The EUT's cables are draped off the HCP (making sure to insulate them from the HCP with 0.5mm plastic sheeting if their own insulation might not be adequate) and taken away from the test area as necessary. EN 61000-4-2 is weak in this respect – although (as with other RF tests) cable layout and termination can make a large difference to the test outcome, it says virtually nothing about how they should be treated, except that they should be "…representative of installation practice".

The test set-up for table-top products
(adapted from Figure 5 of EN 61000-4-2)



Exercising the product during the test

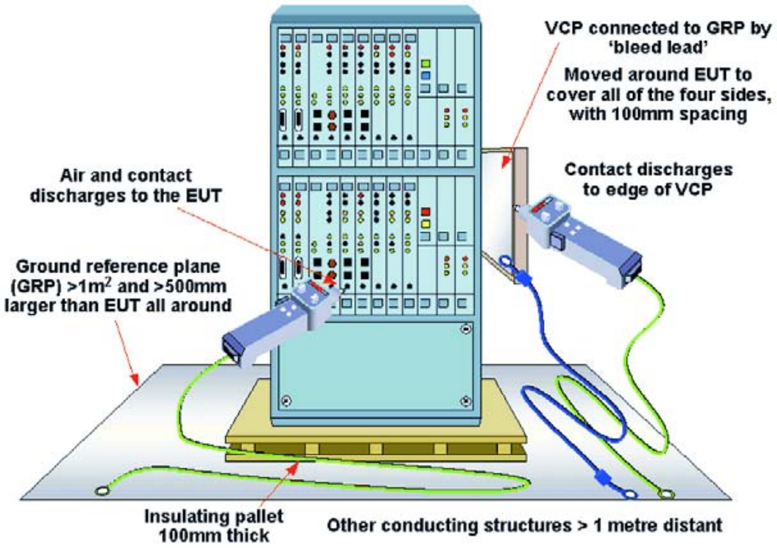
As is usual with EMC test standards, EN 61000-4-2 requires that equipment be set-up and operated as close as possible to its normal operation in real life.

During the execution of software, the susceptibility of a product to interference is usually much worse at some instants than it is for the rest of the time. These instants are usually not known, making it a problem for a transient test, such as ESD, to be applied at just the right instant. This is one of the reasons why there is a proposal to increase the number of discharges applied from 10 to 50 (at each voltage, at each polarity, at each tested location).

EN 61000-4-2, like all other immunity tests in the EN 61000-4 series, requires all of the normal modes of operation of the EUT to be tested. Because of the number of locations that must be tested to find the 'weak spots' (see later) this could take a very long time for some types of product.

Special exercising software can be run on the product instead of normal software, to save testing time, but it must comprehensively exercise the product. EN 61000-4-2 helps to save more time during full compliance testing by requiring that the most sensitive mode of operation be determined in advance by preliminary testing, and the product run in that mode during the test. This seems to ignore the fact that it is possible that there might not be just one 'most sensitive mode of operation' – there may be several, each of them 'most sensitive' for different tested locations. In such a case, a responsible ESD test engineer would no doubt perform the compliance test by using the operating mode that had been found to be the most sensitive for each tested location, but this is not *exactly* what EN 61000-4-2 says shall be done.

The test set-up for floor standing products (adapted from figure 6 of EN 61000-4-2)



For some products, electrical, mechanical, hydraulic or pneumatic loads; high-power three-phase electrical supplies or supplies of hydraulic or pneumatic power (e.g. compressed air) may be required, to test it as it will be used in real life. When testing lift (elevator) drive systems, for instance, it is normal to use a large flywheel that has a moment of inertia similar to that of a loaded lift car.

REO can create custom loads to meet any requirements

Monitoring the EUT for performance degradation during ESD tests

The functional performance degradation allowed during and after personnel ESD immunity tests may be specified by product-family standards (e.g. EN 55024), but if applying the generic standards EN 61000-6-1 (which has replaced EN 50082-1) or EN 61000-6-2 (which has replaced EN 50082-2) all that is necessary is that the performance is no worse than the specification in the manufacturer's 'data sheet' for the product – which should represent what its users would find acceptable given the marketing claims for the product.

Thought should be given to how the functional performance of the product is to be tested with appropriate levels of accuracy and repeatability, well before the product's planned testing date, so that any special testing arrangements can be made. For example, some electrical or electronic test instruments can themselves be upset by nearby ESD events, or by the transient currents that flow down the interconnecting cables.

Where an accredited test laboratory provides the functional instrumentation, they will no doubt have already discovered how to make it immune enough. But where functional testing employs instruments provided by the product manufacturer (e.g. signal or distortion analysers, display screens, computers, etc.) and this can lead to lengthy spells of trying to decide whether it is the EUT that is failing or the test equipment, all the while burning money at premium test lab rates.

Also, test laboratories book their work weeks (or even months) in advance, allocating customers testing timeslots that *should* be long enough to perform the required tests. Where customer-supplied functional test equipment is upset by ESD tests, and no quick fixes seem to work, it is possible to run out of time trying to fix the susceptibility of the test equipment, then having to wait a few weeks (or maybe months) until another timeslot can be booked.

The test procedure

The procedure followed in the test is divided into direct application of contact and/or air discharges, and indirect contact discharges applied to the VCP (and to the HCP, for table-top equipment).

An EN 61000-4-2 compliant ESD gun itself is capable of both contact and air discharges, using interchangeable metal tips. For the contact discharge, the pointed tip is employed to make contact with the tested point, and then the high-voltage relay within the unit is closed to apply the discharge to the tip. Contact discharges remove the variability associated with the breakdown of the air gap in the air discharge method, and it is the preferred method wherever the location to be tested is conducting. Where a conducting object or surface is coated, but the coating is not intended to be insulating, the pointed tip is firstly pressed onto the coating hard enough to penetrate it and reach the conductor underneath.

For insulating surfaces the air discharge method using the rounded tip is employed, with the high-voltage relay closed so that the tip remains 'live' until discharged by the spark (if a spark occurs). Favourite locations for air discharge testing are apertures or seams in plastic enclosures, and the gaps between key caps or around displays.

Where there are metal items or surfaces inside the product, near enough to these gaps, an air discharge will fly through the gaps to reach them. Some insulated surfaces use such thin insulation (e.g. coatings) that the test voltages might break down the insulation itself and the air discharge penetrate right through it.

The orientation of the ESD gun with respect to the product affects the stray capacitance between the front of the gun and the EUT, so to aid test repeatability the gun's tip must be perpendicular to the surface being tested. In addition, to improve repeatability when doing the air discharge, the gun should be handled positively, without hesitation. EN 61000-4-2 says (sic): "…the tip … shall be approached as fast as possible (without causing mechanical damage) to touch the EUT.". This is important, because any spark that occurs is greatly affected by the approach speed. A wavering, cautious approach with the tip will result in large variations in the spark.

The test procedure is as follows…

- Select a suitable set of points for the test application (see below), and make sure these are documented with reference to a drawing (or annotated photograph) of the product.

- At each point and for each test voltage apply at least ten discharges, allowing at least one second between each and checking the EUT's response each time. Unless the most sensitive polarity is already known, apply ten discharges in each polarity. This could be ten positive followed by ten negative, or alternate positive and negative, or any combination in between. Provided that the EUT discharges fully after each pulse it shouldn't matter in what order this is done, although this may conceivably depend on the design of the EUT.

- For each point and each of these sets of discharges, start off at the lowest test level (±2kV) and increase through the other test levels until the maximum specified test level is reached. This is usually ±4kV for contact discharge and ±8kV for air discharge, but some product standards may require higher or lower maximum values. In real life, ESD events with lower voltages than the maximum tested level are much more common, and non-linearities in the EUT's response can mean that products that pass at the maximum voltage can fail at lower voltages. So, testing at intermediate levels is a requirement of EN 61000-4-2 (as it is for most/all of the EN 61000-4 series' transient tests) and is generally known as 'windowing'.

Indirect discharge to the VCP has also to be performed for all types of product, with indirect discharge to the HCP also applied to table-top equipment. Indirect tests uses contact discharges, and are intended to simulate the effect of an ESD event concerning a nearby conductive object. In the case of a well-insulated product, the indirect tests may be the only tests in which the gun actually achieves a discharge.

The gun must be held edge-on to the VCP or HCP being discharged to. In the case of the VCP it must be applied to the centre of a vertical edge – but in the case of the HCP it must be in-line with the centre of the face of the EUT. All four faces of the EUT must be tested, and where the VCP is smaller than a side of the EUT the VCP must be moved around so that each face of the EUT is "…completely illuminated.".

It is common to rotate table-top equipment to perform the indirect tests required on each of its four sides from the same side of the HCP. This means that the VCP can remain in more or less the same place too. But rotating the EUT will alter the ways in which the cables drape, so drawings or photographs should show the different cable layouts in each case so that the test could be repeated if need be.

Selection of test points

Choice of test locations is another area where there is an opportunity for variability between different EN 61000-4-2 tests. Attempting to discharge the tip of an ESD gun all over a product, to find all of the 'weak points', can take a very long time indeed – so this is not done. Instead, ESD test engineers are expected to learn which locations are most likely to cause failures, and test those. Good ESD test engineers will usually find the same weak spots on an EUT, but some experience is required.

Empirical knowledge of products is a great help in locating weak spots – for example, the edges of apertures, seams or joints, displays, membrane switch panels, openings provided for controls, ventilation and removable media, and the controls themselves. Also, exploratory testing using air-discharge with a fast spark rate, whilst monitoring product performance, can help to quickly identify other weak points. With the gun set to continuous discharge (or a rate of 20 discharges per second), repetitively varying the distance from its tip to a part of the product will vary the voltage at which the spark occurs, helping to improve the identification of weak spots by windowing.

An ESD test to EN 61000-4-2 is only required at such points and surfaces which are: "…accessible to persons during normal use.". Section 8.3.1 of the standard gives guidance on what is meant by an *accessible point*, and lists five types of location that are excluded from ESD testing…

a) Locations only accessible during maintenance

b) Locations only rarely accessed during service by the user (e.g. changing batteries, changing the cassette tape in an answering machine)

c) Locations that are not accessible after following the user instructions (e.g. the rear of wall-mounted equipment)

d) The contacts of connectors that have a metallic connector shell

e) Contacts that are ESD sensitive because of functional reasons and are fitted with an ESD warning label (note that the standard does not specify the actual warning label to be used)

In all these above five situations, the user instructions provided by the manufacturer are required to include appropriate ESD precautions for the above list of excluded locations.

Of course, there is nothing to stop a manufacturer from requesting that the EMC test laboratory apply ESD testing to some (or all) of the above locations so that no user ESD instructions are required. It is well known that people only bother to read instructions after the product doesnt work, so additional ESD testing might help reduce warranty claims.

An interesting potential for confusion exists in the list of exclusions (section 8.3.1 of the standard) – because it also lists connector pins that must be tested. It is very odd indeed to find non-excluded items in what is introduced as a list of excluded items, and this is a good example of why it is very important to read all EMC standards very carefully indeed, to try to figure out what it is that they really mean to be done.

So connectors that are accessible to the user, and do not have a metallic shell (or ESD protective cover with ESD warning label) are required by the present version of EN 61000-4-2 to have their pins ESD tested, but only using the air discharge tip. Note, however, that some product or product-family standards might alter this requirement, for instance EN 55024:1998 specifically states (in Clause 4.2.1): “The application of ESD to the contacts of open connectors is not required by this publication.”.

Testing ungrounded products

If the applied charge cannot bleed off the EUT between pulses – because, for example, it has no external connections – then the stress voltage will change after each pulse application. This will either reduce the applied stress, if the voltage on the EUT rises towards the applied value on consecutive applications of the same polarity, or it will increase it, if the polarity is changed between applications.

Section 7.1.3 of EN 61000-4-2 requires the charge on the EUT from a discharge to be removed before the next one. It describes ways in which a bleed resistor cable (similar to those used for the VCP and HCP, see above) can be attached to the EUT during the test. If the 'bleed lead' could affect the test outcome for some reason, a carbon fibre brush attached to a 'bleed lead' can instead be applied to the EUT after each discharge test, or the EUT simply left for long enough for the excess charge to 'leak away' naturally through the air. An air ioniser can be used to hasten the natural air leaking process, and a non-contacting electrostatic field meter may be used to determine that the EUT has discharged.

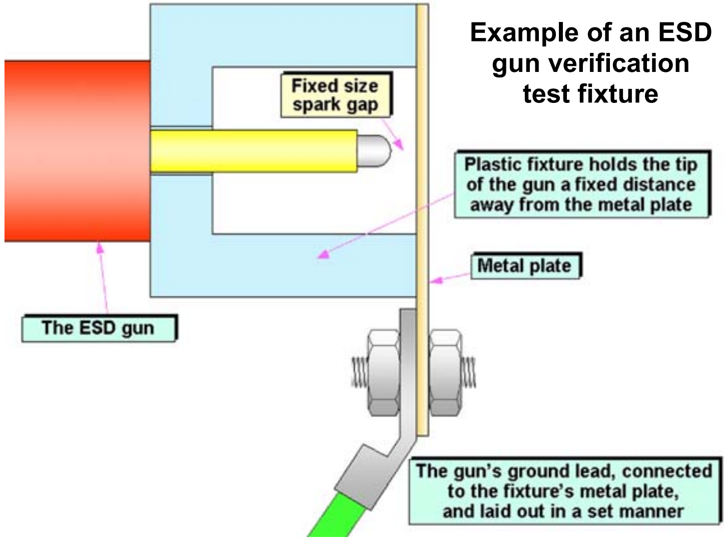
Calibration and verification of the ESD gun and its ground lead

Section 6.2 and Figure 3 of EN 61000-4-2 describe the calibration/verification required for an ESD gun, and Annex B contains the construction of the current sensing transducer that must be used. This is mostly of interest to ESD gun manufacturers and calibration laboratories, although some test labs like to have their own 'cal lab' so as not to waste the time taken in simply sending test gear to a separate lab and getting it back.

But ESD guns can themselves suffer from errors, failures or damage (e.g. by being dropped) so some sort of 'gun checking' procedure is needed, either daily or each time an ESD test is about to be started. IEC/ISO 17025 [18] requires all accredited test laboratories to check their ESD guns in this way, but EN 61000-4-2 does not describe any suitable methods.

One commonly used ESD gun checking method is to make a simple plastic ESD verification fixture that holds the tip of the gun at a fixed distance of 3 mm from an earthed metal plate. No part of the plastic fixture may be closer than 8mm to the tip's metal end, except for the part that holds the earthed metal plate.

When the ESD gun has just returned from a full calibration, and presumably has not yet had time to go wrong, its air-discharge tip is placed correctly in the verification fixture and the gun set to +1kV and operated. No discharge should occur. The gun's voltage should be increased gradually until discharges just begin to occur. The voltage at which this happens must be recorded.



Example of an ESD gun verification test fixture

The process is repeated with negative test voltages, and then again with both positive and negative voltages using the contact discharge tip. The result will be a calibration test report for that specific ESD verification fixture, for that specific ESD gun, which will just list the four voltages displayed by the gun (plus the humidity and altitude of the laboratory – or air pressure – at the time of the test). The identification code for the gun's ground lead, and its arrangement during the above tests, must also be documented in the fixture's calibration report.

To check an ESD gun (daily, or prior to testing) the same verification procedure as above is gone through, using the same verification fixture and the same gun ground lead in the same arrangement.

The voltages at which the gun has to be set for it *just* to begin to discharge are recorded for positive and negative voltages and with the air and contact discharge tips, just as for the original calibration of the verification fixture.

These four voltages are compared with those obtained during the initial calibration of the verification fixture, and the differences noted. If the humidity at the time is known to be close to the value when the ESD fixture was tested in the laboratory, differences of ±300V are considered acceptable. But if it is not the same, differences of ±600V may be considered acceptable depending upon the estimated effects of the differences in humidity and air pressure.

The proposed 2nd Edition of EN 61000-4-2

A first draft of the proposed IEC 61000-4-2 2nd Edition was circulated on 5th January 2001. It is a complete re-write of the existing standard, with several new guidance annexes. Its main differences from the existing EN/IEC 61000-4-2 are…

- The number of discharges to be 50 on each test point
- A clear area around the test site is defined
- The generator specification is substantially more detailed
- There are new requirements for calibration
- There are extra requirements on the GRP, HCP, VCP and bleed wires
- In the setup: the EUT cables are to be terminated with CDNs or EM Clamps; there is a new setup for “small” table-top EUTs; the method for ungrounded equipment is included as per A2 to the first edition
- There is more detailed guidance on test methods; for contact discharge, it is no longer necessary to satisfy all lower levels, though it still is for air discharge
- An “escalation strategy” is presented for difficult-to-reproduce failures

However, there are a number of contentious issues in the above list, and at the time of writing (October 2004) this proposed 2nd edition is still going through the IEC committee process with no end yet in sight.

On-site ESD testing

On-site ESD testing to EN 61000-4-2 is very easy to do, because of the relatively simple test set-up required and the easy portability of the test gear (e.g. using an ESD gun that is battery powered and comes with a spare battery pack, so one can be charging while the other is in use).

Section 7.2 and Figure 7 of EN 61000-4-2 describe what it calls 'post installation tests' which are suitable for on-site testing and merely requires the use of a 0.3 x 2 metre reference plane, which is not *too* difficult to carry onto most sites. On-site ESD tests are also described in considerable detail in chapter 10 of [19].

On-site ESD testing can interfere with other equipment or systems. See the next section on dealing with this.

Preventing ESD tests from causing interference

Important Safety Note: Don't forget that interference, especially with aircraft or other vehicular systems, some machinery or process control systems, and implanted electronic devices such as pacemakers, can have lethal consequences and appropriate precautions **must** be taken to make sure that nobody's safety is compromised by ESD testing.

It is also a good idea to take precautions where there is a possibility of significant financial loss being caused by the interference from on-site testing.

When ESD tests are performed, the very wideband frequencies generated by the spark discharges can be emitted from cables and metalwork, especially at their resonant frequencies. These emissions can interfere with nearby equipment, so it may be necessary to conduct the tests in a location that is far enough away from other equipment not to cause a nuisance.

Some EMC test laboratories perform their ESD tests inside shielded rooms or shielded tents (no need for any RF absorber if the enclosure is room-sized) to prevent emissions from causing interference problems. Shielding tents have the advantage that they are easily movable (compared with a metal screened room) and can be packed away when not in use.

Some EMC laboratories and manufacturers use metal shipping containers – easily modified with gasketted doors, mesh-shielded ventilation and filtered mains supplies – as shielded rooms for ESD and other transient immunity tests, to help avoid interference with nearby equipment. The containers are usually painted nice bright colours inside and make a very low-cost type of shielded room, strong and stable enough to be stacked several high if floor area is tight.

But personnel ESD immunity tests are often done outside shielded chambers, or on-site, for example for diagnostics or when collecting test evidence to support a Technical Construction File for a large system or an installation.

Of course, the product being tested must operate properly in the first place, and if testing on a site that suffers from high levels of electromagnetic 'noise' it may be necessary to use filtering and shielding techniques to be able to distinguish between the effects of the ambient noise and the effects of the test. Similarly, where the ESD testing might cause interference to other equipment, it may be necessary to use filtering and shielding techniques to prevent this from happening.

A selection of typical REO Filters for AC supplies

If either of the above situations arises, 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 [20]. It may be possible to shield the system being tested with a shielded tent, and filter each of the cables entering or leaving the tent at least with a large ferrite clamp or number of small clip-on ferrite clamps, placed at the point where the cable penetrates the tent. Ferrishield, Inc. make some very large ferrites for this purpose: their CS28B2000 has its peak impedance at 300MHz, CS25B2000 at 700MHz, and CS20B2000 at 2.45GHz. Don't forget that a shielded tent usually requires a shielded bottom side that is joined all around its edges – it may not be enough to simply drape a five-sided shielding tent over the equipment being tested.

An example of a low-cost shielded tent
(courtesy of Hitek Electronic Materials Ltd)

If working on exposed live equipment an isolating transformer may be able to be used to help reduce electric shock hazards. 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 the likely surge levels (at least 6kV, using the IEC 61000-4-5 test method) to help ensure safety.

Examples of REO isolating transformers

REO isolating transformer with low primary to secondary capacitances

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 sure 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/IEC 61010-1, at least.

Testing using alternative methods from those in EN 61000-4-2 cannot give any real confidence that "full-compliance" tests for personnel ESD immunity would be passed. But such non-compliant tests may be valuable for improving the reliability of a product, especially if they simulate the personnel ESD voltages and currents that could be present in its real-life electromagnetic environments.

Many equipment rental companies have stocks of EN 61000-4-2 calibrated test gear needed to do personnel ESD immunity 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. Note that saving money on test labs by doing testing yourself requires competence (appropriate skills and experience, and attention to detail and documentation).

The test set-ups for personnel ESD immunity are not difficult to achieve in a typical manufacturing company, as they don't necessarily have to be performed in special test chambers – but see the later section preventing ESD tests from causing interference.

However, a number of alternative personnel ESD generators and test methods can be used if EN 61000-4-2 compliance is not important. The use of home-made ESD guns, for example made by modifying piezo-electric gas lighters, can be helpful for testing during design and development, fault finding and QA, but are not described here, see [11] and [21] for more on these.

Second-hand and hired ESD testers are also available, but it helps to check that they comply with EN 61000-4-2:1995 (or later) – as some older versions might have risetimes of 5ns instead of 0.7-1ns. It is always preferable to use an ESD tester that is compliant to EN/IEC 61000-4-2, where this is the basic ESD standard that the product's EMC immunity standard references.

For all but compliance and 'pre-compliance' tests, using an uncalibrated test (for which the quantitative measurement is not traceable to the national physical standards) is not very important. But it *is* very important for *any* tests to be *repeatable* – so consistency is always required in the test equipment and test methodology.

During design, development or QA testing, always try to reproduce the final assembly of the circuit being tested (shielding, earth bonding, proximity to metal objects or structures, etc.), as the stray inductances and capacitances in the final build state can have an important effect on the ESD behaviour of the circuit. And always carefully record all the details of the test set-up in the test documentation (photographs can be very useful).

Correlating alternative test methods with EN 61000-4-2

When an alternative ESD test method is used for design, development, or troubleshooting after a test failure – repeatability is very important (even though the correlation with EN 61000-4-2 may not be). All such tests will need to follow a procedure that has been carefully worked out and documented to help ensure that adequate repeatability is achieved.

When alternative methods are used as part of a QA programme, or to check variants, upgrades, or small modifications, a 'golden product' is recommended to act as a sort of 'calibration' for the test equipment and test method. Golden product techniques allow low-cost EMC test gear and faster test methods to be used with much more confidence. Refer to section 1.9 of [22] for a detailed description of how to use the golden product correlation method.

If alternative methods are used to gain sufficient confidence for declaring compliance to the EMCD, the golden product method is very strongly recommended. Without a golden product or some similar basis for correlating a proper compliance test (using EN 61000-4-2) with the alternative method actually used, the alternative method might only provide any confidence at all if gross levels of overtesting are applied, and this can result in very expensive products.

For EMC tests where the waveshape of the stimulus is important, as it is for ESD testing, simply increasing the test level may not always compensate for the incorrect test method. In the case of ESD, the risetime, fall-time, waveshape and energy of the test stimulus all have at least as significant an effect as the peak test voltage (in kV).

The closer a test method is to using the proper test transducers and methodology in EN 61000-4-2, the more likely it is that a good correlation will be achieved. So testing with a modified piezo-electric gas lighter (for example) might only be able to correlated with EN 61000-4-2 for a particular build state of a specific product.

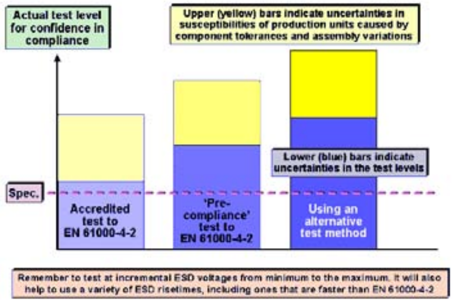
Determining an 'engineering margin'

Even having EN 61000-4-2 fully applied by the same accredited EMC test laboratory cannot guarantee that a given EUT will be exposed to *exactly* the same ESD stimuli each time it is tested. But if EMC enforcement agents test a product, they are unlikely to use the same test laboratory or model of ESD gun as the manufacturer. So, an ESD immunity engineering margin is recommended, because…

- there are differences between the actual ESD test levels when a gun is discharged into the specified 2Ω load, compared with the guns settings or displayed levels;
- there can be significant variations in the actual ESD waveforms produced by different models of guns into the same locations on the same product;
- there are variations in the test methods, even when applied by the same staff at the same test laboratory (for example, different test points may be selected);
- serially-manufactured products have variable immunity performance due to component and assembly tolerances (IC die-shrinks or mask-shrinks are a major concern in this area);
- analogue and digital circuits have non-linear sensitivity to RF, so small variations in risetime or level can have large effects on performance.

So, when testing an example product to EN 61000-4-2 in a fully compliant manner, at least a 6dB higher test level (e.g. 16kV instead of 8kV) is suggested, for all possible test locations, with the product still meeting its required functional specifications.

The need for engineering margins



Where a manufacturer is using an ESD gun or test method that is not identical to EN 61000-4-2, a larger engineering margin is recommended (but very hard to determine other than by direct comparison of test methods on the same EUT).

EN 61000-4-2 requires testing to not exceed the specified maximum test level, to avoid damage to the product – but if the customer requests testing to higher levels the test laboratory will ignore that requirement. ESD testing is usually one of the last tests done during EMC compliance testing, because of the possibility of actual damage to equipment.

The increments in the ESD test levels specified by EN 61000-4-2 can be added to by additional steps, if specified by the customer. So instead of going straight from ±8kV air discharge to ±15kV, additional tests at ±10 and ±12kV might be added, for extra confidence.

It is clear that saving costs by using alternative ESD test methods can lead to over-engineering. The additional cost to make the product pass the alternative test method with the necessary engineering margins should be weighed against the cost of doing the testing properly.

References

[1] IEC 61000-4-2:2001 "*Electromagnetic Compatibility (EMC) – Part 4: Testing and measurement techniques – Section 2: Electrostatic discharge immunity test. Basic EMC Publication"* (a consolidated version with the same content as the 1995 version plus amendments A1:1998 and A2:2000)

[2] EN 61000-4-2:1995 "*Electromagnetic Compatibility (EMC) – Part 4: Testing and measurement techniques – Section 2: Electrostatic discharge immunity test. Basic EMC Publication"* (despite its printed date, the versions supplied by EU National Standards Bodies, such as British Standards, incorporate the IEC amendments A1 and A2, see above).

[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/electr_equipment/emc/index.htm.

[4] European Union Directive 2004/108/EC on Electromagnetic Compatibility (2nd Edition), from: http://europa.eu.int/eur-lex/lex/LexUriServ/site/en/oj/2004/l_390/l_39020041231 en00240037.pdf

[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] "*Study to Predict the Electromagnetic Interference for a Typical House in 2010*", Anita Woogara, 17 September 1999, Radiocommunications Agency Report reference MDC001D002-1.0. This Agency has now been absorbed into Ofcom, and at the time of writing this report is available via the static legacy section of the Ofcom website, at: http://www.ofcom.org.uk/static/archive/ra/topics/research/topics.htm.

[8] The 'Mr Static' series of articles by Niels Jonassen, Compliance Engineering magazine, 2000-2002. Visit http://www.ce-mag.com and search for Niels.

[9] Keytek Minizap MZ-15, supplied by Thermo Electron Corporation. Visit http://www.thermo.com and search by the product name. Information on performing furniture discharge tests is given in the products' handbook.

[10] "*Unusual Forms of ESD and Their Effects*" by Doug Smith, Conformity 2001, page 203. This article originally appeared in the 1999 EOS/ESD Symposium Handbook, and can be downloaded from http://www.emcesd.com.

[11] Doug Smith's website, from which numerous articles on real-life ESD can be downloaded, is: http://emcesd.com.

[12] "*Characterization of Human Metal ESD Reference Discharge Event and Correlation of Generator Parameters to Failure Levels – Part I: Reference Event*" and – "*Part II: Correlation of Generator Parameters to Failure Levels*" by K Wang, D Pommerneke, R Chundru, T Van Doren, F P Centola, and J S Huang, IEEE Transactions on EMC Vol. 46 No. 4 November 2004, pages 498-511.

[13] Examples of interference due to ESD can be found in the "*Banana Skins compendium*", via a link from http://www.compliance-club.com or at: http://www.compliance-club.com/archive1/Bananaskins.htm, especially (at the time of writing) numbers 16, 23, 129, 138, 170, 199, 206, 219 and 251.

[14] The "F-PEG-1 Proximity ESD Field Generator" made by Fischer Custom Communications Inc., visit http://www.emcesd.com/products/peg-1.pdf for details. The product is available from Fischer but does not feature on their website http://www.fischercc.com.

[15] "*Why EMC testing is Inadequate for Functional Safety*", Keith Armstrong, IEEE 2004 International EMC Symposium, Santa Clara, August 9-13 2004, ISBN 0-7803-8443-1, pp 145-149. Also: Conformity magazine, March 2005 pp 15-23, downloadable via http://www.conformity.com.

[16] "*The IEE's Training Course on EMC for Functional Safety (also for high-reliability and legal metrology)*", visit http://www.iee.org for their event calendar to check the date of the next course. If no courses are listed contact the IEE's Functional Safety Professional Network (via the same IEE homepage) and ask.

[17] For example: the 'EM Aware®' ESD Event Monitors (amongst others) from Credence Technologies, http://www.credencetech.com/Aware.htm

[18] EN ISO/IEC 17025:2000 "*General Requirements for the Competence of Testing and Calibration Laboratories*"

[19] "*EMC for Systems and Installations*", Tim Williams and Keith Armstrong, Newnes 2000, ISBN 0-7506-4167-3, RS Components Part No. 377-6463

[20] *"EMC for Systems and Installations – Part 4 – Filtering and Shielding",* Keith Armstrong, EMC & Compliance Journal, August 2000, pages 17-26, download it from: http://www.compliance-club.com/KeithArmstrongPortfolio.

[21] "*EMC Testing Part 3 – Fast Transient Burst, Surge, Electrostatic Discharge*", Tim Williams and Keith Armstrong, EMC & Compliance Journal June 2001, pp 19-29. On-line at http://www.compliance-club.com/KeithArmstrongPortfolio.

[22] "*EMC Testing Part 1 – Radiated Emissions*", Tim Williams and Keith Armstrong, EMC & Compliance Journal February 2001, pp 27-39. On-line at http://www.compliance-club.com/KeithArmstrongPortfolio.

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.

The Author

Keith Armstrong from Cherry Clough Consultants

> ***This guide is one of a series. Email us at main@reo.co.uk if you would like to receive all of our mini guides and to be entered onto our mailing list***

Keith Armstrong graduated in electrical engineering with a B.Sc (Hons.) from Imperial College London in 1972, majoring in analogue circuit design and electromagnetic field theory, with a Upper Second Class Honours (Cum Laude). Much of his life since then has involved controlling real-life interference problems in high-technology products, systems, and installations, for a variety of companies and organisations in a range of industries.

Keith has been a Chartered Electrical Engineer (UK) since 1978, a Group 1 European Engineer since 1988, and has written and presented a great many papers on EMC. He is a past chairman of the IEE’s Professional Group (E2) on Electromagnetic Compatibility, is a member of the IEEE’s EMC Society, and chairs the IEE’s Working Group on 'EMC and Functional Safety'.

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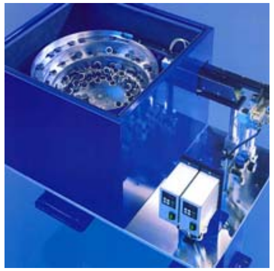

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Controllers for vibratory feeders

Communication Systems

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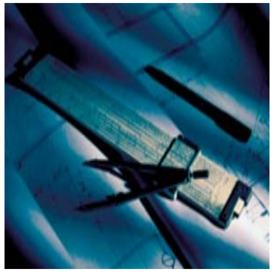
Train Systems

Chokes and high frequency transformers

Inductive Components

Chokes, resistors and transformers



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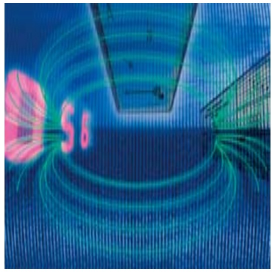
Rheostats and variacs

Renewable Systems

Solar transformers

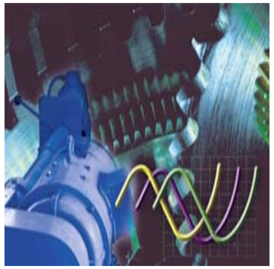


Test Systems

Power supplies and load banks

Power Electronics

Phase-angle and frequency controllers



Motor Control Systems

Soft-starts

Drive Systems

Filters and braking resistors

Medical Systems

Medical Transformers