Chapter 4

Immunity tests

4.1 RF immunity

Until the EMC Directive, most commercial immunity testing was not mandatory, but driven by customer requirements for reliability in the presence of interference. Military and aerospace immunity test standards have been in existence for some time and have occasionally been called up in commercial contracts in default of any other available or applicable standards. These allow for both conducted and radiated RF immunity test methods. The major established commercial standard tests were those listed until the mid-90s in IEC 801. These have now been superseded by IEC 61000-4-3 and -6, for radiated and conducted tests respectively. EN 55 020 (similar but not identical to CISPR 20) requires both conducted and radiated immunity tests but applies only to broadcast receivers and related equipment.

Radiated field immunity testing, in common with radiated emissions testing, suffers from considerable variability of results due to the physical conditions of the test set-up. Layout of the EUT and its interconnecting cables affects the RF currents and voltages induced within the EUT to a great extent. At frequencies where the EUT is electrically small, cable coupling predominates and hence cable layout and termination must be specified in the test procedure.

4.1.1 Equipment

Figure 4.1 shows the components of a typical radiated immunity test set-up in a screened room.

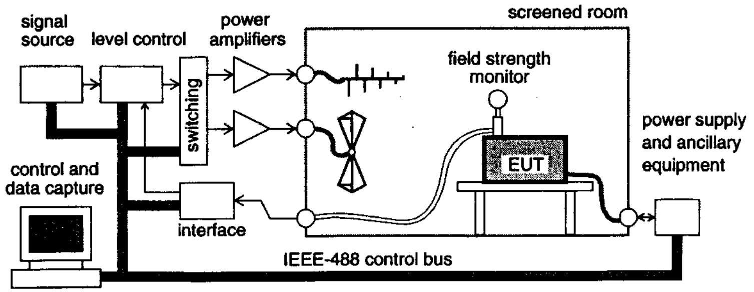

Figure 4.1 RF immunity test set-up

The basic requirements are an RF signal source, a broadband power amplifier and a transducer. The latter may be a set of antennas, a transmission line cell or a stripline. These will enable you to generate a field at the EUT's position, but for accurate control of the field strength there must be some means to control and calibrate the level that is fed to the transducer. A test house will normally integrate these components with computer control to automate the frequency sweep and levelling functions.

4.1.1.1 Signal source

Any RF signal generator that covers the required frequency range (80–1000MHz for IEC 61000-4-3, 150kHz–80MHz for IEC 61000-4-6) will be useable. Its output level must match the input requirement of the power amplifier with a margin of a few dB. This is typically 0dBm and is not a problem.

IEC 61000-4-3 calls for the RF carrier to be modulated at 1kHz to a depth of 80%, although the previous version (IEC 801-3) did not require modulation. This can be done within the signal generator or by a separate modulator. Typically, a synthesized signal generator will be used for stepped application. Control software will set the frequency in steps across the band to be covered. The required frequency accuracy depends on whether the EUT exhibits any narrowband responses to interference. A manual frequency setting ability is necessary for when you want to investigate the response around particular frequencies. Be careful that no transient level changes are caused within the signal generator by range changing or frequency stepping, since these will be amplified and applied as transient fields to the EUT, possibly causing an erroneous susceptibility.

4.1.1.2 Power amplifier

Most signal sources will not have sufficient output level on their own, and you will require a set of power amplifiers to increase the level. The power output needed will depend on the field strength that you have to generate at the EUT, and on the characteristics of the transducers you use to do this. As well as the antenna factor, an antenna will be characterized for the power needed to provide a given field strength at a set distance. This can be specified either directly or as the gain of the antenna. The relationship between antenna gain, power supplied to the antenna and field strength in the far field is:

$$P_t = (r \cdot E)^2/(30 \cdot G) \qquad (4.1)$$

where P_t is the antenna power input
r is the distance from the antenna in metres
E is the field strength at r in volts/metre
G is the numerical antenna gain [= antilog(G_{dB}/10)] over isotropic

The gain of a broadband antenna varies with frequency and hence the required power for a given field strength will also vary with frequency. Figure 4.2 shows a typical power requirement versus frequency for an unmodulated field strength of 10V/m at a distance of 1m. Less power is needed at high frequencies because of the higher gain of the log periodic antenna. You can also see the large increase in power required by the conventional biconical below 80MHz; it is partly because of this that the lowest frequency for radiated immunity testing was chosen to be 80MHz, although subsequent developments in broadband antennas have improved the situation (see section 4.1.1.4).

The power output versus bandwidth is the most important parameter of the power amplifier you will choose and it largely determines the cost of the unit. Very broad band amplifiers (1–1000MHz) are available with powers of a few watts, but this may not be enough to generate required field strengths from a biconical antenna in the low VHF region. A higher power amplifier with a bandwidth restricted to 30–300MHz will also be needed. If you can use two amplifiers, each matched to the bandwidth and power requirements of the two antennas you are using, this will minimize switching requirements to cover the whole frequency sweep. Note that the power delivered to the antenna (net power) is not the same as power supplied by the amplifier unless the antenna is perfectly matched, a situation which does not occur in practice. With high VSWR (such as a biconical or standard bilog below 70MHz) most of the power supplied to the amplifier is reflected back to it, which is inefficient and can be damaging to the amplifier.

Some over-rating of the power output is necessary to allow for modulation, system losses and for the ability to test at a greater distance. Modulation at 80%, as required by IEC 61000-4-3, increases the instantaneous power requirement by a factor of 5.2dB (3.3 times) over the unmodulated requirement, as shown in Figure 4.2. If you will be

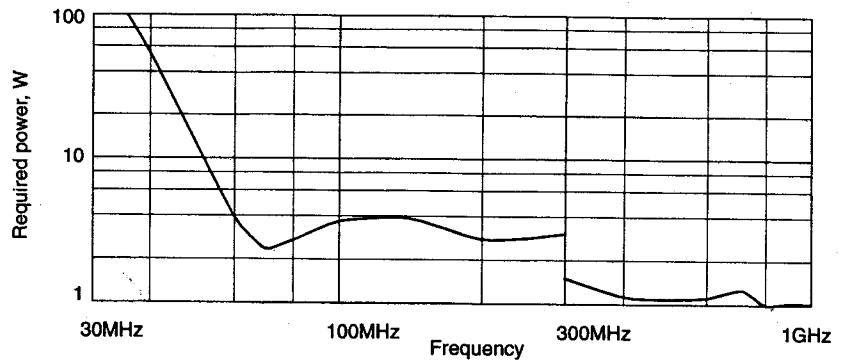

Figure 4.2 Required power versus frequency for 10V/m at 1m, biconical and log periodic antennas

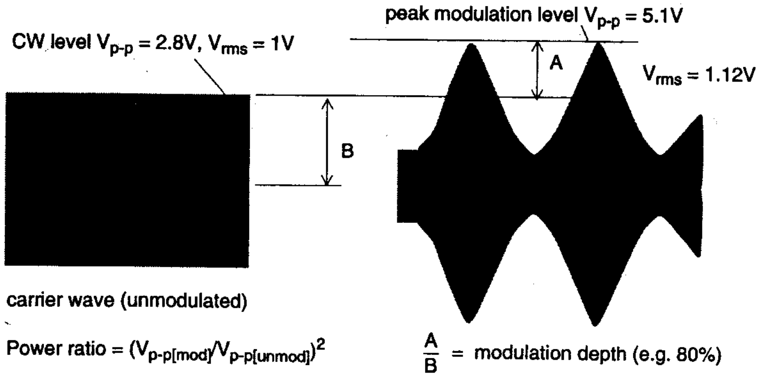

Figure 4.3 Modulated versus unmodulated waveforms

using the system in a non-anechoic screened room (section 4.1.2.1) the system should be further over-rated by at least 6dB (four times power) to allow for field nulls at certain frequencies due to room reflections. If the system uses other transducers such as a TEM cell or stripline (discussed in section 4.1.1.4) rather than a set of antennas, then the power output requirement for a given field strength will be significantly less. Thus there is a direct cost tradeoff between the type of transducer used and the necessary power of the amplifier.

Other factors that you should take into account (apart from cost) when specifying a power amplifier are:

- linearity: RF immunity testing can tolerate some distortion but this should not be excessive, since it will appear as harmonics of the test frequency and may give rise to spurious responses in the EUT; according to the standard, distortion products should be at least −15dB relative to the carrier;
- ruggedness: the amplifier should be able to operate at full power continuously, without shutting itself down, into an infinite VSWR, i.e. an open or short circuit load. Test antennas are not perfect, and neither are the working practices of test engineers!
- power gain: full power output must be obtainable from the expected level of input signal, with some safety margin, across the whole frequency band;
- reliability and maintainability: in a typical test facility you are unlikely to have access to several amplifiers, so when it goes faulty you need to have assurance that it can be quickly repaired.

4.1.1.3 Field strength monitor and levelling

It is essential to be able to ensure the correct field strength at the EUT. Reflections and field distortion by the EUT will cause different field strength values from those which would be expected in free space, and these values will vary as the frequency band is swept. You are recommended to re-read section 3.1.5 on sources of uncertainty in emissions measurements, as the issues discussed there apply equally to measurements of field strength used for immunity tests.

RF fields can be determined by a broadband field sensor, normally in the form of a small dipole and detector replicated in three orthogonal planes so that the assembly is sensitive to fields of any polarization. In the simplest extreme, the unit can be battery powered with a local meter so that the operator must continuously observe the field strength and correct the output level manually. A more sophisticated set-up uses a fibre optic data link from the sensor, so that the field is not disturbed by an extraneous cable.

There are two major methods of controlling the applied field strength, by closed loop levelling, or by substitution. In non-anechoic screened rooms, closed-loop levelling as specified in the early IEC 801-3 is usual. In this method, the field sensor is placed next to the EUT and the power applied to the transducer is adjusted to provide the correct field strength value, while the sweep is in progress. While this method seems intuitively correct, in practice it has several disadvantages:

- the sensor measures the field only at one point; at other points around the EUT, the field can change significantly, especially when the EUT is large compared to a wavelength
- if the sensor by chance is positioned in a null at a particular frequency, the result will be an increase in applied power to attempt to correct the field strength, with a consequent increase, often well over the intended value, at other locations
- with a stepped frequency application, attempting to find the correct field strength at each step may result in over-correction of the applied power and hence a transient excess of field strength

Clearly it is possible to inadvertently over-test the EUT by this method. In an anechoic chamber and with transducers such as TEM cells, the substitution method is preferred, and is the only method allowed in the current standard IEC 61000-4-3. This involves pre-calibrating the empty chamber or cell by measuring, at each frequency, the power required to generate a given field strength. The EUT is then introduced and the same power is applied. The rationale for this method is that any disturbances in field caused by the EUT are taken at face value, and no attempt is made to correct for them by monitoring the actual field at the EUT; instead the field which would be present in the absence of the EUT is used as the controlled parameter. The method is only really viable when the field uniformity is closely defined (see section 4.1.2.2), but in these circumstances it is much preferable. The parameter which is best controlled in the pre-calibration is the amplifier output power (forward power) rather than the net power supplied to the antenna; this is acceptable provided that the antenna characteristics are not significantly changed with the introduction of the EUT, which in turn dictates as great a separation distance as possible.

4.1.1.4 Transducers

The radiated field can be generated by an antenna as already discussed. You will normally want to use the same antennas as you have for radiated emissions tests, i.e. biconical and log periodic, and this is perfectly acceptable. The power handling ability of these antennas is limited by the balun transformer which is placed at the antenna's feed point. This is a wideband ferrite cored 1:1 transformer which converts the *bal*anced feed of the dipole to the *un*balanced connection of the coax cable (hence bal-un). It is supplied as part of the antenna and the antenna calibration includes a factor to allow for balun losses, which are usually very slight. Nevertheless some of the power delivered to the antenna ends up as heat in the balun core and windings, and this sets a limit to the maximum power the antenna can take.

The high VSWR of broadband antennas (see section 3.1.5.1 and Appendix C section C.2), particularly of the biconical at low frequencies, means that much of the feed power is reflected rather than radiated, which accounts for the poor efficiency at these frequencies. Figure 4.4 shows a typical VSWR versus frequency plot for three types of BiLog. Much effort has been put into antenna development for immunity testing and the curves for the extended (X-Wing) models show the advances that have been made. As with radiated emissions testing, the plane polarization of the antennas calls for two test runs, once with horizontal and once with vertical polarization.

Two other types of transducer are available for radiated RF immunity testing of small EUTs. These are the stripline and the TEM cell (or Crawford cell).

Stripline

The difficulties of testing with antennas led to developments in the 1970s of alternative forms of irradiation of the EUT. Groenveld and de Jong [71] designed a simple transmission line construction which provides a uniform electromagnetic field between its plates over a comparatively small volume, and this was written in to both IEC 801 part 3 (1984) and EN 55020 as a recommended method of performing part of the

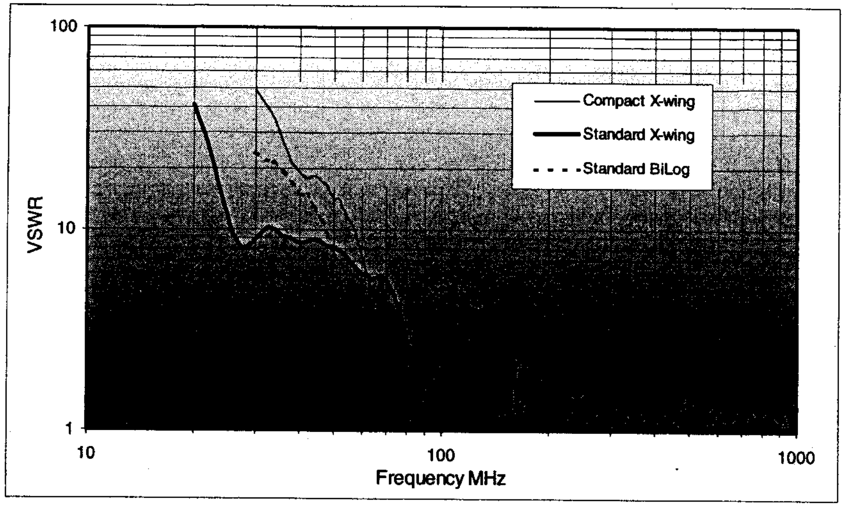

Figure 4.4 VSWR of BiLog antennas (source: Schaffner Chase EMC)

radiated immunity testing. IEC 61000-4-3 allows the use of the stripline only if the field homogeneity requirements are met, and if the EUT and wires can be arranged as the standard dictates.

The stripline is essentially two parallel plates between which the field is developed, fed at one end through a tapered matching section and terminated at the other through an identical section. The dimensions of the parallel section of line are defined in the standards as 80 x 80 x 80cm, and the EUT is placed within this volume on an insulating support over one of the plates (Figure 4.5). The field between the plates is propagated in TEM (transverse electro-magnetic) mode, which has the same characteristics as free space. The calibration of the stripline is theoretically very simple: assuming proper matching, the field is directly proportional to the voltage at the feed point divided by the distance between the plates:

$$E = V/h \text{ volts per metre} \tag{4.2}$$

In practice some variations from the ideal are likely and calibration using a short probe extending into the test volume is advisable. If the stripline test is conducted in a screened room reflections from the walls will disturb the propagation characteristics quite severely, as they do with antennas, and you will have to surround the stripline with absorbing plates to dampen these reflections. This will be cheaper than lining the walls with anechoic absorber.

The accuracy of the stripline depends to a large extent on the dimensions of the EUT. IEC 801-3 recommends that the dimensions should not exceed 25cm, while EN 55020 allows a height up to 0.7m with a calibration correction factor. Either way, you can only use the stripline on fairly small test objects. There is also an upper frequency restriction of 150–200MHz, above which the plate spacing is greater than a half-wavelength and the transmission mode becomes complex so that the field is subject to variability. It would be quite possible though to use the stripline for immunity testing below 200MHz (theoretically down to DC if required) along with a log periodic antenna above 200MHz, to get around the unsuitability of the biconical for low frequency immunity tests. The power requirement of the stripline for a field strength of 10V/m is no more than a few watts.

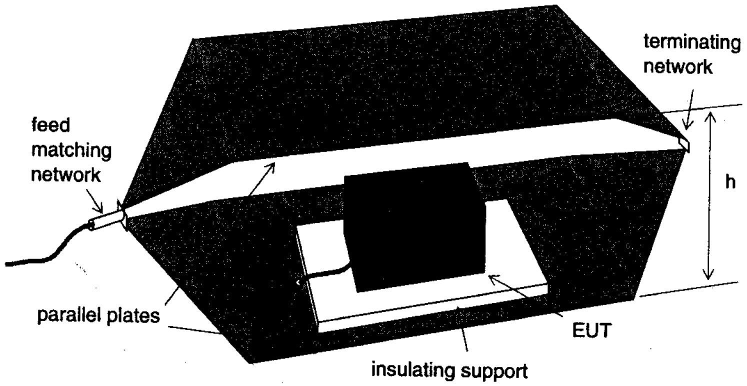

Figure 4.5 The stripline

A particular characteristic of testing with the stripline is that the connecting cables for the EUT are led directly through one of the plates and are not exposed to the field for more than a few centimetres. Thus it only tests for direct exposure of the enclosure to the field, and for full immunity testing it should be used in conjunction with common mode conducted current or voltage injection. Also, you will need to be able to re-orient the EUT through all three axes to determine the direction of maximum susceptibility.

The TEM cell

An alternative to the stripline for small EUTs and low frequencies is the TEM or Crawford cell. In this device the field is totally enclosed within a transmission line structure, and the EUT is inserted within the transmission line. It is essentially a parallel plate stripline in which one of the plates has been extended to completely enclose the other. Or, you can think of it as a screened enclosure forming one half of the transmission line while an internal plate stretching between the sides forms the other half.

The advantage of the TEM cell, like the stripline, is its small size, low cost and lack of need for high power drive; it can easily be used within the development lab. A further advantage, not shared with the stripline, is that it needs no further screening to attenuate external radiated fields. The disadvantage is that a window is needed in the enclosure if you need to view the operation of the EUT while it is being tested, if for example it is a television set or a measuring instrument. It is not so suitable for do-it-yourself construction as the stripline. As with the stripline, it can only be used for small EUTs (dimensions up to a third of the volume within the cell, see Table 4.1) and it suffers from a low upper frequency limit. If the overall dimensions are increased to allow larger EUTs, then the upper frequency limit is reduced in direct proportion.

The GTEM

The GTEM cell [63][72] overcomes some of these disadvantages and holds out the promise of lower cost, well defined testing. The restriction on upper frequency limit is

Table 4.1 TEM cell dimensions versus frequency range

Cell size cm^2	Maximum EUT size W x D x H cm	Frequency range
30.5	15 x 15 x 5	DC – 500MHz
61	20 x 20 x 7.5	DC – 300MHz
91.5	30.5 x 30.5 x 10	DC – 200MHz
122	40.5 x 40.5 x 15	DC – 150MHz
183	61 x 61 x 20	DC – 100MHz

removed by tapering the transmission line continuously outward from feed point to termination, and combining a tapered resistive load for the lower frequencies with an anechoic absorber load for the higher frequencies. This allows even large cells, with test volume heights up to 1.75m and potentially larger, to be made with a useable upper frequency exceeding 1GHz (hence the "G" in GTEM). The actual unit looks from the outside something like a pyramid on its side. Its use for emissions testing has already been discussed in section 3.1.2.8.

The GTEM has clear advantages for immunity testing since it allows the full frequency range to be applied in one sweep, without the need for a screened enclosure – or for high power amplifiers, since its efficiency is much higher than an antenna. As with the other TEM methods, the EUT must be subjected to tests in a number of orthogonal orientations, and cable dressing needs to be considered carefully. A feature of TEM cells is the intentionally transverse nature of the field, but at some frequencies it has been shown [62] that the field distribution in a GTEM includes a large longitudinal component (Figure 4.6). The amplitude and frequency of this component depends on the size of the cell and the position along the length at which it is measured. In the graph, 0.0m refers to a position opposite the centre of the door, –1.0m is close to the absorber and +1.0m is towards the apex. The existence of a field in this orientation means that if the field strength is controlled only on the primary (vertical) component, there is the likelihood of over-testing or at least variability in the actual test field at such frequencies.

Its advantages are so attractive though, particularly in terms of allowing one relatively inexpensive (c. £50,000) facility to perform all RF EMC testing, that considerable resources are being put into characterizing the GTEM's operation and in persuading the standards authorities to accept it as an alternative test method. Two drafts are in circulation at the time of writing: an extended annex to IEC 61000-4-3 describing the use of TEM and GTEM cells for immunity tests, and a new document, IEC 61000-4-20, which is intended to cover both emissions and immunity tests in such cells. A large part of the work in producing these drafts involves finding acceptable solutions to the field uniformity and cable layout problems outlined above, that are consistent with existing test methods in screened chambers.

4.1.2 Facilities

RF immunity testing, like radiated emissions testing, cannot readily be carried out on the development bench. You will need to have a dedicated area set aside for these tests – which may be in the same area as for the emissions tests – which includes the RF field generating equipment and, most importantly, has a screened room.

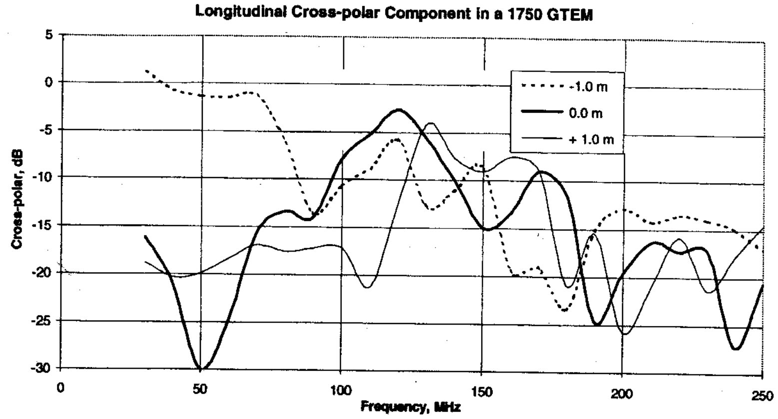

Figure 4.6 Longitudinal field components in the GTEM (dB with respect to vertical component)
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4.1.2.1 The screened room

RF immunity tests covering the whole frequency bands specified in the standards should be carried out in a screened room to comply with various national regulations prohibiting interference to radio services. Recommended shielding performance is at least 100dB attenuation over the range 10MHz to 1GHz [143]; this will reduce internal field strengths of 10V/m to less than 40dBμV/m outside. The shielding attenuation depends on the constructional methods of the room in exactly the same way as described for shielded equipment enclosures in section 8.3. It is quite often possible to trade off performance against reduced construction cost, but a typical high-performance room will be built up from modular steel-and-wood sandwich panels, welded or clamped together. Ventilation apertures will use honeycomb panels; the room will be windowless. All electrical services entering the chamber will be filtered. Lighting will be by incandescent lamps as fluorescent types emit broadband interference. The access door construction is critical, and it is normal to have a double wiping action "knife-edge" door making contact all round the frame via beryllium copper finger strip.

In addition, the screened room isolates the test and support instrumentation from the RF field. The interconnecting cables leaving the room should be suitably screened and filtered themselves. A removable bulkhead panel is often provided which can carry interchangeable RF connectors and filtered power and signal connectors. This is particularly important for a test house whose customers may have many and varied signal and power cable types, each of which must be provided with a suitable filter. As well as for RF immunity tests, a screened room is useful for other EMC tests as it establishes a good ground reference plane and an electro-magnetically quiet zone. Figure 4.7 shows the features of a typical screened chamber installation.

4.1.2.2 Room resonances and field uniformity

An un-lined room will exhibit field peaks and nulls at various frequencies determined by its dimensions. The larger the room, the lower the resonant frequencies. This

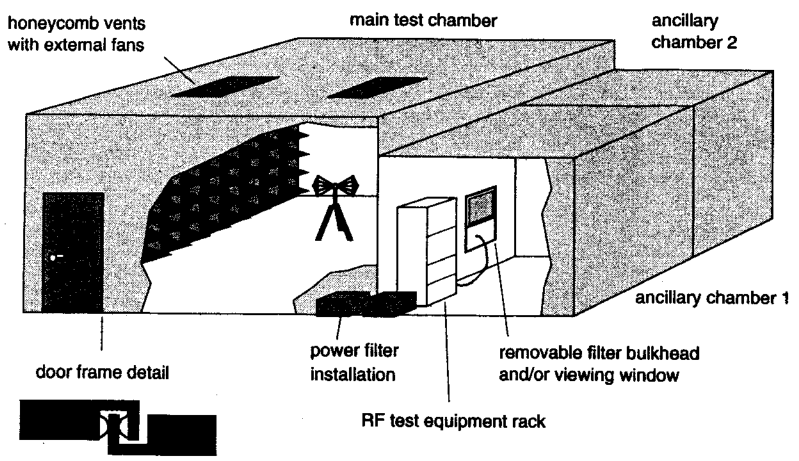


Figure 4.7 Typical screened room installation

phenomenon is discussed again in section 8.3.3 and equation (8.6) gives the lowest resonant frequency. For a room of 2.5 x 2.5 x 5m this works out to around 70MHz.

To damp these resonances the room can be lined with absorber material, typically carbon loaded foam shaped into pyramidal sections, which reduces wall reflections. The room is then said to be "anechoic" if all walls and floor are lined or "semi-anechoic" if the floor is left reflective. Such material is expensive – a fully-lined room will be more than double the cost of an unlined one – and in any case loses its efficiency below about 200MHz, although developments in materials are improving the situation. Very large absorber pyramids are needed for lower frequencies and these reduce the useable volume of the room unacceptably. Measurements made in the frequency range 30–200MHz can therefore be subject to very large uncertainties, of the order of 30–40dB, at the resonant frequencies, and are also not repeatable, because a small change in the antenna or EUT position can give a large change in the field distribution. The discussion in respect of emissions testing in screened rooms is relevant here; see Figure 3.14 for an example of the frequency response of a poorly-lined chamber.

An alternative to pyramidal absorbers is to line the walls with ferrite tiles or ferrite grid absorbers. These materials are now widely available and can claim extremely good results in damping room resonances, but the ferrites are also expensive and heavy and bring their own problems in fixing and mechanical support. Careful placement of absorbing blocks at E-field maxima within the room, or of ferrite absorbers at current maxima on the walls, has been shown [29][56] to have a helpful effect on resonances at comparatively little cost, and can be recommended for pre-compliance work when a chamber is available that would be too expensive to line completely.

Field uniformity

A serious effect of these resonances is that they cause standing waves in the field distribution throughout the chamber. At the higher frequencies these standing waves can result in significant variation in the field strength over quite a small volume, certainly smaller than is occupied by the EUT. As a practical measure of the effectiveness of anechoic lining, and to calibrate the field strength that will be used in the actual test, IEC 61000-4-3 specifies a test of the field uniformity to be made at 16 points over a grid covering a plane area. The measurements are made in the absence of the EUT and the grid corresponds to the position of the front face of the EUT. The field strength over at least 75% (i.e. 12) of the measurement points must be within the tolerance –0dB/+6dB to be acceptable, though a tolerance of greater than +6dB is allowed provided it is stated in the test report. The tolerance is quoted in this asymmetrical way to ensure that the applied field strength is never less than the stated level, but it does imply that over-testing by up to a factor of two is possible. Figure 4.8 shows the geometry of the recommended field uniformity criterion. This approach is still under development as more experience is gained in its application, and we can expect further amendments to the method in years to come.

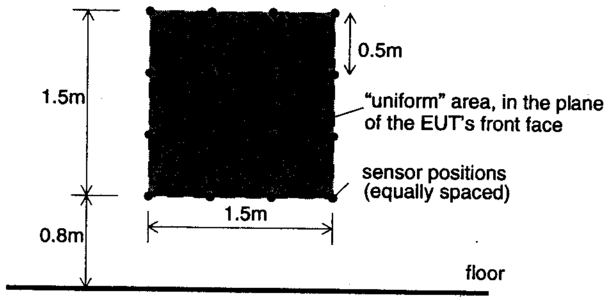


Figure 4.8 Field uniformity measurement in IEC 61000-4-3

4.1.2.3 Ancillary equipment

You will need a range of support equipment in addition to the RF test equipment described in detail in section 4.1.1. Obviously, control and data capture computing equipment will be required for a comprehensive set-up. Various test jigs and coupling networks, depending on the type of EUT and the detail of the standards in use, must be included. Beyond that, some form of communication will be needed between the inside of the screened room and the outside world. This could take the form of RFI-proof CCTV equipment, intercoms or fibre optic data communication links.

The ancillary equipment housed outside the screened room will also include all the support equipment for the EUT. Test houses will normally have two subsidiary screened chambers abutting the main one, one of which contains the RF test instrumentation, the other housing the support equipment. This ensures that there is no interaction between the external environment, the RF instrumentation and the support equipment. Provided the environment is not too noisy and the RF instrumentation is individually well screened, you do not really need these two extra screened chambers for your own EMC testing.

4.1.3 Test methods

As with radiated emissions, the major concern of standardized immunity test methods is to ensure repeatability of measurements. The immunity test is complicated by not having a defined threshold which indicates pass or failure. Instead, a (hopefully) well defined level of interference is applied to the EUT and its response is noted. The test procedure concentrates on ensuring that the applied level is as consistent as possible and that the means of application is also consistent.

4.1.3.1 Preliminary checking

You will need to carry out some preliminary tests to find the most susceptible configuration and operating mode of the EUT. If it is expected to pass the compliance test with a comfortable margin, you may need to apply considerably greater field strengths in order to deliberately induce a malfunction. Hopefully (from the point of view of the test), with the initially defined set-up and operation there will be some frequency and level at which the operation is corrupted. This is easier to find if the EUT has some analogue functions, which are perhaps affected to a small degree, than if it is entirely digital and continues operating perfectly up to a well-defined threshold beyond which it crashes completely.

Once a sensitive point has been found, you can vary the orientation, cable layout, grounding regime and antenna polarization to find the lowest level which induces a malfunction at that frequency. Similarly, the operating mode can be changed to find the most sensitive mode. It is often worthwhile incorporating special test software to continuously exercise the most sensitive mode, if this is not part of the normal continuous operation of the instrument. Note that some changes may do no more than shift the sensitive point to a different frequency, so you should always repeat a complete frequency sweep after any fine tuning at a particular frequency.

4.1.3.2 Compliance tests

Once the sensitive configuration has been established it should be carefully defined and rigorously maintained throughout the compliance test. Changes in configuration halfway through will invalidate the testing. If there are several sensitive configurations these should be fully tested one after the other. Notwithstanding this, equipment should always be tested in conditions that are as close as possible to a typical installation – that is with wiring and cabling as per normal practice, and with hatches and covers in place. If the wiring practice is unspecified, leave a nominal length of 1m of cable exposed to the incident field. If the EUT is floor-standing (such as a rack or cabinet) it will be placed on but insulated from the floor, otherwise it should be on a wooden table. The antenna will normally be placed at least 1m from it, at a greater distance if possible consistent with generating an adequate field strength; the preferred distance is 3m. Too close a distance affects the uniformity of the generated field and also, because of mutual coupling between antenna and EUT, invalidates the basis on which the substitution method is used.

The compliance test will concentrate on making sure that the specified test level is maintained throughout the frequency sweep. This will be achieved by using the field strength monitoring or control methods referred to in section 4.1.1.3. The parameters which have been chosen to represent the operation of the EUT must be continuously monitored throughout the sweep, preferably by linking them to an automatic data capture and analysis system – although the test engineer's eyeball still remains one of the most common monitoring instruments.

Assuming that the EUT remains correctly operational throughout the sweep, i.e. it passes, it can be useful to know how much margin there is in hand at the sensitive point(s). You can do this by repeating the sweep at successively higher levels and mapping the EUT's response. This will indicate both the margin you can allow for production variability, and the possibilities for cost reduction by removing suppression components.

4.1.3.3 Sweep rate

The sweep rate itself may be critical to the performance of the EUT. According to the standards, the signal generator should either be manually or automatically swept across the output range at $1.5 \cdot 10^{-3}$ decades per second or slower, depending on the speed of response of the EUT, or it can be automatically stepped at this rate in steps of typically 1% – that is, each test frequency is 1.01 times the previous one, so that the steps are logarithmic. The dwell time for stepped application should be at least enough to allow time for the EUT to respond; slow responses translate directly to a longer test time. As an example, to cover the range 80–1000MHz with a step size of 1% and a dwell time of 3s takes 12.7 minutes.

For many systems there may be little sensitivity to sweep rate since demodulation of applied RF tends to have a fairly broad bandwidth; usually, responses are caused by structural or coupling resonances which are low-Q and therefore several MHz wide. On the other hand, some frequency sensitive functions in the EUT may have a very narrow detection bandwidth so that responses are only noted at specific frequencies. This may easily be the case, for instance, with analogue-to-digital converters operating at a fixed clock frequency, near which interfering frequencies are aliased down to the baseband. If the sweep rate through these frequencies is too fast (or the step spacing is too great) then a response may be missed. Such narrowband susceptibility may be 25–30dB worse than the broadband response. Therefore some knowledge of the EUT's internal functions is essential, or considerably more complex test procedures are needed.

4.1.3.4 Safety precautions

At field strengths not much in excess of those defined in many immunity standards, there is the possibility of a biological hazard from the RF field arising to the operators if they remain in the irradiated area for an appreciable time. For this reason a prudent test facility will not allow its test personnel inside a screened chamber while a test is in progress, making it necessary for a remote monitoring device (such as a CCTV) to be installed for some types of EUT.

Health and safety legislation differs between countries. In the UK at the time of writing there are no *mandatory* requirements placed on maximum permissible RF field exposure, but the National Radiological Protection Board (NRPB) has published guidelines [174] for this purpose and it would be advisable from the point of view of potential health and safety claims for any employer to adhere at least to these. In 1998 the International Commission on Non-Ionizing Radiation Protection (ICNIRP) published its own guidelines [175] covering exposure to RF radiation. The ICNIRP guidelines for the public have been incorporated in a European Council Recommendation (1999), which has been agreed in principle by all countries in the European Union (EU), including the UK.

The NRPB and ICNIRP guidelines take into account the known thermal and electric shock effect of RF fields. They do not consider possible athermal effects, which is a highly controversial field of study and for which no firm guidance has yet been produced. The guidelines contained in [174] for occupational exposure (small children excepted) to continuous fields over the frequency range of interest for RF immunity testing are reproduced in Table 4.2. The ICNIRP guidelines for the general public are lower.

Table 4.2 NRPB guidelines for maximum field strength exposure

Frequency range	RMS field strength
10 to 60MHz	60 V/m
60 to 137MHz	1000 · F (GHz) V/m
137 to 1100MHz	137 V/m
1.1 to 1.55GHz	125 · F (GHz) V/m
1.55 to 300GHz	194 V/m

4.1.3.5 Short cuts in immunity testing

There will be many firms which decide that they cannot afford the expense of a full RF immunity set up, including a screened room, as described in section 4.1.2. One possibility for reduced testing is to restrict the test frequencies to the "free radiation" frequencies as permitted by international convention, on which unrestricted emissions are allowed. These are primarily intended for the operation of industrial, scientific and medical equipment and are listed in Table 1.1 on page 18. Another course known to be taken by some firms, is to use the services of a licensed radio amateur transmitting on the various amateur bands available to them – 30MHz, 50MHz, 70MHz, 144MHz and 432MHz; although on a strict interpretation this is outside the terms of the amateur radio licence. Yet another possibility is to use an actual cellular telephone transmitting on 900MHz to check for immunity to this type of signal.

In each case the use of particular frequencies removes the need for a screened room to avoid interference with other services. All of these *ad hoc* tests should at least use a field strength meter to confirm the field actually being applied to the EUT; bear in mind that the RF field near to the transmitting antenna will vary considerably with small changes in separation distance. If the EUT's response to RF interference was broadband across the whole frequency range then spot frequency testing would be adequate, but this is rarely so; resonances in the coupling paths emphasize some frequencies at the expense of others, even if the circuit response is itself broadband. It is therefore quite possible to believe an optimistic performance of the EUT if you have only tested it at discrete frequencies, since resonant peaks may fall between these. A compliance test must always cover the entire range.

Transient testing

In practice, it has been found that for many digital products transient and ESD performance is linked to good RF immunity, since susceptible digital circuits tend to be sensitive to both phenomena. Therefore much development work can proceed on the basis of transient tests, which are easier and less time-consuming to apply than RF tests, and are inherently broadband. Where analogue circuits are concerned then a proper RF field test is always necessary, since the demodulated offset voltage which RF injection causes cannot be simulated by a transient. But a minimal set of transient plus spot frequency RF tests may give you an adequate assessment of the product's immunity during the development stages.

4.1.4 Conducted RF immunity

Because of the difficulty and expense of performing radiated RF immunity tests, there is growing pressure to allow conducted immunity testing at the lower frequencies, by analogy to the distinction between radiated and conducted emissions testing. The basic standard IEC 61000-4-6 defines the test method for conducted immunity testing, and it is now referred to in revisions to the generic standards and in product standards. The immunity standard for broadcast receivers, EN 55020, also defines test methods for immunity from conducted RF currents and voltages. The method of "bulk current injection" (BCI) developed within the aerospace and military industries for testing components of aircraft systems, and now being adapted for application to automotive components, is another similar technique. See also section 5.3.1.2.

4.1.4.1 Coupling methods

Three methods of coupling are defined in IEC 61000-4-6. The preferred method is direct voltage injection via a coupling/decoupling network (CDN). This has zero insertion loss and therefore needs little power. One alternative is the clamp-on current probe, which is simple to use but has a much higher insertion loss and therefore requires significantly more power for the same stimulus. In between the two is the EM clamp, which is a ferrite clamp device similar in appearance to the MDS-21 clamp described in Figure 3.10, but markedly different in internal construction. The EM-clamp provides both E- and H-field coupling to the cable and it is more efficient than the current probe, but less so than the CDN.

Any method of cable RF injection testing requires that the common mode impedance at the end of the cable remote from the EUT is defined. Thus each type of cable must have a common mode decoupling network or impedance stabilizing network (ISN) at its far end, to ensure this impedance and to isolate any ancillary equipment from the effects of the RF current on the cable. (This is analogous to the mains LISN used for emission testing and discussed in section 3.1.2.3. Unfortunately, the emissions LISN specification doesn't agree with that for the conducted immunity ISN, so different units are needed.) Direct voltage injection in addition requires that this network is used to couple the RF voltage onto the cable, a complication which is absent when current injection via a clamp-on probe is used. A test house which handles these methods must have a wide range of CDNs available, to cater for the variety of different cable and signal types that will come its way. If your company makes equipment which predominantly uses only one or two types of cable – say single-channel RS-232 data links and mains – then this is not an onerous requirement. Figure 4.9 shows the general arrangement for making conducted immunity tests.

4.1.4.2 Disadvantages and restrictions

Conducted immunity testing has the major advantage of not requiring expensive anechoic screened room facilities, but it does have some disadvantages. It is particularly questionable whether it accurately represents real situations when there are several cables connected to the EUT. When the whole system is irradiated then all cables would be carrying RF currents, but in most conducted immunity test methods only one is tested at a time. Each of the other cables represents a common mode load on the test system and this must be artificially created by including extra impedance stabilizing networks on them. Networks for direct coupling to cables with many signal lines are expensive to construct, bulky and may adversely affect the signal line

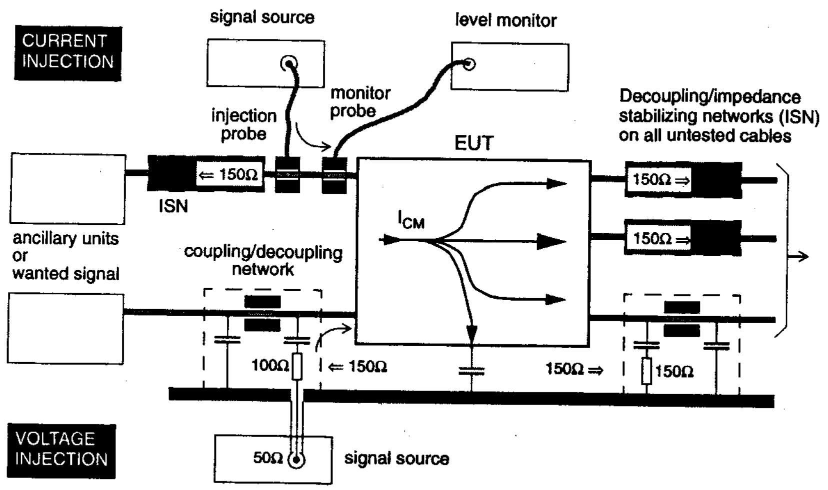


Figure 4.9 Conducted immunity test set-up

characteristics. The method is therefore less well suited to equipment which has many cables connected to it routinely.

The current probe method has the considerable advantage, compared to voltage injection, that it is non-intrusive; the probe just clamps over the cable to induce a common mode current with no direct connection to it. This makes it very attractive for cables with many conductors. It has the disadvantage, though, that the stray capacitance between probe and cable is ill defined. This restricts its useable frequency range since at the higher frequencies, both the inductive coupling path and the cable common mode impedance are seriously affected by this capacitance. Just as importantly, cable resonances are not decoupled or damped by the probe and cause serious errors as they are approached by the test frequency. The EM clamp suffers less from these problems and is similarly non-intrusive.

A further question hangs over the levels used to establish compliance. When either voltage or current injection are used, the actual power applied to the EUT will depend on the common mode impedance at the EUT port: a low impedance will run the risk of over-testing if a voltage source is used, and under-testing if a current source is used, and vice versa for a high impedance. To get around this problem, some standards specify limits in terms of current into a calibration jig, for which the EUT is then substituted at a constant power level.

Frequency range

The major restriction on conducted immunity testing is one of frequency. For EUT sizes much less than the wavelength of the test frequency, the dominant part of the RF energy passing through equipment that is exposed to a radiated field is captured by its cables, and therefore conducted testing is representative of reality. As the frequency rises so that the EUT dimensions approach a half-wavelength, the dominance of the cable route reduces and at higher frequencies the field coupling path interacts with the EUT structure and internal circuits, as well as with its cables. For this reason the upper frequency limit is restricted in IEC 61000-4-6 to between 80 and 230MHz (corresponding to equipment dimensions of between about 0.6m and 2m). For higher frequencies, radiated testing is still necessary.

4.2 ESD and transient immunity

By contrast with RF testing, ESD (electrostatic discharge) and transient test methods are rather less complicated and need less in the way of sophisticated test equipment and facilities. Nevertheless the bandwidth of fast transients and of the electrostatic discharge is very wide and extends into the VHF region, so many precautions that are necessary for RF work must also be taken when performing transient tests.

4.2.1 ESD

4.2.1.1 Equipment

The electrostatic discharge generator described in IEC 61000-4-2 is fairly simple. The circuit is shown in Figure 4.10. The main storage capacitor C_s is charged from the high voltage power supply via R_{ch} and discharged to the EUT via R_d and the discharge switch. The switch is typically a vacuum relay under the control of the operator. Compliance testing uses single discharges, but for exploratory testing the capability of a fast discharge rate of 20 per second is suggested. The output voltage should reach 8kV for contact discharge, or 15kV if air discharge is included, although for the tests required in the present immunity standards lower voltages are specified. Product and generic standards for most environments have settled on a level of 4kV for the contact method and 8kV for air.

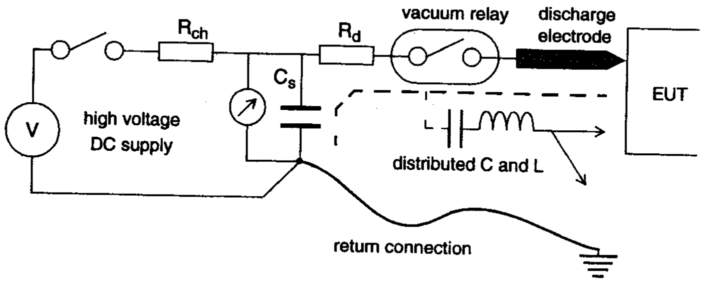


Figure 4.10 ESD generator (per IEC 61000-4-2)

The critical aspect of the ESD generator is that it must provide a well defined discharge waveform with a rise time of between 0.7 and 1 nanosecond. This implies that the construction of the circuit around the discharge electrode is important; C_s, R_d and the discharge switch must be placed as close as possible to the discharge electrode which itself has specified dimensions. A round tip is used for air discharge, and a sharp tip for contact. The distributed capacitance and inductance of the electrode and associated components forms part of the discharge circuit and essentially determines the initial rise time, since the return connection to the EUT is relatively long (2m) and its inductance blocks the initial discharge current. As these distributed parameters cannot be satisfactorily specified, the standard requires that the generator's waveform is calibrated in a special test jig using an oscilloscope with a bandwidth of at least 1GHz.

If you use a ready-built ESD generator this calibration will have already been done by the manufacturer, though it should be re-checked at regular intervals. If you build it yourself you will also have to build and use the calibration jig.

4.2.1.2 Test methods

Because of the very fast edges associated with the ESD event, high frequency techniques are essential in ESD testing. The use of a ground reference plane is mandatory; this can of course be the floor of a screened room, or the same ground plane that you have installed for the tests outlined in section 3.1.3. You may want to apply ESD tests to equipment after it has been installed in its operating environment, in which case a temporary ground plane connected to the protective earth should be laid near to the equipment. Other co-located equipment may be adversely affected by the test, so it is wise not to carry out such tests on a "live" operating system.

For laboratory tests, the EUT should be set up in its operating configuration with all cables connected and laid out as in a typical installation. The connection to the ground is particularly important, and this should again be representative of installation or user practice. Table-top equipment should be placed on a wooden table 80cm over the ground plane, with a horizontal coupling plane directly underneath it but insulated from it. Floor standing equipment should be isolated from the ground plane by an insulating support of about 10cm. Figure 4.11 illustrates a typical set-up. Any ancillary equipment should itself be immune to coupled ESD transients, which may be induced from the field generated by the ESD source/EUT system or be conducted along the connected cables.

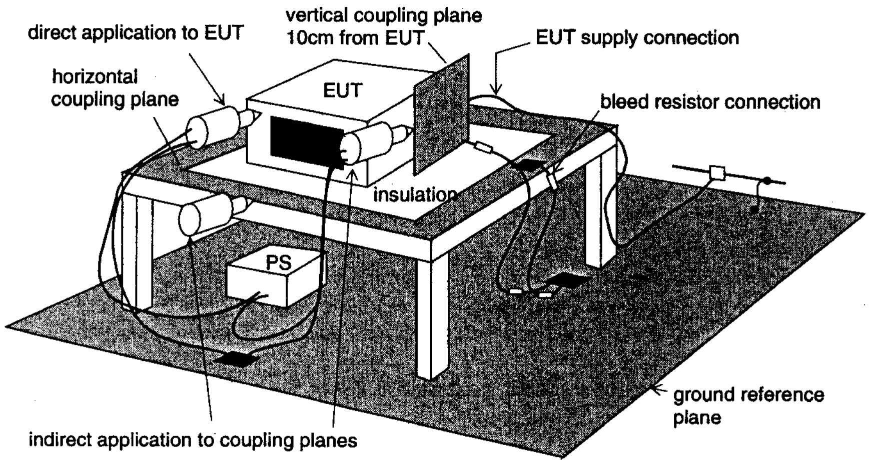


Figure 4.11 ESD test set-up

Discharge application

The actual points of application of the discharges should be selected on the basis of exploratory testing, to attempt to discover sensitive positions. These points should only be those which are accessible to personnel in normal use. For the exploratory testing, use a fast repetition rate and increase the applied voltage from the minimum up to the specified test severity level, to ascertain any threshold of malfunction. Also, select both polarities of test voltage. Compliance testing requires the specified number of single discharges with at least 1 second between them, on each chosen point at the specified test level and all lower test levels, with the most sensitive polarity, or with both polarities.

Contact discharge is preferred, but this requires that the EUT has conducting surfaces or painted surfaces which are not regarded as insulating. For a product where this is not possible (e.g. with an overall plastic enclosure) use air discharge to investigate user accessible points where breakdown to the internal circuit might occur, such as the edges of keys or connector or ventilation openings.

In cases where neither direct contact nor air discharge application to the EUT is possible, and to simulate discharges to objects near to the equipment in its operating environment, the discharge is applied to a coupling plane located a fixed distance away from the EUT. This can be either the horizontal coupling plane shown in Figure 4.11 or an ancillary vertical coupling plane. It is worth noting that, if you were to perform this indirect test in some manner akin to the radiated RF immunity test, an equivalent plane wave field strength of between 1000V/m and 7500V/m would be needed.

The ESD generator should be held perpendicular to the EUT surface, or edge-on to the centre edge of the coupling plane. For air discharge, the discharge tip should be brought up to the EUT as fast as possible without causing mechanical damage: this is not a test which rewards a cautious approach, you need to be vigorous and positive. Both of these factors make a considerable difference to the effectiveness and repeatability of the test.

4.2.1.3 Future amendments

The 1995 version of the standard, even with amendments, still has serious shortcomings. A full-scale revision of the standard is underway in the IEC and is at the time of writing expected to be published some time in 2002. Significant changes that are to be expected in this new version may include [49]:

- the calibration method for the generator: a more rigorous specification for the measured parameters, and the possibility of extending the calibration set-up to be more representative of small EUTs;
- the test set-up: cable routing and termination, and perhaps a change to the height of the EUT above the ground reference plane;
- the test procedure: better definition of the practical aspects which affect the applied stress, and how to deal with ungrounded EUTs which retain their charge (presently subject to a separate amendment, likely to be published in 2001);
- processing the results, that is defining a statistical approach to the EUT failure criteria.

4.2.2 EFT burst transients

4.2.2.1 Equipment

When testing equipment for immunity to conducted transients the transients themselves, and the coupling network by which the transients are fed into the ports must be well defined. The network must decouple the side of the line furthest from the EUT and at the same time provide a fixed impedance for the coupling route. In this respect it is similar to the LISN used in emissions testing, and the CDNs used for conducted RF immunity tests. IEC 61000-4-4 (formerly IEC 801-4) specifies the test generator and the coupling methods for bursts of fast transients such as are caused by local inductive load switching.

The fast transient burst is specified to have a single pulse rise time/duration of 5ns/50ns from a source impedance of 50Ω. Bursts of 15ms duration of these pulses at a repetition rate of 5kHz (2.5kHz at maximum test voltage) are applied every 300ms (see Figure 4.12). The voltage levels are selected depending on specified severity levels from 250V to 4kV. In order to obtain these high voltages with such fast rise times, the generator was traditionally constructed with a spark gap driven from an energy storage capacitor, although more modern solid-state generators have now superseded this approach. In fact, the original specification of IEC801-4:1988 has been subject to some criticism [112] regarding its applicability. Now that better generators are being built, a revised version of IEC 61000-4-4 is under consideration which addresses these criticisms, notably by requiring a burst repetition frequency of 100kHz as well as 5kHz, and ensuring that the calibrated waveform is also the waveform that is delivered to the EUT. This new revision has been stalled for some time because of its implications for obsolescence of the older generation of test equipment.

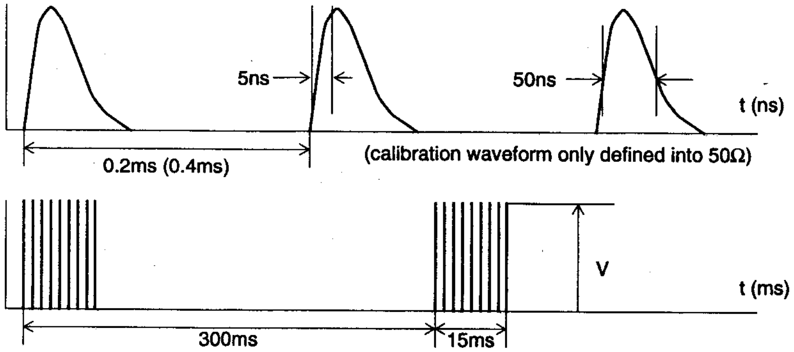


Figure 4.12 Fast transient burst specification (per IEC 61000-4-4)

The coupling network for power supply lines applies the pulse in common mode with respect to the ground plane to each line via an array of coupling capacitors, while the source of each line is also decoupled by an LC network. Coupling onto signal lines uses a capacitive clamp, essentially two metal plates which sandwich the line under test to provide a distributed coupling capacitance and which are connected to the transient generator. Any associated equipment which may face the coupled transients must obviously be immune to them itself.

4.2.2.2 *Test methods*

As with ESD tests, a reference ground plane must be used. This is connected to the protective earth on the decoupled side of the transient coupling network. Floor standing equipment is stood off from this ground plane by a 10cm insulating block, and table top EUTs are placed on an insulating table 80cm above it. A 1m length of mains cable connects the EUT to the coupling network, which itself is bonded to the ground plane. If the EUT enclosure has a separate protective earth terminal, this is connected to the ground plane via the coupling network and transients are applied directly to it also. I/O cables are fed through the capacitive clamp which is located 10cm above the ground plane. A typical set-up is shown in Figure 4.13.

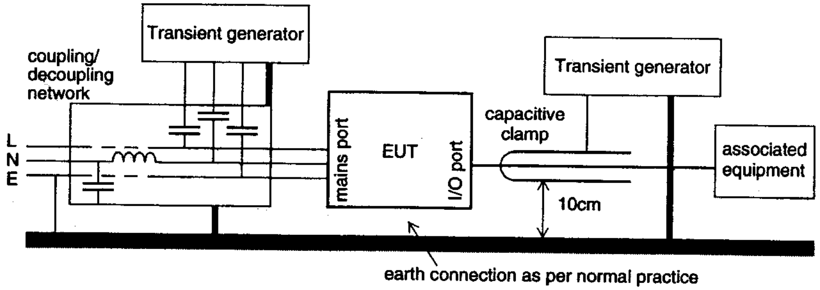


Figure 4.13 Fast transient test set-up

Actual application of the transients is relatively simple, compared to other immunity tests. No exploratory testing is necessary except to determine the most sensitive operating mode of the equipment. Typically, bursts are applied for a duration of 1 minute in each polarity on each line to be tested. The required voltage levels are defined in the relevant standard, and vary depending on the anticipated operating environment and on the type of line being tested.

4.2.3 Surge

The surge test of IEC 61000-4-5 simulates high energy but relatively slow transient overvoltages on power lines and long signal lines, most commonly caused by lightning strikes in the vicinity of the line. This part of IEC 61000-4 was also previously published as a European pre-standard, ENV 50142.

4.2.3.1 *Surge waveform*

The transients are coupled into the power, I/O and telecommunication lines. The surge generator called up in the test has a combination of current and voltage waveforms specified, since protective devices in the EUT (or if they are absent, flashover or component breakdown) will inherently switch from high to low impedance as they operate. The values of the generator's circuit elements are defined so that the generator delivers a 1.2/50μs voltage surge across a high-resistance load (more than 100Ω) and an 8/20μs current surge into a short circuit. These waveforms must be maintained into a coupling/decoupling network, but are not specified with the EUT itself connected.

Three different source impedances are also recommended, depending on the application of the test voltage and the expected operating conditions of the EUT. The effective output impedance of the generator itself, defined as the ratio of peak open circuit output voltage to peak short circuit output current, is 2Ω. Additional resistors of 10 or 40Ω are added in series to increase the effective source impedance as necessary.

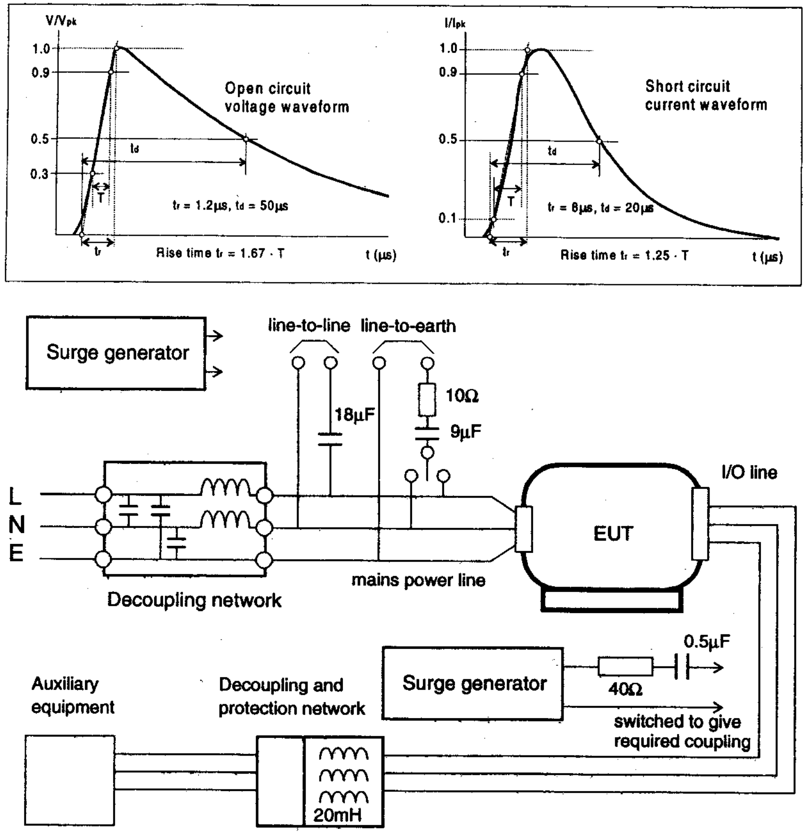


Figure 4.14 Surge waveform specification and coupling

4.2.3.2 Applying the surge

High energy surges are applied to the power port between phases and from phase to ground. For input/output lines, again both line-to-line and line-to-ground surges are applied, but from a higher impedance. 2Ω represents the differential source impedance of the power supply network, 12Ω represents the line-to-ground power network impedance while 42Ω represents the source impedance both line-to-line and line-to-ground of all other lines.

Power line surges are applied via a coupling/decoupling network incorporating a back filter, which avoids adverse effects on other equipment powered from the same supply, and provides sufficient impedance to allow the surge voltage to be fully developed. For line-to-line coupling the generator output must float, though for line-to-ground coupling it can be grounded. A 10Ω resistor is included in series with the output for line-to-ground coupling.

I/O line surges are applied in series with a 40Ω resistor either via capacitive coupling with a decoupling filter facing any necessary auxiliary equipment, or by spark-gap coupling if the signals on the I/O line are of a high enough frequency for capacitive coupling to affect their operation.

The purpose of the surge immunity test at equipment level is to ensure that the equipment can withstand a specified level of transient interference without failure or upset. It is often the case that the equipment is fitted with surge protection devices (varistors, zeners etc.). Typically such devices have low average power ratings, even though they can dissipate or handle high instantaneous currents or energies. So the maximum repetition rate of applied surges will normally be limited by the capabilities of the devices in use, and a maximum of 10 surges (5 positive and 5 negative) is recommended for any one test procedure. Over-enthusiastic testing may lead to premature and unnecessary damage to the equipment, with possible consequential damage also occurring. Because of this latter risk, it is wise to physically isolate the EUT during the test. In any case, the EUT should be disconnected from other equipment where possible and the whole set-up should be well insulated to prevent flashover.

Each surge should be synchronized to the peak of the AC supply waveform to give a repeatable and maximum stress, and to the zero crossing to induce maximum follow-on energy if this is likely to occur. Also, the stress voltage should be increased in steps up to the maximum, to check that the protective devices do not allow upset or damage at lower levels of applied voltage whilst satisfactorily clamping high levels.

4.2.4 Sources of variability

Assuming that the EUT's response can be accurately characterized, the major variabilities in transient testing stem from repeatability of layout and the statistical nature of the transient application. The climatic conditions may also have some bearing on the results of air discharge ESD tests.

4.2.4.1 Layout

The wide bandwidth of the ESD and fast burst transients means that cables and the EUT structure can act as incidental radiators and receptors just as they do in RF testing. Refer to section 3.1.5 in this connection. Therefore the test layout, and routing and termination of cables, must be rigorously defined in the test plan and adhered to throughout the test. Variability will affect the coupling of the interference signals into and within the EUT and may to a lesser extent affect the stray impedances and hence voltage levels. Equally, variability in the EUT's build state, such as whether metal panels are in place and tightened down, will have a major effect on ESD response.

4.2.4.2 Transient timing

In a digital product the operation is a sequence of discrete states. When the applied transient is of the same order of duration as the states (or clock period), as is the case with the ESD and fast burst transients, then the timing of application of the transient with respect to the internal state will affect the unit's immunity. If the pulse coincides with a clock transition then the susceptibility is likely to be higher than during a stable clock period. There may also be some states when the internal software is more immune than at other times, for example when an edge triggered interrupt is disabled. Under most circumstances the time relationship between the internal state and the applied transient is asynchronous and random.

Therefore, for fast transients the probability P of coincidence of the transient with a susceptible state is less than unity, and for this reason both ESD and transient test procedures specify that a relatively large number of separate transients are applied before the EUT can be judged compliant. If the probability of coincidence P is of the same order or less than the reciprocal of this number, it is still possible that during a given test run the coincidence will not occur and the equipment will be judged to have passed, when on a different run coincidence might occur and the equipment would fail. There is no way around this problem except by applying more test transients in such marginal cases.

4.2.4.3 Environment

In general, the non-electromagnetic environmental conditions do not influence the coupling of interference into or out of electronic equipment, although they may affect the operational parameters of the equipment itself and hence its immunity. The major exception to this is with air discharge ESD. In this case, the discharge waveform is heavily influenced by the physical orientation of the discharge electrode and the rate of approach to the EUT, and also by the relative humidity of the test environment. This means that the test repeatability will vary from day to day and even from hour to hour, all other factors being constant, and is one of the main reasons why the air discharge method has fallen out of favour.

4.3 Magnetic field and power quality immunity

The two low frequency immunity tests that are most significant in the context of the EMC Directive are power frequency magnetic field, and voltage dips and interruptions on the power supply.

4.3.1 Magnetic field

Testing with a steady magnetic field may apply to all types of equipment intended for public or industrial mains distribution networks or for electrical installations. Testing with a short duration magnetic field related to fault conditions, requires higher test levels than those for steady state conditions; the highest values apply mainly to equipment to be installed in exposed areas of electrical plants. (IEC 61000-2-7 gives values for various environments.)

Magnetic fields at power frequencies are common in the environment but are only a threat to certain types of equipment. Although the basic test method gives no especial advice as to which products should and should not be tested, all the generic and product standards, when they refer to the magnetic field test, state that it should be applied only to equipment "containing devices susceptible to magnetic fields". Experience suggests that this certainly applies to anything with a cathode ray tube – although the humble domestic TV set isn't included, since its own product standard makes no mention of magnetic field testing – and various other specialized components such as magnetic sensors. Audio apparatus that might be sensitive to hum pick-up should also be considered, but otherwise, general electronic circuitry can be assumed not to be relevant for this test.

The test field waveform is sinusoidal at power frequency. In many cases (household areas, sub-stations and power plant under normal conditions), the magnetic field produced by harmonics is negligible, but in special cases such as industrial areas with a concentration of large power convertors they can occur. Testing at present does not take them into account.

The magnetic field immunity test method is specified in IEC 61000-4-8. It requires the EUT to be immersed in a magnetic field of 50Hz or 60Hz sinusoidal (< 8% distortion) generated by an induction loop surrounding it, in three orthogonal orientations. Severity levels are defined as 1, 3, 10, 30 and 100A/m for continuous application, and 300 and 1000A/m for short duration (1–3 seconds) application.

The magnetic field is generated within the loop and the field uniformity is required to be 3dB within the volume occupied by the EUT. For various loop sizes, the maximum volume available is as follows:

- single square loop, 1m side: 0.6m x 0.6m x 0.5m high
- double square loops, 1m side, 0.6m spaced: 0.6m x 0.6m x 1m high (0.8m spacing gives 1.2m height)
- single rectangular loop, 1m x 2.6m: 0.6m x 0.6m x 2m high

The loop factor (H/I, magnetic field/current injected) is calibrated at the centre of the loop and allows a direct correlation between the current measured in series with the loop and the amplitude of the magnetic field that is produced. Although the standard describes particular designs of coil used with a ground reference plane, it does not forbid other designs provided that they meet the field homogeneity condition. For instance, multi-turn coils, which would allow a lower test current for a given field, would be acceptable. The requirements of the AC source and its output transformer turns ratio for use with a particular coil are given in Table 4.3 [76].

Table 4.3 Coil and source current and voltage for 1.5 ohms, 19 mH, 65.73 A/m/A loop factor coil

H (A/m)	Coil		Transformer turns ratio N:1	AC source		
	I (A)	V (V)		I (A)	V (V)	VA
1	0.015	0.094	240	6.34×10^{-5}	22.5	0.001
3	0.046	0.281	240	1.90×10^{-4}	67.4	0.013
10	0.152	0.936	240	6.34×10^{-4}	224.7	0.142
30	0.456	2.809	8	0.057	22.5	1.282
100	1.521	9.363	8	0.190	74.9	14.245
300	4.564	28.090	8	0.571	224.7	128.21
1000	15.214	93.635	2.5	6.086	234.1	1424.53

4.3.2 Voltage dips and interrupts

There should be a defined and controlled response of the EUT to discontinuities in the mains supply. IEC 61000-4-11: 1994 defines immunity test methods for these phenomena.

Electrical and electronic equipment may be affected by voltage dips, short interruptions or voltage variations of the power supply. Voltage dips and short interruptions are caused by faults in the network, in installations or by a sudden large change of load. In certain cases, multiple dips or interruptions may occur. Voltage variations are caused by the continuously varying loads connected to the network. These phenomena are random in nature and can be characterized in terms of their deviation from the rated voltage and their duration.

Voltage dips and short interruptions are not always abrupt. If large mains networks are disconnected the voltage will only decrease gradually due to the many rotating

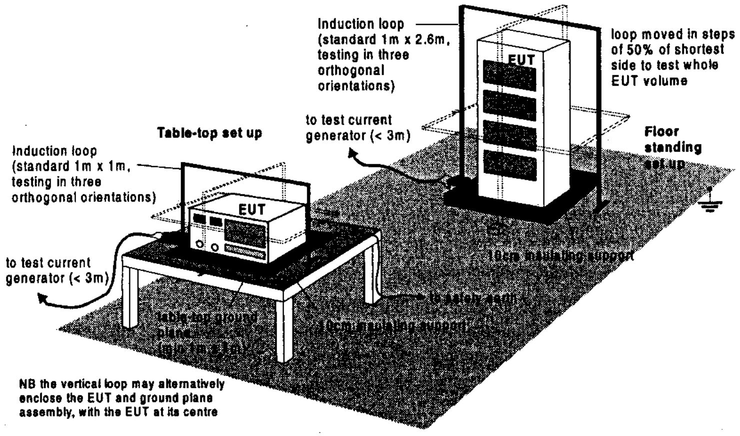


Figure 4.15 The magnetic field immunity test

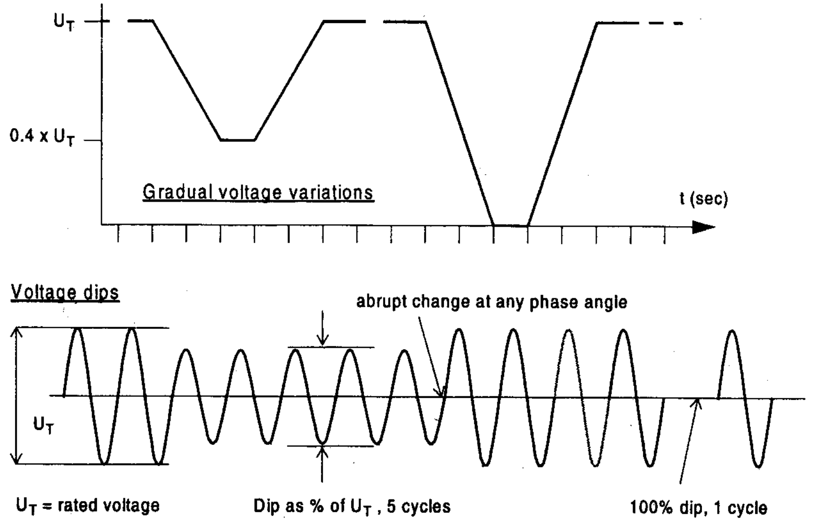
machines which are connected. For a short period, these will operate as generators sending power into the network. Some equipment is more sensitive to gradual variations in voltage than to abrupt change.

4.3.2.1 *Applying voltage dips and interruptions*

Different types of tests are specified in the standard to simulate the effects of abrupt change of voltage, and, optionally, a type test is specified also for gradual voltage change. Testing can be done either using electronically-controlled switching between the outputs of two variacs or by controlling the output of a waveform generator fed through a power amplifier. The latter is more usual for low-to-medium power applications.

Tests are given for voltage dips and short interruptions (an interruption is a dip to 0% of the supply) and for short-period voltage variations. The preferred values for period and level of dips are listed in the table in Figure 4.16. Tests of dips and interruptions are significant as these are referenced in the generic immunity standards and many product standards. The generic standard requirements are for a half-cycle dip to 70% of rated voltage, a 5-cycle dip to 40% of rated voltage and a 5 second interruption. The performance criterion which applies to the latter two tests is that temporary loss of function is allowed, provided that it is self recoverable or can be restored by operation of the controls; i.e. a latch-up or a blown fuse is unacceptable.

A significant part of the specification of the test generator is its ability to cope with the peak inrush current of the EUT without affecting the test result. The maximum capability of the generator need not exceed 500A for 230V mains, or 250A for 110V mains. If the EUT draws significantly less than this, a generator with lesser capability is allowed provided that the EUT inrush current is less than 70% of the peak drive capability.



Preferred test level % U_T	Preferred duration # of cycles
0 (interruption) 40 70	0.5, 1, 5, 10, 25, 50

Figure 4.16 Supply voltage dips and variations

4.4 Evaluation of results

The variety and diversity of equipment and systems makes it difficult to lay down general criteria for evaluating the effects of interference on electronic products. Nevertheless, the test results can be classified on the basis of operating conditions and the functional specifications of the EUT according to the criteria discussed below.

It is up to the manufacturer to specify the limits which define "degradation or loss of function", and to decide which of these criteria should be applied to each test. Such specifications may be prompted by preliminary testing or by known customer requirements. In any case it is important that they are laid out in the final EMC test plan for the equipment. If the equipment is being supplied to a customer on a one-to-one contractual basis then clearly there is room for mutual agreement and negotiation on acceptance criteria, but this is not possible for products placed on the mass market, which have only to meet the essential requirements of the EMC Directive. In these cases, you have to look to the immunity standards for general guidance.

4.4.1 Performance criteria

The generic immunity standards [140] lay down guidelines for criteria against which to judge the EUT's performance when the various test levels are applied. These are quoted in full in section 9.3.4, but can be summarized as follows:

> ***Performance criterion A****: The apparatus shall continue to operate as intended. No degradation of performance or loss of function is allowed below a performance level or a permissible loss of performance specified by the manufacturer.*
>
> This criterion applies to phenomena which are normally continuously present, such as RF interference.
>
> ***Performance criterion B****: The apparatus shall continue to operate as intended after the test. No degradation of performance or loss of function is allowed below a performance level specified by the manufacturer, when the apparatus is used as intended. During the test, degradation of performance is however allowed. No change of actual operating state or stored data is allowed.*
>
> This applies to transient phenomena.
>
> ***Performance criterion C****: Temporary loss of function is allowed, provided the loss of function is self recoverable or can be restored by the operation of the controls.*
>
> This applies to mains interruption.

If you do not specify the minimum performance level or the permissible performance loss, then either of these may be derived from the product description and documentation (including leaflets and advertising) and what the user may reasonably expect from the apparatus if used as intended. Thus, for example, if a measuring instrument has a quoted accuracy of 1% under normal conditions, it would be reasonable to expect this accuracy to be maintained when subject to RF interference at the level specified in the standard, unless your operating manual and sales literature specifies a lower accuracy under such conditions. It may lose accuracy when transients are applied, but must recover it afterwards. A personal computer may exhibit distortion or "snow" on the image displayed on its video monitor under transient interference, but it must not crash nor suffer corruption of data.

The "reasonable expectation of the intended user" is quite likely to be enshrined in the essential requirements of the EMC Directive, according to the draft revision circulated in 2000 (see section 1.5.2). In the same document great emphasis is also placed on the information provided with the product, particularly that which indicates any restrictions in use or in meeting the protection requirements.

Product specific criteria

Some product specific immunity standards can be more precise in their definition of acceptable performance levels. For example EN 55020, applying to broadcast receivers, specifies a wanted to unwanted audio signal ratio for sound interference, and a just perceptible picture degradation for vision interference. Even this relatively tight definition may be open to interpretation. Another example is EN 55024 for IT equipment, which gives particular criteria for the lack of interference to audio links, fax machines and VDUs. Telecommunications equipment is now covered by a number of ETSI standards; typically it might be required to comply with a defined criterion for bit error rate and loss of frame alignment.

The subjectivity of immunity performance criteria can still present a major headache in the legal context of the EMC Directive. It will undoubtedly be open to many manufacturers to argue if challenged, not only that differing test procedures and layouts have been used in judging compliance of the same product, but that differing criteria for failure have also been applied. It will be in their own interest to be clear and precise in their supporting documentation as to what they believe the acceptance criteria are, and to ensure that these are in line as far as possible with either the generic guidelines or those given in applicable product standards.