Chapter 8

Immunity tests

8.1 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 were occasionally 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 originally listed until the mid-90s in IEC 801. These have long since been superseded; we now have IEC 61000-4-3 third edition and IEC 61000-4-6 fourth edition, for radiated and conducted tests respectively. CISPRs 20 and 24, eventually to be superseded by CISPR 35, require both conducted and radiated immunity tests but apply only to broadcast receivers and related equipment, and information technology equipment.

8.1.1 Equipment

Figure 8.1 shows the components of a typical radiated immunity test system using a screened room.

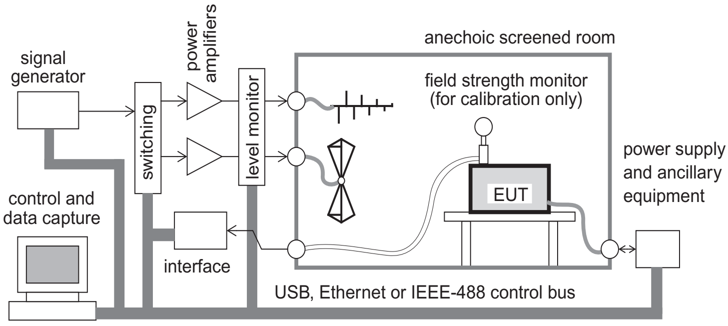

Figure 8.1 RF immunity test system

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 and to meet the field calibration requirements of the standard.

8.1.1.1 Signal source

Any RF signal generator that covers the required frequency range (80–1000MHz and above 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%. This will normally be done within the signal generator; other more specialized modulation, such as the 1Hz pulse requirement for testing alarm products, may need 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.

8.1.1.2 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. In contrast to the antenna factor for emissions measurements, an antenna for RF immunity 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:

$$P_t = (r \cdot E)^2/(30 \cdot G) \tag{8.1}$$

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 8.2 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 8.1.1.4).

The [power output · bandwidth] product 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 restricted bandwidth 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

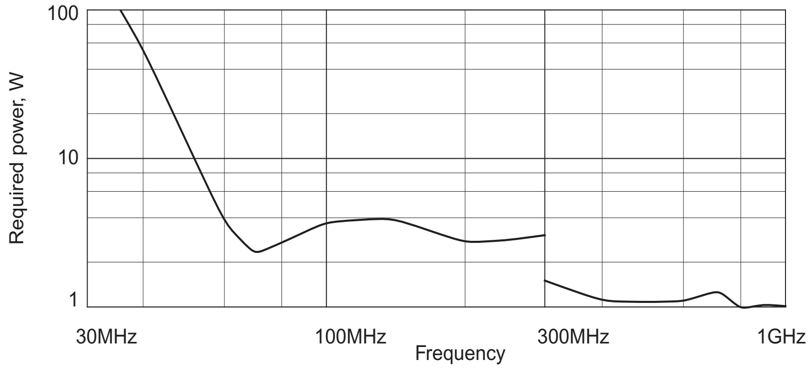

Figure 8.2 Required power versus frequency for 10V/m at 1m, biconical and log periodic antennas

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 from the amplifier is reflected back to it, which is inefficient and can be damaging to the amplifier.

Modulation

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 8.2. If you will be using the system in a non-anechoic screened room 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 8.1.1.4) rather than antennas, then the power requirement for a given field strength will be significantly less. Thus there is a direct cost trade-off between the type of transducer used and the necessary power of the amplifier.

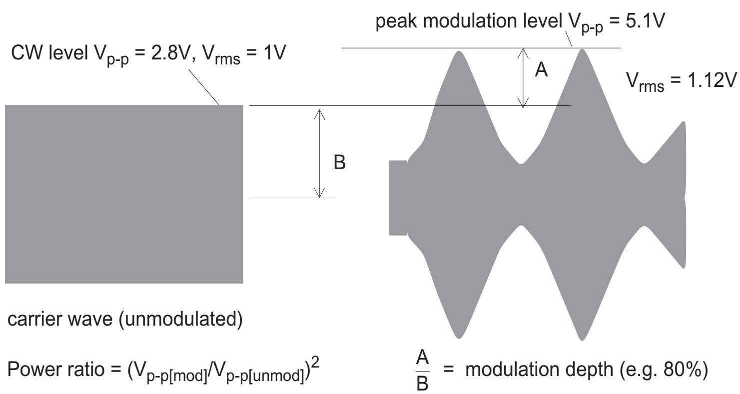

Figure 8.3 Modulated versus unmodulated waveforms

The 1kHz modulation requirement is common to most tests that reference IEC 61000-4-3. Other standards may take a different approach; for instance in the automotive immunity tests of ISO 11452 the modulation is also 1kHz at 80% depth, but the specification field strength is quoted at the peak of the modulation, rather than on an unmodulated waveform. Historically, some product standards specified a particular test for immunity to GSM phones at a spot frequency of 900MHz, which used pulsed modulation at 200Hz to simulate more accurately the effects of the GSM signal; this has been dropped in many later versions, on the grounds that experimental results on several different types of test object showed that the 1kHz sinewave always gave the most severe results and it was of universal applicability, a rationale which is detailed in Annex A to IEC 61000-4-3. There are a few standards that specify different frequencies for their own reasons, for instance the alarm immunity standard EN 50130-4 requires a 1Hz pulsed modulation, since many alarm detectors will be sensitive to a slow rate of change of the RF stress.

Note that when you are setting the applied power level during calibration for any RF immunity test, the modulation should be disabled; RF power meters and field strength meters give inaccurate results on modulated signals.

Secondary parameters

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 earlier versions of IEC 61000-4-3, distortion products should be at least −15dB relative to the carrier, but this has been revised. The present requirement is to confirm that the overall system (power amplifier and antenna) is not saturating beyond the 2dB compression point at a level of 1.8 times the maximum stress level (to allow for modulation);
- 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.

8.1.1.3 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 7.5 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, and one that is essential for calibrating to IEC 61000-4-3, 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 military tests is necessary. 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 test 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 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 viable as long as the field uniformity is closely defined (see section 8.1.2.2), but in these circumstances it is much preferable. The parameter which is controlled in the pre-calibration is the amplifier output power (forward power) rather than the net power supplied to the antenna; this implies 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.

8.1.1.4 Transducers

The radiated field can be generated by an antenna as already discussed. You may well want to use the same antennas as you have for radiated emissions tests, and in principle this is acceptable: but, 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 consequence may be that a balun is over-cooked during an immunity test and the antenna characteristics are affected, which would have serious consequences for an emission test with the same antenna if not detected. For this reason accredited test houses generally do keep separate antennas for emissions and immunity; and a belt-and-braces approach requires a system check before each test.

The high VSWR of broadband antennas (see section 7.5.2.1 and Appendix D section D.2.4), 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 8.4 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.

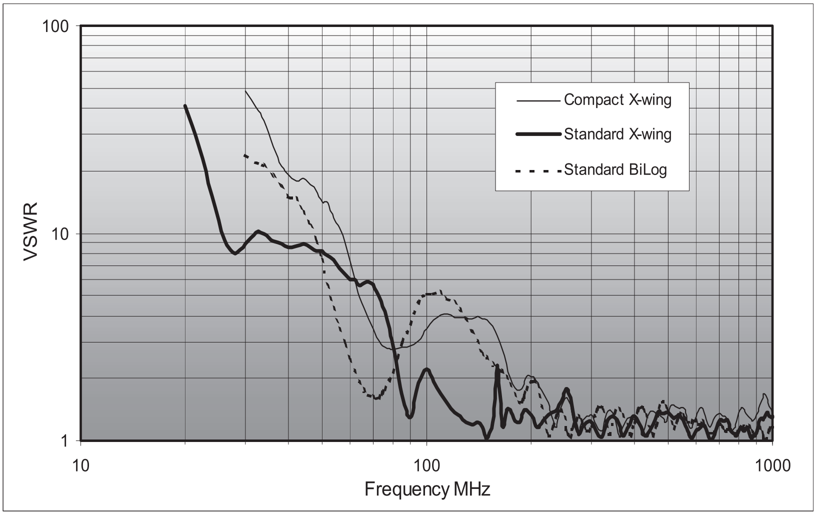

Figure 8.4 VSWR of BiLog antennas (Source: Teseq)

Two other types of transducer are available for radiated RF immunity testing of small EUTs. These are the stripline and the TEM 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 [80] designed a simple transmission line construction which provides a uniform electromagnetic field between its plates over a comparatively small volume, and this was written into both IEC 801-3 (1984) and CISPR 20 as a recommended method of performing part of the radiated immunity testing. It doesn't appear in the latest (third) edition of IEC 61000-4-3.

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 8.5). The field between the plates is propagated in TEM (transverse electro-magnetic) mode. 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:

$$E = V/h \quad \text{volts per metre} \tag{8.2}$$

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.

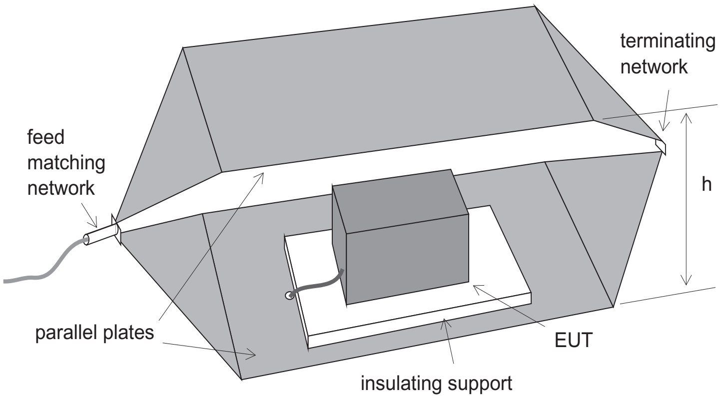

Figure 8.5 The stripline

The accuracy of the stripline's applied field depends to a large extent on the dimensions of the EUT. IEC 801-3 recommended that the dimensions should not exceed 25cm, while CISPR 20 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.

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 reorient 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 transverse electromagnetic mode is defined as a waveguide mode in which the components of the E and H fields in the direction of propagation are much less than the primary field components across any transverse cross-section; it shares this property with the free-space plane wave.

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 8.1), 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.

Table 8.1 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

8.1.1.5 The GTEM

The GTEM cell [72][81] overcomes some of these disadvantages and holds out the promise of lower cost, well-defined testing. The restriction on upper frequency limit is 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 7.2.4.

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 [69] that the field distribution in a GTEM includes a large longitudinal component (Figure 8.6). 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.

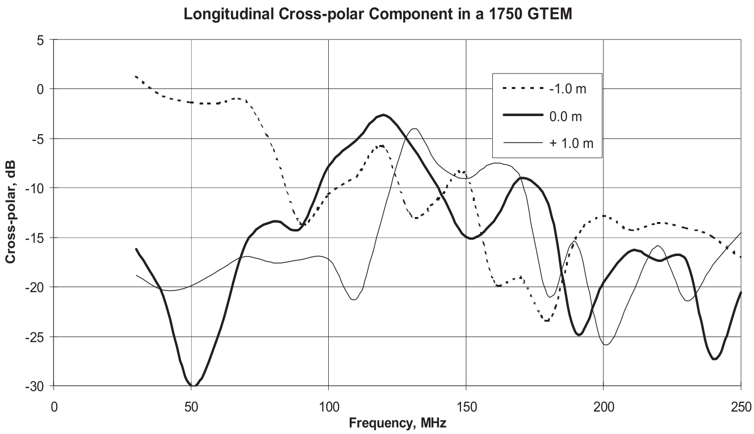

Figure 8.6 Longitudinal field components in the GTEM (dB with respect to vertical component) (Source: NPL [73] © Crown Copyright 2000. Reproduced by permission of the Controller of HMSO)

Its advantages are attractive particularly in terms of allowing one relatively inexpensive (c. £50,000) facility to perform all RF EMC testing. Considerable resources have been put into characterizing the GTEM's operation and in persuading the standards authorities to accept it as an alternative test method. This has resulted in a new document, IEC 61000-4-20, which covers both emissions and immunity tests in such cells. A large part of the work in producing this standard has involved finding acceptable solutions to the field uniformity and cable layout problems outlined above, that are consistent with existing test methods in screened chambers. IEC 61000-4-20 gives a method for calibrating the uniform area and requires that the secondary electric field components are at least 6dB less than the primary component, over at least 75% of the uniform area. By comparison with the emissions testing requirements (section 7.2.4), it doesn't place an explicit limit on immunity testing of large EUTs, but does say that the maximum EUT height should be no greater than $0.33 \cdot h$, where h is the distance between the septum and floor of the cell at the centre of the EUT.

8.1.2 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 – that includes the RF field generating equipment and, most importantly, has a screened room.

8.1.2.1 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 [162]; 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 15.2. 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 electromagnetically quiet zone. Figure 8.7 shows the features of a typical screened chamber installation.

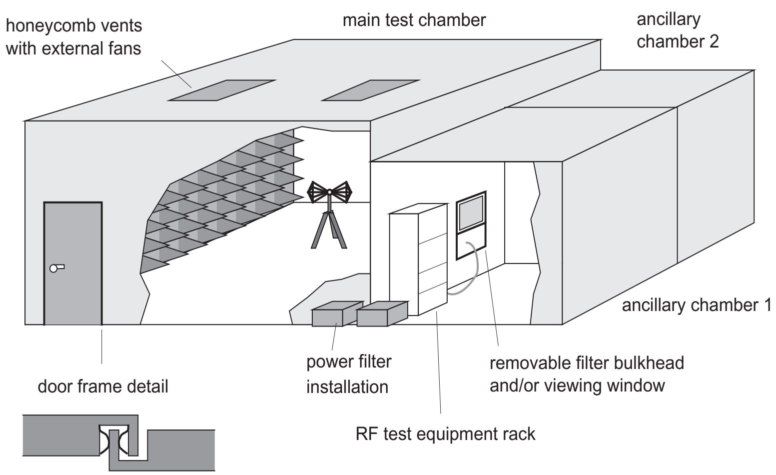

Figure 8.7 Typical screened room installation

8.1.2.2 Room resonances and field uniformity

An unlined room will exhibit field peaks and nulls at various frequencies determined by its dimensions. The larger the room, the lower the resonant frequencies; equation (15.3) on page 439 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 to reduce wall reflections, either carbon loaded foam shaped into pyramidal sections, or ferrite tiles, or a hybrid of both. The room is then said to be "fully anechoic" if all walls and floor are lined, or "semi-anechoic" if the floor is left reflective. The use of screened chambers for emissions measurements is covered in section 7.3.1.3, and the same considerations regarding anechoic absorber material apply here. For commercial radiated immunity tests (not for military), some absorber is needed on the floor; if you are using the same chamber for emissions and immunity, you will need to move the floor absorber in and out on a regular basis.

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 any EUT but with the chamber contents, especially the antenna and absorber positions, set up as they would be in the test itself; the grid corresponds to the intended position of the front face of the EUT. The field strength over at least 75% (i.e. 12) of the grid points must be within the tolerance –0dB/+6dB to be acceptable, though a tolerance up to +10dB is allowed for no more than 3% of test frequencies provided it is stated in the test report. The 0dB reference is the field strength specified for exposure of the EUT; it may, and usually does, occur at a different position in the 16-point grid for each different frequency. 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 (+6dB) at any other point in the grid is possible. This is not a mistake; it is the best that can be achieved with a reasonable-sized chamber. Figure 8.8 shows the geometry of the recommended field uniformity criterion.

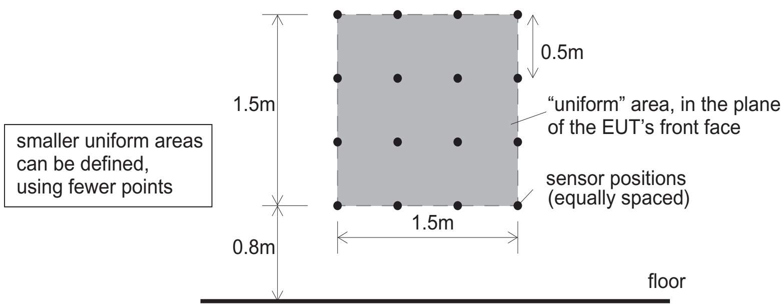

Figure 8.8 Field uniformity measurement in IEC 61000-4-3

The actual test then uses the same forward power values that have been used to create the uniform field calibration, with the EUT in place. This is why it is called a "substitution" method. No closed loop control of the *field strength* level takes place during testing, only forward power is controlled.

8.1.2.3 *Ancillary equipment*

You will need a range of support equipment in addition to the RF test equipment described in detail in section 8.1.1. 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 often 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.

8.1.3 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.

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.

8.1.3.1 *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.

8.1.3.2 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.

The test set-up

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" as the standard says: this can be interpreted as leaving this length between the EUT and the floor, and/or applying ferrite clamp absorbers at this distance from the EUT.

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 non-conductive, preferably plastic 0.8m high 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.

Running the test

During the compliance test the specified test level is maintained throughout the frequency sweep. This will be achieved by controlling the forward power to replicate the field uniformity calibration level. 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. For most EUTs, eight sweeps are needed: two for each of the four faces of the EUT, once in horizontal polarization and once in vertical. A different calibration file is needed for the two polarizations. If the EUT can be used in any orientation (e.g. hand-held equipment) then all six faces must be exposed, and twelve sweeps are necessary.

Assuming that the EUT remains correctly operational throughout the sweep, 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 testing uncertainty and production variability, and the possibilities for cost reduction by removing suppression components.

8.1.3.3 Testing above 1GHz

The third edition of IEC 61000-4-3 states that tests from 80 to 1000MHz are "related to general purposes"; for the frequency ranges 800 to 960MHz and 1.4 to 6GHz they are "related to the protection against RF emissions from digital radio telephones and other RF emitting devices". Meanwhile, a number of product and generic standards have started demanding immunity testing up to at least 2GHz and so the test method has to be extended above 1GHz.

Equipment

The same basic system configuration is used irrespective of frequency, but signal sources, amplifiers and antennas have to cover the highest frequency to be tested. This will normally need investment in at least one extra amplifier and antenna, although some BiLogs can cover the range up to 3GHz. You need to make sure that other equipment such as power meters, directional couplers and field strength sensors are suitable for the higher frequencies. You may also find that cable losses become unacceptably high, forcing investment in new cables.

Method

Even with a test distance of 3 m, using an antenna with a narrow beam width or a ferrite-lined chamber at frequencies above 1GHz, you may not be able to satisfy the field uniformity requirement over the 1.5 ∞ 1.5 m calibration area. The standard gives an alternative method (the "independent windows method") for frequencies above 1GHz, which divides the calibration area into an array of 0.5 ∞ 0.5 m windows such that the whole area to be occupied by the face of the EUT is covered. The field uniformity and field strength level is independently calibrated over each window, using a variation of the procedure given for tests below 1GHz. The field generating antenna is placed 1m from the calibration area and repositioned during the test to illuminate each of the required windows in turn.

Cable length and geometry are less critical at these high frequencies; therefore, the face area of the EUT is the determining factor for the size of the calibration area. On the other hand, maintaining the position of the antenna and the uniform window areas in the chamber is more critical, since even small displacements will significantly affect the field distribution.

8.1.3.4 Sweep rate, step size and modulation

The sweep rate of the applied field may be critical to the performance of the EUT. According to earlier versions of IEC 61000-4-3, 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 automatically stepped at this rate in steps of 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.

The third edition recognizes that sweeping has been almost entirely replaced by stepping and has explicitly removed the sweep rate limit of $1.5 \cdot 10^{-3}$ decades per second. Instead, it mandates a minimum dwell time of 0.5 seconds with AM on at each step, but retains the need for the EUT to be exercised and to respond. It would be rare to be able to achieve this at 0.5 seconds with most EUTs and in practice a default dwell time of 2 to 3 seconds is advisable. In fact, this doesn't slow down the total test time appreciably since many test systems take several seconds to step from one frequency to the next and re-establish the correct level; this has to be done with AM off since power meters respond incorrectly to a modulated signal. The typical software-controlled sequence is:

- step to the next frequency with modulation off;
- set and check the correct power level with modulation off;
- apply modulation for the desired dwell time;
- set modulation off and step to the next frequency, etc... .

For many systems there may be little sensitivity to sweep rate or step size 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 step spacing is too great then a response may be missed. Such narrowband susceptibility may be many times worse than the broadband response. Therefore some knowledge of the EUT's internal functions is essential, or considerably more complex test procedures are needed. IEC 61000-4-3 says "The sensitive frequencies (e.g. clock frequencies) shall be analysed separately according to the requirements in product standards" but the product standards rarely if ever say anything about this aspect, so it is up to your test plan to determine such details.

8.1.3.5 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 system) to be installed for some types of EUT.

Health and safety legislation differs between countries. In 1998 the International Commission on Non-Ionizing Radiation Protection (ICNIRP) published a set of guidelines [210] covering exposure to RF radiation. The ICNIRP guidelines have been incorporated into the EU EMF Directive (see section 1.4.3), which comes into force in 2016.

The ICNIRP guidelines take into account the known thermal and electric shock effects 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 [210] for occupational exposure to continuous fields over the frequency range of interest for RF immunity testing are reproduced in Table 8.2.

Table 8.2 ICNIRP guidelines for maximum field strength exposure, occupational

Frequency range	Electric field strength
0.065 to 1MHz	610 V/m
1 to 10MHz	610 / F (MHz) V/m
10 to 400MHz	61 V/m
400MHz to 2GHz	$3 \cdot \sqrt{F}$ (MHz) V/m
2 to 300GHz	137 V/m

8.1.3.6 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 8.1.2. 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 15. Another course known to have been taken by some firms is to use the services of a licensed radio amateur transmitting on the various amateur bands available to them – 30, 50, 70, 144, 432 and 1296MHz; 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.

8.1.4 Conducted RF immunity

The basic standard IEC 61000-4-6 defines the test method for conducted immunity testing, and it is referred to in tandem with the radiated field test in the generic standards and in product standards. In its most usual implementation it covers the frequency range from 150kHz to 80MHz. The immunity standard for broadcast receivers, CISPR 20, 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 adapted for application to automotive components, is a related technique. See also section 11.3.1.2.

8.1.4.1 Coupling methods

Three methods of coupling are defined in IEC 61000-4-6. The transducers for each are illustrated in Figure 8.9.

CDN

The preferred method is voltage injection via a coupling/decoupling network (CDN). This has zero insertion loss and therefore needs little power.

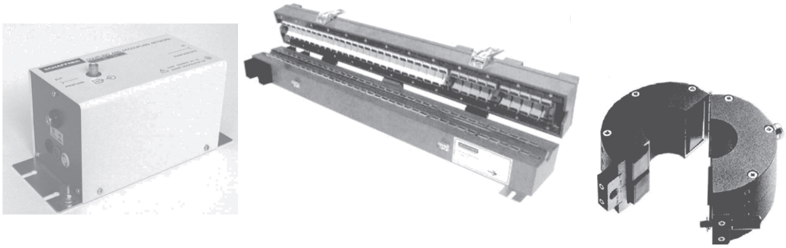

Figure 8.9 The CDN, the EM-clamp and the current probe

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 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 7.2.2.1. Unfortunately, the emissions LISN specification doesn't agree with that for the conducted immunity CDN, so different units are needed.) Direct voltage injection in addition requires that this network is used to couple the RF voltage onto the cable, and at the same time present a common mode source impedance of a known 150Ω. This means that the CDN is inherently invasive.

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 you have an in-house test lab and 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. For generalist test houses, the method is most often used for injection only onto the mains power supply port.

EM-clamp

Like the absorbing clamp used for measuring disturbance power (section 7.2.2.3), the EM-clamp consists of a tube of split ferrite rings which can be clamped over the cable to be tested, and it is therefore non-invasive and can be used on any cable type. Unlike the absorbing clamp, it provides both inductive and capacitive coupling and can be used down to 150kHz.

The signal is fed in via a single-turn loop which extends the whole length of the clamp. This loop is terminated at each end in an impedance which creates a voltage along the loop next to the cable, as well as allowing a current to flow in the loop. The voltage gives capacitive coupling and the current gives inductive coupling to the cable. The ferrite sleeve is composed of a low-μ (low permeability) grade at the EUT end and a high-μ grade at the AE end. The combination of graded ferrite and capacitive/inductive coupling gives the clamp significant directivity, particularly above 10MHz, so that substantially less signal is applied to the AE end of the cable, and the common mode impedance seen by the EUT is quite close to 150Ω across a large part of the frequency range of the test signal.

As with the CDN, the EM-clamp should be properly bonded to the ground plane to give a repeatable impedance. But also as with the CDN, variations due to cable layout on the AE-side of the test set-up, and due to the AE itself, are minimized. The coupling loss of the clamp is low enough that it does not require very much more power than a CDN for comparable stress levels.

Current injection probe

The current injection probe is an alternative to both the EM-clamp and the CDN. It is less effective than either, but is more convenient to use. The current probe is essentially a clip-on current transformer which can be applied to any cable. It is shielded, and so applies only inductive coupling, without capacitive coupling of the test signal. It has been in common use in military and automotive testing (the bulk current injection, BCI test) for many years and has been included in IEC 61000-4-6 since many test laboratories are familiar with it, but this has resulted in some anomalies with respect to setting the injected level.

A principal disadvantage of the current probe is that it gives no isolation from the associated equipment (AE) end of the cable, and no control of the cable common mode impedance. The current will flow in the cable according to the ratio of the common mode impedances provided by the EUT and the AE, and at the higher frequencies, according to the cable resonances. At 80MHz, 94cm is all that is necessary to give a quarter wavelength of cable; despite the strictures in the standard, shorter lengths are impractical, and the test is often performed on much longer cables. The actual stress current applied to the EUT is therefore very variable and also very hard to repeat, because of its dependence on AE and cable impedances. At the same time, the stress current also flows through the AE, which must therefore be at least as immune as the EUT. The standard requires the AE impedance to be set to 150Ω, but recognizing that this is often impractical, it provides for a modified method whereby the level is monitored by a secondary probe and limited if it increases above the intended value.

The current probe should only be used if all other methods are either impractical or unavailable. It is best suited to system-level injection where the AE and cable layout are fixed and known, and the physical limitations make it difficult to apply CDNs or the EM-clamp. A further disadvantage is that because of the higher coupling loss, the power required for a given stress is greater for the current probe than for any other method.

Test set-up

Figure 8.10 shows the general arrangement for making conducted immunity tests. The EUT is supported by an insulator 0.1m above the ground plane. Cables leaving the EUT in close proximity or in conduit are treated as one cable. The AE impedance on the tested cable should be stabilized at 150Ω; for the EM-clamp or current probe methods, this requires extra precautions at the AE itself.

8.1.4.2 Procedure

The open circuit test level V_{stress} (NB: not the level actually applied to the EUT) is usually 3V or 10V. An attenuator of at least 6dB is placed between the power amplifier and the transducer to prevent the power amplifier's output impedance, which is poorly defined, from affecting the results; the 50Ω offered by the output impedance forms part of the 150Ω source impedance for the test stress. As with the radiated test, the applied level is actually set by substitution.

Until the fourth edition there have been two basic calibration systems, a 150Ω one for the CDN or EM-clamp and another at 50Ω for the BCI probe. The object in either case is to terminate the transducer in a known impedance and then to set the stress level applied into that impedance. The power required to give this level is then repeated in the actual test. For the 150Ω system the required power level must give a reading of $V_{stress}/6$, or V_{stress} – 15.6dB. For the 50Ω system it was $V_{stress}/2$, or V_{stress} – 6dB. The

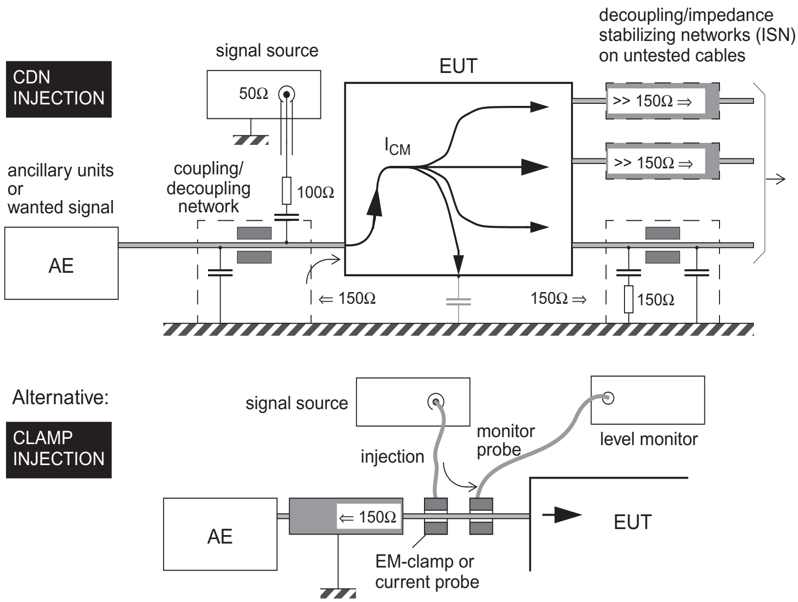

Figure 8.10 Conducted immunity test set-up

factor of 2 is needed because the stress voltage is given as an open circuit value, and the factor of 3 in the 150Ω system is needed because of the effect of the 50-to-150Ω resistive divider. In both cases, the level can be measured by any RF measuring device, for instance a power meter or spectrum analyser. The fourth edition has now deleted the 50Ω calibration system and insists that all devices are calibrated in 150Ω; this requires 100Ω resistors in series with the 50Ω jig's terminals.

Having calibrated the transducer for a particular level, this is then applied to the cable to be tested, and the applied stress is then stepped across the frequency range in 1% steps with an appropriate dwell time and 80% 1kHz modulation, exactly as with the radiated RF immunity test. You then need to repeat the test for all the appropriate cable ports as mandated by the test plan.

8.1.4.3 Disadvantages and restrictions

Conducted immunity testing has the major advantages of not requiring expensive anechoic screened room facilities, and being more efficient for applying the RF stress at the lower frequencies. 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 connection to cables with many signal lines are expensive to construct, bulky and may adversely affect the signal line characteristics, although clamp-on decoupling ferrites are simple and relatively cheap.

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 either 80 or 230MHz (corresponding to equipment dimensions of between about 0.6m and 2m). For higher frequencies, radiated testing is still necessary.

8.1.5 Measurement uncertainty for RF immunity

The application of measurement uncertainty for RF immunity tests differs from that for RF emissions, in that the uncertainty budget that a lab can create relates only to the uncertainty of the applied stress, not to that of the test result. It should be clear that if the transfer function between the applied stress and the EUT's response is unknown – and not only is it unknown in detail, but very often the only thing known about it is that it is highly non-linear [154] – then there is no way that an uncertainty can be stated for the outcome of the test. All that the lab can do is to calculate a budget for the uncertainty of the applied level.

What is then done with this value is a matter of some debate. If you simply ignore it and set the stress level to exactly the specification figure, then you have only a 50% level of confidence that the required stress level has been applied, since the actual stress could be either above or below the desired stress. Alternatively, you could increase the programmed stress above the required level by a factor related to the uncertainty value, which will then give a higher degree of confidence; a factor of 1.64 times the standard uncertainty gives a 95% confidence. As outlined in section 10.2.7.3, the CENELEC standards for RF immunity testing have been amended to avoid the increased level. But as a test lab customer, it is your choice as to what level of confidence you require in the testing you have commissioned.

8.1.5.1 Radiated immunity contributions

For radiated RF immunity to IEC 61000-4-3 it is taken as read that the –0dB/+6dB field uniformity criterion, with relaxations as allowed in the standard, has been achieved. This is *not* then a contributor to the uncertainty budget, since it is an inherent aspect of the standard method of test. The remaining uncertainty is that which applies to the actual setting of the field strength level. LAB 34 [209] gives some guidance on this and includes the following contributions:

- calibration of the field strength meter used for the uniform area measurements;
- the extent of the "window" within which the test software will accept a re-established forward power value for each frequency during the test;
- drift in the power meter;
- distortion in the power amplifier, creating harmonic content in the test signal;

- the effects of field disturbance caused by various supports and other extraneous structures in the chamber;
- measurement system repeatability from test to test, for which a value is obtained by analysis of a series of repeated readings.

8.1.5.2 Conducted immunity contributions

The method of IEC 61000-4-6 actually offers the choice of three different transducers, and also requires the level to be limited using a monitor probe if either of the clamp methods has to use an uncontrolled AE source impedance. This means that a budget should be developed for each of these situations. The factors that should be considered, for example for the CDN method, are:

- calibration of the measuring device, i.e. RF voltmeter or power meter;
- the extent of the re-established voltage level acceptability window, set in the software;
- drift of the signal generator or power meter, depending on the method used to re-establish the set level;
- distortion in the power amplifier, creating harmonic content in the test signal;
- mismatch error between the CDN and the measuring device (RF voltmeter or power meter), including the effect of the 50-to-150Ω adaptor;
- mismatch error between amplifier with 6dB attenuator and the CDN;
- measurement system repeatability.

8.2 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. But the bandwidth of fast transients and particularly of the electrostatic discharge is very wide and extends into the UHF region, so many precautions that are necessary for RF work must also be taken when performing transient tests.

8.2.1 ESD

8.2.1.1 Equipment

The electrostatic discharge generator described in IEC 61000-4-2 is conceptually fairly simple. The circuit is shown in Figure 8.11. 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 standard describes two modes of application, contact and air discharge. The output voltage should reach 8kV for contact discharge, or 15kV if air discharge is included, although for most products lower voltages are specified. Product and generic standards for common environments have settled on a level of 4kV for the contact method and 8kV for air.

The critical aspect of the ESD generator is that it must provide a well-defined discharge waveform with a rise time of 0.8 nanoseconds ±25%. This implies that the

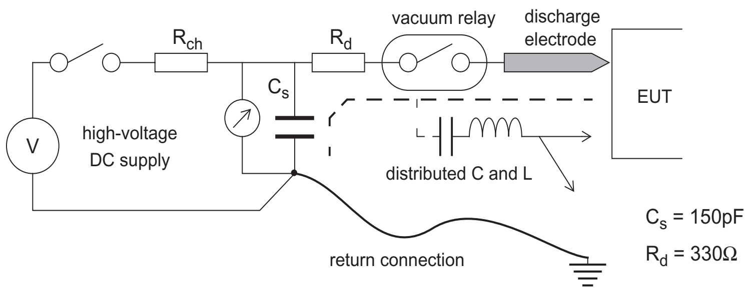

Figure 8.11 ESD generator (according to IEC 61000-4-2)

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 using an oscilloscope with a bandwidth of at least 2GHz, in a special test jig with a measured performance up to 4GHz.

If you use a commercial ESD generator this calibration will have already been done by the manufacturer or a calibration laboratory, 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. This is not trivial.

8.2.1.2 Test set-up

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 7.3. 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. Tabletop 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 8.12 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 cables.

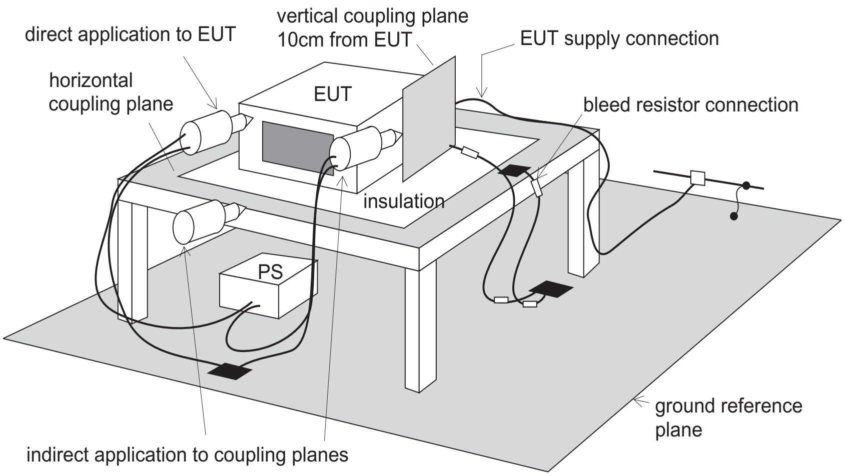

Figure 8.12 ESD test set-up

8.2.1.3 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, and exclude points that are only accessible under maintenance or are inaccessible after installation. Contact pins of connectors that have a metallic connector shell should not need to be tested, since the shell will be expected to take the discharge in real situations – but contacts within a plastic connector *should* be tested, by air discharge only, unless there is a rationale which states that the connector will never be left open in normal operation. 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 find 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 (since you may not be able to tell which is the most sensitive) with both polarities.

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 approach speed and angle make a considerable difference to the effectiveness and repeatability of the test.

Contact versus air discharge

Contact discharge is preferred, but this can only be done against conducting surfaces or painted metal surfaces. Here, the voltage is held off the tip by the relay, the tip is applied directly to the contact point and the relay is then triggered to give a single discharge; there is therefore no air gap between the tip and the EUT to contribute to variations in the stress. 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. As the tip approaches the EUT's surface, the increasing electric field gradient causes breakdown either of the air gap, or by creepage along the surface of a plastic moulding, just before contact occurs, the distance of the breakdown depending on the applied voltage level.

Indirect discharge

To simulate discharges to objects near to the equipment in its operating environment, and to apply the test in cases where neither direct contact nor air discharge application to the EUT is possible, the discharge is also applied by contact to coupling planes located a fixed distance away from the EUT. This uses both the horizontal coupling plane and the vertical coupling plane shown in Figure 8.12. These planes are emphatically not *ground* planes: they are connected to the true ground reference plane by single wires which include 470kΩ bleed resistors at each end. The bleed resistors disconnect the coupling planes from the ground plane as far as the ESD pulse is concerned, but allow the charge applied to the coupling plane to bleed off within microseconds after the pulse is over, ready for the next one. The resistors are placed at each end so that the connecting wire is decoupled from each plane, a precaution which reduces the effect its position might otherwise have on the stress field waveform.

Ungrounded EUTs

A particular problem arises with EUTs which have no direct connection to the ground of the test set-up: handheld, battery operated devices, or mains powered safety class II devices are typical examples. The standard provides for a method of discharging the EUT in between applications of the ESD pulse, in situations where the equipment cannot discharge itself because of this lack. The principal method is through use of a cable with 470kΩ bleed resistors at each end, attached at one end to the HCP or ground plane and at the other end to the point where the ESD pulse is applied. This bleed cable can be in place during the application of the pulse. Alternatively, a conductive earthed brush incorporating 470kΩ bleed resistors to discharge the EUT between applications is suggested, or extending the time between applications to allow natural charge decay.

Without these precautions, the EUT's self capacitance will gain charge with each pulse applied during the testing, resulting in a progressive increase in static potential and a consequent reduction in stress over a series of pulses of the same level and polarity; or, if the polarity is reversed, up to twice the intended stress could be applied.

8.2.2 Electrical fast transient (EFT) bursts

The EFT-B test checks the immunity of the product against high frequency, low energy transient bursts due to switching events in the near environment.

8.2.2.1 Equipment

When you are 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 (but not identical) to the LISN used in emissions testing, and the CDNs used for conducted RF immunity tests. IEC 61000-4-4 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 are applied every 300ms (see Figure 8.13). 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 originally constructed with a spark gap driven from an energy storage capacitor, which limited the achievable repetition rate, although more modern solid-state generators have for some time superseded this approach. Later editions of IEC 61000-4-4 require a burst repetition frequency of 100kHz as well as 5kHz ("Use of 5 kHz repetition rates is traditional; however, 100 kHz is closer to reality"), though the majority of product standards have yet to catch up and still specify 5kHz. The standard also ensures that the waveform is calibrated into both 50 and 1000Ω, which means that the waveform that is actually delivered to the EUT is specified more rigorously [127]. This revision was stalled for some time because of its implications for obsolescence of the older generation of test equipment.

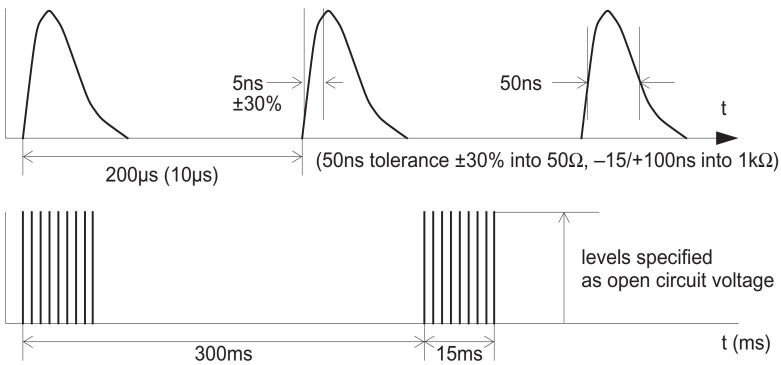

Figure 8.13 Fast transient burst specification (according to IEC 61000-4-4)

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.

8.2.2.2 Test methods

As with ESD tests, a reference ground plane must be used. This is connected to the protective earth, and the generator ground is directly bonded to it with a short strap. Both tabletop and floor standing equipment (in later editions) is stood off from this ground plane by a 10cm insulating block. A 0.5m 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 8.14.

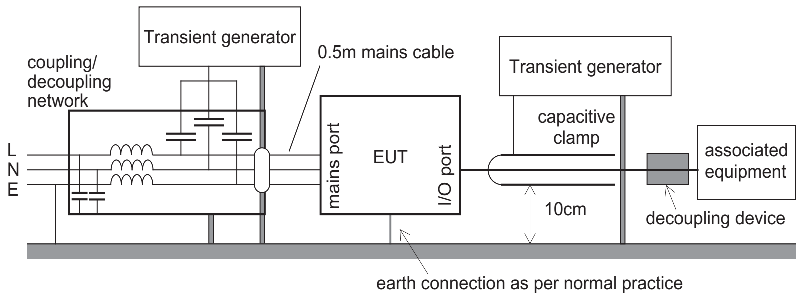

Figure 8.14 Fast transient test set-up

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. Note that later editions of IEC 61000-4-4 make explicit that the bursts are applied only in common mode, that is all lines together, with respect to the ground plane – not to individual mains lines (L, N, or E). The required voltage levels are defined in the relevant product standard, and vary depending on the anticipated operating environment and on the type of line being tested.

8.2.3 Surge

The surge test of IEC 61000-4-5 (Figure 8.15) 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. It's normally only required on signal lines if their cables extend outside a building.

8.2.3.1 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. Note that the third edition of the standard subtly changed the definition of the duration of the two waveforms, which has caused some consternation amongst purists.

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 and therefore not purely resistive, is 2Ω. Additional resistors of 10 or 40Ω are added in series to increase the effective source impedance as necessary.

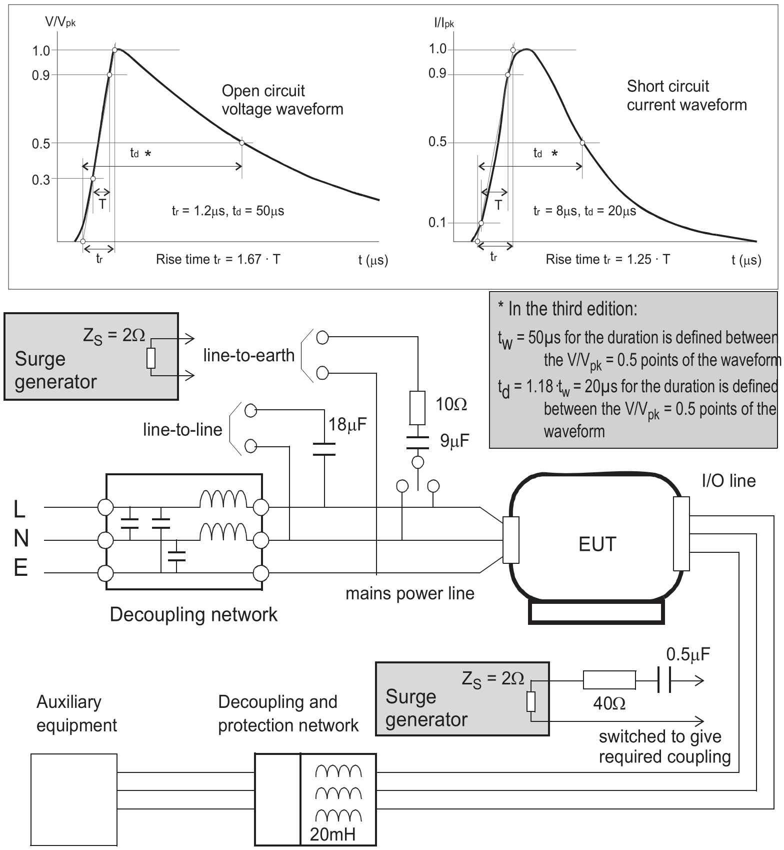

Figure 8.15 Surge waveform specification and coupling

8.2.3.2 *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 (the standard rather unhelpfully says for the time between successive impulses, "1 minute or less"), and a maximum of 10 surges (5 positive and 5 negative) is recommended at any one level. Overenthusiastic 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.

For mains supply tests, 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. Thus, tests are required at each of the phase angles (with respect to the 50 or 60Hz waveform) 0˚, 90˚, 180˚ and 270˚. 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.

Wideband signal lines

A significant problem with unscreened high-speed data lines, such as Ethernet, is that any coupling-decoupling network is likely to damp the lines to the extent that signal transmission is affected. Earlier versions of the standard got around this by proposing to test these ports only for damage, i.e. removing the active line for the surge test and reinstating it afterwards, checking for continued functionality. The third edition has given up even on this: clause 7.5 says "For surge testing to high speed interconnection lines, no surge test shall be applied when normal functioning cannot be achieved because of the impact of the CDN on the EUT".

8.2.4 Other transient immunity tests

8.2.4.1 Ring and damped oscillatory waves

A potential alternative to the surge test is given in IEC 61000-4-12, whose first edition defines the ring wave and the damped oscillatory wave. The damped oscillatory wave was deleted from the second edition of IEC 61000-4-12 and given its own standard, IEC 61000-4-18. It is a highly specialized waveform, intended only to represent the kind of surges found in high-voltage electrical substations. The ring wave, on the other hand, represents a very typical oscillatory transient occurring frequently in power supply networks and control and signal lines, due to load switching, power faults and lightning.

† Follow-on occurs when the surge causes a protective device to break down, and this then puts a low impedance across the supply, which maintains the current through the protector; so that (for an AC supply) energy is dissipated in the protector not just by the surge, but also by the following half-cycle of the supply.

The propagation of the wave in the power and signal lines is always subject to reflections, due to the mismatched line impedance. These reflections create oscillations, whose frequency is related to the propagation speed, length of line and parasitic parameters such as stray capacitance. The rise time is slowed due to the low-pass characteristic of the relevant line. The resultant phenomenon at the equipment ports is an oscillatory transient, or ring wave, which is bipolar compared to the unidirectional surge discussed above in section 8.2.3.

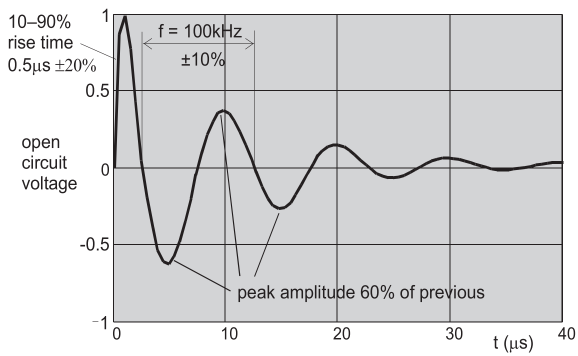

Figure 8.16 Waveform of the ring wave

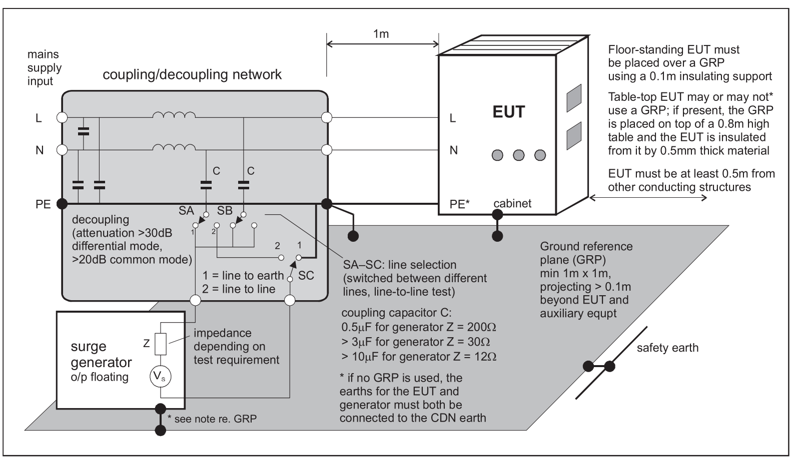

Figure 8.17 Application of the ring wave for AC and DC supplies

The parameters of the ring wave defined in the standard are shown in Figure 8.16 and the test set-up and coupling modes are shown in Figure 8.17. A minimum of 5 positive and 5 negative transients are to be applied, both line-to-ground (common mode, simultaneously between all terminals and ground) and line-to-line (differential mode), and/or between cabinets (for communication ports). The generator output impedance and minimum repetition period are varied for different applications:

- 12Ω with a minimum repetition period of 10s: EUT supply ports connected to major feeders, and for application between communication ports on cabinets interconnected with 10m long screened data comms cables;

- 30Ω with a minimum repetition period of 6s: EUT supply ports connected to outlets;
- 200Ω with a minimum repetition period of 1s: I/O ports, unless the test involves protection devices or filters, in which case 12Ω or 30Ω is applicable.

In fact, the ring wave immunity test is rarely called up in any product standards and so although it is quite a good test for medium energy transient immunity, few products have to undergo it. This may be because of the relatively complicated evaluation of installation conditions that is needed in order to be able to select the appropriate test generator impedance, which probably encourages product committees to favour the IEC 61000-4-5 surge test.

8.2.4.2 Automotive transients

Historically, vehicle manufacturers have each had their own specifications for transient immunity of electrical and electronic parts that they sourced from outside manufacturers. An international standard provides a partial solution to the multiplicity of different requirements. ISO 7637 parts 1, 2 and 3 refer to conducted transient immunity of equipment fitted to cars and light vehicles. Part 1 gives general requirements, and Part 2 gives technical requirements for 12V and 24V systems. Part 3 is for coupling via lines other than supply lines, and defines only the test pulses to be used for simulating switching transients.

Part 2 defines both a means of testing transient emissions (using an oscilloscope and 5µH/50Ω artificial network), without defining any emissions limits, and also a series of standard test pulses (see Figure 11.23 on page 286) to be generated by a test pulse generator and applied to the device under test via its DC power supply leads. No test layout is specified other than that the power lead from the generator to EUT is 0.5m long and stretched straight.

Severity levels (peak voltages) of these pulses are to be agreed between manufacturer and user. Pulses 3 and 4 are called up in the ETSI radio standards with an applied value of level II. If the manufacturer states that a direct connection to the vehicle battery is not required, then pulses 1 and 2 are mandated as well, also at level II.

8.2.5 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.

8.2.5.1 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. 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 and fast transient response.

8.2.5.2 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 for 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 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.

8.2.5.3 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 contact method is preferred over air discharge.

8.2.6 Measurement uncertainty for transient tests

Measurement uncertainty for transient tests has to take a completely different approach to that for the other tests discussed so far. This is because the variables in transient testing include voltage or current parameters, time domain parameters and set-up parameters, and there is no meaningful way to combine these into a budget expressing a single value which could then represent the uncertainty of the applied stress. As an escape from this impasse, the accreditation standard ISO 17025 says:

> In those cases where a well-recognised test method specifies limits to the major sources of uncertainty of measurement and specifies the form of presentation of calculated results, the laboratory is considered to have satisfied this clause (on estimation of uncertainty of measurement] by following the test method and reporting instructions.
>
> [189] note to clause 5.4.6.2

Interpreting this statement, the requirements for ESD, transient and surge tests are deemed to have been satisfied (given that the lab does actually follow the test method) if the generator has been shown to meet the various individual requirements of the appropriate specification: clause 6 of IEC 61000-4-2, -4 and -5, for example. This demands that you should compare the traceable calibration details of the generator you use against the tolerances provided against all of the parameters in this clause, adjusted by the declared calibration uncertainty of the cal lab that has provided the figures. So for instance, IEC 61000-4-2 calls for a peak current at 4kV indicated of 15A ±10%; say the stated calibration uncertainty for this parameter is ±3%, then the current actually measured in your generator calibration could fall within the range 15A ±7%. As long as it does, then the requirement for estimation of measurement uncertainty has been satisfied, using the above rationale. If it doesn't you would need to adjust the generator to bring it within tolerance. This validation of calibration data should be carried out for each polarity of all test levels and all parameters. Setting up a spreadsheet for each instrument simplifies and speeds the process.

Uncertainty annexes have been added to most of the major test standards in the IEC 61000-4 series in the last few years; they generally do two things, firstly give you a specific list of contributions so that you can set up a standardized uncertainty budget; and secondly, tell you not to pay any attention to measurement uncertainty when considering compliance issues.

8.3 Military susceptibility tests

As with emissions measurements, military requirements to DEF STAN 59-411 or MIL-STD-461 cover similar phenomena to the commercial tests but do so in different ways.

8.3.1 Continuous RF susceptibility

There are two groups of tests in this category, conducted (CS) and radiated (RS). They were listed in Table 5.7 and Table 5.9.

Applied RF field levels, as with emissions limits, can show wide variations depending on the required application and consequent expected environment. DEF STAN 59-411 DRS02 has a "Manhattan skyline" of levels versus frequency, ranging from typically 10V/m at low frequency to 1000V/m, pulse modulated, in the microwave region, if equipment will be sited potentially in the main beam of a radar transmitter (2000V/m for aircraft). MIL-STD-461 RS103 has a rather more uniform set of requirements, ranging from 10V/m for ships below decks to 200V/m for aircraft. Frequency ranges are tailored to the application as well, but can extend from 10kHz to 40GHz.

Compare this to the majority of commercial standard requirements, which are generally fixed at 3V/m for residential and 10V/m for industrial and marine applications. And the frequency range for these radiated requirements starts at 80MHz and goes up to 2.7GHz at the most, with much lower levels being the norm above 1GHz; it may be fair comment that most commercial products aren't expected to find themselves in the main beam of a surveillance radar.

8.3.1.1 Test method

As with radiated emissions, there are differences in the susceptibility test procedure too. The military test layout is the same for emissions and susceptibility. For RF radiated susceptibility, the biggest issue lies in how the field strength is controlled. For the tests in MIL-STD-461 and DEF STAN 59-411 the applied field strength at a probe near to the EUT is monitored and controlled during the test. For the commercial test to IEC 61000-4-3, the field is pre-calibrated in the absence of the EUT and the same recorded forward power is replayed during the test. These two methods can produce fundamentally different results, for the same specification level in volts per metre, depending on the nature of the EUT.

In addition to this, there are differences in the modulation that is applied to the RF stress. The military tests prefer 1kHz square wave modulation, but also pulse modulation where it is relevant (at radar frequencies), along with other more specific types of modulation in some cases (that most likely to have the greatest effect on the EUT is to be specified in the EMC Test Plan). The IEC 61000-4-3 test uses only 1kHz sinusoidal modulation; but it does require 80% modulation depth, which effectively raises the peak applied stress level to 1.8 times the specification level (Figure 8.2). In this narrow sense, the commercial test is more stressful than the military, for a given specified level.

The radiated RF test requires various antennas to cover the frequency range. Note that the BiLog, beloved of test labs for commercial radiated testing, is not included; the standards are prescriptive about the antennas that can be used for radiated emissions, and labs tend to assume that the same types should be used for susceptibility.

- Parallel plate: 14kHz–30MHz
- Power biconical: 30MHz–200MHz
- Large double-ridge waveguide horn: 200MHz–1GHz
- Small double-ridge waveguide horn: 1GHz–18GHz

Power is monitored into the antenna and field strength is monitored around the EUT during the test using isotropic probes. The antenna position depends on EUT size and antenna beamwidth. There is no specification for uniform field area; the test is performed with the same set-up as for the radiated emissions test in a screened room which meets the relaxed NSIL criteria discussed in section 7.4.4.2. If a malfunction occurs when sweeping through the frequency range the signal strength is reduced to establish the threshold level. At frequencies above 1GHz discontinuities in the screening of the EUT (connectors, displays, etc.) are presented to the transmitting antenna directly.

8.3.1.2 Conducted RF

Similar issues apply to the specifications for conducted RF susceptibility. Direct comparisons are harder because commercial standards, based around IEC 61000-4-6, apply a voltage level to the cable from a source impedance of 150Ω; virtually all other standards use the method of “bulk current injection” which applies a current level via a clip-on current transformer. Relating the two is only possible if you know the common mode input impedance of the interface you are testing. It would be fair to say that even the designers most familiar with their product will be guessing – it’s not a feature which is necessary to know for the functioning of the equipment, even though it has a direct impact on EMC performance.

Beyond this, as with radiated RF susceptibility, the military and aerospace requirements have a palette of levels versus frequency for different applications. MIL-STD-461 CS114 has 280mA and DEF-STAN 59-411 DCS02 has 560mA for their most severe applications. If we take the power into the 50Ω calibration jig, this is between 4 and 15 watts. Compare this with the typical 10V emf from 150Ω which gives 5Vrms into a 150Ω calibration, as required by IEC 61000-4-6, which is only 166mW.

DCS02 applies to both power and signal lines and uses current injection only, with the bulk current injection probe. The applied stress is determined by either of two criteria, both of which must be monitored simultaneously, forward power (set up in a calibration jig) or induced current measured on the cable under test.

8.3.2 Transient susceptibility

The various military transient tests were shown in Table 5.6 and Table 5.9 on page 116. These require different types of transient waveform using various generators. In most cases, levels and waveform are set up into a calibration jig before the test, and the transients are applied by current probe on cable bundles; this is the case for MIL-STD-461 CS115 and 116, and for DEF STAN 59-411 DCS04, 05, and 08. DCS06 is applied on power supply lines individually, as is also DCS08. A noteworthy difference from commercial testing is that all the DEF STAN tests bar DCS09 and DCS10 require DCE01 (conducted power emissions) to be applied both before and after the transient test to ensure that the power filter has not been damaged.

DCS05 has two parts, switching simulation and NEMP (Nuclear ElectroMagnetic Pulse), the latter being much more severe. DCS10 ESD is similar to the commercial ESD test, IEC 61000-4-2, but otherwise there is no comparability in waveforms. DCS09 tests aircraft equipment for lightning susceptibility and applies similar and in some cases identical waveforms to RTCA DO-160 for commercial aircraft. A wry note at the beginning of DCS09 says

> When testing with the Long Waveform, in particular, it is advisable for personnel in the vicinity of the EUT to wear eye protection. Some components have been known to explode and project debris over distances of several metres. Some types of pulse generators can produce a high intensity burst of noise when they are fired. Operators, trials engineers and observers should be made aware of this and advised to wear ear protection.

8.4 IC immunity tests

Another, very different, set of immunity tests have been standardized for integrated circuits. Section 7.4.6 reviewed an IEC standard for emissions from ICs; for immunity, the relevant numbers are IEC 62132-X for RF and IEC 62215-X for transients. The set of each is listed in Table 8.3.

Like the emissions tests, the conducted techniques reflect the different interest groups that have contributed to this standard: the BCI and DPI methods have their roots in automotive testing and are basically modifications of already-existing methods for vehicle module testing, to adapt them to application to ICs. The Workbench Faraday Cage method is similarly derived from a method widely used in IEC 61000-4-6.

Also like the emissions tests, the IC immunity tests haven’t caught on in a big way, at least partly because they call for a very specific test plan and test board for each IC type. So you won’t find test results to these standards quoted in off-the-shelf product datasheets; but if your application calls for a good control of EMC characteristics, and needs application-specific parts in high volume so that it’s worth spending extra time on the characterization, then the standards provide a defined way to do this.

8.4.1 RF test methods

8.4.1.1 BCI

The advantage of the bulk current injection method is that it can be applied to any wire or a group of wires, without a direct connection. The stress can be induced into, say, the

Table 8.3 IC immunity test standards

Standard	Title
	Integrated circuits – Measurement of electromagnetic immunity
IEC 62132-1	General conditions and definitions
IEC 62132-2	Measurement of radiated immunity – TEM cell and wideband TEM cell method
IEC 62132-3	Bulk current injection (BCI) method
IEC 62132-4	Direct RF power injection method
IEC 62132-5	Workbench Faraday cage method
IEC 62132-8	Measurement of radiated immunity – IC stripline method
IEC TS 62132-9	Measurement of radiated immunity – Surface scan method
	Integrated circuits – Measurement of impulse immunity
IEC TS 62215-2	Synchronous transient injection method
IEC 62215-3	Non-synchronous transient injection method

power supply alone, or into both the power supply and its return in common mode, or into a collection of signal wires. The induced current must flow in a loop which includes the device under test, its ground plane, and the AE with its ground connection. The probe is calibrated by injecting a defined current into a 50 ohm jig, and the power needed to achieve this current is re-played into the IC device under test (DUT). Because the DUT's input impedance may be lower than 50 ohms, a monitor probe detects the actual current induced.

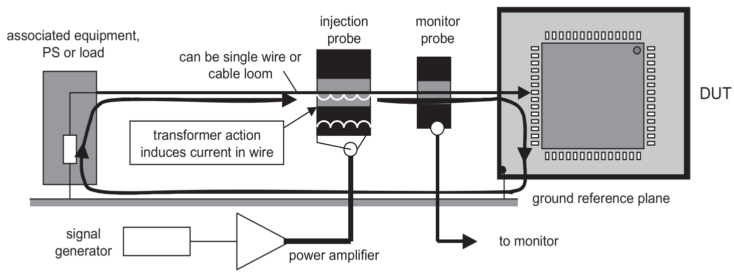

Figure 8.18 The IEC 62132-3 BCI test

The method is very similar to the automotive and military BCI techniques, as well as the current probe injection method in IEC 61000-4-6 which was discussed in section 8.1.4.1. It suffers from the same disadvantages, mainly that it gives no isolation from the associated equipment (AE) end of the cable, and no control of the cable common mode impedance.

8.4.1.2 DPI

Direct power injection is reasonably easy and repeatable when only a few pins need to be tested; for large pin count devices it becomes cumbersome and time consuming, and it is better to identify a reduced set of representative pins rather than to test each pin.

The RF disturbance is applied to a given pin via a decoupling and DC blocking network, sometimes referred to as a “bias tee”. The network should separate the wanted signal from the applied RF without affecting the wanted signal, and this can limit its application for wideband or balanced circuits. Simultaneously, other pins are passed out of the test set-up via similar networks to allow for functional monitoring of the DUT. The RF power is monitored via a directional coupler to detect both forward and reverse power.

The RF generating system is matched to 50Ω throughout, but the impedance at the DUT pin is not, and is likely to vary substantially with frequency. To reduce the effect of the mismatch and consequent cable reflections, it is helpful to put a 3–6dB attenuator at the connector to the board and the PCB tracks up to the capacitor should be designed for 50Ω impedance. Characterization of the setup is required, replacing the DUT with a 50Ω load and measuring the loss from connector to pin; with no resistor, this should be 0dB with a ±3dB tolerance.

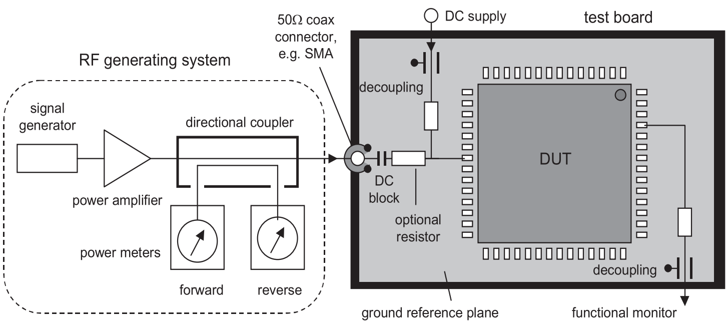

Figure 8.19 The IEC 62132-4 DPI test

8.4.1.3 *TEM/GTEM*

Both emissions and immunity tests can be done in a TEM or GTEM cell. As described in section 8.1.1.5, this is an enclosed transmission line structure, loaded at one end and fed at the other, whose body forms one half of the transmission line and an internal septum plate forms the other. The principle of the TEM and GTEM cells are the same, but the GTEM cell is flared and terminated in a broadband absorber, so that its bandwidth is not limited by resonances and is consequently much greater than that of the TEM cell.

The test board is laid out with the DUT on one side and all support components on the other, with the board ground plane exposed such that it can be bonded to the floor of the cell (Figure 8.20). Only the DUT itself is contained within the walls of the cell. Provided the frequency remains low enough to excite only the cell’s TEM mode, then electric fields are coupled in the y-direction and magnetic fields are coupled in the x-direction, with no coupling in the z-direction. The board is square, and it should be tested twice, at 0˚ and 90˚ orientations, to exercise coupling to both directions of bond wires and tracks.

With a matched termination, the E-field within the cell is related to the voltage V at the termination by

$$E \text{ (V/m)} = V/h \tag{8.3}$$

where h is the height (m) between the septum and the floor

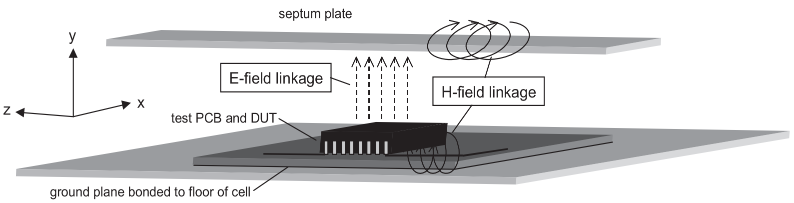

Figure 8.20 The IEC 62132-2 TEM/GTEM test

This test method is non-invasive and non-specific with respect to individual signals on the device under test. Whilst it accurately characterizes the radiated coupling to and from the package on the test board, this is rarely representative of the coupling the same device will experience in a real application, unless the test board layout is very close to that of the application.

8.4.1.4 Test board

Several parts of the IC test standards give instructions for the design of a test board, which is necessary to allow RF testing of any given IC type, and is specific to that type. The layout of such a board will have a direct effect on the outcome of the test, and must be carefully thought out.

Part 1 of both the emissions and immunity standards gives virtually identical guidance for a generic structure, which is intended to be used for both radiated and conducted tests. It defines a 10cm square board and places the device under test on top of the board and all support components underneath, so that when the board is placed into a radiated transducer (TEM or GTEM cell) only the device itself is exposed. The rest of the top side is continuous ground plane which can be bonded around its edge to the wall or floor of the test cell, so forming a continuous screening structure. Bonding of the top side ground plane and other layers also used as ground planes is regarded as important and specific instructions for vias are given in this respect.

8.4.2 Transient tests

IEC 62215's two parts are an attempt at defining methods to evaluate the immunity of ICs against fast transients (not ESD). One method applies the transients synchronously with the activity of the IC; the other doesn't. The latter makes reference to the transient definitions of IEC 61000-4-4, -4-5 and ISO 7637-2. As might be expected, a large part of each standard is a description of the coupling method and the test board.