EMC STANDARDS

Another EMC resource
from EMC Standards

A Practical Guide for EN 61000-4-3: Immunity to radiated radio frequencies

Helping you solve your EMC problems

9 Bracken View, Brocton, Stafford ST17 0TF T:+44 (0) 1785 660247 E:info@emcstandards.co.uk

REO **A Practical Guide for EN 61000-4-3**

Immunity to radiated radio frequencies

REO INDUCTIVE COMPONENTS AG
Bruehler Strasse 100, D-42657 Solingen, Germany
Tel: 00 49-(0) 2 12-88 04-0
Fax: 00 49-(0) 2 12-88 04-188

REO USA
3250 North Post Road, Suite 132, Indianapolis
IN46226, USA
Tel: 001 317 8991395 Fax: 001 317 8991396

REO (UK) LTD, Units 2 - 4 Callow Hill Road, Craven Arms
Business Park, Craven Arms, Shropshire SY7 8NT UK
Tel: 01588 673411 Fax: 01588 672718
Email: sales@reo.co.uk Website: www.reo.co.uk

REO UK LTD

Contents

Immunity to radiated radio-frequencies and compliance with the EMC Directive

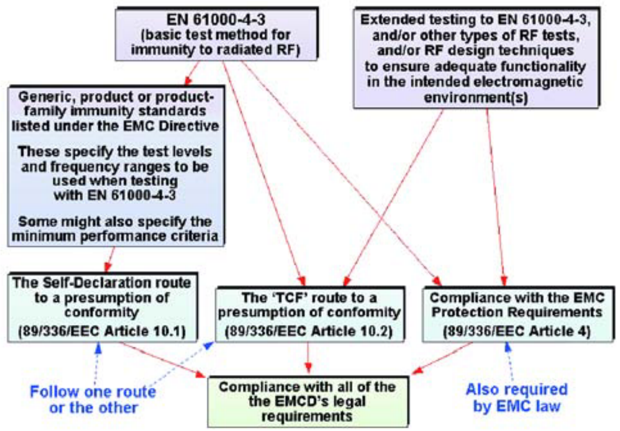
The basic immunity test method for radiated continuous radio-frequency (RF) is IEC 61000-4-3 [1]. This has been adopted as the harmonised European standard EN 61000-4-3 [2], which is often called up as a basic test method by immunity standards listed under the Electromagnetic Compatibility (EMC) Directive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

Since all equipment is subjected to radiated electromagnetic fields at RF, and since these can induce voltages and currents into conductors and so can interfere with every kind of electronic device, product, equipment, system or installation (called equipment in the rest of this booklet), it makes good sense to test equipment for immunity to RF fields to ensure it will work reliably in its intended operating environment. This is especially important in safety-related, high-reliability, mission-critical, or legal metrology electronic applications.

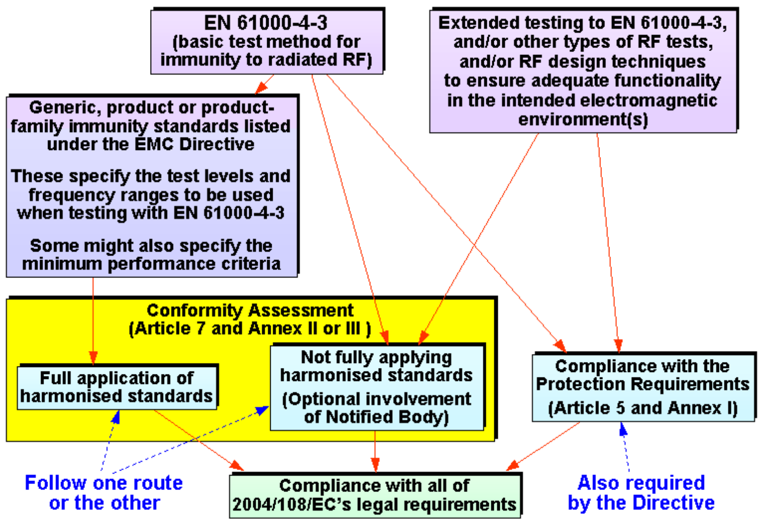
EN 61000-4-3 is a basic test standard, so when following the self-declaration to standards route to conformity (Article 10.1 in [3]), EN 61000-4-3 should *not* be listed on the EMC Declaration of Conformity. Only the relevant generic or product-family harmonised EMC standards should be listed. These will usually call-up EN or IEC 61000-4-3 as a test *method*, but it is always the generic or product-family standard that sets the minimum test *levels* and the frequency ranges that are to be applied to allow conformity to be claimed. They may also specify other aspects of the test, such as the minimum functional performance criteria to be achieved during the test.

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

The relationship between EN 61000-4-3 and the first edition of the EMC Directive (89/336/EEC)



The relationship between EN 61000-4-3 and the second edition of the EMC Directive (2004/108/EC)



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

Under 2004/108/EC, equipment manufactured specifically for use at a named 'fixed installation' may not have to comply with any EMC requirements when it is supplied. But testing to EN 61000-4-3 at specified levels will generally be a requirement by the customer to help ensure that his fixed installation complies with the EMC Directive's Protection Requirements.

There may be significant financial or compliance benefits in performing conducted RF immunity tests which go beyond simple compliance with the *minimum* requirements for Self-Declaration to the EMC Directive. This is especially true where mobile radio transmitters (e.g. cellphones, walkie-talkies, etc.) could be used nearby, or where industrial scientific or medical equipment that uses radio frequency energy to perform its direct function (CIPSR 11 or EN/IEC 55011 refer), is nearby.

These two situations are specifically *not* covered by the generic or product-family immunity standards listed under the EMC Directive, meaning that it is up to the manufacturer to assess the electromagnetic (EM) environment that their equipment will be used in and test it accordingly, to comply with the EMC Directive's Protection Requirements.

Compliance with the EMC Protection Requirements is a legal requirement that applies *in addition* to the requirement to follow one of the conformity assessment routes (Self-Declaration, Article 10.1; or TCF, Article 10.2). Equipment that passes tests to all relevant immunity standards listed under the EMC Directive but nevertheless is unreliable or performs badly in normal use because it is not immune enough for its real-life EM environment – does not comply with the EMC Directive's Protection Requirements, and is therefore illegally CE marked.

Applying EN 61000-4-3 (or similar) tests which go beyond the minimum requirements of the EMC Directive's listed standards, and/or appropriate design methods, can help make equipment more reliable, reduce warranty costs, improve customer satisfaction and reduce exposure to liability claims – for more on this refer to the section on “Radiated RF testing and real-life reliability” later in this booklet.

This series of booklets is concerned with testing to the EN standards for typical domestic, commercial, light industrial and industrial environments. But other kinds of immunity tests may be required by the EMC standards for automotive, aerospace, rail, marine and military environments. Some of these industries have developed their own test methods based on their own particular kinds of EM environments.

For instance, commercial avionics manufacturers might be required by DO160 to test with pulsed fields of up to 3,000V/m peak, 300V/m average, at frequencies of up to 40GHz. Automotive manufacturers' in-house EMC standards typically require their suppliers of electronic modules to have passed tests with fields of up to 200V/m (and/or its equivalent in conducted RF current) at frequencies of up to 2GHz.

This guide describes how to apply EN 61000-4-3:2003 (the version that is current at the time of writing) and applies equally well to the 2003 version of IEC 61000-4-3. The IEC and EN versions of this standard are continually being amended to keep pace with technical progress (see later) so it is always best to use the latest version of the test standard, except where regulatory requirements for the EU or elsewhere specify the exact version that is to be used. Since many national EMC tests outside the EU are based on IEC standards, this guide may be of use where non-EU EMC specifications apply.

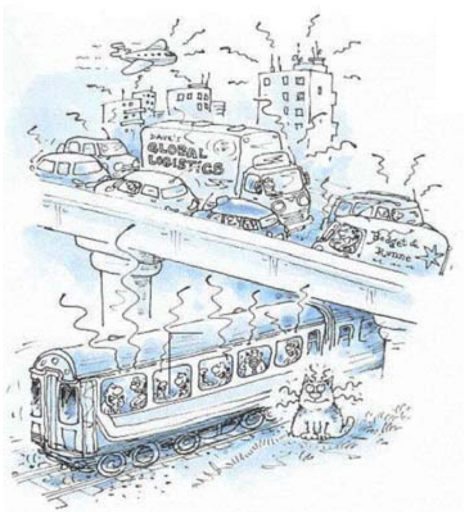
Where an electronic equipment has a safety-related or legal metrology function, requires high reliability, or is mission-critical – mere compliance with the EMC Directive is often insufficient for ensuring that it has been designed correctly – additional and/or tougher immunity requirements may need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

Electronic activity at radio frequencies in an item of equipment causes radiated electromagnetic fields to be created, and these will 'leak' out of the equipment or the cables attached to it, to some degree. Every type of electrical and electronic equipment 'leaks' such fields, and this is known as unintentional emissions. Equipment that suffers from unintentional emissions (they all do) is sometimes called an unintentional transmitter.

Some types of industrial, scientific or medical equipment (ISM) use RF energy to perform their direct functions. These include: diathermic heaters for melting or welding plastics (e.g. in some packaging machines), butter, and processing other materials (e.g. vulcanising rubber); diathermic gluing machines used in the manufacture of wood products; medical diathermy for physiotherapy; 'electrosurgical' equipment such as diathermic knives and coagulators; hair and wart removal in beauty salons; induction hotplates for cookers and stoves; domestic and industrial microwave cookers and industrial microwave dryers; induction heaters for metal treatment; and many other applications. The emissions for this type of equipment is covered by CIPSR 11 or EN/IEC 55011, which allows very high levels of emissions at specified 'ISM frequencies' that are not dedicated for use by radiocommunications and broadcasting (as so much of the rest of the spectrum is).

Fixed radio, TV and radar transmitters emit very powerful fields into the air, at the radio frequencies they are permitted to employ. They are known as intentional emitters (sometimes, intentional transmitters). This type of equipment is generally only connected to dedicated equipment designed for that purpose, and if they are very powerful (such as broadcast transmitters) they are usually located some distance away from other equipment. Broadcast transmitters are often situated on hills and tall buildings to maximise the area they cover, but when they are located in cities or when other buildings or electronic equipment are nearby they can cause significant interference problems [7], [8], [9].

The modern electromagnetic environment is increasingly noisy



A modern problem is the rapid growth in personal radio communications using walkie-talkies, cellphones, Bluetooth, Wi-Fi, and many other wireless technologies. Although these generally use low-powered transmitters (under 5W) they generate quite powerful fields nearby and there are few practical ways to prevent them from being used in very close proximity to other electronic equipment. Even 25mW Bluetooth transmitters can inject tens of milliamps of current at 2.45GHz into a nearby wire [10].

Some examples of field strengths

Total emitted RF power and type of radio transmitter typical of the UK	Typical proximity (metres) for a field strength of...			
	1V/m	3V/m	10V/m	30V/m
0.8W typical hand-held GSM cellphone; 1W leakage from domestic microwave ovens	5	1.6	0.5	0.16
2W maximum hand-held GSM cellphone (far from base-station or in standby)	7.8	2.5	0.8	0.25
4W private mobile radio (hand-held) (e.g. typical VHF or UHF walkie-talkies)	11	3.6	1.1	0.36
10W emergency services walkie-talkies, and CB radio	16	5.0	1.6	0.5
20W car mobile cellphone, also aircraft, helicopter, and marine VHF radio-communications	25	8	2.5	0.8
100W land mobile (taxis, emergency services, amateur); paging, cellphone and private mobile radio base-stations	54	18	5.4	1.8
1.0kW DME on aircraft and at airfields; 1.5kW land mobile transmitters (e.g. some CBs)	210	70	21	7
25kW marine radars (both fixed and ship-borne)	850	290	89	29
100kW long wave, medium wave, and FM radio broadcast	1.7k	580	170	58
300kW VLF/ELF communications, navigation aids	3k	1k	300	100
5MW UHF TV broadcast transmitters	12k	4k	1200	400
100MW (peak pulse power) ship harbour radars	55k	18k	5.5k	1.8k
1GW (peak pulse power) air traffic control and weather radars	170k	60k	17k	6k
10GW (peak pulse power) military radars	550k	180k	55k	18k

These figures are based on simplifying assumptions including: omnidirectional antennae; anechoic environment. Antenna structures can have gain, increasing field strength in the direction they are pointing. Reflections from nearby features (the ground, metal surfaces, etc.) can increase field strengths. Resonances in some structures can increase field strengths *very* considerably.

When conductors (such as cables, wires, printed circuit board traces, semiconductor lead-frames and bond wires, etc.) are exposed to RF fields, RF currents and voltages are coupled into them. This is sometimes called field-to-conductor coupling. Shielded cables and connectors are never perfect, so there is always some coupling from the field to their inner conductor(s).

These coupled RF currents and voltages have nothing to do with the signals or power that are supposed to be carried by those conductors, so they are classed as noise. Natural resonances in the conductors and their circuits will amplify the amount of noise coupled from the radiated RF fields at some radio frequencies, whilst attenuating it at others.

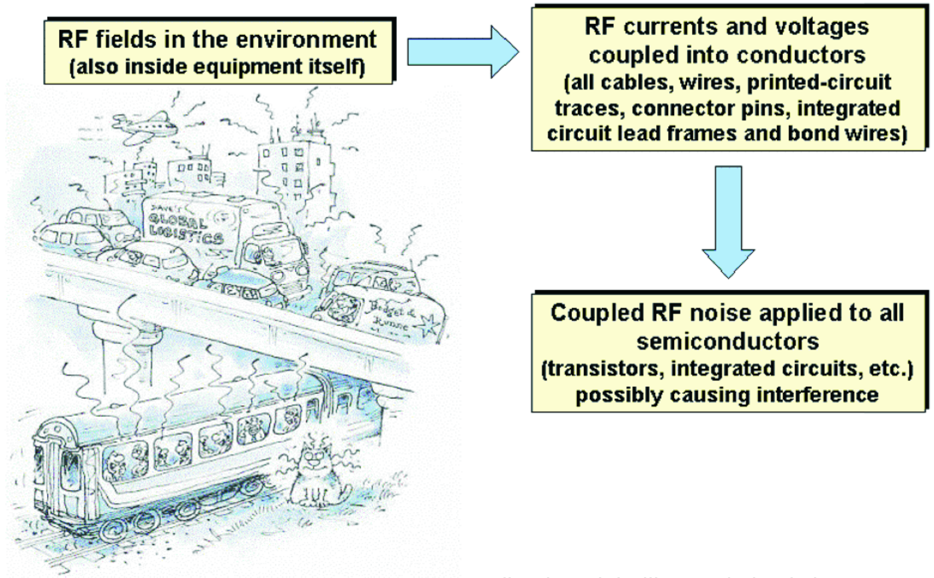
Sufficient levels of noise can cause errors or malfunctions in the analogue or digital semiconductors connected to the conductors by means of three different interference mechanisms (discussed later). In analogue circuits, noise and signal distortion from interference can reduce the signal-to-noise ratio to negative values (more noise than signal). This is especially a problem for sensitive circuits such as amplifiers for millivolt-output transducers such as thermocouples, resistance thermometers, strain gauges and microphones. Measurement errors and noise, even up to full-scale deflection errors in analogue signals are quite common in such circuits during testing with RF fields to comply with the EMC Directive. Digital circuits running software can suffer from false keypresses or control signals, false resets, software looping (continuously repeating a section of code), and stopped execution, commonly called a 'crash'.

Analogue circuits are generally more susceptible to continuous modulated RF fields than digital circuits, because of the noise thresholds used by digital devices – but anything that uses electronics can misbehave when exposed to certain RF fields or combinations of fields. Without adequate protection from RF fields, few modern electronic circuits behave reliably in the modern world.

If the conducted noise levels are high enough they can even cause permanent damage to semiconductors, and even to other electronic components. This is mainly of concern for avionics, military and security organisations who have to worry about high intensity radiated fields (HIRF) very near to powerful radar transmitters, the electromagnetic pulses from nuclear explosions (EMP), and/or HIRF or EMP intentionally generated during electronic warfare and its civilian equivalents. See 'Banana Skin' no. 91 [8] for more on this.

It used to be generally thought that most wires and cables are increasingly lossy at frequencies above 100MHz, so that mobile transmitters such as cellphones, Bluetooth and Wi-Fi that transmitted at 900MHz and above were unlikely to interfere with equipment unless they were very near to the actual equipment itself. However, work carried out by the University of York [11] showed, amongst other valuable information, that common-mode (CM) currents picked up by a typical twisted-pair Ethernet cable from an ensemble of nearby 900MHz cellphones only diminished at about 0.9dB per metre with distance along the cable. So it seems that mobile transmitters operating at 900MHz and above can indeed have a significant effect on equipment by coupling into its cables at some metres distance.

The relationship between EN 61000-4-3 and the first edition of the EMC Directive (89/336/EEC)



Clearly, being within a metre of mobile radio transmitters, or within a kilometre of powerful broadcast or radar transmitters, can be a problem for electronic devices unless they are sufficiently well protected by the design of their equipment or the building they are used in. But some ISM equipment uses RF powers of hundreds of kilowatts, even megawatts, and as a result their unintentional emissions can be very large indeed, in some cases enough to be a direct hazard to human health.

Even though powerful emissions at ISM frequencies are permitted by the spectrum management authorities, and by EN 55011 (under the EMC Directive), electronic equipment can be vulnerable to these frequencies at the levels that can be unintentionally emitted from ISM. This is often a problem in the food industry, where an automatic 'checkweigher' is immediately followed on the production line by a labelling and plastic bag packaging machine that uses diathermy to seal the bags, sachets, or cartons. Even though both items might have been fully tested to their respective standards under the EMC Directive, a spacing of a few metres is usually required so that they do not cause the sensitive checkweigher to record the wrong weight, leading to incorrect pricing or excessive product wastage. See 'Banana Skin' No. 49 for an example of this [8].

The first, and most obvious interference mechanism – by which the conducted noises from radiated fields can interfere with electronic circuits – is called 'direct interference'. It occurs when the RF noise frequency coincides with (or is close enough to) the frequency of a signal in a conductor to distort it. This is a common problem at the clock frequency of digital processors or display drivers, and also at their harmonics. Noise frequencies that are close to rates of certain circuit operations can also interfere with correct circuit operation.

The second type of interference mechanism is audio rectification, sometimes called demodulation. *All* semiconductors respond *non-linearly* to voltages and currents, with some types responding more non-linearly than others. The typical semiconductor is often assumed to have a square-law response at low levels of current. The effect of passing a noise current through a non-linearity is that positive-going waveforms are amplified more than negative-going – or vice-versa, depending on the polarity of the device – resulting in a level of d.c. offset that depends upon the level of the RF noise. This process is known as rectification, and amplitude modulation of the RF signal causes this d.c. offset to vary in turn, so the envelope modulation of the RF waveform is demodulated, just as it is in a radio receiver.

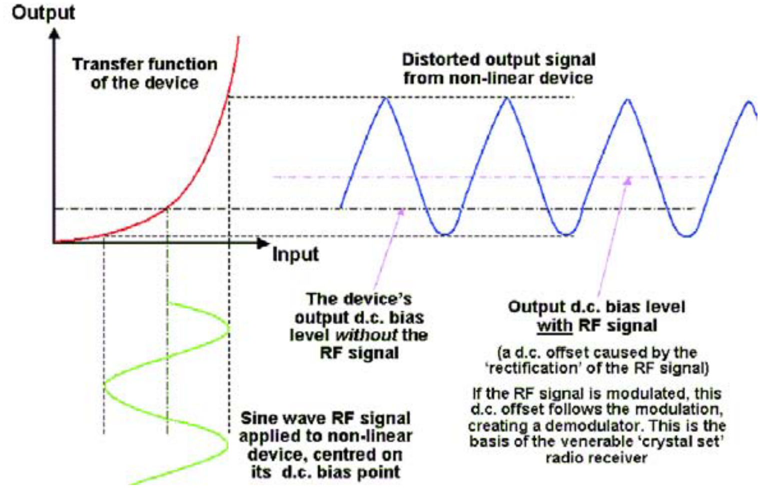
Rectification (demodulation) occurs naturally in all semiconductors, so every semiconductor can be thought of as an 'RF detector', essentially an 'accidental crystal set' radio receiver. Integrated circuits can contain many tens, even millions of semiconductor junctions, all waiting for the opportunity to demodulate RF noise signals.

Many interference problems with audio and instrumentation circuits are caused by the fact that the demodulated noises tend to lie in the same frequency range as the wanted signals, reducing the quality of the output or leading to erroneous measurements. In audio circuits the 1kHz modulation of the EN 61000-4-3 is usually clearly heard over the loudspeakers, earpiece or headset. Interference with digital circuits is most likely to occur when the demodulated RF noise contains a frequency that coincides with (or is close enough to) the frequency of a signal or the rate of certain circuit operations. However, high enough levels of d.c offset from noise rectification can alter the biasing of circuits, both digital and analogue, by enough to prevent them from working correctly.

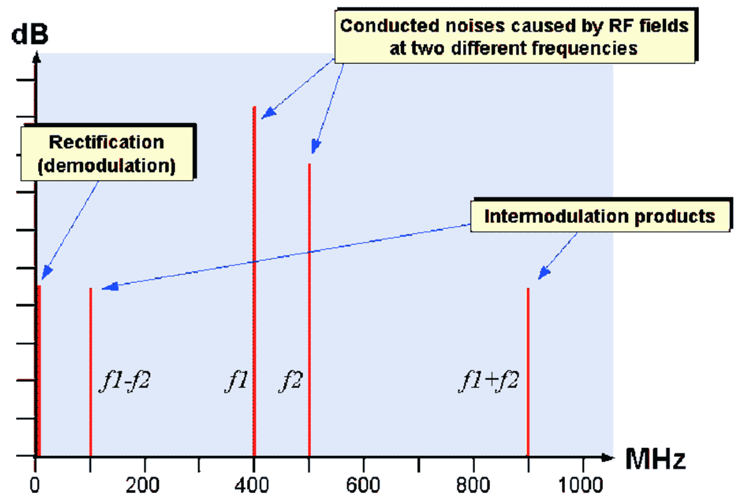
The third interference mechanism is intermodulation, caused by the same non-linearities that cause audio rectification. When more than one RF signal is present at the same time in a non-linear device, 'intermodulation products' – new frequencies – are created inside the circuit itself. The presence of f_1 together with f_2 (for example: 200MHz and 200.1MHz) will result in intermodulation products at f_1 - f_2 and at f_1 + f_2 (100kHz and 400.1MHz respectively, in this example). Three initial frequencies create eight intermodulation products in total, and with four and more initial frequencies the situation is even more complex. In some circumstances, intermodulation products can have high enough levels to cause 'direct interference', as for RF noise described earlier. Intermodulation products can also fall into the passbands of audio and video signals, and instrumentation circuits, reducing the quality of the output or leading to false measurements.

EN 61000-4-3 only applies one RF test frequency at a time, so can fail to discover susceptibilities that can occur in real life due to intermodulation. Real-life environments usually have significant levels at more than one radio frequency, for example the numerous VHF radio broadcast and UHF TV channels. An item of equipment that is susceptible to RF fields, for example at 100MHz, will probably be well-protected by its designers

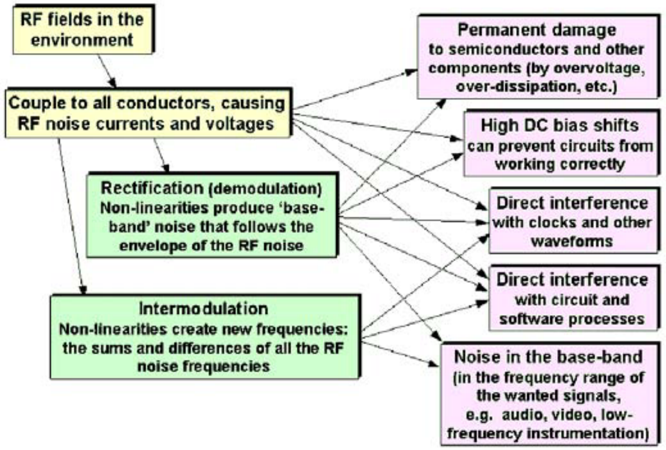
Transposition via non-linear function resulting in a d.c. offset (more commonly known 'audio rectification' or 'demodulation')



Example of RF noise in a semiconductor circuit showing demodulation and intermodulation



The three interference mechanisms



against this RF frequency. But if it is exposed to two simultaneous RF fields at other frequencies (e.g. 1.8 and 1.9 GHz) that it is not well protected against because it is not susceptible to those frequencies individually (or because they were not tested, so susceptibility to them was unknown), the equipment might fail due to the 100MHz noise generated by the intermodulation in its own circuits.

All transistors are semiconductors, and are used in all analogue and digital integrated circuits as well as in discrete devices (e.g. power transistors). But many other types of devices are also semiconductors, for example: diodes, rectifiers, thermistors (NTC and PTC), and many types of overvoltage protection devices. Adding transient voltage suppression to protect a chip connected to a cable from electrostatic discharge has sometimes increased the chips susceptibility to radiated RF noise. Metalwork can also create 'unintentional semiconductors' when corrosion causes a film of oxide to form at joints. This can lead to some very unexpected real-life problems due to demodulation or intermodulation; such as the Saturn launch vehicle safety concerns described in 'Banana Skin' No. 267 [8]. Also see 'Banana Skin' No. 179 [8].

The levels of the noises caused by demodulation and intermodulation are usually assumed to be proportional to the square of the increase in the conducted RF noise level (that was coupled from the RF field). This means that small variations in the level of the RF field during testing can have a large difference on equipment functional performance, making it difficult to compare the results of different kinds of RF immunity tests.

Since few, if any, real-life radio transmissions are modulated solely at 1kHz, the 1kHz modulation frequency used by EN 61000-4-3 (and EN 61000-4-6) is a poor test for real-life susceptibility or reliability. And, as was mentioned before, the use of a single RF test frequency cannot give rise to any intermodulation frequencies within the equipment, so it also a poor test of real-life performance for that reason.

EN 61000-4-3 is usually used to test from 1000MHz down to 80MHz, with EN 61000-4-6 (described in another REO booklet) used to test from 80MHz down to 150kHz. But many types of equipment use circuits that operate at frequencies below 150kHz, and are consequently much more susceptible at those frequencies. Conducted noise under 150kHz can be caused by the electromagnetic fields emitted by switch-mode or phase-angle power converters; or when an RF field at any frequency is modulated with frequencies below 150kHz (as most are), or when the presence of two or more RF fields at different frequencies create intermodulation frequencies that are below 150kHz.

One way to discover potential susceptibilities at frequencies below 150kHz is to test using EN 61000-4-16, which covers immunity from 0 to 150kHz (and will be covered by another REO booklet). Another way is to test equipment using a range of modulation frequencies for each RF frequency tested using EN 61000-4-6 and EN 61000-4-3. The range of modulation frequencies should be chosen to cover the range over which the equipment concerned is susceptible. This method is mostly used by certain military and aerospace organisations at the time of writing, but is not yet commonplace. The testing should extend up to the highest RF frequencies that the equipment is likely to be exposed to throughout its operational life. The third edition of EN 61000-4-3 describes testing methods for up to 6GHz – for even higher frequencies military test methods may need to be used.

Often, the most extreme electromagnetic environment that a device, circuit, printed-circuit-board (PCB) or subassembly has to face is that caused by other parts of the same equipment. This is known as intra-system interference.

Devices, circuits and printed circuit boards that are designed to be immune to RF fields will be easier to integrate with other components of modern products, such as high-resolution displays, switch-mode AC/DC and DC/DC power converters, digital processors, etc. This will save time and cost by reducing the number of design iterations ('re-spins') during product development.

Similar intra-system interference issues arise for items of equipment that are placed in close proximity (e.g. inside an industrial cubicle, or stacked on a bench or racked in a frame). Once again, ensuring that each item has good RF immunity performance, can often help save time and cost in the development or commissioning phases of a project.

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

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

As can be seen from the above text and figures, EN 61000-4-3 only covers a small range of possible RF fields. But complying with <u>any</u> immunity test standards (even the ones used for flight control computers on civil airliners) does not necessarily <u>ensure</u> sufficient real-world reliability. This can be a problem for safety-related equipment and systems, or for equipment and systems that require very high reliability (such as speed cameras). This issue is too large to be discussed here, for more on this refer to [12] and the IEE's training course on EMC for Functional safety, high reliability and legal metrology [13]. Also see 'Banana Skin' No. 284 [8].

Full compliance testing using EN 61000-4-3

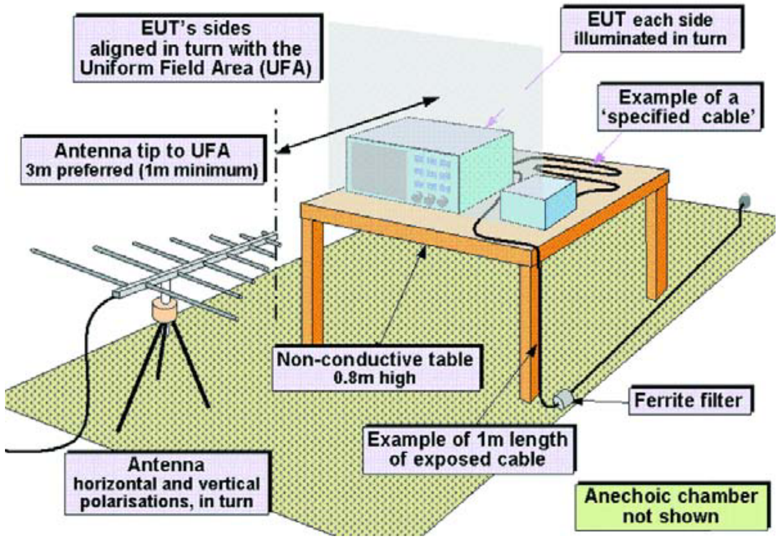
The major established commercial standard test, referenced in all up-to-date product and generic standards harmonised under the EMC directive, is EN 61000-4-3. EN55020 (similar but not identical to CISPR 20) requires both conducted and radiated immunity tests but applies only to broadcast receivers and related equipment; it is quite different to EN 61000-4-3 and is not discussed in this guide.

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. The layout of the equipment under test (EUT) and its interconnecting cables affects the RF currents and voltages induced within the EUT to a great extent. At frequencies where the EUT's dimensions are much smaller than the wavelength, cable coupling predominates and hence cable layout and termination must be specified in the test procedure.

The basic requirements are an RF signal source, a broadband RF power amplifier and an antenna, which are used to generate a field at the EUT's position. But accurate control of the field strength is also required so there must be some means to control and calibrate the level that is fed to the antenna at each tested frequency. A test house will normally integrate these components with computer control to automate the frequency sweep and levelling functions.

The major concern of standardised immunity test methods is to ensure repeatability of measurements. Immunity testing does not have a defined threshold that indicates a pass or a failure, like emissions tests do. Instead, a well-defined level of an electromagnetic phenomena is

The set-up for radiated RF immunity tests



applied to the EUT and its functional response is noted and compared with what is considered to be acceptable to decide a pass or fail. The test procedure concentrates on ensuring that the applied field strength is as consistent as possible and that the means of application is also consistent.

Test standards such as EN 61000-4-3 contain a great deal more detail than can be included in a guide like this, so when testing always make sure that a copy of the appropriate standard is at hand – and follow it.

Signal sources

Any RF signal generator that covers the required frequency range (e.g. 80-1000MHz) 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.

EN 61000-4-3 calls for the RF carrier to be amplitude modulated with a 1kHz sine-wave to a depth of 80%, which is usually a standard feature within of the signal generator. Some product standards specify other types of modulation as well, for instance the alarms immunity standard EN 50130-4 requires 1Hz on-off modulation, which not all signal generators can provide, so external modulation may be required.

Typically, a synthesised signal generator will be used to cover the frequency range required as a series of discrete frequency steps, under the control of the test system's software. The required frequency accuracy depends on whether the EUT exhibits any narrowband responses to interference. A manual frequency setting ability is necessary for investigating the response around particular frequencies.

Some signal generators suffer from 'dirty switching', when the frequency and/or amplitude of their output suffers from transient changes in frequency or level as they change from one setting to another. This is undesirable because the erroneous transient frequencies or amplitudes will be amplified and applied to the EUT, possibly causing the erroneous recording of a failure.

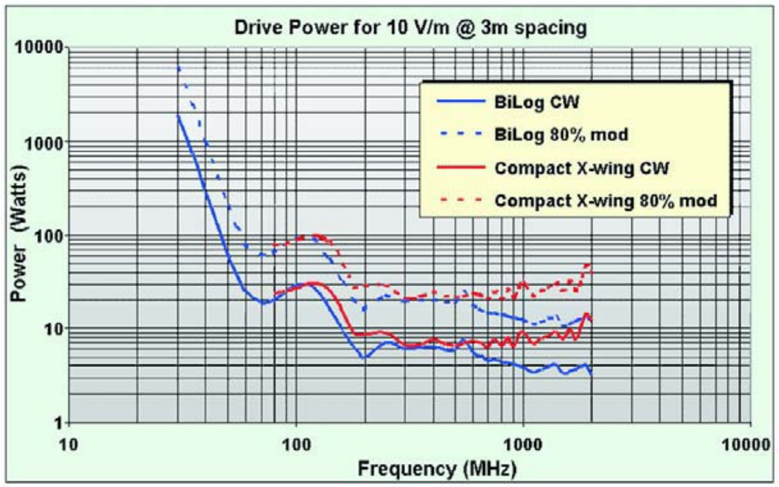
RF power amplifiers

Signal sources do not have sufficient output power to directly drive an antenna with enough power to achieve the desired field strengths at the EUT's position, so an RF power amplifier is required. The power output needed will depend on the field strength required at the EUT and on the characteristics of the transducers used. As well as the antenna gain (G), an antenna will be characterised 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: $P_t = (r \times E)^2/(30 \times G)$ 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

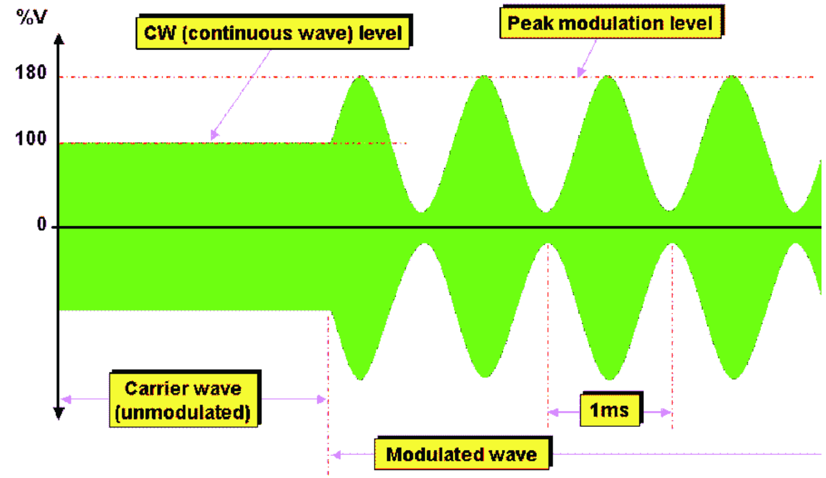
The power output multiplied by the bandwidth is the most important parameter of the power amplifier, and largely determines its cost. The gain of a broadband antenna varies with frequency, so the required RF power for a given field strength will also vary with frequency. Careful selection of antennas can save the considerable cost of more powerful RF amplifiers.

RF power *vs* frequency for some 'BiLog' antennas



The RF test waveform is 80% amplitude modulated (AM) with a 1kHz sinewave

The EN 61000-4-3 test level is always specified for the unmodulated wave, so (for example) a 10V/m test has a peak RF level of 18V/m



Power amplifiers are now available which are specified to cover the range 80-1000MHz and which can be optimised for a particular antenna and required field strength. Note that the power delivered to the antenna (net power) is *not* the same as power supplied by the amplifier, unless the antenna is perfectly matched, a situation that does not occur in practice. When the antenna has a high voltage standing wave ration (VSWR) – such as a biconical or standard BiLog below 70MHz – most of the power supplied to the amplifier is reflected back to it, which is inefficient and can be damaging to the amplifier. (A high VSWR also means a high reflection coefficient.)

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 or at higher levels. Amplitude modulation at 80%, as required by EN 61000-4-3, increases the instantaneous power requirement by a factor of 5.1dB (3.24 or 1.8^2 times) over the unmodulated requirement.

Other factors that should be taken 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. No distortion products should be more than -15dB relative to the level of the carrier wave.
- Ruggedness: the amplifier should be able to operate at full power continuously into an infinite VSWR, i.e. an open or short circuit load.

- 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: a typical test facility only has a single RF power amplifier for each frequency range, so when it goes faulty it needs to be quickly repaired.

EN 61000-4-3 includes the requirement to carry out the calibration of the test set-up at 1.8 times the unmodulated test field level, to verify that the power amplifiers used have sufficient capability without introducing compression effects or harmonic distortion and without failing.

Field strength monitoring

It is essential to be able to ensure the correct field strength at the EUT. Reflections and field distortion by the EUT and the chamber walls will cause different field strength values from those which would be expected in free space, and these values will vary as the tested frequency is changed.

RF fields can be measured by a broadband field sensor, which usually takes the form of a small dipole and detector replicated in three orthogonal planes, so that the assembly is sensitive to fields of any polarisation. In the simplest extreme, the unit can be battery powered with a local meter so that the operator must continuously observe the field strength and correct the output level manually. A more sophisticated set-up uses a fibre optic data link from the sensor, so that a copper cable does not disturb the field. Partly because of their simplicity, field sensors are not particularly linear, and it is preferable to have them calibrated at the same field strength at which they will be mostly used. Also, it is important to realise that they will give erroneous readings on a modulated signal; accurate level setting must only be attempted on an unmodulated field.

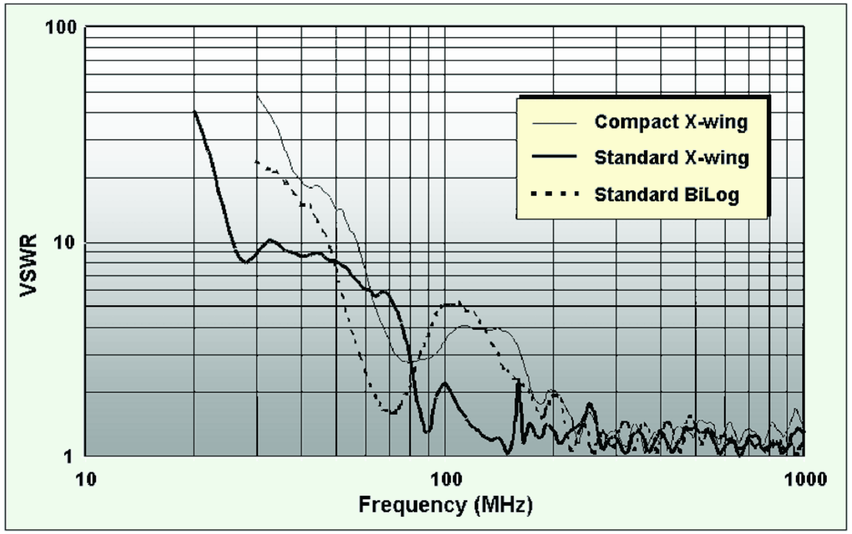
EN 61000-4-3 specifies the use of the substitution method of power control. This involves pre-calibrating the empty chamber or cell by measuring, at each frequency, the power required to generate a given field strength. The chamber calibration process is described in the section entitled “Field uniformity” below. The EUT is then introduced and the same power is applied at each frequency. The rationale for this method is that any disturbances that the EUT causes in the field 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.

This method is only really viable when the field uniformity is closely defined, and this puts great emphasis on the requirements for anechoic lining of the chamber, but given a good anechoic chamber it is much the preferred method. The parameter which is best controlled in the pre-calibration is the amplifier output power (forward power) rather than the net power supplied to the antenna. Controlling the net power would be acceptable provided that the antenna characteristics were not significantly changed by the introduction of the EUT, which in turn dictates as great a separation distance as possible between antenna and EUT.

Antennas

It is perfectly acceptable to use the same antennas as for the radiated emissions tests, for example BiLog, biconical or log-periodic types – providing care is taken to ensure that they are not electrically damaged by the high powers used during the immunity tests. The balun transformers used at their feed points limit antenna power handling ability. A balun 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 from the test equipment (hence bal-un). It is supplied as an integral 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.

Examples of VSWR of some 'BiLog' antennas



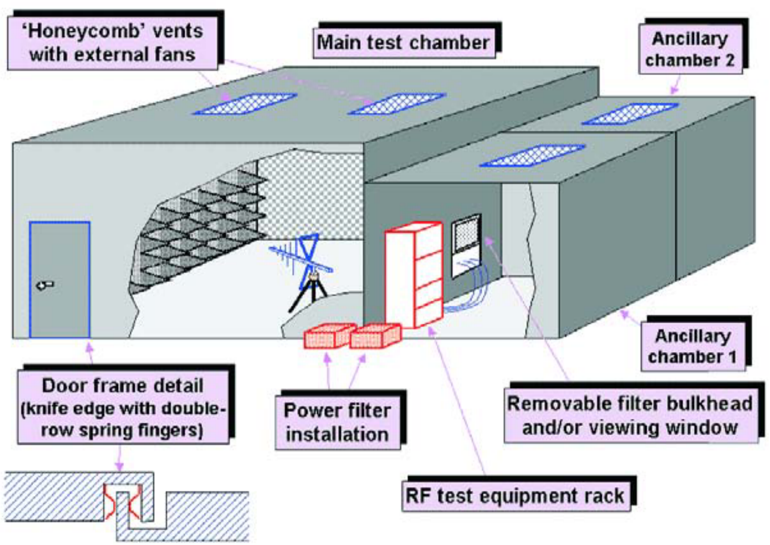
The high VSWR of broadband antennas, particularly of the biconical at low frequencies, means that much of the RF power from the power amplifier is reflected back down the cable, rather than being radiated into the chamber, and this accounts for the poor efficiency at these frequencies. Much effort has 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 polarisation of the antennas calls for two test runs, once with horizontal and once with vertical polarisation.

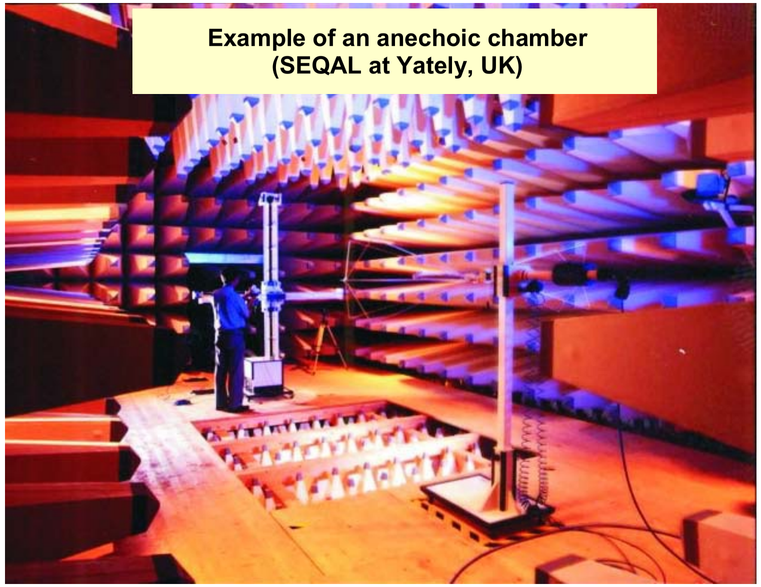
The test chamber

Radiated RF immunity tests covering the frequency ranges specified by product or generic standards should be carried out in a shielded room to prevent interference to other radio services. Recommended shielding performance is at least 100dB attenuation over the range 10MHz to 1GHz – to reduce internal field strengths of 10V/m to less than 40dBμV/m outside the room. The shielding effectiveness achieved by the room depends on its construction – a typical high-performance room will be built from modular steel-and-wood sandwich panels, welded or clamped together. Ventilation apertures will use 'honeycomb' panels, and the room will be windowless. All electrical services entering the chamber will be filtered by special high-performance 'room filters'. The construction of the access door 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.

The shielded room also helps protect the test equipment and ancillary instrumentation from the RF field used for the testing. The interconnecting cables leaving the room should be suitably shielded and filtered themselves. A removable bulkhead 'connector 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.

A typical shielded room installation





Example of an anechoic chamber (SEQAL at Yately, UK)

Chamber resonances

A plain shielded room (known as an 'unlined' room) will exhibit field peaks and nulls at various frequencies determined by its internal dimensions. The larger the room, the lower the resonant frequencies of these 'standing waves'. This phenomenon is exactly the same as that which causes problems for emissions tests in shielded rooms. For a room of 3 x 3.5 x 6m the lowest resonant frequency works out to around 50MHz.

To damp these resonances the room is lined with absorber material, typically carbon-loaded foam shaped into pyramidal sections, which reduces wall reflections. The room is then said to be “anechoic” if all walls and floor are lined, as is necessary for a compliant immunity test, or “semi-anechoic” if the floor is left reflective. Such material is expensive – a fully-lined room will be more than double the cost of an unlined one.

An alternative to pyramidal absorbers is to line the walls with ferrite tiles or ferrite grid absorbers. These materials are now widely available and can claim extremely good results in damping room resonances, but the ferrites are also expensive and heavy and bring their own problems in fixing and mechanical support. A compromise increasingly in use in modern test facilities is to use ferrites for lower frequency response combined with small pyramidal absorbers to extend the high frequency response to over 1GHz.

Field uniformity

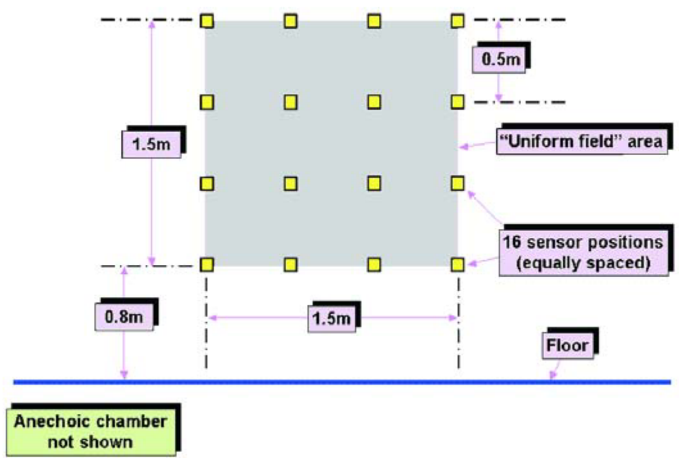
Absorber linings are not perfect, so there will still be some resonances in the test chamber, and at higher frequencies these can cause significant variation in the field strength over quite a small volume, certainly smaller than is occupied by the EUT. As a practical measure of the effectiveness of anechoic lining – and to calibrate the field strength that will be used in the actual test – EN 61000-4-3 specifies a measurement of the field uniformity to be made at 16 equi-spaced points covering a 1.5 metre square vertical plane, called the Uniform Field Area (UFA). The measurements are made in the absence of the EUT.

The UFA corresponds to the position of the front face or one of the other three sides of the EUT during actual testing. For the chamber to be acceptable, the variation in the field strength of 75% (i.e. 12) of the UFA measurement points must be within the range -0dB to +6dB. A variation of greater than +6dB is allowed provided it is stated in the test report.

The variation 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 overtesting by up to a factor of two is possible. For smaller EUTs, a smaller uniform area, for instance 3 x 3 points giving a 1m square, may be acceptable.

EN 61000-4-3 covers testing at frequencies above 1GHz, and the types of antennas used at these frequencies have such narrow beamwidths (are very directional) so that they cannot fully illuminate the UFA from one antenna position at any reasonable distance. So alternative methods are given for testing at over 1GHz, using the 'partial illumination' and 'independent windows' methods with an antenna to EUT distance of 1m.

Field uniformity measurement



Preliminary checking

Some preliminary tests should be carried out to find the most susceptible configuration and operating mode of the EUT. Sometimes very large field strengths need to be applied to deliberately induce a malfunction, to discover sensitive points.

Once a sensitive point has been found, the orientation, cable layout, grounding regime and antenna polarisation is varied to find the lowest level that induces a malfunction at that frequency. Similarly, the operating mode is changed (if the EUT has more than one) to find the most sensitive. It is reasonable to write special test software to continuously exercise the most sensitive mode, if this is not part of the normal continuous operation of the instrument.

Equipment should always be tested in conditions that are as close as possible to its typical installation, with wiring and cabling following normal practice, and with hatches and covers in place, doors closed, loaded as it will be in real life, etc. – and preliminary checking should bear this in mind.

REO can create custom loads to meet any requirements

Conducting the test

Once the most sensitive configuration has been established it should be carefully defined and rigorously maintained throughout the compliance test.

The default cable length exposed to the test field is 1m, with excess cable length filtered by a clip-on ferrite and then run close to the metal floor (or walls) of the anechoic chamber. But if the wiring practice is specified, then the specified cabling set-up should be used instead. For example: the length of process control I/O cables is generally unspecified so these are only exposed by 1m. But where (for example) a printer is being tested, if its manufacturer specifies a 2m length of printer cable from the computer, and the computer is in the test environment too, then both printer and computer are set up on the wooden table in the chamber with the specified 2m of printer cable between them. If the computer is *outside* the anechoic chamber and the printer cable has to be extended to reach a bulkhead connector in the chamber wall, then the default 1m exposed length of cable applies.

If the EUT is floor-standing (such as a rack or cabinet) it should be placed on (but insulated from) the floor of the test chamber – otherwise it should be on a wooden table. The antenna will normally be placed at least 1m from it, at a greater distance if possible consistent with generating adequate field strength; the preferred distance is 3m. Too close a distance affects the uniformity of the generated field and also, because of mutual coupling between antenna and EUT, invalidates the basis on which the substitution method is used.

The 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 eyes still remain one of the most common monitoring instruments.

For most types of electronic equipment, a total of eight sweeps are needed – one in each polarisation of the antenna, with each of the four sides of the EUT facing the antenna. If the equipment can be used in any plane, such as a portable handset, then it should also be tested with its top and bottom facing the antenna, requiring twelve sweeps in all.

Sweep rate, dwell time and step size

The Sweep rate is critical to the test time, and hence the cost of the test, but also it affects the performance of the EUT. According to EN 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. Alternatively, it can be automatically stepped at this rate in steps of typically 1% – that is, each test frequency is 1.01 times the previous one, so that the steps are logarithmic.

The dwell time for stepped application should be at least enough to allow time for the EUT to fully respond (if it is going to) and for its response to be measured with sufficient accuracy to determine pass or fail. EUTs with slower responses therefore require 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 at each frequency step theoretically takes 12.7 minutes (although in practice the control software imposes an overhead and they can take as long as 30 minutes). Eight sweeps at 12.7 (30) minutes each take about 1¾ (4) hours to complete.

For many systems there may be little sensitivity to sweep rate since RF demodulation (rectification) itself tends to have a broad bandwidth, and structural or coupling resonances are generally 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. If the sweep rate through these frequencies is too fast (or the step spacing is too great) then a response may be missed. Such narrowband susceptibility may be 25 – 30dB worse than the broadband response. Therefore some knowledge of the EUT's internal functions is essential when setting the dwell time, or considerably more complex test procedures are needed.

Monitoring the EUT for performance degradation during testing

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

Thought should be given to how the functional performance of the equipment is to be tested, especially if it is to be tested in a shielded room with no observers inside. Where performance can be assessed visually (e.g. screens and other displays, LEDs and lamps) it is usually checked by careful positioning of one or more shielded video cameras relaying their view to monitors outside the test chamber. It may require several people to watch all of the functional features on all of the monitors whilst the test is progressing, to avoid long dwell times at each frequency.

Modifications may be needed to the EUT's software or hardware to provide the necessary diagnostics via the display. For example, it often happens that a microprocessor will crash but the display continues to show the same image – giving the impression that all is well and wasting expensive testing time. So displays should always be changing in a way that shows that as much as possible is working correctly. Display change rate should preferably be in the order of twice per second, so that the 'dwell time' at each frequency can be less than one second and testing time is not made too long (and expensive).

Where the signals on an existing cable need to be monitored, the cable should be passed through the bulkhead connectors provided in the test chamber's connector panel and tested by external instrumentation. A problem with this is that the bonding of the cable shield to the wall and any filtering applied to the signal conductors alters the termination of the cables from what would occur in real life, hence can alter the EUT's immunity performance. The effect of the chamber wall terminations and filters is to alter their resonant frequencies, but also to increase the amplitude of the cable resonances – both can lead to overtesting or undertesting. Most test laboratories simply ignore this issue, although some use rows of ferrite clamps rather than terminating the cable at the chamber wall. Richard Marshall Ltd (www.design-emc.co.uk) have developed a 150Ω chamber exit filter intended to overcome this problem [14].

It is sometimes found that the external equipment is susceptible to the RF test signals that remain on the cables after passing through the chamber wall, or to the RF fields in the test laboratory caused by the powerful RF amplifiers used for the test. So whenever a performance failure is observed, it should be checked that it is due to a failure in the EUT and not in the equipment used to test it. This is often the case for sensitive instrumentation (e.g. noise and distortion analysers, oscilloscopes, etc.) and for external personal computers connected to the EUT using USB or Firewire. Most digital voltmeters and multimeters are also very susceptible, so it may be worthwhile hanging on to those old electronics-free moving-coil meters – even though they are not totally immune either.

Always suspect functional test instrumentation, which might show a fail result when one is not in fact present, or might show a pass when the EUT is failing. The usual way to deal with the latter issue is to set the EUT up in such a way that the functional test meter (or whatever) is indicating a non-zero quantity (if possible) and then watch it during the EUTs immunity testing for it to reduce or increase when it shouldn't do either.

Unshielded cables should be passed through filtered bulkhead connectors, and this can cause problems for high-frequency data (e.g. Ethernet) that uses unshielded twisted-pair cables. Special techniques may be required to deal with such problems, and most accredited test laboratories should have the necessary knowledge and experience.

Where there are other aspects of the equipment's functional performance that need to be tested during the immunity test, it may be necessary to place test equipment in the test chamber with the EUT (e.g. measuring motor speed with a tachometer) or to monitor various signals inside the EUT. It is important that these do not disturb the electromagnetic environment around the EUT, or alter the EUT's response. Given the very high frequencies used for these tests, connecting extra wires to parts of the EUT will alter its response, so this is not advised. At least two manufacturers have developed tiny probes that are connected to external measuring gear (well away from the effects of the tests being applied) by fibre-optic cables. Two of these are described in references 6 and 7 in [15]. Tiny probes used by these types of systems have been developed for measuring voltage, current, and local field strengths, sometimes with bandwidths exceeding 1GHz.

Fibre-optic cables – providing they are completely metal-free – can simply be passed through the waveguide-below-cutoff tube normally set in the wall of EMC test chambers, without compromising the test or causing chamber leakage.

Some types of equipment employ very long time constants, and it may be impractical to speed them up without changing their EMC characteristics – in which case lengthy testing times may be necessary. Where a equipment has multiple functions, a test could be done on each function in turn, or the functions may be able to be multiplexed quickly, so that all are tested in sequence during the dwell time at each frequency. Sometimes a equipment runs through a sequence of states or functions that can be speeded up to shorten radiated immunity test times, often by removing wait states from the software.

So it is quite common to create special software for EUTs intended for radiated immunity testing, to shorten the test time and reduce testing costs. Few test laboratories would challenge such software and would merely record the software version number in their test report. It appears that a few engineers write this special software in such a way as to make their equipment appear to have greater immunity than it would have when using the software that is normally supplied to users. Cheating at the tests may enable a pass report to be obtained from a prestigious test laboratory, but leaves the equipment itself open to compliance challenges.

The proposed 3rd Edition of EN 61000-4-3

A first draft of the proposed IEC 61000-4-3 3rd Edition was circulated in January 2004. At the time of writing it has just been published as a "Committee Draft for Vote" (CDV) – IEC 77B/429/CDV. It includes a number of detail changes, but its main differences from EN 61000-4-3:2003 are…

- It covers testing up to 6GHz
- It covers testing in stirred-mode or reverberation chambers

If this CDV passes its vote and is adopted as IEC 61000-4-3 3rd Edition, and is then adopted as an EN, it will probably be a further two years or so before it becomes the version of the test method called up by EMC product or generic standards.

On-site testing for continuous radiated RF immunity

Because of the possibilities for causing interference over a wide area, on-site (or in-situ) radiated RF immunity testing using a transmitting antenna without a shielded room (anechoic or not) is illegal in the UK unless a special license has been received from the Radiocommunication Agency (www.radio.gov.uk). Other EU member states may have similar licensing systems, and their radio spectrum control authorities can be contacted using contact details from the RTTE Directive's website (http://europa.eu.int/comm/enterprise/rtte/spectr.htm). Where licenses are required (as in the UK) they might be granted for limited frequency ranges for short periods of time, but are unlikely to be granted for the range 80 -1000MHz (unless the site is in a very remote area with no overflying aircraft).

It will probably be acceptable to do radiated immunity testing in the 'ISM' bands (13.6, 27, 40.68, 434 and 915MHz, and 2.45GHz) without a transmitting license, if suitable precautions are taken not to cause interference, but permission should be obtained from the spectrum control authority in the country concerned in any case. Unfortunately, these are only a few narrow frequency bands so using them cannot prove immunity to most of the rest of the frequency range.

Section 10.2.5 of [16] describes the methods that Competent Bodies have developed for on-site testing for radiated immunity:

- Reliance on the radiated immunity test results for individual items of equipment, plus good installation practices (i.e. no actual site testing at all).
- Using licensed radio transmitters (see the section on 'Alternative transducers' below) and possibly get a special transmitting license for the site for the period of the tests.

- Using conducted methods instead, such as BCI or EM-clamp (see the section on 'Alternative transducers' below) to as high a frequency as possible, using ferrite clamps to reduce the re-radiation from the cables.

Usually a combination of these three methods is used to give confidence that the EMC Protection Requirements are being met, as required by the EMC directive.

Important Safety Note: Don't forget that interference, especially with aircraft or other vehicular systems, some machinery or process control systems, and implanted electronic devices such as pacemakers, can have lethal consequences and appropriate precautions **must** be taken to make sure that nobody's safety is compromised. It is also a good idea to take precautions where there is a possibility of significant financial loss being caused by the interference from on-site testing.

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

It may be possible to drape a shielding tent (made of metallised fabric) over the apparatus to be tested on-site, to reduce the 'leakage' and possible interference nuisance caused by the radiated or alternative testing methods being used outside of the EMC laboratory. Shielding tents have the advantage that they are easily movable, and can be packed away when not in use. Don't forget that a shielded tent usually requires a shielded bottom side that is joined all around its edges – it may not be enough to simply drape a five-sided shielding tent over the equipment being tested.

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

If on-site shielding and/or filtering is required, there are a number of issues that will need to be taken into account to suppress the interfering frequencies effectively. Suitable filtering and shielding techniques are described in [17]. If using a shielded enclosure, such as a shielding tent, each of the unshielded cables entering or leaving the tent will need to be filtered, at least with a large ferrite clamp or number of small clip-on ferrite clamps placed at the point where the cable penetrates the tent. Ferrishield, Inc. make some very large ferrites just for this purpose: their CS28B2000 has its peak impedance at 300MHz, CS25B2000 at 700MHz, and CS20B2000 at 2.45GHz.

Where cables are fitted with wired-in filters the metal body of the filter must have multiple metal-metal bonds with a metal 'connector panel' set into the wall of the tent and electrically bonded to the tent's shielding surface all around its perimeter. Any shielded cables should also pass through the wall of the tent via through-bulkhead connectors mounted on the connector panel.

A selection of typical REO Filters for AC supplies

If working on exposed live equipment an isolating transformer may be able to be used to help reduce electric shock hazards. It is best to choose special 'high isolation' types of transformers, which have a very low value of primary-to-secondary capacitance, plus choose transformers that are rated for the likely surge levels (at least 6kV, using the IEC 61000-4-5 test method) to help ensure safety.

REO isolating transformer with low primary to secondary capacitances

Examples of REO isolating transformers

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

There are many alternative radiated RF immunity methods that can be used. Some of them have little or no correlation with the results achieved by EN 61000-4-3 testing, but nevertheless might be very useful indeed for testing during development or QA in serial manufacture, or for troubleshooting after failing a test (purposes for which the EN 61000-4-3 test method is not very suitable). Alternative test methods are not just a low-cost alternative to full-compliance testing, they have their own particular strengths as part of a commercially-successful company's EMC activities.

Testing to EN 61000-4-3 is only cost-effective for QA and variant testing where a company has its own fully compliant anechoic chamber located near to the people who need it. Otherwise some of the alternative test methods come into their own, this time simply as low-cost or faster alternatives to the 'proper' test method.

When used for design and development purposes, and to help fix compliance problems, the lack of a calibration for alternative test methods is not very important. But it is necessary for the tests to be repeatable, so consistency is required in the test equipment and test methodology.

If using alternative methods to do remedial work after an immunity test failure, the frequencies at which the equipment fails are known, so testing at only those frequencies quickly finds the problem areas. However, when design changes are made to fix the known immunity problems, retesting should cover the full frequency range, in case all that has happened is that the problem areas have been 're-tuned' so that they reappear at different frequencies.

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

Where passing tests to EN 61000-4-3 is the main aim, but the test methods used are very different to EN 61000-4-3 – always try to follow the proper EN 61000-4-3 methods as far as possible. For example:

- Use RF fields or test signals that are 80% amplitude-modulated by a 1kHz sinewave.
- Set the EUT and its cables up in according to EN 61000-4-3 (as far as possible).
- Establish the most susceptible set-up and mode of operation, and test that.

Alternative test methods such as TEM cells are mentioned in EN 61000-4-3, and can be used for full compliance testing *if* their equivalence with the 'proper' anechoic method has been established. But demonstrating such equivalence is very difficult indeed, not least because of the non-linear responses of semiconductors to RF fields described earlier.

Alternative test methods that are not mentioned in EN 61000-4-3 are briefly mentioned below. For more information on these, refer to [18].

- Close-field magnetic and electric field probes
- 'Pin' probes
- 'Crosstalk' RF injection methods
- Licensed radio transmitters
- EN 61000-4-6 conducted test methods, including…
  - Coupling-Decoupling Networks (CDNs) for direct voltage injection into cables. There are many designs of CDN to suit the many different kinds of cables and the different power and signals they may be carrying.
  - The EM-Clamp, which simply clips over a cable (or cable bundle) and injects via a current transformer and simultaneously via the small capacitance. The EM-Clamp is long because it includes a row of ferrite absorbers to reduce the exposure of the ancillary equipment to the test. This means it must be used the correct way around.
  - Bulk Current Injection (BCI), which uses clip-on current transducers. BCI has been a favourite technique of the military and automotive industries for many years, and appears as a formal test method in some of their EMC standards, e.g. DEF STAN 59-41 Part 3 test DCS02 (available free from http://www.dstan.mod.uk/home.htm) and ISO 11452-4:1995 respectively.

The conducted methods described in EN 61000-4-6 can be used as alternatives to radiated emissions testing above 80MHz. Some suppliers offer CDNs that operate to 500MHz, and some BCI clamps will operate to 400MHz. EM-Clamps are specified for use up to 1GHz, and are preferable to BCI because the injected currents are more accurate and repeatable. Although it is possible to use conducted techniques to such high frequencies, at frequencies for which any dimensions of the EUT become comparable with (or larger than) the wavelength of the tested frequency, any correlation between conducted and radiated test methods degrades very quickly. Note that the wavelength (in metres) of a frequency f (in MHz) in air is given by $300/f$.

There is a REO booklet on EN 61000-4-6 that describes alternative test methods for conducted RF immunity, so they are not described in detail here.

- Striplines (TEM devices)
- A variety of test cells and compact chambers, including GTEM cells
- The IEC 801-3 test method in a plain shielded room
- Mode-stirred or reverberation chambers

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

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

Correlating alternative test methods with EN 61000-4-3

When an alternative radiated RF immunity test method is used for design, development, or troubleshooting after a test failure, repeatability is very important but the correlation with EN 61000-4-3 is less so. All such tests will need to follow a procedure that has been carefully worked out to help ensure that adequate repeatability is achieved.

When alternative methods are used as part of a QA programme, or to check variants, upgrades, or small modifications, a 'golden product' is recommended to act as some sort of a 'calibration' for the test equipment and test method. Golden product techniques allow low-cost EMC test gear and faster test methods to be used with much more confidence. Refer to section 1.9 of [19] for a detailed description of how to use the golden product correlation method.

If alternative methods are used to gain sufficient confidence for declaring compliance to the EMC directive, the golden product method is very strongly recommended. Without a golden product or some similar basis for correlating an EN 61000-4-3 test with the alternative method used, the alternative methods can only give any confidence at all if gross levels of overtesting are applied, and this could result in gross levels of over-engineering. Refer to 1.9 in [19].

The closer a test method is to the actual EN 61000-4-3 test method, the more likely it is that a good correlation will be achieved. So testing with a close-field probe (for example) can probably only be correlated on a particular build state of a specific equipment, while GTEM testing can often be correlated for a *type* of equipment (e.g. laptop computer, cellphone, etc.).

There is a strong drive to make the GTEM an official alternative to the anechoic chamber when testing to EN 61000-4-3, so the correlation between the two has often been tested. Although it is possible to show that some individual GTEM sites give results which correlate with an anechoic chamber for specific types of equipment, no general correlation can yet be made. Golden product test methods are still recommended where GTEMs are used for testing related to compliance.

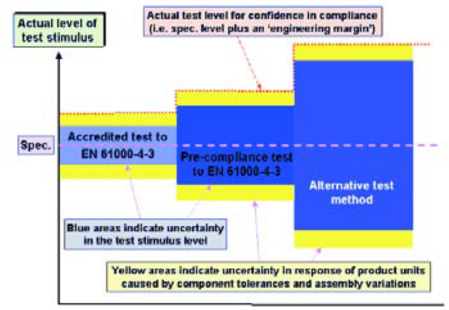
Striplines, IEC 801-3, current injection methods (BCI, EM Clamp), and the wide variety of proprietary test cells and compact chambers probably fall between close-field probes and GTEMs. They may well be able to be correlated for a specific equipment (or even a type of equipment) – if the testing is done by a skilled tester who is aware of the differences between the test method used and EN 61000-4-3.

Determining an 'engineering margin'

Even having EN 61000-4-3 fully applied by accredited test laboratories cannot guarantee that a given EUT and its cables will be exposed to *exactly* the same RF stimuli (say, within ±3dB) each time it is tested. So, because of the non-linear sensitivity of analogue and digital circuits to RF (see above) and because serially-manufactured equipment has variable immunity performance due to component and assembly tolerances (often uncontrolled for EMC), an 'engineering margin' is recommended.

When testing an example equipment to EN 61000-4-3 in a fully compliant manner, at least a 6dB higher test level (e.g. 6V/m instead of 3V/m) is suggested, with the equipment still meeting its required functional specifications. Where there are significant differences in the test method compared with EN 61000-4-3, a larger engineering margin is recommended.

The need for engineering margins



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

[1] IEC 61000-4-3:2003 "*Electromagnetic Compatibility (EMC) – Part 4-3: Testing and measurement techniques – Radiated, radio-frequency, electromagnetic field immunity test".*

[2] EN 61000-4-3:2003 "*Electromagnetic Compatibility (EMC) – Part 4-3: Testing and measurement techniques – Radiated, radio-frequency, electromagnetic field immunity test".*

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

[4] European Union Directive 2004/108/EC on Electromagnetic Compatibility (2nd Edition), from:http://europa.eu.int/eur-lex/lex/LexUriServ/site/en/oj/2004/l_390/l_39020041231en00240037.pdf.

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

[6] "*EMC-Related Functional Safety – An Update*", Keith Armstrong, EMC & Compliance Journal, Issue No. 44, January 2003, pp 24-30, download it via the link from http://www.compliance-club.com or http://www.compliance-club.com/keith_armstrong.asp.

[7] Visit http://www.brookmans.com and Search for '*Interference at Brookmans Park'*. Also visit http://website.lineone.net/~greenbelt/BP%20Transmit.htm.

[8] Examples of interference from both intentional and unintentional transmitters can be found in the "*Banana Skins compendium*", via the link from www.compliance-club.com or at: http://www.compliance-club.com/index.asp. For interference from broadcasting transmitters see especially (at the time of writing) numbers: 142, 143, 251 and 252.

[9] "*Electromagnetic Environmental Measurements in Specific Populated Areas of Brazil*", B S M C Galvao et al, IEEE 2001 International Symposium on Electromagnetic Compatibility, Montreal, Canada, August 2001, Symposium Record ISBN: 0-7803-6569-0 pp 106-110.

[10] "*Two Dimensional Simulation and Measurement of the Coupling of Bluetooth Signals Into Conductive Structures*", A.Schoof, T. Stadler, J.L. ter Haseborg, IEEE 2003 EMC Symposium, Boston, August 2003, Symposium Record ISBN: 0-7803-7835-0 pp 258-262.

[11] "*Electromagnetic Compatibility Aspects of Radio-based Mobile Telecommunications Systems*" final report, LINK Personal Communications Programme, University of York http://www.emc.york.ac.uk/reports/linkpcp/contents.html.

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

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

[14] "*Chamber Exit Filters for Radiated EMC Testing*" Richard Marshall, EMC2000 Conference, York 10/11 July 2000, www.yes.co.uk. Information on these filters also at: http://www.design-emc.co.uk .

[15] "*EMC Testing Part 3 – Fast Transient Burst, Surge, Electrostatic Discharge*" Keith Armstrong and Tim Williams, EMC Compliance Journal June 2001, pages 19-29, download it via the link from http://www.compliance-club.com or http://www.compliance-club.com/keith_armstrong.asp.

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

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

[18] "*EMC Testing Part 4 – Radiated Immunity*", Tim Williams and Keith Armstrong, EMC & Compliance Journal August 2001 pp 22-32 and October 2001 pp 16-20, download via the link from http://www.compliance-club.com or http://www.compliance-club.com/keith_armstrong.asp.

[19] "*EMC Testing Part 1 – Radiated Emissions*", Tim Williams and Keith Armstrong, EMC & Compliance Journal February 2001, pp 27-39, download it via the link from http://www.compliance-club.com or http://www.compliance-club.com/keith_armstrong.asp.

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

Keith Armstrong from Cherry Clough Consultants

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

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

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

Contact: Keith Armstrong by email at keith.armstrong@cherryclough.com or visit the Cherry Clough website www.cherryclough.com

Acknowledgement

Some of this material was previously published in 2001 - 2002 in the EMC Compliance Journal's, series "EMC Testing": http://www.compliance-club.com or http://www.compliance-club.com/Keith_ArmstrongPortfolio. Many thanks are due to Tim Williams of Elmac Services,http://www.elmac.co.uk, timw@elmac.co.uk, my co-author for that series.

REO is an original manufacturer of high quality power equipment, including electronic controllers, components and electrical regulators, all backed by the application expertise demanded by specialised, industrial sectors, such as …..

Controllers designed specifically for use in the parts and materials handling industry, together with a wide range of electromagnets for driving vibratory feeders.

Power controllers for adjusting and regulating voltage, current, frequency or power, as well as its long established variable transformers (variacs) up to 1MVA and sliding resistors of all types. These are complemented by a range of modern, electronic, variable power supplies.

Components for adapting variable speed drives employed in non-standard applications; including inductors, EMC filters and braking resistors. The range of inductive devices extends into railway components for electrical traction and rolling stock, which includes chokes and high-frequency transformers.

Special, toroidal transformers used in safety, medical and energy-saving systems plus high-frequency transfomers used in switch-mode power supplies.

Test equipment such as load banks and variable AC/DC power supplies,

REO actively searches for development partners, particularly in niche markets, and considers this to be an essential stimulus for creating new and original ideas.

A selection of REO chokes

Typical REO common-mode chokes

Typical REO differential-mode chokes

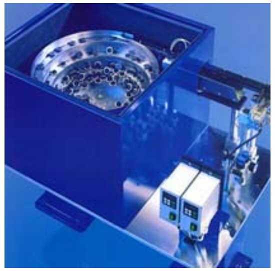
REO - Market Sectors

Train Systems

Chokes and high frequency transformers

Inductive Components

Chokes, resistors and transformers

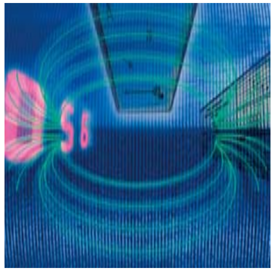


Automation Systems

Controllers for vibratory feeders

Communication Systems

Field bus and gsm

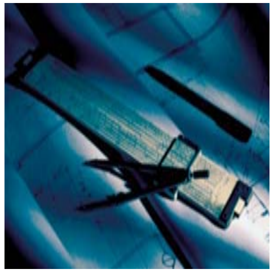


Test Systems

Power supplies and load banks

Power Electronics

Phase-angle and frequency controllers



Classics

Rheostats and variacs

Renewable Systems

Solar transformers

Drive Systems

Filters and braking resistors

Medical Systems

Medical Transformers

Motor Control Systems

Soft-starts