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from EMC Standards

A Practical Guide for EN55022 and EN5011: Testing Conducted Emissions

Helping you solve your EMC problems

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A Practical Guide for EN55022 and EN55011

Testing Conducted Emissions

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EN 55022 and EN 55011 and compliance with the EMC Directive

This handbook is concerned with testing conducted emissions on the AC (mains) supply lead, to the typical domestic/commercial/industrial EN standards over the frequency range of 150kHz to 30MHz. Some people will need to measure below 150kHz or above 30MHz – for example when measuring equipment to some automotive or military standards.

The radio-frequency (RF) emissions standard for information technology and telecommunications equipment, and business machines is the venerable CISPR22 [1], which has been adopted in the European Union (EU) as EN 55022 [2] and listed under the Electromagnetic Compatibility Directive (EMCD) [3]. Although EN 55022 is a product family standard in its own right, its test methods are often called up as a *basic* test method by other emissions standards (generic, product, and product-family) listed under the EMCD, such as the generic emissions standard for residential, commercial and light industrial environments: EN 50081-1 (soon to be made obsolete by EN 61000-6-3).

CISPR11 [4] is another RF emissions standard, originally developed for industrial, scientific and medical (ISM) equipment that uses RF energy to perform its intended function. It has been adopted in the EU as EN 55011 [5], with some modifications from the original CISPR document, and listed under the EMC Directive. It too has an extra duty as a basic test method for generic, product and product-family emissions standards, such as the generic emissions standard for the industrial environment: EN 50081-2 (soon to be made obsolete by EN 61000-6-4).

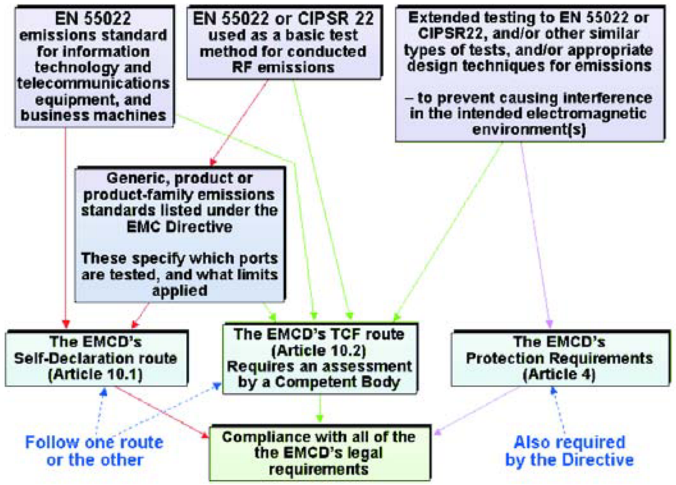
When a product-family standard like EN 55022 or EN 55011 is used as a basic test method by other standards, only the actual test methodology and equipment specified in the basic standard is used. The emissions limits and other aspects relevant to the type of product the basic standard was originally written for are not employed.

When complying with the conformity assessment part of the EMCD, you can either follow the “standards route” (Article 10.1 of [3]) or the Technical Construction File (TCF) Route (Article 10.2 of [3]). When EN 55022 and EN 55011 are used for their specified types of equipment, they should be listed on the equipment's EMC Declaration of Conformity (DoC). But when they are used as basic test methods they should not be so listed – only the relevant generic, product or product-family harmonised EMC standards (that in turn call up EN 55022 or EN 55011) should be listed.

When using the TCF route, it is possible to use CISPR22, EN 55022, CISPR11 or EN 55011 directly, in which case they *should* be listed on the equipment's EMC DoC. In such cases the product manufacturer should assess the electromagnetic environment of the equipment and ensure that it is designed and/or tested so as to comply with the EMC Directive's essential 'Protection Requirements' (Article 4 of [3]).

There may be significant financial or compliance benefits in performing conducted RF emissions tests which go beyond simple compliance with the *minimum* conformity assessment requirements, when following the Self-Declaration route under the EMC Directive. This is especially true where sensitive electrical or electronic equipment

Relationship between EN 55022 and the EMC Directive (EMCD)



(e.g. radio or TV receivers, scientific instrumentation, etc.) could be used nearby. The emissions limits in EN 55022 are chosen to protect radio and TV receivers whose antennas are at least 10 metres away from the equipment being tested. Even then, the limits are not low enough to *guarantee* protection. In the case of EN 55011 this 'protection distance' is 30m.

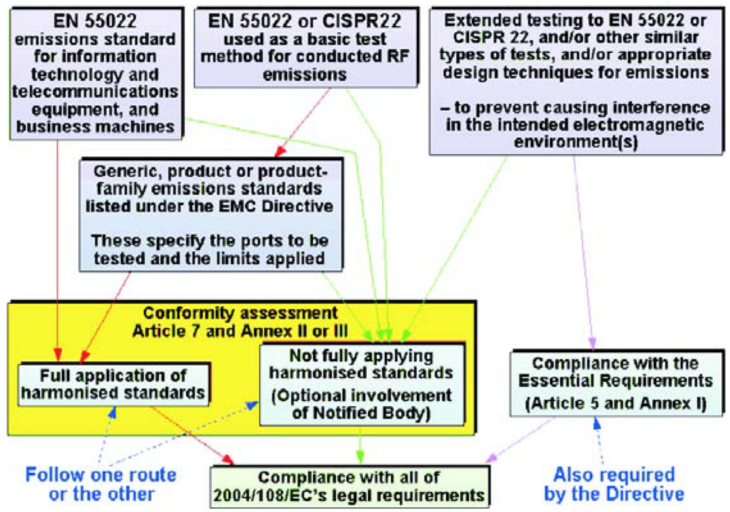
Many items of equipment are operated closer than 10 (or 30) metres to radio or TV receivers. In such cases, simply complying with the emissions limits in EN 55022 or EN 55011 may not ensure conformity with the EMCD's Protection Requirements.

Close proximity to sensitive electrical or electronic equipment is specifically *not* covered by any of the generic, product or product-family immunity standards listed under the EMC Directive. This means that it is up to the manufacturer to assess the electromagnetic (EM) environment that their product will be used in, and test it accordingly to comply with the EMC Directive's Protection Requirements. How to deal with this issue is described in the later section: "*When EN 55022 (or EN 55011) are insufficient in real life*".

Compliance with the EMC Protection Requirements is a legal requirement that applies *in addition* to the requirement to follow one of the conformity assessment routes (Self-Declaration, Article 10.1 or TCF, Article 10.2). Products that pass tests to the relevant emissions standard listed under the EMCD, but nevertheless cause interference in normal use because their emissions are too high for their intended real-life EM environment, do not comply with the EMC Directive's Protection Requirements and are therefore illegally CE marked.

Applying emissions tests which go beyond the minimum requirements of the EMC Directive's listed standards (e.g. by extending the tested frequency ranges and/or applying lower limits) can also be away to improve the functional performance of an equipment, increase

The relationship between EN 55022 and the second edition of the EMC Directive (2004/108/EC)



customer satisfaction and reduce exposure to product liability claims.

The second edition of the EMC Directive, 2004/108/EC [5], replaces [3] on the 20th July 2007. Equipment already being supplied in conformity with 89/336/EEC will be allowed to be supplied until 20th July 2009, by which date it too must comply with [5] if it is to continue to be supplied in the EU. Whereas [3] requires the involvement of a Competent Body with all TCFs, [5] 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, all 'fixed installations' must comply with the EMC Directive's Essential Requirements and have documentation that shows how this has been achieved. Equipment manufactured specifically for use at a named 'fixed installation' may not have to comply with any EMC requirements at all, when it is supplied – but testing to EN 61000-4-27 at specified levels could be one of the EMC specifications imposed on the supplier by the purchaser, to help ensure that a particular 'fixed installation' complies with the Essential Requirements of [5].

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

This handbook describes how, in basic terms, to apply EN 55022:1994 and describes conducted emissions testing in a manner that will also be of use for

What to do when new versions of test standards are issued

CISPR22, EN 55011 and CISPR11. Details peculiar to EN 55011 testing are not gone into here, and there are a number of modifications to these standards in preparation at the time of writing (especially CISPR22 and EN 55022) which will also not be described here. It is always best to use the latest version of the test standard, except where regulatory requirements for the EU (or elsewhere) specify the version or edition to be used. Since many national tests for RF emissions in countries outside the EU are based on CISPR standards, this handbook may also be of use where non-EU EMC specifications apply.

Where an electronic product could interfere with equipment performing a safety-related or legal metrology function, or requires high reliability or is mission-critical – mere compliance with the EMCD is often insufficient for ensuring that it has been designed correctly. Additional and/or tougher emissions requirements may need to be applied. Refer to the IEEs guide [6] and the on-line article [7] for more on this.

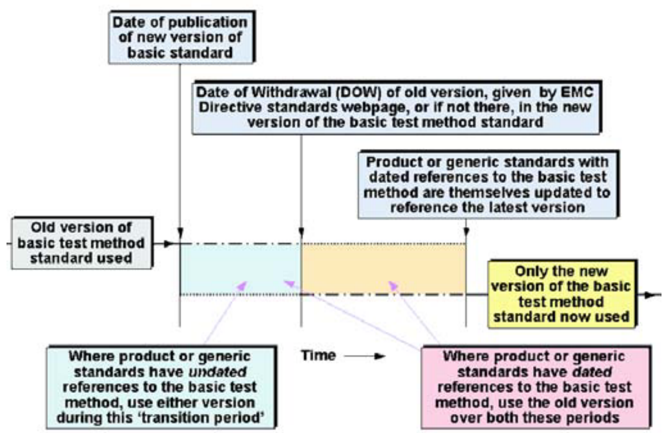
It is clearly impractical for manufacturers to rush to test labs to retest all of their types of equipment on the very day a new version of a test standard is issued, so each new version of a CIPSR emissions standard includes a date on which it supersedes its previous version. This is the "date of withdrawal" (DOW), and it provides a transition period during which manufacturers can choose between using the old or the new versions of the standard. After the DOW only the new version should be used. The DOW is preserved in the EN versions of the IEC standards.

Where a generic or product EMC standard uses an emissions standard such as EN 55022 as a basic test method, it will specify either a dated reference (e.g. "EN 55022:1998"), or an undated reference (e.g. "EN 55022"). If it specifies a dated reference, then this is the version of the basic test method standard that should be used. If it specifies an undated reference then the *latest* published version of the standard should be used. The generic and product standards also have DOWs, so there is always a transition period before the new version must be used.

But the European Commission (EC) has ruled that where compliance with an EU Directive is concerned, only the DOW dates that are published in the Official Journal of the EU (OJEU) have any relevance, and not any DOW dates put into standards by their committees. These will often be the same dates, but not always. So it is always best to use the DOW dates published on the Commissions homepage for EMC Directive standards: http://europa.eu.int/comm/enterprise/new-approach/standardization/harmstds/reflist-/emc.html, instead of the DOW dates published in the standards themselves.

Usually it makes best commercial sense to test new equipment to the latest version of a standard, retesting older equipment when they are due for retesting anyway as a result of a design change or upgrade (as long as this happens before the DOW). Some equipment is sold for such short periods of time that they may never need to be retested to any new versions of standards.

What to do when new versions of standards used as basic test methods are issued



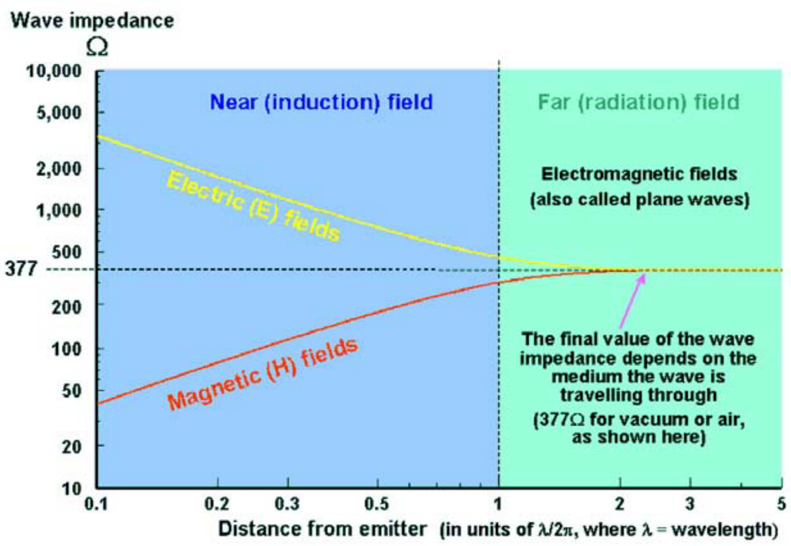
What are conducted RF emissions and how are they caused?

Conducted RF emissions are electromagnetic disturbances (noise voltages and currents) caused by the electrical and electronic activity in an item of equipment, and conducted out of that equipment along its interconnecting cables, such as power, signal or data cables. Sometimes the conducted emissions are due to the activity of circuits connected directly to a particular conductor, and sometimes they are coupled into that conductor from unrelated circuits inside the equipment, due to common-impedances, electric or magnetic fields, or even electromagnetic fields.

The conducted disturbances in a particular conductor, emitted by one item of equipment, can couple directly into another item of equipment that is connected to the same conductor. Conducted disturbances are also radiated from the conductors they travel along, as both electric and magnetic waves, and in this sense the conductor is acting as an 'accidental transmitting antenna'.

Fluctuating voltages in a conductor of any type creates conducted electric waves in the air and other insulators (dielectrics, e.g. plastic cable insulation). Fluctuating currents in a conductor of any type creates magnetic waves. After travelling for a distance equivalent to approximately one-sixth of their wavelength, both electric and magnetic waves have turned into electromagnetic (EM) waves, comprising electric and magnetic waves travelling together with intensities in a ratio known as the 'wave impedance'; appropriate to the medium they are travelling in. These electromagnetic waves are sometimes also called plane waves.

The propagation of E and H fields



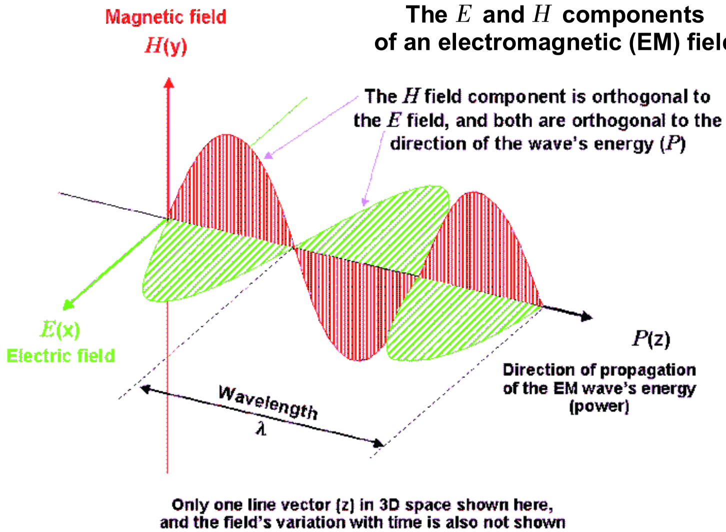
The strength of the waves as they spread out in space varies, creating an electromagnetic field. Electric field strengths are measured in Volts/metre (usually dBμV/m for emissions measurements, where 0dBμV/m = 1μV/m). Magnetic field strengths are measured in Amps/metre (usually dBμA/m for emissions measurements, where 0dBμA/m = 1μA/m).

The creation of magnetic waves from electric waves (and vice-versa) is a bit like Ohms law – pass a current through a resistor and a voltage will appear – apply a voltage across a resistor and a current appears. In fact, the formula: $Z_W = E/H$ (where Z_W is the wave impedance of the medium, E is the electric field strength in Volts/metre and H is the magnetic field strength in Amps/metre) is often described as "Ohms Law for fields". The Z_W for air (and vacuum) is almost exactly 377Ω.

If we measure our field strengths in the 'far field', at distances greater than one-sixth of a wavelength (no closer than 1.5 metres at 30MHz), we can choose whether to measure E or H, since they have a fixed relationship with each other (Z_W). Typically we measure the electric field (dBμV/m), when we are measuring conducted emissions at frequencies above 30MHz. However, when we need to know the E and H fields at distances closer than one-sixth of a wavelength (known either as the 'near field' or 'induction field') we need to use both electric and magnetic field transducers because it is hard to predict the complex relationship between the two quantities in this region.

These waves pass through the air, vacuum, and insulating materials such as wood, brick, plain plasterboard, concrete, plastic, fibreglass, etc. Every type of electronic equipment 'leaks' such fields, either unintentionally, or because it is an intentional radio transmitter.

The E and H components of an electromagnetic (EM) field

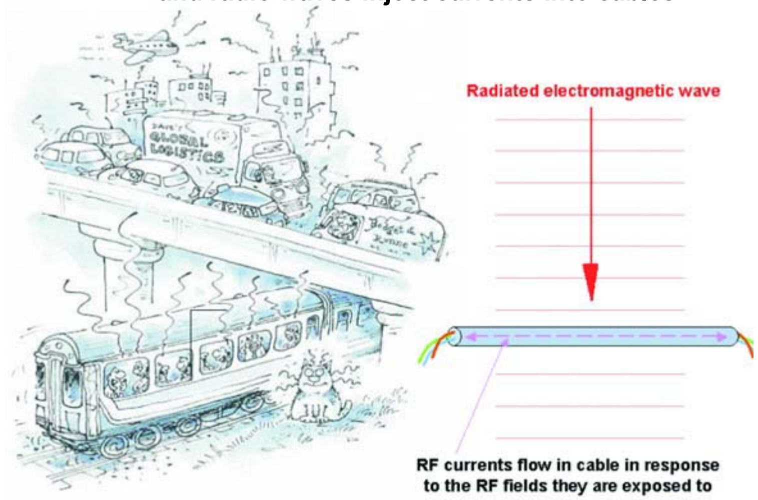


Radio, TV and radar transmitters, and industrial scientific or medical equipment (ISM) that uses RF energy to perform their direct functions (covered by CISPR 11 or EN 55011), can emit very powerful fields, at the radio frequencies they are permitted to employ. But the focus of emissions testing using EN 55022 is on unintentional emissions, not intentional transmitters. EN 55011 sets limits for the emissions from ISM equipment, at the specified ISM frequencies as well as at the other frequencies in its range.

CISPR 22, EN 55022, CISPR 11 and EN 55011 measure the emissions from equipment in the frequency range 150kHz to 30MHz simply by using a conducted measurement technique on the AC mains supply cable. The conducted emissions limits applied by these standards are intended to protect equipment connected to the same AC mains supply, and also are assumed to protect the radio communications spectrum below 30MHz from the fields radiated by an equipment's AC supply cables. These standards do not test the conducted emissions from other cables, so they obviously cannot completely define all of an equipment's possible effects on its electromagnetic environment.

As frequencies fall below 30MHz any reasonable antenna distance soon becomes in the near field, so it would become necessary to make two measurements – one of the E field and one of the H field – to completely define the emissions in this frequency range. Some military standards employ such near-field radiated field measurements as well as conducted emissions tests on AC mains supply and other cables.

The modern electromagnetic environment is very busy – and radio waves inject currents into cables



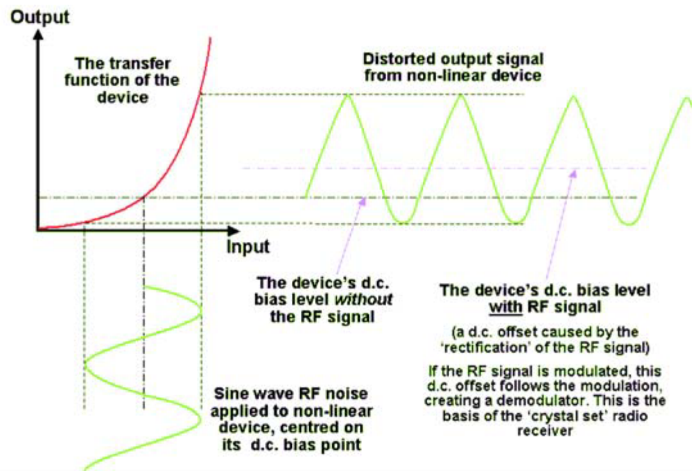
Noise voltages and currents can of course be conducted directly from an item of interconnected equipment, via the AC mains supply cables they share, or via any other conductors such as signal or data cables. But conducted emissions are also radiated into the environment, and the resulting RF fields can affect equipment that does not share any conductors with the source of the noise. When wires, cables, connectors and any other conductors are exposed to E, H or EM fields – currents and voltages are induced in them the conductor behaves as an 'accidental receiving antenna'.

All of the conducted and accidentally received currents and voltages are *noise* as far as the victim equipment is concerned, with the potential ability (if at too high a level and/or at certain frequencies) to cause unacceptable variations in its circuits' electrical and electronic performances (including misoperation of software). When the variations caused by the induced electrical noise are too great, we say that the equipment is suffering from electromagnetic interference (EMI) or, sometimes, just interference.

Obviously, when the noise voltage or current is within the operating frequency range of a circuit, a sufficient level of noise will affect the circuit. But there are two ways by which disturbances outside the frequency range of a circuit can interfere with it: rectification (sometimes called demodulation) and intermodulation.

All semiconductors respond *non-linearly* to voltages and currents, with some responding more linearly than others. The typical semiconductor is often assumed to have a square-law response at low levels of current, although this is often a very crude assumption. The effect of passing a voltage or current through a semiconductor is that positive-going waveforms are amplified more than negative-going (or vice-versa,

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



depending on the polarity of the device) – resulting in a signal-dependent d.c. offset, known as signal 'rectification'. When an RF signal passes through a semiconductor, modulation of the RF signal causes the d.c. offset to vary accordingly. This effect is used in radio receivers to demodulate the RF signal, but it occurs in *all* semiconductors (including low-frequency operational amplifiers used for audio and instrumentation), so *all* semiconductors should be thought of as 'RF detectors', essentially little radio receivers.

When more than one RF noise signal is present at the same time, non-linearities create 'intermodulation products'. The presence of f_1 together with f_2 (say 100MHz and 100.02MHz, typical of two adjacent FM broadcast channels) will result in intermodulation products at $f_1 - f_2$ (20kHz) and at $f_1 + f_2$ (200.02MHz). Three initial frequencies create eight intermodulation products in total, and with four and more initial frequencies the situation is even more complex. The simple sum and difference frequencies between pairs of initial frequencies can have significantly high levels in some circumstances, leading to the situation where it is the intermodulation product that causes the equipment to fail.

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. 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; such as the Saturn launch vehicle range safety concerns described in Banana Skin No. 267 [8].

11 Different versions of EN 55022

The 1998 version of EN 55022 was originally intended to replace the 1994 version in August 2001, but it added a new conducted test for telecommunications cables that caused a great deal of debate, exacerbated by an error in the standard that meant that many of the new telecom's test transducers had an error of 10dB. So it was decided to delay the DOW (the “Date Of Withdrawal”, the date on which a new standard totally replaces an old one) by two years, until August 2003.

When the new DOW of August 2003 loomed the debate over the new tests was still not resolved, so another delay of two years was agreed. The 1998 version of EN 55022 now has a DOW of 1st August 2005, but even this may be further delayed, which is why this handbook is based on the 1994 version and its amendments.

As was mentioned above, over the years there have been numerous versions of CISPR 22 and EN 55022, each with their own modifications, and sometimes the EN standards have modifications that make them a little different from their CISPR originals. When non-European countries adopt CISPR 22 for use with their own EMC regulations, they sometimes make small modifications too.

Testing with different versions of the standards can give different results, so it is important to be sure that you are applying the correct version. If you are only supplying a product into the EU, the situation is clear enough and the version of the standard and its amendments that should be used to satisfy the conformity assessment requirements is described in the official list of standards that can be reached via the website mentioned at [3].

But when supplying the same product to a number of countries or trading blocs, of which the EU may only be one, they will probably require testing to be done to a different version of CISPR 22, with different Amendments and maybe some of their own modifications. To save repeating the same tests over and over, with slight variations each time, some test labs are able to combine a number of national requirements into one test that, although longer than one test to CIPSR 22 or EN 55022, saves time and cost overall. These test labs can often, at extra cost, provide a special certificate (e.g. the IEC's “CB Scheme”) that is acceptable in many countries, supposedly avoiding the need to have their own national test labs retest your product.

When EN 55022 (or EN 55011) are insufficient in real life

The problem that the emissions limits set by EN 55022 (or EN 55011) could be too high for the normal use of a type of equipment, so that it creates interference, was mentioned above in connection with the legal issues of complying with the EMCD's Protection Requirements (Article 4 of [3]). Neither of these standards addresses the situation where sensitive electrical or electronic equipment (e.g. radio receivers, scientific instrumentation, etc.) could be used nearby. The emissions limits in EN 55022 were chosen to protect broadcast receivers whose antennas are at least 10 metres away from the equipment being tested, and even then they are not low enough to *guarantee* protection. In the case of EN 55011 this 'protection distance' is 30m.

If a product causes interference in real life, it will annoy people and can harm the future prospects of its manufacturer. Where a safety-related or mission-critical system is interfered with, people could suffer more than mere annoyance, and (in the EU) claims under the Product Liability Directive and/or Health and Safety at Work Directives could be a possible result.

Where it is wished to avoid such potential situations, designers should assess the likely proximity of their new product to sensitive equipment, or equipment whose reliability is paramount. From this will come a conducted emissions specification for the new product, usually based on EN 55022 (or EN 55011) but with lower emissions limits for some frequency ranges and/or a tested frequency range that extends lower than 150kHz and/or higher than 30MHz. They should then design and test their product to comply with that new specification. This will help ensure compliance with the EMCD's Protection Requirements as well as helping to maintain good customer perceptions and reduce financial risks.

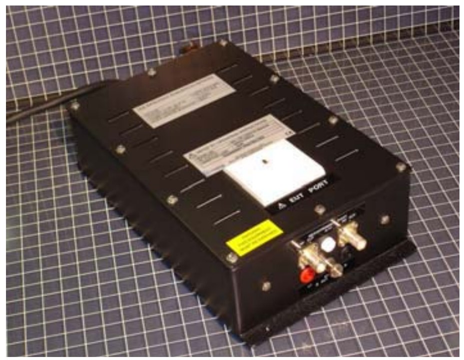
12 Transducers for conducted emissions tests

A wide variety of transducers are available for diagnostic, development and QA measurements of conducted RF emissions, for example close-field probes and current probes, and these are discussed in [9] and [10]. Many of these can be made at low-cost using readily available components, and can provide very useful information throughout a project.

LISNs, AMNs and V-Networks

Full-compliance EN 55022 and EN 55011 tests for conducted emissions use Line Impedance Stabilisation Networks (LISNs) – sometimes called 'Artificial Mains Networks' (AMNs) or 'V-Networks', and these are the standard transducer for measuring conducted emissions on the mains lead in a great many test standards. They are invasive transducers that must be connected in series with the conductors being tested to standardise their CM and DM impedances. Reference [11] is a detailed analysis of LISNs and their application.

An example of a LISN courtesy of Laplace Instruments Ltd, www.laplace.co.uk



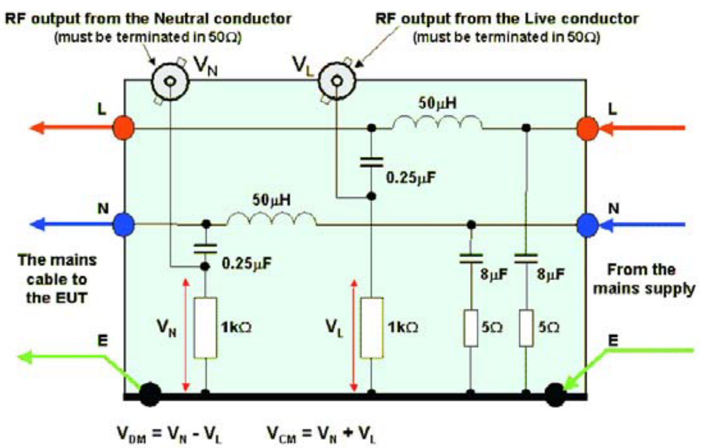
A LISN couples the interference emitted by the equipment under test's (EUT's) AC supply connection (mains port) to the measuring instrument (spectrum analyser or EMC receiver). It also presents a stable and well-defined impedance to the EUT across the desired frequency range. The actual measured voltage depends on the ratio of the EUT's source impedance and the LISNs load impedance, so if the impedance were not stabilised, there would be no repeatability between different test locations. CISPR 16 defines the LISN and its impedance for some different classes of network: the most common one is known as the "50Ω/50µH+5Ω" network, since the impedance curve is determined by these values. A "50Ω/50µH+1Ω" network is sometimes specified where currents are very high.

1kΩ resistors are used to discharge the 0.25µF voltage coupling capacitors when no external termination is fitted, helping to prevent damage to sensitive RF 'front ends'. The use of transient limiters (see section 2.1.9 in [9]) should protect against such damage, but 1kΩ resistors are cheap and the RF front ends expensive so why take the risk.

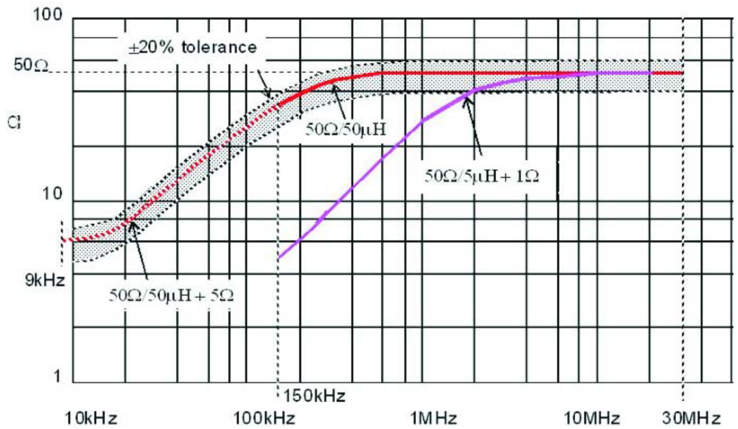
The frequency response of the 50Ω /50µH+5Ω network is defined down to 9kHz, and a fully compliant LISN will stay within the specified tolerance of ±20% of this curve whatever the termination at the mains side of the unit. This is easily achieved across most of the frequency range, but poorly designed units can exceed the specification below 50kHz or above 25MHz.

Like all EMC transducers, LISNs must be calibrated and their calibration factors (sometimes called transducer factors) taken into account whenever they are used in an accurate measurement of conducted emissions. Professional emissions measuring instruments usually incorporate algorithms that take all the calibration factors into account, so that their screen display and printouts show

The schematic of a single-phase LISN that uses the "50Ω/50µH+5Ω" network



Standardised impedance curves for LISNs



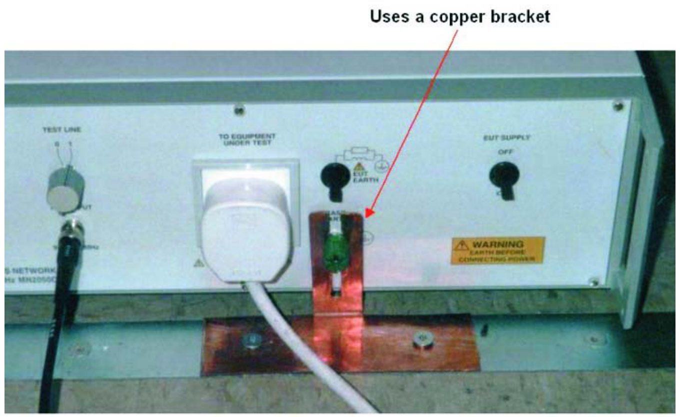
the accurate emissions levels. This feature makes it possible to show the pass/fail limit line on the instrument's screen along with the corrected data, saving a great deal of time in development and diagnostic testing. (Of course, the calibration data for the transducers (such as LISNs and antennas) and cables to be used must first be entered into the instrument's memory.)

The LISN's earth is connected to the ground reference plane (GRP) of the test set-up. Since this is the ground reference for the measurement, no extra RF impedance should be introduced by this connection because it would affect both the impedance seen by the EUT and the voltage developed across the LISN's impedance. This means that wires or straps of more than a few inches must not be used, since their inductance is unacceptable. The best connection here is a solid copper or brass bracket, firmly bonding the LISN to the GRP.

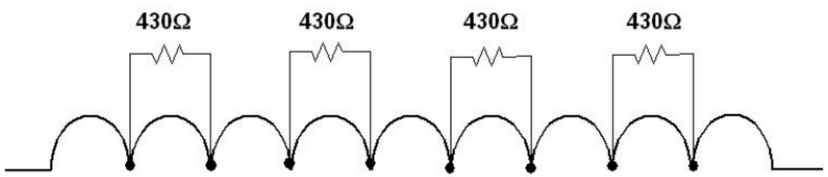
Perfectly good LISNs can be purchased for around £600 (600 UK Pounds), but if you wish to construct your own you should recognise that constructing an accurate LISN is not as simple as its schematic might lead you to believe. Here are a few essential construction tips extracted from [11] and [12]:

- For the 50µH inductor, follow the construction described by [12].
- Use a number of large-value safety-rated capacitors (preferably Y1 rated) in parallel for the 8µF parts, and low-inductance resistors (not wire-wound types) for the 5Ω. Keep all lead lengths very short and use the chassis of the unit as the earth connection for the schematic, rather than any earth wires. Any unavoidable wired earth connections (e.g. from the earth pin of the EUT mains socket to the chassis must be no longer than 50mm and should use braid straps or metal plates at least 10mm wide.
- For the general assembly of the LISN follow [10].

An example of good bonding between a LISN and its ground reference plane (from reference [11])



An example of LISN coil design and construction (from reference [12])



35 turns single-layer solenoid, 6mm diameter wire spaced with 8mm pitch

Air-cored, 130mm diameter

Alternate sections each of 4 turns are damped by 430Ω resistors

Inductance is 58µH in free space, 50µH in a metal enclosure 300 x 300 x 180mm

An example of 50µH inductor under construction for a home-made LISN

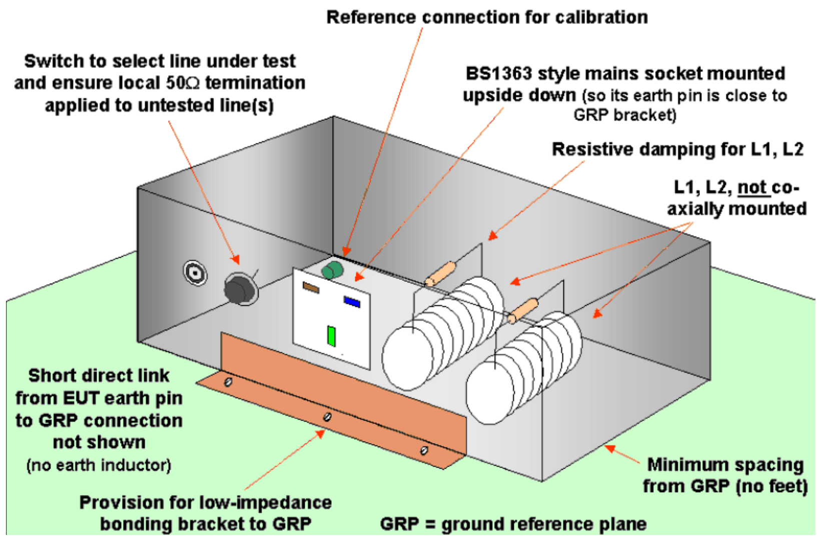
This inductor is being constructed according to reference [12]

The plastic former for the coil is short length of 5 inch (127 mm) outside-daimeter high-pressure polypropylene gas pipe

The 6mm diameter wire used has 1mm think insulation, so the turns can be tightly wound to automatically provide the specified conductor spacing (8mm)

Every fourth turn has not yet had its conductor exposed for soldering the 430Ω damping resistors

The essential construction details for a LISN (from reference [11])



Ferrite-cored inductors are available which are much smaller than the air-cored components described above and permit the construction of very compact LISNs. But when using a ferrite-cored inductor for a LISN, bear in mind that most AC-DC mains power converters do not draw sine-wave currents and if the size of the core is inadequate it may saturate at the current peaks and give incorrect results.

Commercially available LISNs may be fitted with 'added value' enhancements to the basic circuit, such as additional low-pass filtering for the incoming mains, and high-pass filtering for the RF output to remove most of the mains frequency.

LISNs create an artificial supply impedance of 50Ω from each line to earth making the common-mode (CM) impedance 50Ω and the differential-mode (DM) impedance 100Ω, both across a wide range of frequencies, whereas real mains supplies have CM and DM impedances that vary from 2Ω to 2000Ω (at least) depending upon the mode, the time of day, and the frequency (above 10kHz). This means that filters that give good results on conducted emissions tests might not provide the same degree of filtering in real applications. For more on the problems of source and load impedances for filters, and on how to choose filters that are more likely to provide reliable attenuation both on LISN tests and with a very wide variety of real-life impedances, refer to section 3.8 of [13], section 8.1.3.1 of [14] or Part 3 of [15].

A Very Important Safety Note for All LISNs, AMNs and V-Networks:

Because of the high levels of continuous earth-leakage currents associated with these devices, residual current circuit breakers (RCCBs) and other types of earth-leakage protection devices can't be used.

So **all** LISNs, AMNs or V-networks **must** have two independent protective (safety) earth connections in place **before** mains voltage is applied to them. Each protective (safety) earth connection must be rated for the full value of the possible fault current (i.e. the maximum current if the live supply should short-circuit directly to the chassis).

Staff training in the safe and correct use of LISNs is strongly recommended, and untrained people and third parties must not be allowed to be within reach of LISNs or equipment or cables connected to them. A regular and documented safety check of the integrity of both the protective earth bonds is also recommended.

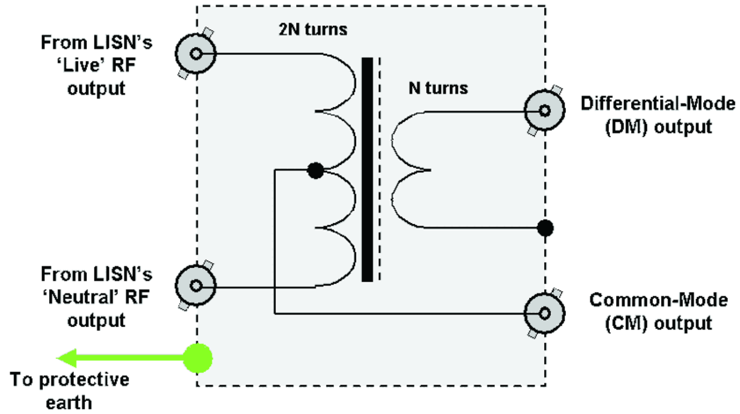
Warning labels on LISNs
are also strongly recommended for:

- Their lethally high earth-leakage current
- The need to maintain two independent protective earth connections at all times
- Their use only by authorised and trained personnel

If a purchased (or home-made) LISN does not have the necessary warning labels already fitted, add them immediately – and in very conspicuous places.

When designing or selecting mains filters it often helps to know the levels and frequencies of the CM and DM emissions from an item of equipment. The RF outputs from a LISN are neither; they are a mixture of CM and DM – but [16] describes how a simple transformer wound on a ferrite toroid or 'pot core' can provide both CM and DM signals from a LISN's outputs.

An transformer that derives the CM and DM emissions from a single-phase LISN



A similar CM/DM splitter product is supplied by AEMC, France
Note: The case of the transformer is connected to the case of the LISN by the shields of both the BNC cables from the LISN

Transient limiters

Transient limiters are employed between the LISN's RF outputs and the measuring instrument to protect the instruments sensitive RF 'front-end' from mains transients. The LISN itself will attenuate most of the transients on the mains supply – the real problem is the connection and disconnection of the EUT, which can cause 400V transients to appear at the RF outputs.

Limiters usually consist of a -10dB attenuator plus a pair of back-to-back small-signal diodes to clip the maximum signal to about ±1V. They should be calibrated, and their 'correction factors' taken into account along with the LISN's own transducer factors and any correction factors for the cables, on every measurement where they are used.

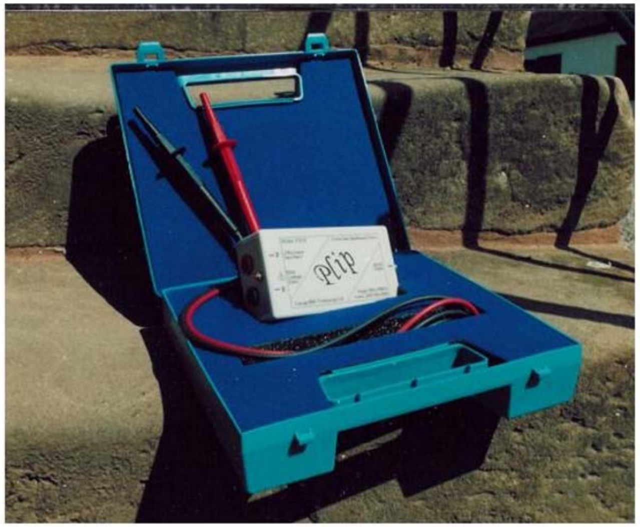
(Some EMC receivers or spectrum analysers have built-in transient limiters, in which case they are calibrated when the test instrument is calibrated and can be ignored.)

Voltage probe

CISPR, ANSI, and the FCC all describe a voltage probe that may be used to measure the conducted emissions on power terminals, usually when LISNs aren't available or aren't appropriate, often due to the high currents involved. But neither EN 55022 nor EN 55011 permit the use of a voltage probe, so where it is desired to use such a probe instead of a LISN it will not be possible to apply either standard in full – so for EMC Directive compliance this would mean following the 'TCF route' instead of self-declaration.

Safety Note: To help prevent damage to the measuring equipment the capacitor should be a class Y type, and to prevent electric shock the probe and its output should be suitably insulated and designed with a handle that keeps its user's fingers protected from the terminal being probed.

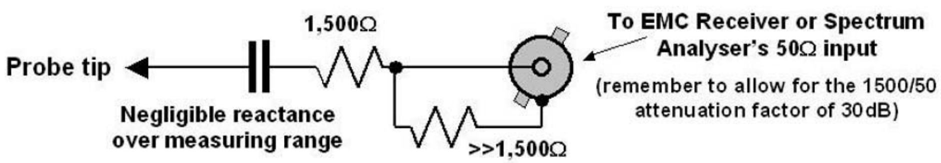
The Voltage Probe



Example of a commercial voltage probe

(Cranage EMC Ltd)

This 9kHz to 30MHz model includes a safety isolation transformer and fused probes



Instrumentation requirements for full compliance conducted emissions tests

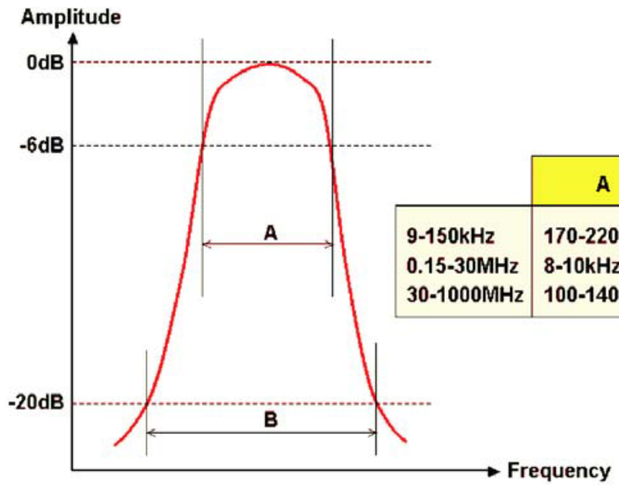
There are two main types of interference measuring instruments: 'EMC Receivers' (usually just 'Receivers') and 'EMC Spectrum Analysers' and they must both comply fully with the provisions of CISPR 16-1 if they are to be used for full compliance measurements. Instruments sold as "pre-compliance", or without any claims regarding compliance, cost less (of course) and do not fully comply with all aspects of CISPR 16-1, so may give erroneous measurements under some conditions. To understand the issues it is worth a brief look at the constraints imposed by the specifications of CISPR 16-1. These are:

- Bandwidths
- Detectors
- Overload performance and pulse accuracy
- Input VSWR and sensitivity

Bandwidths

If an interference signal spectrum is wider than the bandwidth of the instrument that measures it, then the indicated value will depend on that bandwidth. If it is narrower, then the indicated value is independent of bandwidth. This is the basis of the distinction between "narrowband" and "broadband" interference. If you are measuring known radio signals then you can tailor the measurement bandwidth to the characteristics of the signal, but this is not possible for EMC measurements, since the characteristic of the interference is almost by definition not known in advance. Therefore the CISPR 16-1 specification includes defined values, not only for the bandwidths required for each measuring frequency range, but also for the *shape* of the filters that are used to provide these bandwidths.

The CISPR 16-1 bandwidth specifications



	A	B
9-150kHz	170-220Hz	170-440Hz
0.15-30MHz	8-10kHz	8-20kHz
30-1000MHz	100-140kHz	100-280kHz

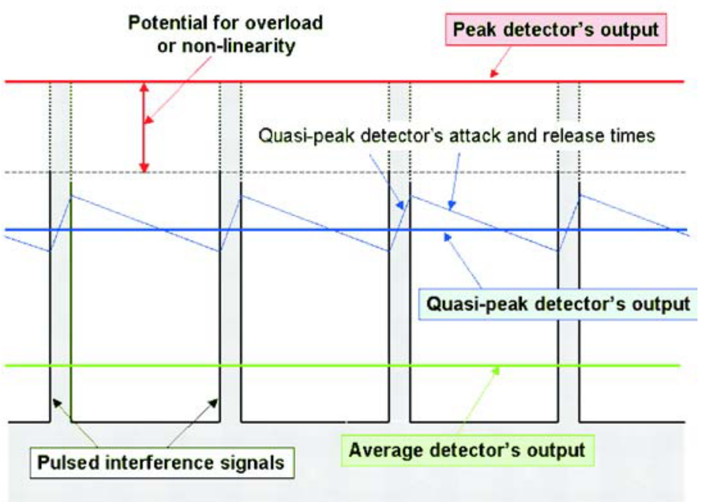
Only a receiver whose bandwidth characteristics fully comply with this specification should be used for full compliance measurements. However, if you are only measuring narrowband interference, such as individual emissions from the harmonics of microprocessor clocks, the actual performance of the receiver filters will have little or no effect on the outcome. This is the root of much of the confusion over bandwidth requirements.

Detectors

CISPR 16-1 specifies three principal detector types: peak (PK); quasi-peak (QP) and average (AV). Most initial measurements are made with the PK detector, which responds in about 1μs to the peak value of the interference signal. Conducted emissions limits are specified by standards using the QP detector, although some ETSI emissions standards use the PK detector instead. (The AV detector is only used for conducted emissions). Full compliance measurements must use only the correct detectors. The difference between the detectors resides in how they respond to pulsed or modulated signals. All three types of detector give the same response to unmodulated, continuous signals.

The QP detector weights the indicated value in terms of its perceived 'annoyance factor': low pulse repetition frequencies (PRF) are less annoying when experienced on broadcast radio and TV channels than high PRFs. The detector is specified in terms of its attack and decay time constants, and these are fairly straightforward to implement. The average detector simply returns the average value rather than the peak value of the interference with which it is presented. This can, in principle, be achieved with a simple low-pass filter whose time constant is slower than the slowest pulse repetition frequency of the input.

The CISPR 16-1 detectors' responses to pulses



Overload performance and pulse accuracy

The difficulty which faces designers of measuring receivers is that to give an accurate measure of the actual quasi-peak or average level of interference with a low pulse repetition frequency, the linear dynamic range of the RF circuits before the detector, and of the detector itself, must be at least equal to the dynamic range of the desired pulse if they are not to be compressed and the test results made erroneous.

This dynamic range (according to the CISPR 16-1 specification) can approach 43dB, which means closer to 60dB in the receiver design. If the measuring equipment does not adjust its gain continually to achieve the optimum level at the detector – spectrum analysers, for instance, can't do this – then the needed dynamic range is several tens of dB more. This is a serious design challenge for RF circuits, and as a result linearity and overload performance for pulsed signals are the most important factors that distinguish low-cost and 'pre-compliance' test instruments from fully compliant measuring receivers.

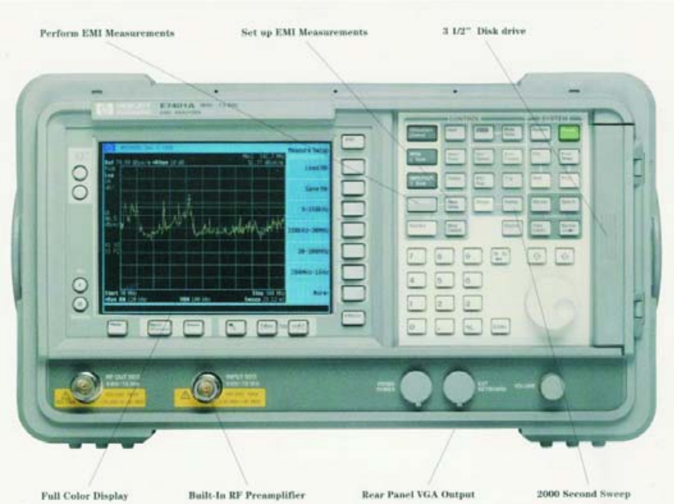
Input VSWR and sensitivity

Of somewhat lesser importance, but still part of the CISPR 16-1 spec, is the requirement on input VSWR (Voltage Standing Wave Ratio). This is specified to be 2:1 with no input attenuation, dropping to 1.2:1 with 10dB attenuation. VSWR is directly related to measurement error due to mismatch. For a broad-spectrum receiver (remember, 9kHz to 30MHz is more than three decades) the spec of 2:1 without attenuation is quite hard to meet – many ordinary radio receivers can't achieve this even over a narrow range. It's easy enough if you allow yourself some attenuation at the input, but then the receiver sensitivity is degraded.

The sensitivity requirement in CISPR 16-1 is expressed in the form that the noise component should not degrade the measurement accuracy by more than 1dB. This implies that the system noise floor must be at least 6dB below the lowest level it is desired to measure accurately. The system noise floor is the receiver noise plus the losses imposed by the transducer or antenna factor and connecting cables. In practice, the limiting performance is usually found at the top end of the conducted test around 1GHz. Low-cost receivers and antennas are often found to have inadequate sensitivity at these frequencies even to measure at the limit line, let alone below it.

In summary, there are several reasons for the high price of fully compliant measuring receivers, and the stringency of the CISPR 16-1 specification is a direct result of the need to make accurate measurements of an unknown and variable interfering signal, over an extremely wide range of the spectrum. Any 'pre-compliance' instrument will necessarily compromise some or all of these aims.

Example of a portable spectrum analyser
(the agilent E7400 A-Series EMC Analyser)



EMC Spectrum Analysers

There are a number of manufacturers of spectrum analysers, some of them aiming directly at the low-cost EMC testing market. Very low-cost analysers are also low on features and functionality, and almost nothing about them will comply with CISPR 16-1, but they are useful for development, diagnostic and QA work [9]. A good quality portable spectrum analyser is a very useful EMC tool for a wide variety of tasks including pre-compliance testing but will almost certainly not fully comply with CISPR 16-1. It will save a great deal of time and effort if your analyser provides automatic compensation for cable and antenna factors, scales in dBμV, shows limit lines, has reasonably accurate quasi-peak and average detectors and can save results to disc or send them to a printer.

Spectrum analysers can be overloaded by strong signals, even if they are outside the frequency band being measured, so a purist (or EMC laboratory accreditation assessor) will say that they should be used with what is known as a 'preselector' (basically a band-pass RF filter). Whilst most test laboratories will accept the added expense, it is often unnecessary for an unaccredited test facility unless the products being tested have high levels of pulsed or continuous emissions (as some ISM equipment covered by EN 55011 does), or if there are some very powerful ambient signals.

To discover whether a spectrum analyser is being overloaded is easy: after making a measurement, connect a 10dB through-line 50Ω attenuator between the transducer and the analysers RF input and re-measure. If all the displayed signals are reduced by nearly 10dB (ignoring those that fall beneath the noise floor), a preselector (or an EMC receiver) is not required.

Example of a full-specification EMC compliance test receiver
(Rohde & Schwarz EMI Test Receiver ESIB)

Any signals that don't reduce by 10dB are probably overloading the analyser, and signals that reduce by more than 13dB could be artefacts caused by RF overload at some other frequency, which may not even be within the measured band. Some analysers are much more resistant to overload than others, and some warn the user if they detect overload.

EMC Receivers

Spectrum analysers have a significant edge over receivers for everyday use in development, diagnostics, and QA, because it is easier to use them to quickly get a visual display of what is going on. But it can be argued that the very best EMC measurements require a receiver rather than a spectrum analyser, to achieve the best noise floor (dynamic range), freedom from overload, and most accurate detectors, even if compared to a spectrum analyser that is used with a preselector.

But at the expensive end of the market, both receivers and spectrum analysers are so good these days that the difference is only of importance to world-class EMC test laboratories, or to those measuring emissions to automotive equipment standards that have some very low emissions limits (hardly any higher than the noise floor of the best available equipment).

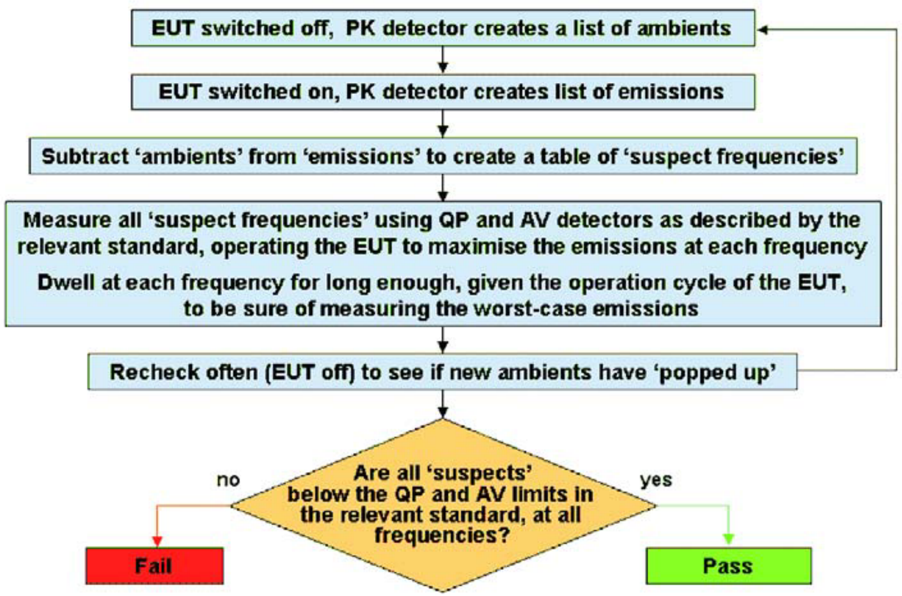
Traditional emissions measuring receivers used to only have a tuning dial and a signal level meter, but most are now available with built-in spectrum displays or else can be connected to computers running application software that provides a spectrum display, and some can be used in 'spectrum analyser mode' for faster measurements.

Conducted emissions testing may be carried out on an Open Area Test Site (OATS) intended for testing radiated emissions, but it is not necessary to use an OATS and conducted emissions can be tested relatively easily, with high accuracy, in the comfort of your own building.

The test site requirements for conducted emissions are very relaxed compared with the problems of radiated testing, and a simple arrangement of metal plates can be sufficient if the ambient noise of the site is low enough in the frequency range to be measured. Ambient noises can be separated out from the emissions of the EUT by first making a measurement with the EUT switched off – using the peak (PK) detector to save time – then again with the EUT switched on, to create a list of 'suspect frequencies' that are known to be caused by the EUT and not by the ambients. Where it is thought that an EUT emission might be lying on top of an ambient, the frequency span of the measuring instrument can be 'zoomed in' and the EUT switched off and on again, to check.

Dealing with numbers of ambients can take a lot of time, especially where they change during a measurement. Where noisy ambients are a problem (either conducted via the site's mains supply, or radiated) a low-cost screened room with a filtered mains supply can be used. There is no need for any RF absorber (cones or ferrite) in the room to control the resonances in the room.

A typical compliance measurement procedure to deal with ambients, for *each* mains conductor

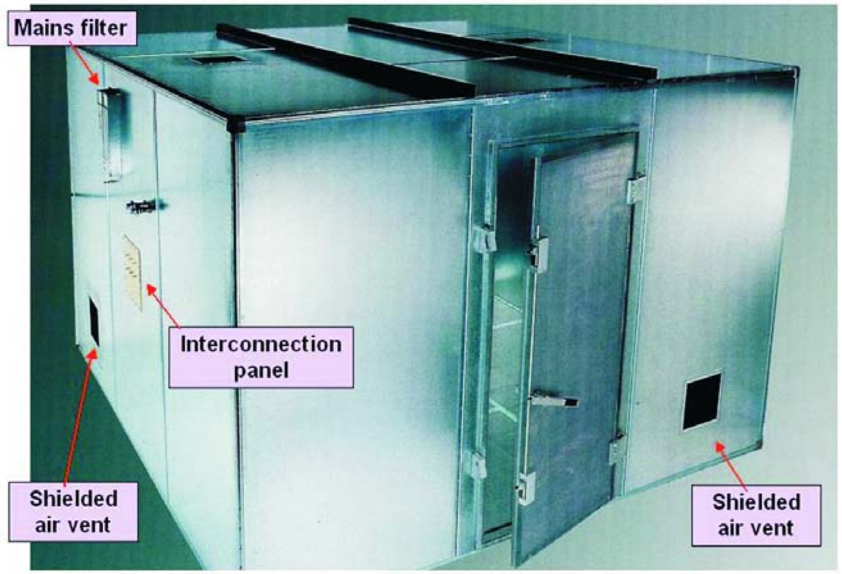


Example of a low-cost 'D-I-Y' shielded room

This room was constructed by Expamet Ltd, using their expanded metal products

Similar rooms are easy to construct yourself, the largest problem usually being leakage around the door's gaskets

An example of a plain shielded room (courtesy of Lindgren-Rayproof)



Virtually all CISPR-based test standards specify limits on conducted emissions on the AC (mains) supply, measured from 150kHz to 30MHz. The three most commonly referenced standards EN 55011, EN 55014-1 and EN 55022 (based on CISPR 11, CISPR 14-1 and CISPR 22 respectively) all set such limits and their methods are largely common, although there are detailed differences. EN 55013 and EN 55015 (based on CISPR 13 and CIPSR 15) for broadcast receivers and lighting equipment respectively also require a similar test, although EN 55015 extends the measurement range down to 9kHz for some apparatus.

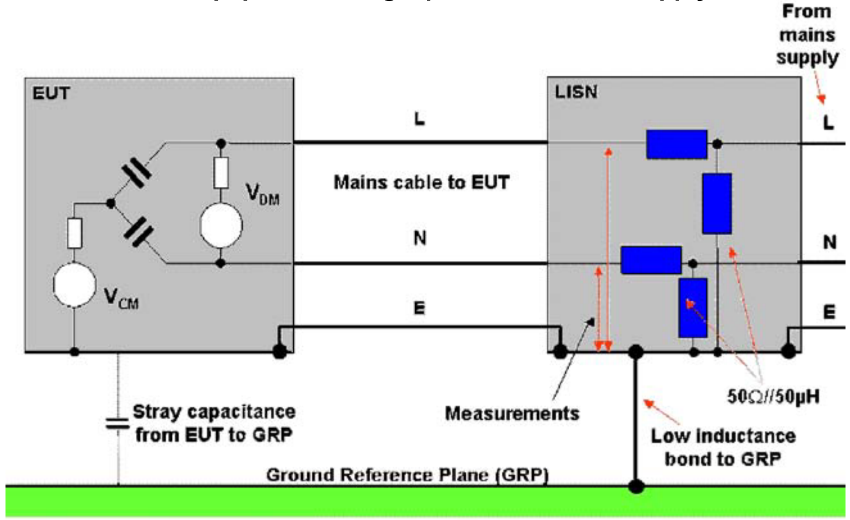
To appreciate the constraints on fully compliant conducted emissions tests it helps to be familiar with the 'test equivalent circuit' shown in the nearby figure. This shows that in the mains port test you are measuring a combination of DM and CM sources on each line (L or N) with respect to the ground reference plane (GRP), which is connected to the EUT's 'earth' connections, if it has any.

The factors outside the EUT that control the coupling, and hence the measured value, are:

- Stray capacitance from EUT to GRP
- RF impedance of the mains cable
- RF impedance of the LISN

The equivalent circuit shows that stray capacitance between the EUT and the GRP is an important part of the coupling path. The standard test set-up for table-top EUTs in a screened room is shown by Figure 9 of [2] and regularises stray capacitance by insisting on a fixed separation distance between the two; 400mm is the norm, with at least 800mm clearance from all other conducting

The 'test equivalent circuit' for a conducted emissions test on an equipment's single phase AC mains supply

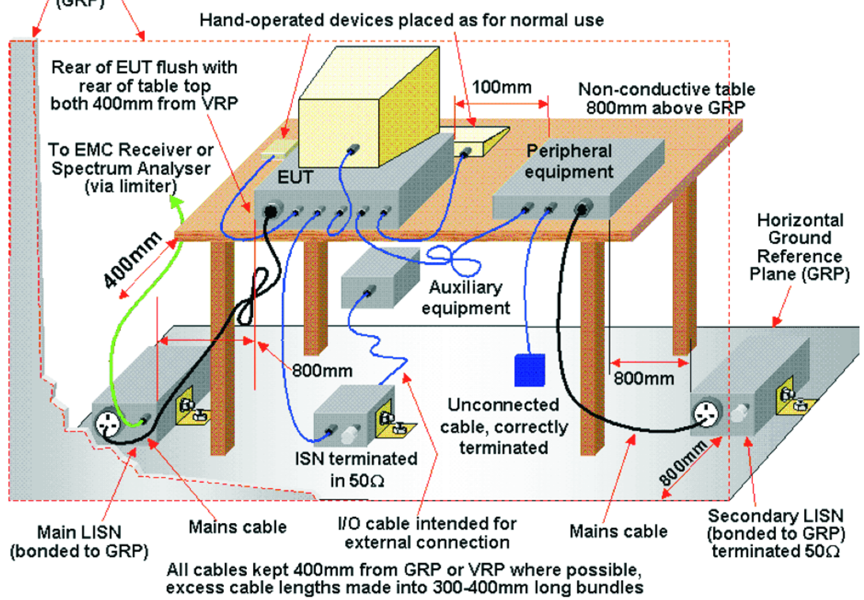


surfaces. A fully compliant test requires great care in achieving these distances. All test houses have a 800mm high wooden table on which the EUT can be spaced 400mm away from a vertical GRP (or a wall of a screened room). An alternative that is allowed in some standards is a 400mm separation from the bottom of the EUT to a horizontal GRP (the floor of a screened room).

The third important aspect is the impedance introduced by the mains cable, which can have a significant effect above 15MHz and so must be controlled. Laying it on the GRP will introduce excess stray capacitance; coiling extra length will introduce more inductance. Keeping it off the GRP, and bundling it if necessary in the way prescribed by the standard, controls both these factors and minimises the variations introduced by the cable. However, nobody bundles cables exactly the same way, making cable bundling rather hit-and-miss, so it is preferable to use a standard unbundled 1m length of cable for these tests, whatever length the final product will be supplied with.

All the necessary test set-up details for table-top and other styles of EUT (e.g. floor standing equipment) will be found in the relevant sections of the appropriate test standard. [17] contains some useful detail on performing full compliance conducted emissions tests, especially as regards the control of the test instrumentation.

Example of a conducted emissions test setup in a screened room (derived from Figure 9 of [2])



Example of a spreadsheet
used to calculate actual conducted emissions in dBµV

Frequency in MHz	Measured QP signal dBµV	LISN's transducer factor dB	Transient limiter's cal. factor dB	Cable cal. factor dB	Receiver QP cal. factor dB	Final measured QP value dBµV	EN55022 Class B QP limit dBµV	Margin and pass/fail
0.1502	53.9	0.1	10.3	0.01	-0.4	63.91	66	-2.09
0.5374	51.8	0.05	10.1	0.02	-0.6	61.37	56	5.37 fail
4.012	44.6	0.0	10.1	0.1	0.5	55.3	60	-4.7
8.024	46.8	0.0	10.0	0.15	0.7	57.65	60	-2.35
12.036	50.6	0.0	10.0	0.2	0.3	61.1	60	1.1 fail
16.048	53.1	0.0	10.0	0.25	0.2	63.55	60	3.55 fail
20.060	48.9	0.05	10.1	0.3	-0.2	59.15	60	-0.85
24.072	41.5	0.1	10.2	0.35	-0.4	51.75	60	-8.15

The above table is an example of a spreadsheet to calculate the Quasi-Peak (QP) detector measurements for one mains conductor — similar spreadsheets are required for other conductors and to calculate the Average (AV) detector measurements

More sophisticated spectrum analysers or receivers, or their control software, can apply these correction factors automatically (when the calibration data has been entered into their internal memory)

Pass / fail can then be seen immediately from their displays, saving a great deal of time and making diagnostic and QA testing much more intuitive

This was discussed in general, and from the point of view of radiated emissions testing, in section 1.11 of [10]. Chapter 10 of [14] is also a useful reference.

Which ground Earth reference to use is a crucial factor when testing on-site. At an EMC test site it is defined by the ground reference plane (GRP, see earlier), but in-situ referencing has to make do with what exists and what can practically be achieved. CISPR 16-2 recommends the following:

> The existing ground at the place of installation should be used as reference ground. This should be selected by taking high frequency (RF) criteria into consideration. Generally, this is accomplished by connecting the EUT via wide straps, with a length-to-width ratio not exceeding 3, to structural conductive parts of buildings that are connected to earth ground. These include metallic water pipes, central heating pipes, lightning wires to earth ground, concrete reinforcing steel and steel beams.
>
> In general, the safety and neutral conductors of the power installation are not suitable as reference ground as these may carry extraneous disturbance voltages and can have undefined RF impedances.
>
> If no suitable reference ground is available in the surroundings of the test object or at the place of measurement, sufficiently large conductive structures such as metal foils, metal sheets or wire meshes set up in the proximity can be used as reference ground for measurement.

"Sufficiently large" probably means that the added metal foils, sheets, or meshes should underlie the whole of the EUT and spread beyond it for at least half its height, so as to maximise its stray capacitance. But it all depends on what you are trying to achieve – if you are trying to test a product which will be manufactured in volume and sold into other environments, maximising stray capacitance with metal sheets corresponds more closely to the proper test set-up (see above) and represents a worst-case set-up.

However, if you are measuring the conducted emissions from a custom-made item of apparatus when it is installed at the site where it is permanently installed, to determine whether this single apparatus is compliant as installed (for example when following the Technical Construction File route for the compliance of a large system) then it is more reasonable to use only the existing bonded metal structures and not add to them.

Both LISN and voltage probe tests require a reference, which would typically be the boundary of the system where the power supply connects to it – often the terminals of a power outlet or a supply transformer dedicated to the system. Transducer reference connections must be bonded using a very short, wide strap to the chosen reference point – lengths of green-and-yellow wire are not adequate.

Loading, filtering and isolation

The layout of the mains cable should be as close as possible to normal operation during the test and excess cable or coils of cable should be avoided. Whatever the mains cable layout is, it should be fixed for the duration of the tests and drawn (or photographed) for the test report.

Almost no test standards provide adequate guidance for in-situ testing of conducted emissions on the AC (mains) supply, so site-specific test plans have to be developed. Many decisions will have to be taken by EMC engineers on the spot. Some basic practices (which also apply to conducted tests in the laboratory) also apply here:

- Take an ambient scan with the EUT switched off. Create a list of ambients.
- With the EUT switched on and operating, take a peak detector sweep with a reasonably fast scan speed, taking into account the EUT's cycle time, to create a list of significant emission frequencies. Subtract known ambients from this list, leaving a list of 'suspects'.
- Test the suspect frequencies individually using the quasi-peak and average detectors as required to make the comparison with the limits in the relevant standard, modifying the EUT's operation to maximise the emissions if this is relevant.
- It is a good idea to recheck the ambients from time-to-time during a test to make sure that new ambient sources (such as someone using an electric drill nearby) aren't being mistaken for EUT emissions.

This procedure is repeated for all the mains phases at each location to be measured.

When being tested for conducted emissions, the EUT should be operated in its normal manner. Some equipment may require the use of resistive loads to replace auxiliary equipment that it would be impractical to bring to the OATS or other test site.

REO can create custom loads to meet any requirements

If you are testing on a site that suffers from high levels of electrical noise in its mains power supply, it may be possible to use filters to help reduce the noise levels. There are a number of issues that will need to be taken into account to suppress the interfering frequencies effectively. Suitable filtering techniques are described in Chapter 8 of [14] and Part 4 of [15].

A selection of typical REO Filters for AC supplies

Mains isolation transformers can sometimes be used to help reduce the electrical noise at an emissions test site by breaking ground current paths. The lower their leakage and the higher their isolation the better (in other words the lower their low primary-to-secondary capacitance).

If working on exposed live equipment whilst performing emissions tests (e.g. when trying to modify an EUT to make it pass the test) an isolating transformer can help reduce electric shock hazards. As before, high-isolation types are the best, also 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.

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

REO isolating transformer with low primary to secondary capacitances

Measurement uncertainty

All measurements suffer from inaccuracies, and EMC measurements are no exception. Accredited test labs in the UK are required to calculate the measurement uncertainty for their conducted emissions tests and make the result available to customers. The method described by LAB 34 (from the United Kingdom Accreditation Service, UKAS) is suitable for calculating measurement uncertainty. A typical measurement uncertainty for a full compliance conducted emissions test to EN 55022 or EN 55011 would be ±2.5dB.

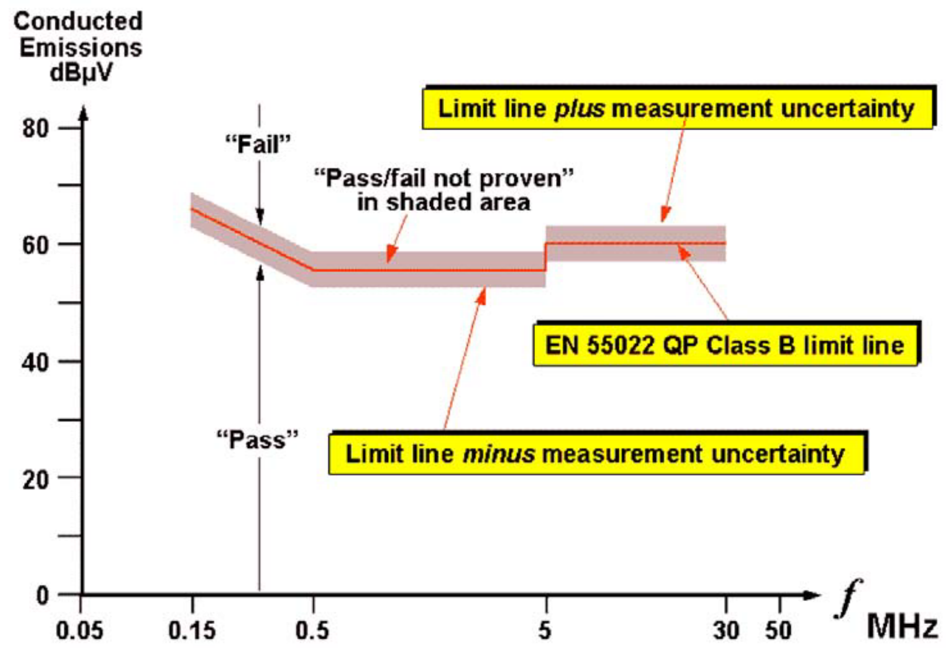
In the UK it has been the custom for accredited test laboratories to draw lines either side of the limit line being tested to.

The upper line represents the limit line plus the measurement uncertainty, and the lower line the limit line minus the measurement uncertainty. Then, in a test report for a full compliance emissions test, if the emissions fell between the upper and lower limit lines, the report would state "Pass not proven".

Only if the emissions were above the upper limit line would the report state "Fail" and only if they were below the lower limit line would the report state "Pass".

It is very easy to make erroneous emissions measurements, and the process of calculating the measurement uncertainty helps to ensure good quality results.

Example of reporting mesurement uncertainty
(EN 55022 QP Class B shown)



Low-cost and/or non-compliant testing

Testing using alternative methods from those in EN 55022 or EN 55011 cannot give any confidence that "full-compliance" tests for conducted RF emissions would be passed. But such non-compliant tests may be valuable for improving the performance and reliability of a product, and its ability to be used in close proximity to other equipment.

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

A comprehensive discussion of low-cost and 'pre-compliance' testing methods for conducted emissions can be found in [9]. But always remember that saving money on test labs by doing testing yourself requires skill and attention to detail. RF testing is difficult enough to do accurately even on a purpose-built EMC testing site. So the more money it is desired to save, the greater will be the skill and attention to detail required.

Correlating alternative test methods

When an alternative conducted RF emissions test method is used for design, development, or troubleshooting after a test failure: repeatability is very important (even though the correlation with EN 55022 or EN 55011 may not be). 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 [10] for a detailed description of how to use the golden product correlation method.

If alternative methods are used to gain sufficient confidence for declaring compliance to the EMCD, the golden product method is very strongly recommended. Without a golden product or some similar basis for correlating a full compliance test with the alternative method actually used, the alternative method can only give any confidence at all by using severely reduced emissions limits, and this can result in very expensive products.

The closer a test method is to using the proper test transducers and methodology in the relevant standards, the more likely it is that a good correlation will be achieved. So-called "pre-compliance" testing should always use the correct test equipment and methods, with the deviations from the full compliance tests not being sufficient to cause significant measurement errors.

Buying second-hand test gear

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

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

References

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[3] European Union Directive 89/336/EEC (as amended) on Electromagnetic Compatibility. The Directives 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] CISPR 11:1997, "*Industrial, scientific and medical (ISM) radio frequency equipment – Radio disturbance characteristics – Limits and methods of measurement*" (Note: Amendment A1:1999 applies and Amendment A2:2002 is available for use now and must be applied from 1st October 2005.)

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[6] 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.

[7] "*EMC-related Functional Safety – An Update*", Keith Armstrong, EMC & Compliance Journal, Issue 44, January 2003, pp 24-30, at: http://www.compliance-club.com/KeithArmstrongPortfolio

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

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