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A Practical Guide for EN55022 and EN5011: Measuring Radiated Emissions

Helping you solve your EMC problems

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A Practical Guide for EN 55022 and EN 55011

Measuring Radiated Emissions

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EN 55022 and EN 55011 and compliance with the EMC Directive

This handbook is concerned with testing radiated emissions to the typical domestic/commercial/industrial EN standards over the frequency range of 30MHz to 1GHz. Some people will need to measure above 1GHz – for example for some types of radio-frequency (RF) equipment when applying EN 55011 (CISPR11); or when meeting FCC requirements for the USA with a product containing a digital clock of over 108MHz. Some people need to measure below 30MHz – for example when measuring cable TV distribution systems or military equipment. Military radiated emissions testing also covers a much wider range than 30MHz to 1GHz.

The 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).

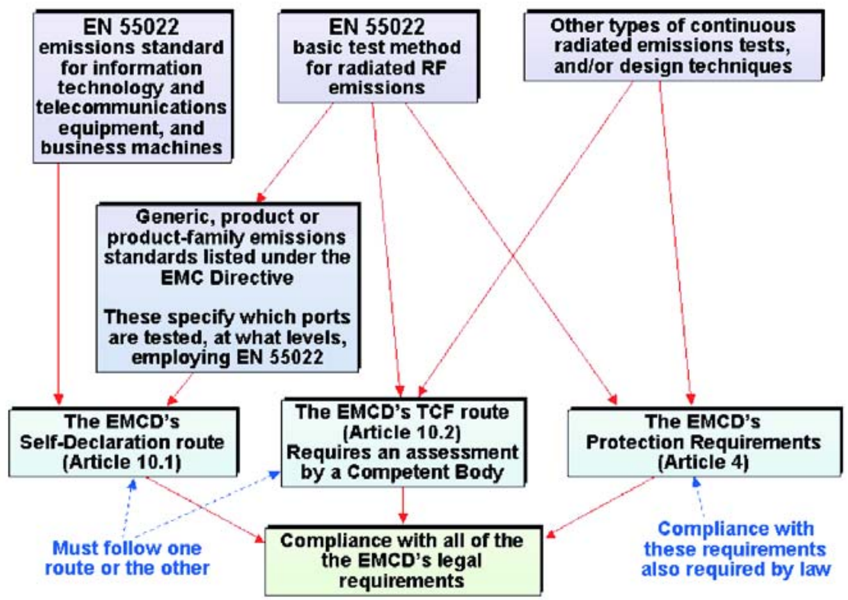
CISPR11 [4] is another venerable RF emissions standard, and this was originally developed for industrial, scientific and medical (ISM) equipment that uses RF energy to perform its intended function. It has been adopted in the EU as EN 55011 [5], with some modifications from the original CISPR document, 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 5501 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]).

Relationship between EN 55022 and the EMC Directive (EMCD)



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 (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 the 'protection distance' is 30m.

Many items of equipment are operated closer than 10 (or 30) metres to radio or TV receivers, and this is especially true for cellphones and other mobile radio communications. 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 a way to improve the performance of an equipment's wireless data link(s), increase customer satisfaction and reduce exposure to product liability claims.

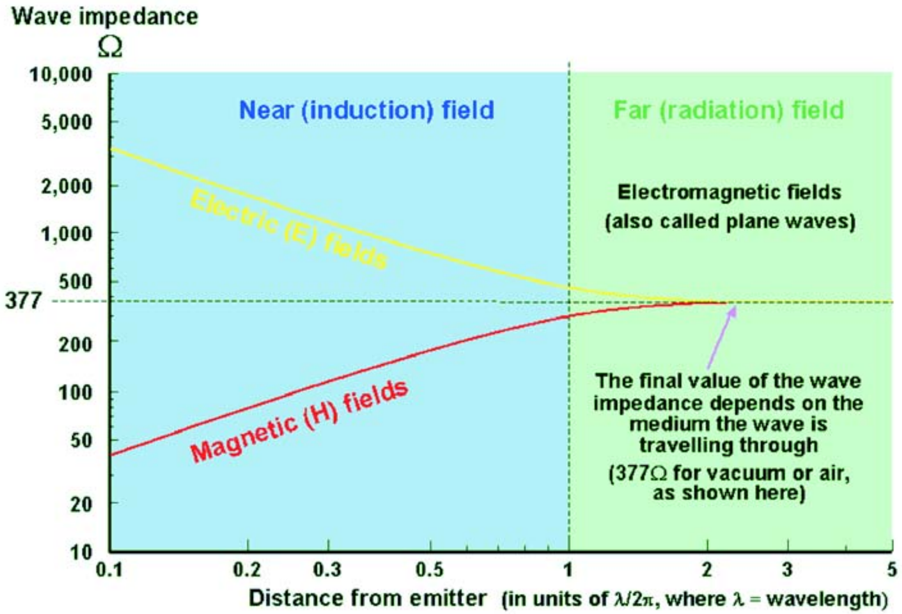
This series of handbooks is concerned with testing to the EN standards for typical domestic, commercial, light industrial and industrial environments. But other kinds of immunity tests may be required by the EMC standards for automotive, aerospace, rail, marine and military environments. Some of these 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 radiated emissions testing in a manner that will also be of use for 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 IEE's guide [6] and the on-line article [7] for more on this.

What are radiated RF emissions and how are they caused?

The propagation of E and H fields

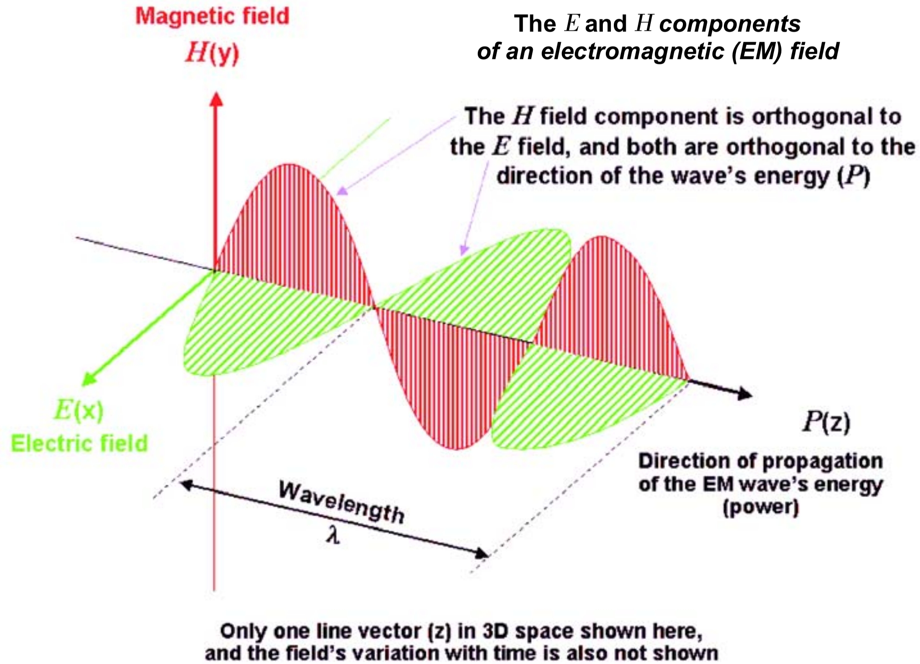


Fluctuating voltages in a conductor of any type creates radiated electric waves in the air and other insulators (dielectrics, e.g. plastic cable insulation). Fluctuating currents in a conductor of any type creates magnetic waves. After travelling for a distance equivalent to approximately one-sixth of 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 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.

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



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 radiated 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.

Radio, TV and radar transmitters, and very powerful processing such as industrial scientific or medical equipment (ISM) that use RF energy to perform their direct functions (covered by CIPSR 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.

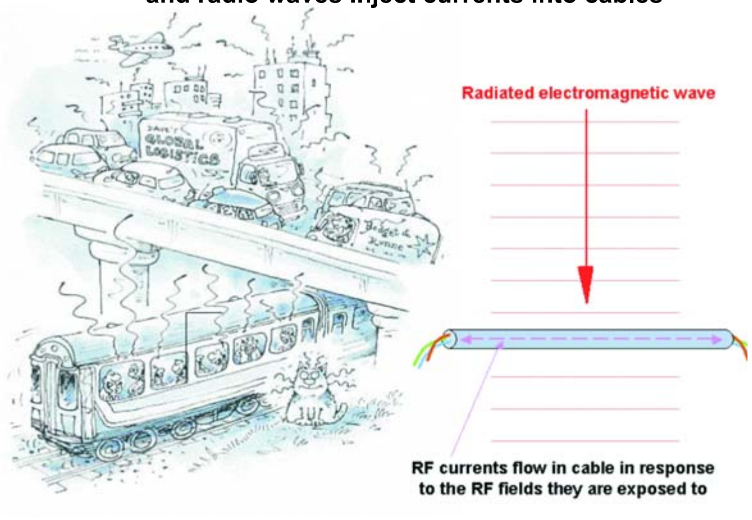
What problems are caused by radiated RF emissions?

When wires, cables, connectors and any other conductors are exposed to E, H or EM fields, currents and voltages are induced in them, in what is essentially the reverse process from that which gave rise to the fields in the first place. These currents and voltages are, of course, *noise* as far as the victim circuit is concerned, with the potential ability (if at too high a level and/or at certain frequencies) to cause unacceptable variations in electrical and electronic performance (including the misoperation of software). When the variations caused by the induced electrical noise are too great, we say that the circuit is suffering from electromagnetic interference (EMI), or sometimes, just interference.

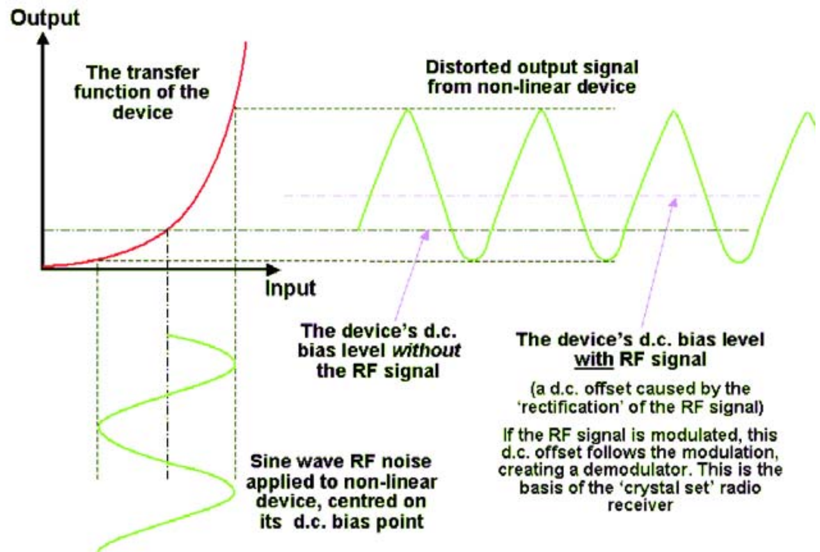
Obviously, when the noise voltage or current is within the operating frequency range of a circuit, a sufficient level of noise will affect the circuit. But there are two ways by which disturbances outside the frequency range of a circuit can interfere with it: rectification (sometimes called demodulation) 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, 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, so all semiconductors can be thought of as 'RF detectors', essentially little radio receivers.

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



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



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].

9 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 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.

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.

10 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 or TV receivers, cellphones, scientific instrumentation, etc.) could be used nearby. The emissions limits in EN 55022 were chosen to protect radio and TV 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 the 'protection distance' is 30m.

If a product causes interference in real life, it will annoy people and can harm to 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 an 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 30MHz and/or higher than 1GHz. 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.

But there is another more immediate problem that can affect the design of many modern products. Co-located wireless receivers are becoming very common on many personal computing products (e.g. laptop PCs, palmtops, PDAs, etc.). These include GSM and GPRS at 900, 1800 or 1900MHz, and Bluetooth and IEEE 802.11 at 2.45 and 5GHz. Not only are the emissions limits in EN 55022 and EN 55011 far too high to give any confidence that the equipment will not interfere with its own wireless data link, but also the test methods used only measure in the 'far field' (further away than one-sixth of the wavelength) and so cannot predict what 'near fields' may be experienced by a wireless device that is attached to the product itself.

The usual problem is that the range of the wireless data receiver is severely compromised, due to its RF stages being affected by the high levels of noise from the product itself. It is rare for an emission from the product to coincide with the radio channel the wireless receiver is using, but the very narrow frequency selectivity of radio receivers is only achieved by several stages of processing – the early stages of a receiver, following its antenna, have a much wider bandwidth and so can often pick up a lot of noise from the product's emissions. The receiver thus 'thinks' it has a strong wanted RF signal and turns down its automatic gain control (AGC) accordingly, reducing its sensitivity to its *wanted* radio signals.

This problem is not uncommon, especially when a wireless data capability is being added to an existing product. Simply complying with EN 55022 is little help. Even extending the EN 55022 tests to cover the wireless frequency range and setting a lower emissions limit in that range might not help, because EN 55022 does not measure (or even allow the prediction of) the near fields that can affect the wireless device.

Close-field probing is a valuable technique that can help resolve such problems (see [9]). At frequencies of 1.8GHz and above it is also possible to make a quarter-wave whip antenna (with counterpoise) that is sufficiently small to probe the local fields in the location chosen for the wireless device's antenna, and can also measure the received signal in a way that allows reasonable comparison with the strength of the wanted data signal.

Antennas

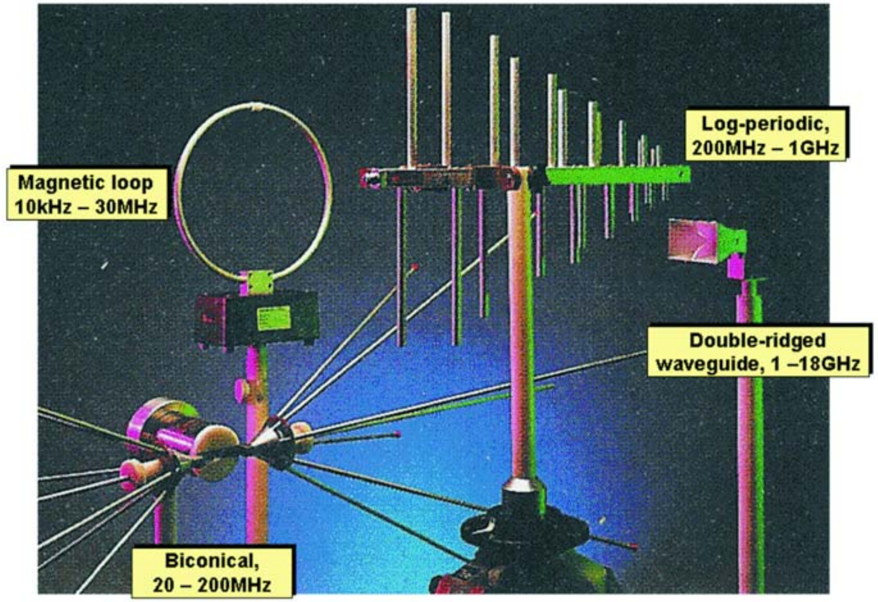
Various alternative transducers are available for diagnostic and QA measurements of radiated RF emissions, for example close-field probes and current probes, and these are discussed in [9].

Full-compliance EN 55022 and EN 55011 tests for radiated emissions use electric-field antennas designed for use in the far field. Between 30MHz and 1GHz dipoles can be used, but they have limited frequency ranges and changing over from one model to another makes the testing very time-consuming. But because dipoles have a 'calculable response' they are still the standard transducer for radiated emissions site calibration (see later).

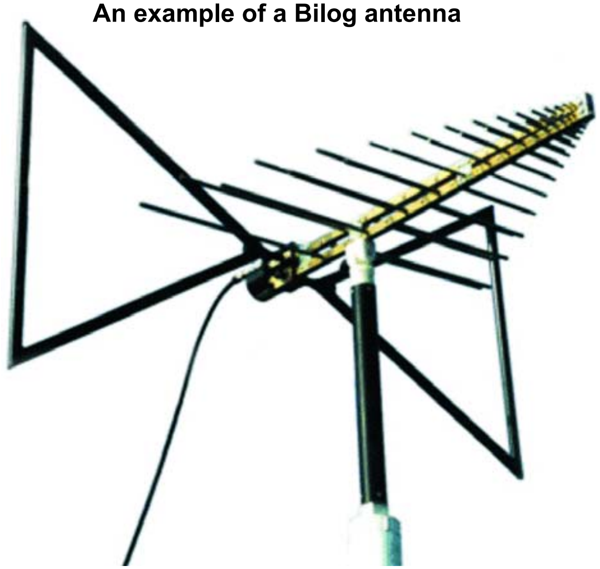
A variety of antennas have been designed to help the EMC engineer test quickly over the range 30MHz to 1GHz, and they can have quite interesting shapes [10]. The biconical (which looks like two egg-whisks back-to-back) is a favourite and typically covers from 20 to 200MHz, while the typical log-periodic (like a rooftop TV antenna, but with elements that vary in length) covers from 200MHz up to 1 or 2GHz.

Nowadays the industry standard antenna for full compliance testing is the Bilog, which normally covers 30MHz to 1GHz although versions are available that go down to 20MHz and up to 2GHz. But some Bilogs can be large, heavy, and cumbersome. Smaller, lighter and lower-cost alternative antennas are available from a number of manufacturers (often using built-in amplification to compensate for their lower sensitivity) and these may be acceptable for pre-compliance testing.

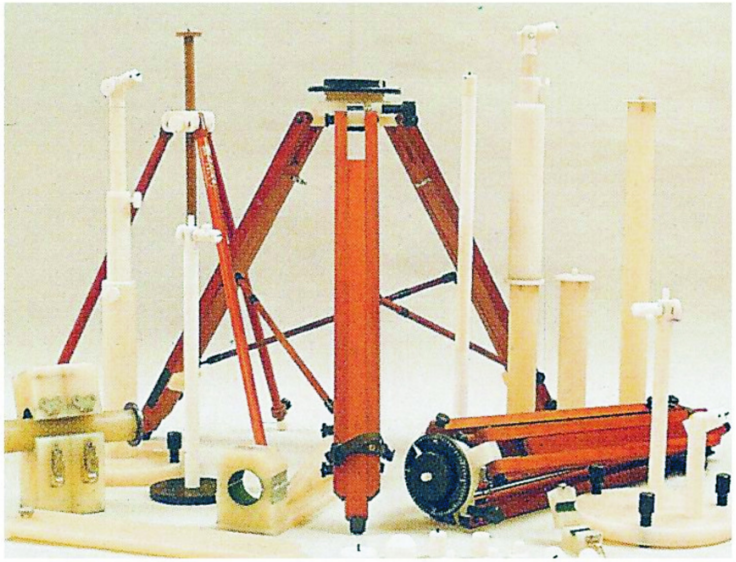
Examples of antennas for radiated emissions from 10kHz to 18GHz (courtesy of EMCO)



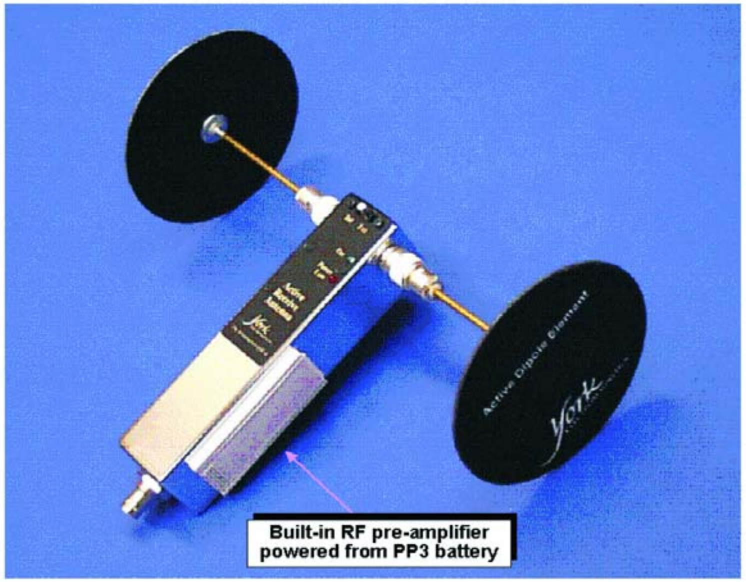
An example of a Bilog antenna



Examples of antenna stands and accessories



A very small 30MHz to 1GHz antenna (courtesy of York EMC Ltd)



A very important point about all antennas is that they need to be calibrated, and their calibration factors (sometimes called 'transducer factors', or 'antenna factors') must be taken into account in any measurement of radiated emissions [11]. Many wide-band antennas can have calibration factors that vary between 0 and 20dB over their frequency range, so it is very important to take these into account if the emissions from an equipment under test (EUT) are to be measured correctly.

Spreadsheets are used to calculate actual emissions from the raw measurements of an antenna, by adding the antenna's calibration factors to them. These spreadsheets can usefully also incorporate the calibration factors for the cable that connects the antenna to the measuring instrument and for the measuring instrument itself. The various calibration factors come from regular calibrations of the antennas, cables and measuring instruments at specially equipped 'calibration laboratories'.

Professional emissions measuring instruments usually incorporate algorithms that take all the calibration factors into account, so that their screen display and printouts show the accurate emissions levels. Of course, the calibration data for the antennas and cables used have first to be added to the instruments memory for this feature to work.

Example of a spreadsheet used to calculate actual radiated emissions in dBμV/m

Frequnecy In MHz	Measured signal at 10min dBμV	Attenna factor in dB/m	Cable factor in dB	Receiver factor in dB	Final value of radiated field	EN55022 Class B QP limit	EN55022 Class B QP limit
48.336	18.3	17.8	0.3	0.2	36.6	30	6.6 fail
80.560	27.5	14.1	0.4	0.7	43.0	30	13.0 fail
112.78	22.0	11.2	0.5	-0.6	33.1	30	3.1 fail
145.01	34.7	7.9	0.6	0.8	44.0	30	14.0 fail
177.23	29.1	5.6	0.8	1.1	36.6	30	6.6 fail
209.46	31.3	4.2	1.0	-0.2	36.3	30	6.3 fail
241.68	31.0	2.4	1.1	-0.9	33.5	37	-3.5 fail
273.90	29.0	1.8	1.3	-0.7	31.4	37	-5.6 fail

More sophisticated spectrum analysers or receivers, or their control software, can apply these correction factors automatically. Pass / fail can then be seen immediately from their displays, saving a great deal of time and makes diagnostic testing much more intuitive.

Some can also display an alarm when a user-specified limit is exceeded, making QA test work easier.

Instrumentation requirements for full compliance radiated emissions tests

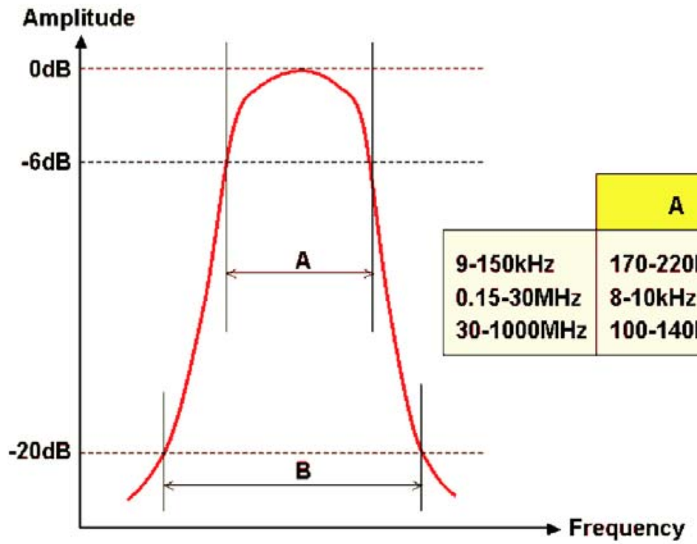
Interference measuring receivers have to comply with the provisions of CISPR 16-1 if they are to be used for full compliance measurements. 'Pre-compliance' measuring equipment, of course, costs less and does not fully comply with CISPR 16-1, so may give erroneous measurements under some conditions. To 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

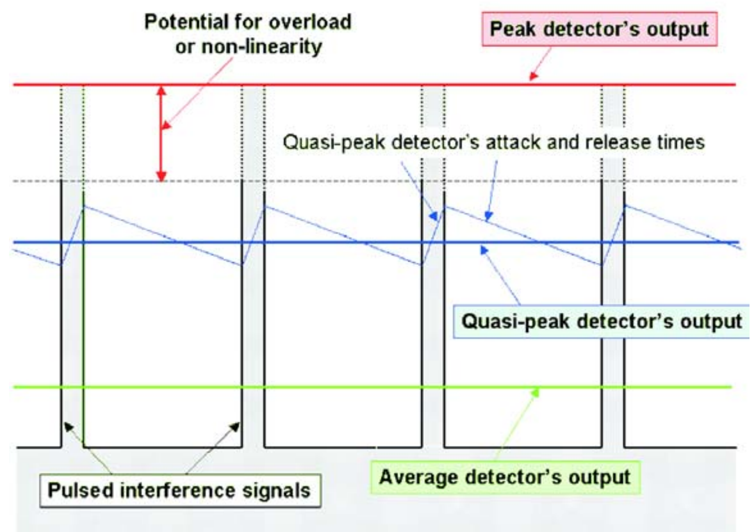
Only a receiver whose bandwidth characteristics fully comply with this specification should be used for full compliance measurements. However, if you are only measuring narrowband interference, such as individual emissions from the harmonics of microprocessor clocks, the actual performance of the receiver 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. Radiated 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. Its easy enough if you allow yourself some attenuation at the input, but then the receiver sensitivity is degraded.

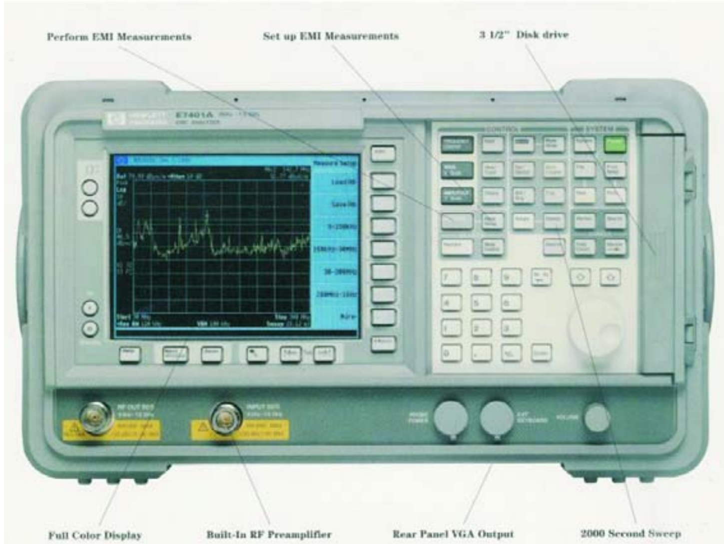
The sensitivity requirement in CISPR 16-1 is expressed in the form that the noise component should not degrade the measurement accuracy by more than 1dB. This implies that the system noise floor must be at least 6dB below the lowest level it is desired to measure accurately. The system noise floor is 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 radiated 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.

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].

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

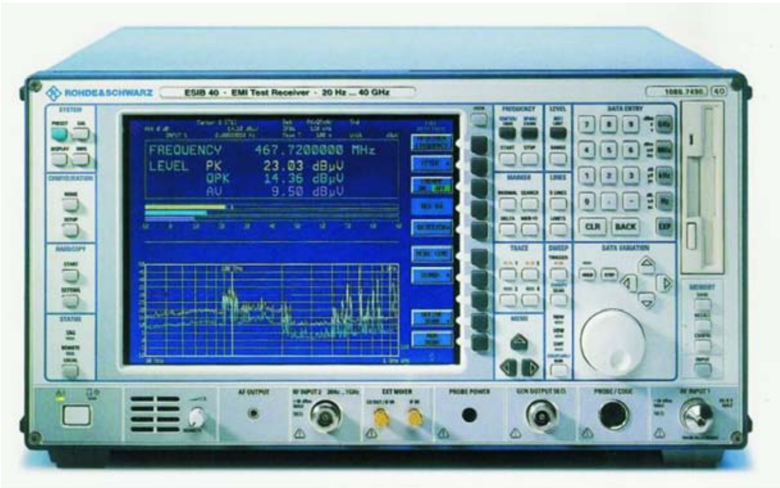


A good quality portable spectrum analyser is a very useful EMC tool for a wide variety of tasks including pre-compliance testing but will almost certainly not fully comply with CISPR 16-1. It will save a great deal of time and effort if your analyser provides automatic compensation for cable and antenna 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 will say that they should always be used with what is known as a 'preselector'. Whilst most test laboratories will accept the added expense, it is often unnecessary for an in-house 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's is being overloaded is easy: after making a measurement, connect a 10dB through-line 50Ω attenuator between the transducer and the analyser's 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. 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



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

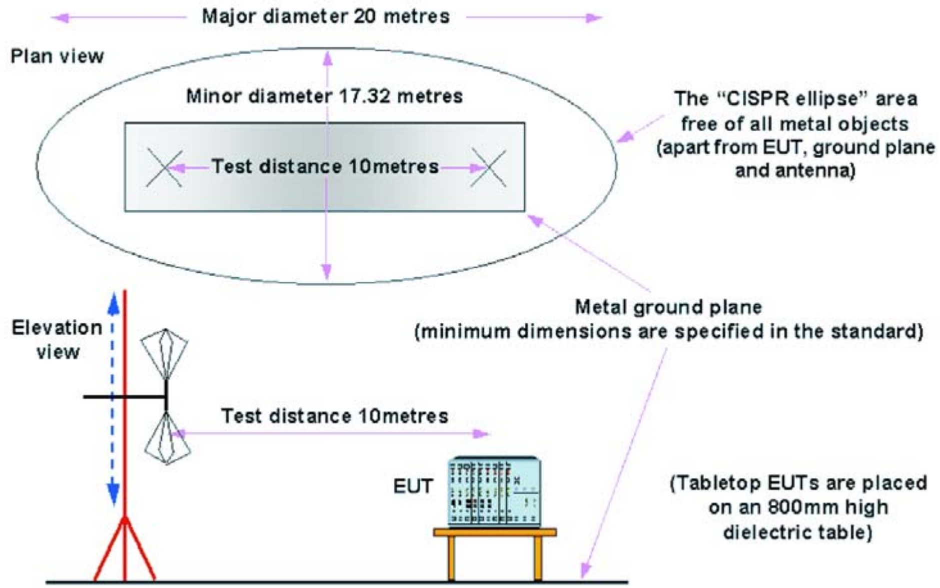
Spectrum analysers have a significant edge over receivers for everyday use in development, diagnostics, and QA, because it is easier to use them to quickly get a visual display of what is going on. But it can be argued that the very best EMC measurements require a receiver rather than a spectrum analyser, 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.

Testing on an Open Area Test Site (OATS)

General OATS requirements in EN 55022



Antenna (various types) height-scanned over 1-4 m to find the maximum emissions at each frequency (for both vertical and horizontal polarisations)

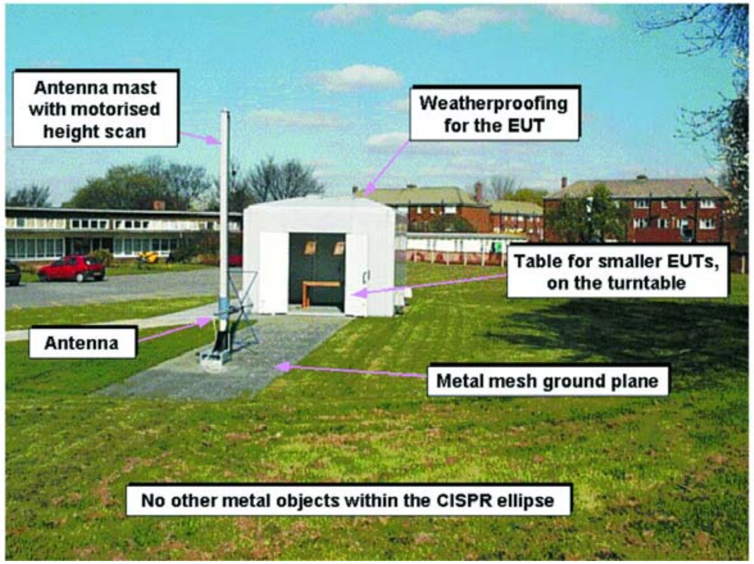
The OATS used by EN 55022 and EN 55011 are very simple and easy to construct. They must be in the open air, and have a defined elliptical area (the "CISPR ellipse") that is free from all metal objects except the antenna, the equipment under test (EUT), and a metal ground plane with a defined shape centred in the ellipse.

The ground plane can be solid metal, or a closely spaced mesh, or a combination of them both. The EUT and antenna are placed 10m apart in defined positions on the ground plane, and the EUT is rotated to find its maximum emissions at every frequency. Floor-standing equipment is placed directly on the ground plane, and table-top or portable equipment is placed on a wood or plastic table at a height of 800mm above the ground plane.

Where a turntable is set into the floor, it must have a metal top fitted with EMC gaskets around its perimeter, so that it acts as part of the ground plane.

For every measurement, the antenna is 'height scanned' from 1 to 4m to maximise the emissions from the EUT at each measured frequency, with each antenna polarisation (i.e. horizontal and vertical). This can make the tests quite complex and time-consuming, and most test labs automate the testing process to ensure that nothing is missed and reduce the time taken.

Example of a 10 metre OATS (courtesy of York EMC Ltd)



The height scanning was devised to overcome the problem of reflections from the ground that reached the antenna with a delay compared to the direct path between EUT and antenna (because of the greater distance the reflected wave has to travel to the antenna). When two waves with a delay between them are combined in one antenna, some frequencies will be amplified (by up to 6dB) and some will be attenuated, with complete cancellation possible. Height scanning the antenna helps ensure that doubling of the measured level almost always occurs, and attenuation never occurs. The limits in the emissions standards that use OATS test methods have been increased by 6dB to take account of the effect of the height scanning.

Without a conductive ground plane reflections from the ground still exist, but their amplitude depends on the type of soil, weather and wetness of the ground (the best location for an OATS is suspended 100m in the air, but this is of course impractical). So a metal sheet or mesh ground plane is used to help ensure repeatability and consistency between different sites.

For many years EN 55022 and EN 55011 both required radiated emissions to be tested on an OATS. But as the ambient is becoming noisier – especially due to the use of digital terrestrial broadcasting – it is becoming more difficult to find a convenient site for an OATS that does not suffer from very high levels of ambient noise. As a result, a number of shielded site alternatives are now acceptable, such as the semi-anechoic chamber (see later).

If you intend to test your products exactly as the standards dictate – so-called 'full compliance' testing, as distinct from pre-compliance tests – then there are three aspects to consider. These are:

- The quality of the test site
- The quality of the test equipment
- The correctness of the test procedures

The quality of test equipment has been discussed earlier in this handbook

Qualifying the OATS – Normalised Site Attenuation (NSA)

As described above, a fully compliant OATS includes a metal ground plane that stretches between the EUT's position and the measuring antenna and beyond them, a means of rotating the EUT and, for tabletop apparatus, of positioning it 800mm above the plane, and a mast that allows the antenna to be scanned in height from 1 to 4m as well as giving both horizontal and vertical antenna polarisation. The commercial standards allow three measurement distances, 3m, 10m and 30m, but the latter is very rarely used in practice and is not considered here. In EN 55022 the measurement distance is taken from the boundary of the EUT to the reference point on the antenna.

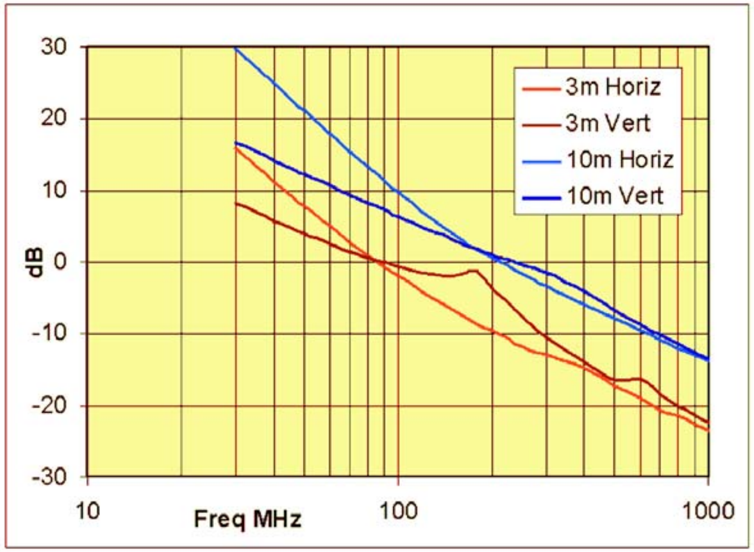
The parameter that distinguishes a test site that can be used for full compliance tests, from one that cannot be so used, is called Normalised Site Attenuation (NSA). This is a measure of the attenuation from the position of the EUT to the position of the measurement antenna. CISPR standards, including CISPR 16-1 and CISPR 22, include tables of the theoretical NSA versus frequency for different measurement distances and antenna polarisations. The measured NSA for your test site is compared against the theoretical, and as long as it differs by less than ±4dB then the site can be used for compliance purposes.

As you would expect, the 3m measurement distance shows a lower loss than the 10m. There are differences between horizontal and vertical antenna polarisations due to the effects of the reflections from the ground plane.

Measurement of NSA, while simple in theory, is not an easy procedure. The loss from a signal generator to a receiver is measured using two antennas – one placed at the EUT's position and driven by an RF signal source, the other at the measuring antenna's position and connected to a measuring receiver. Two tests are performed: one with the two antennas in their respective positions on the site; the other with the antenna cables disconnected from the antennas and instead directly connected to each other.

The NSA is then the difference between these measurements, taking into account the correction factors for both of the antennas. CISPR allows 3dB for uncertainties in the instrumentation and only 1dB for variations in the site itself. A well-constructed site can meet this requirement, but there is very little margin for inadequacies in the measurement. A particular problem is that the antennas used must be calibrated for the specific geometry of the NSA measurement and not for free space. Differences in antenna factors between these two conditions can be quite enough to mar the results for an otherwise satisfactory site.

Theoretical NSA curves for broadbrand antennas



Strictly speaking the measured NSA cannot be used as a 'correction factor' to massage the results from a test site that is outside the ±4dB margin. This is because it relates only to the artificial attenuation between two antennas at specific locations on the site. The attenuation between an EUT and the measurement antenna, even at the same locations, may be quite different because of electromagnetic coupling between the two (and the radiation characteristics of the EUT) are not the same as those of the antenna that replaced the EUT during the NSA tests. The NSA is used for compliance purposes as an indication of the *quality* of your site, not as a site calibration.

Using a semi-anechoic test chamber instead of an OATS

The CISPR standards have historically described an OATS as an open site in which there are no obstructions within a defined distance of the measurement range, so that any extraneous reflections that are introduced are adequately controlled. Usually this has been interpreted as meaning a site that is actually out in the open, although a large building such as an aircraft hangar or bus garage could also be suitable. Weather is of course a problem, but by far the greatest difficulty with an OATS, in Europe at any rate, is the presence of ambient radio signals. These can be broadcast transmissions, pagers, mobile phones, telecommunications of all sorts – the very signals that emissions limits are intended to protect – as well as broadband noise from industrial operations and computer networks.

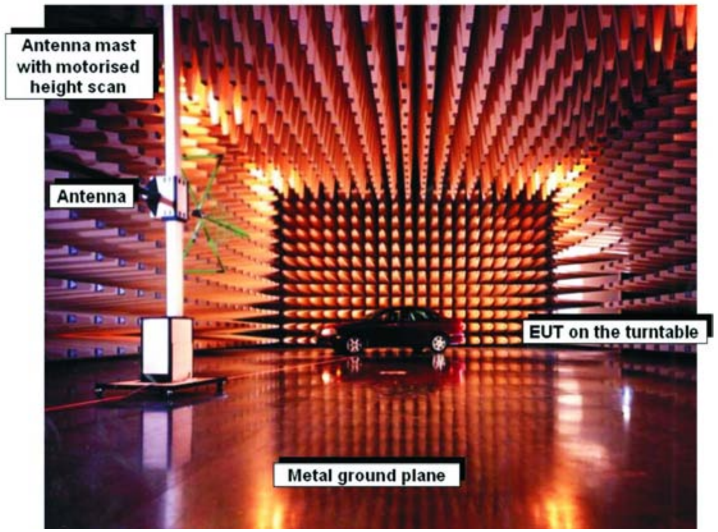
Reflections from the four walls and ceiling of a shielded test chamber will severely distort the NSA figures. A typical small unlined screened room, just big enough to encompass a 3m test range, will have such bad reflections that the actual NSA could vary by more than ±30dB at some frequencies. Making an accurate measurement of emissions levels in such a room is impossible: the best you can hope for is to identify the emissions *frequencies* at which there might be problems, then measure those individual frequencies on an OATS.

However, lining the four walls and ceiling of a shielded test chamber with RF absorber (ferrite tiles or pyramidal carbon loaded foam) will 'dampen' their reflections, improve the NSA within the chamber, and make it more suitable for measuring radiated emissions to EN 55022 or EN 55011. The advances in absorber material technology in the last ten years now make it feasible (but not low-cost) to build a 'compact' semi-anechoic screened chamber that meets the ±4dB NSA criterion.

Even so, because of imperfections in the absorber, the performance is worse than a true open site – and so CISPR require a 'volumetric' NSA characterisation, rather than an NSA test at a single position. Five NSA measurements are needed, at the centre, left, right, front and back of the area to be occupied by the EUT, and all must be within ±4dB of the theoretical for the chamber to be acceptable. This is a challenging but not impossible requirement.

A shielded test chamber with RF absorber on its ceiling and all four walls but with its floor left as plain metal is called a semi-anechoic chamber (SAC). For such a chamber to be able to be used for EN 55022 radiated emissions tests it must be tall enough for the 1-4m antenna height scan, making it quite a large room and hence quite costly due to the large areas of RF absorber needed to cover the walls.

Example of a large semi-anechoic room (courtesy of SEQAL, Yately Hants)



Testing procedures

The best equipment and facilities are useless if you don't do a compliance test correctly. Procedures can only partly be automated – much depends on the skill of the test engineer.

Remember that the overriding requirement is to ensure that you have found and measured the worst-case emission level from your EUT. This means that you have to deal with a number of variables:

- EUT related: physical radiation pattern, operating configuration, build state, layout, connected cables, periodic and cyclic effects.
- Measurement related: frequency range, antenna polarisation, antenna height, detector time constant.

The vast majority of electronic products are not intentionally designed as radiating antennas; they just act that way by accident. Therefore you cannot easily predict the direction of maximum radiation, and must check all around the unit at each frequency. The layout of the EUT's components and any external conducting structures, especially cables, will modify the pattern and some layouts will maximise it, but you cannot normally predict this in advance – although it is a fair bet that matching the polarisation of cables to the polarisation of the antenna will be significant.

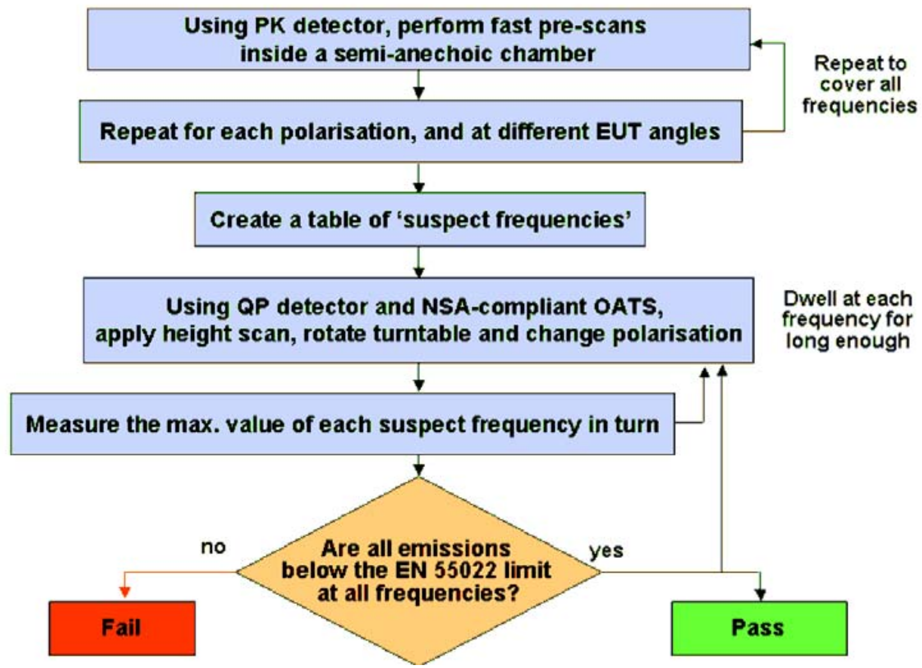
Maximum emissions are also likely to change in time if there are periodic functions within the EUT, and they may change depending on its exact build state and its functional state. So it will be necessary to dwell at each tested frequency step for long enough to be sure of detecting the worst-case emission. The frequency step size, dwell time at each frequency, measurement bandwidth, detector response time and EUT emission cycle time are all interrelated and the eventual interaction of these determines how long any given test will take.

A good argument for pre-compliance testing is to use it to determine all the worst-case build and functional parameters of the EUT, thereby saving the time spent exploring these parameters during full-compliance testing.

With all these factors in mind, a typical full compliance measurement procedure that has largely become standard practice reduces the total measurement time by doing an initial series of scans inside a semi-anechoic chamber to eliminate the problem of ambient pollution, using the peak detector, which always reads as high or higher than the QP detector.

Any emissions that exceed a level 10dB lower than the emissions limit in the standard, are listed in a 'table of suspects'. Each of these suspect frequencies is then measured on a NSA-compliant OATS, using the QP detector. The maximum value of each emission is found by scanning the height of the antenna, rotating the EUT, and swapping the antenna polarisation between horizontal and vertical. This maximum value is then compared to the limit in the standard.

A typical compliance mesurement procedure to help deal with ambients on OATS



The crucial issue is that suspect emissions must not be missed during the scans in the semi-anechoic room, for instance because the scan was done too fast or over an inadequate range of orientations. This aspect, as much as any other, calls for skill and competence on the part of the test engineer.

Of course, if the semi-anechoic chamber is large enough to perform the full EN 55022 test, and if it meets the appropriate NSA requirements, there is no need to move the EUT to an OATS – all of the testing can be done in the semi-anechoic chamber.

On-site testing of systems and installations

Systems and installations by their very nature tend to be large and only become functioning entities when constructed on their operational site, so testing a system or an installation at a test laboratory is often completely impractical. EN 55022 does not cover testing anywhere other than a calibrated OATS, but EN 55011 does include a test method for use on site, so most people wishing to do on-site testing for radiated emissions employ the EN 55011 method and include the results in the draft TCF they pass to their EMC Competent Body for assessment.

A fair amount of information (including the applicable international standards) is available to describe how to do EMC tests at a dedicated test site, but much less has been written to cover the special requirements of on-site tests. Some EMC test labs specialise in on-site testing, and their services may be hired by the day or by the test to be done, although (at least for EU compliance) there is no reason why companies should not do on-site EMC testing themselves.

Being aware of the problems associated with non-ideal test sites and testing accordingly can help give confidence in the overall test results. For more on on-site testing, read Chapter 10 of [12].

There is some debate as to whether on-site testing can be used to represent the compliance status of similar systems or installations on other sites. EN 55011 (CISPR 11) states explicitly that…

> “Measurement results obtained for an equipment measured in its place of use and not on a test site shall relate to that installation only, and shall not be considered representative of any other installation and so shall not be used for the purpose of statistical assessment.”

In contrast, CISPR16-2 suggests that where a given system has been tested at three or more representative locations, the results may be considered representative of all sites with similar systems for the purposes of determining compliance. The US FCC Rules have a similar condition. But in any case, for compliance with the EMC Directive via the technical construction file (TCF) route, a manufacturer may write his TCF around whatever degree of on-site testing he wishes, if his chosen Competent Body agrees.

An example of on-site testing for radiated emissions using a Bilog (antenna courtesy of York EMC Ltd)

Dealing with ambients

A problem for any EMC measurement that uses antennas on an 'open' test site such as an OATS is that some emissions from the EUT may be swamped by strong broadcast and other legitimate radio transmissions present in the electromagnetic ambient. All radio and EMC receivers and all but the lowest-cost spectrum analysers, provide a demodulated output (in the case of a domestic radio receiver it is the loudspeaker or headphones) and it is useful to listen to this to decide whether the signal is coming from the EUT or not. Voices or music indicate a broadcast station or private mobile radio, and you soon get used to the characteristic noises from teleprinters and other data communications, TV vision channels, and your office's lighting and Ethernet.

Simply removing all mains power from an EUT can help identify whether it is the cause of a measured RF signal or not. Sometimes it may be necessary to switch the EUT power off and on several times to help discriminate between its emissions and ambient signals.

Some analysers and receivers, or their test software, have an 'A-B' function – sometimes called ambient cancellation – that can help to some degree. The idea is to make a measurement with the EUT switched off, store it as B, then repeat the same measurement with the EUT switched on, and store it as A. 'A-B' means that at each frequency measured, the ambients are subtracted from the EUT+ambients, leaving just the EUT's emissions. Although it sounds good, this method has significant limitations: it does not deal with ambient variations or 'pop-ups', and it is inaccurate when the EUT's emissions occur at the same frequency as the ambient. 'Pop-ups' are ambient signals that come and go almost at random – often in the VHF bands – and are usually caused by portable or mobile radio transmitters.

A recently developed system called CASSPER claims to remove ambients from OATS measurements by using two antennas and receivers and some powerful correlation algorithms running on a computer. It is not known whether this system is accepted by UKAS for full compliance tests.

Some alternative ways of making measurements in the presence of ambients have been described in a CISPR draft, but these are limited in scope and will only occasionally be successful.

Underground car parks or cellars can have quieter RF environments for testing with antennas, as can places out in the country (the further away from civilisation, and the deeper the valley location, the better). Celestica went one better by building an OATS in an old salt mine hundreds of metres underground in Cheshire.

Loading, filtering and isolation

When being tested for radiated 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 [12].

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.

REO isolating transformer with low primary to secondary capacitances

Important Safety Note: Always take all safety precautions when working with hazardous voltages, such as 230V or 400V (3-phase) electricity. If you are not 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.

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 radiated 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 radiated emissions test to EN 55022 or EN 55011 would be ±4dB, mostly due to the NSA of the OATS or semi-anechoic chamber.

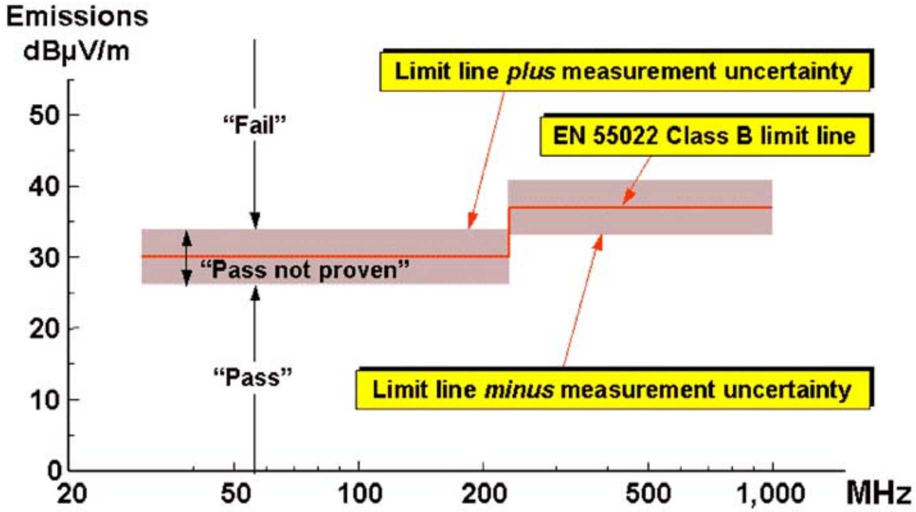
Even so, if the same equipment, set up in exactly the same way, is tested at a number of EMC test laboratories that are each accredited by UKAS for radiated emissions tests, the results can vary from one lab to another by ±6dB, sometimes as much as ±10dB. While this may at first seem to be a surprisingly high level of variation, in fact it represents something of a triumph – twenty years ago such a test lab comparison would have given wildly different results, ±20dB (or worse).

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 measurement uncertainty



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 radiated RF emissions would be passed. But such non-compliant tests may be valuable for improving the reliability of a product, or enabling its use in close proximity to other equipment.

Many equipment rental companies have stocks of the calibrated test gear needed to do radiated 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 radiated 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, especially above 100MHz, is difficult enough to do accurately even on a purpose-built OATS. 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 radiated 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 [9] 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

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

[1] CISPR 22:1993, "*Limits and methods of measurement of radio disturbance characteristics of information technology equipment*" (Note: Amendment A1:1995 and Amendment A2:1996 both apply.)

[2] EN 55022:1994, "*Limits and methods of measurement of radio disturbance characteristics of information technology equipment*" (Note: Amendment A1:1995 and Amendment A2:1997 both apply.)

[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://www.europa.eu.int/comm/enterprise/electr_equipment/emc/index.htm.

[4] CISPR 11:1997, "*Industrial, scientific and medical (ISM) radiofrequency 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.)

[5] EN 55011:1998, "*Industrial, scientific and medical (ISM) radiofrequency 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.)

[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.

[8] Many examples of interference can be found in the "*Banana Skins compendium*", via a link from www.compliance-club.com or at: http://www.compliance-club.com/archive1/Bananaskins.htm.

[9] "*EMC Testing Part 1 – Radiated Emissions*", Tim Williams and Keith Armstrong, EMC & Compliance Journal Feb 2001, http://www.compliance-club.com/KeithArmstrongPortfolio.

[10] "*What to look for in an EMC antenna*" Tim Williams, Compliance Engineering European Edition 1999 Annual Reference Guide, Pages 77-79, http://www.ce-mag.com, http://www.elmac.co.uk.

[11] "*Calibration and use of EMC antennas*" M J Alexander, Measurement good practice guide No. 4 from the National Physical Laboratory, phone: +44 (0)20 8977 3222, fax: +44 (0)20 8943 6458, http://www.npl.co.uk.

[12] "*EMC for Systems and Installations*" Tim Williams and Keith Armstrong, Newnes, January 2000, ISBN: 0-7506-4167-3

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 www.iec.ch, and many of them can be delivered by email within the hour.

The Author

Keith Armstrong from Cherry Clough Consultants

This guide is one of a series. You can request all published and future guides by sending an email to **main@reo.co.uk** or from our website at **www.reo.co.uk**

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

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