RF Emission Testing

a handy guide

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The Handy Guide to RF emissions tests

Introduction

Radio frequency EMC emissions tests are a common feature for EMC compliance of most electronic and electrical products. The purpose of these tests is not so much to check the operation of the product, as to ensure the protection of innocent users of the radio spectrum when the product is used in their neighbourhood. All commercial products (including many aspects of automotive applications) will be tested against the standards listed on page 49, most of which are based on CISPR tests. This handy guide describes the most important aspects of the basic methods used to make measurements against these standards.

CISPR 16-1 instrumentation

IEC CISPR publication 16-1: October 1999, "Specification for radio disturbance and immunity measuring apparatus and methods", specifies the characteristics and performance of equipment for measuring EMI in the frequency range 9kHz to 18GHz. It includes specifications for:

- the quasi-peak, peak, average and rms measuring receivers;
- artificial mains networks;
- current and voltage probes;
- absorbing clamps;
- antennas and test sites.

All commercial standards refer to CISPR 16 measurements.
Table 1 gives the principal measuring receiver parameters versus frequency range.

Bandwidths

The amplitude of broadband interference depends on the bandwidth in which it is measured. The amplitude of narrowband interference on the other hand, is by definition independent of the measuring bandwidth. The CISPR bandwidths are given in Table 1. These are the bandwidths at which the receiver response is -6dB relative to the centre frequency.

Parameter	Frequency range		
	9 to 150kHz	0.15 to 30MHz	30 to 1000MHz
Quasi-peak			
Charge time	45ms	1ms	1ms
Discharge time	500ms	160ms	550ms
Overload factor	24dB	30dB	43.5dB
Peak			
$\tau_{Discharge} / \tau_{Charge}$ min	$1.89 \cdot 10^4$	$1.25 \cdot 10^6$	$1.67 \cdot 10^7$
General			
Bandwidth (-6dB)	200Hz	9kHz	120kHz
Sine-wave accuracy	±2dB	±2dB	±2dB
Input impedance	50Ω VSWR ≤ 2:1 with 0dB atten, ≤ 1.2:1 with ≥10dB atten		

Table 1 - CISPR16-1 instrumentation characteristics

Detectors

The CISPR quasi-peak and average detectors weight the indicated value according to its pulse repetition frequency (PRF). Continuous interference is unaffected; the indicated level of pulsed interference is reduced by the degree shown in Figure 1, as a result of the time constants and bandwidths given in Table 1. A receiver is calibrated using pulses of defined impulse area, spectral density and repetition rate.

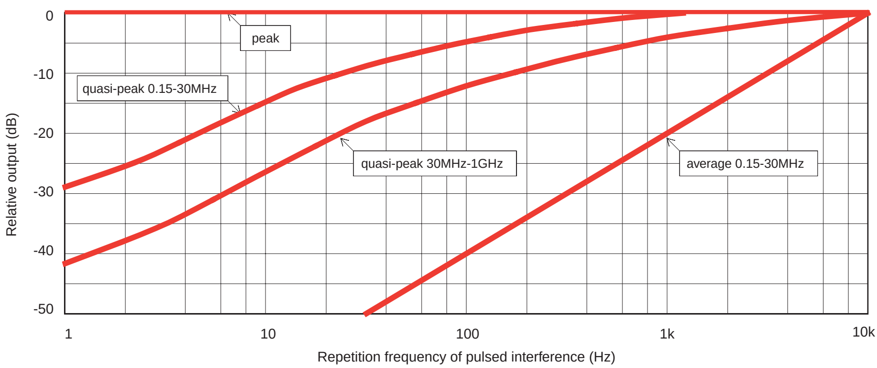


Figure1 - Relative output versus PRF for CISPR detectors

It is normal practice to perform initial emissions testing with the peak detector. Provided that the receiver dwells on each frequency for long enough to capture the maximum emission – this depends on the EUT's emission cycle time – the peak detector will always give the maximum output level. A list of frequencies at which high emissions are detected is created, and these frequencies are re-visited individually with the quasi-peak (and average, for conducted emissions) detectors, which will give the reading which should be compared against the limit. This procedure is shown in Figure 2.

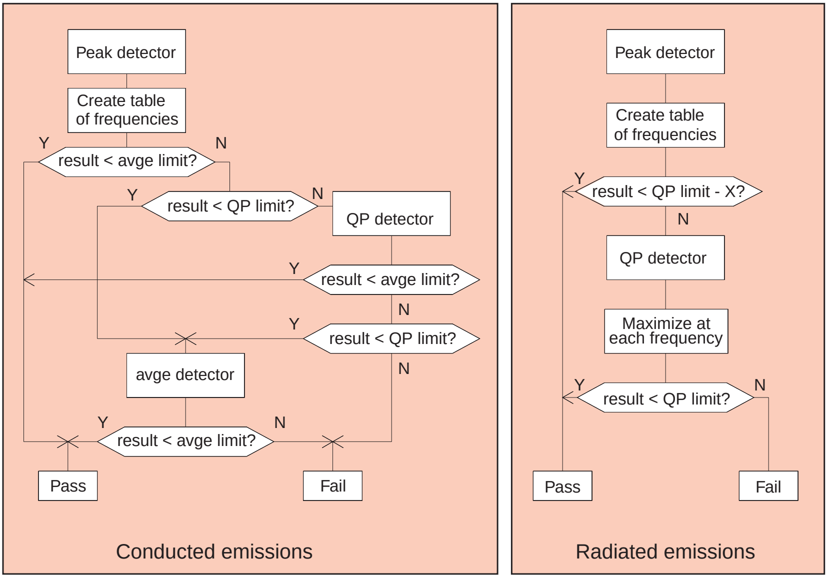


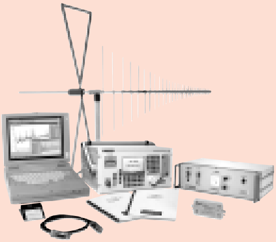
Figure 2 - Flow chart for use of detectors

Overload factor

Because the QP detector reduces the indicated amplitude, the circuits preceding the detector must remain linear at levels which exceed the full-scale indication. The degree to which this is necessary is quoted as the "overload factor" of the receiver and is given in Table 1 for the different frequency bands.

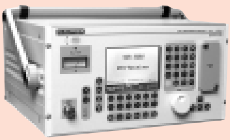
Emission test solutions

Emipak



Schaffner Emipaks are low cost, compliance and pre-compliance emission test systems. Since their introduction in 1994, Emipaks have been used by a wide range of electronics manufacturers to ensure that their products meet the requirements of the European directive on EMC. The flexible Emipak, based on a spectrum analyser with CISPR features, can be used during the design phase of a product to test prototypes, bought-in sub components and equipment packaging to ensure that the lowest cost EMC solutions can be applied. Later, the Emipak can be used to pre-test the finished product prior to a visit to an accredited test house. This will ensure that money is not wasted on the testing of non-compliant products. Emipaks can be used in diagnostic testing on faults found during testing and can also be used for production sample testing. With an Emipak Plus package, using a CISPR receiver as an upgrade or originally supplied, uncertainties can be reduced closer to test house standards. The diversity of uses at all stages of development and production makes the Schaffner Emipak an ideal system for ongoing assurance of compliance even where the primary strategy is to use external test houses for compliance testing.

Test Receivers



CISPR 16-1 defines the performance criteria to be met by measuring receivers. Only receivers that fully meet these criteria can be used in a test system to guarantee compliance with international standards. Schaffner offers two SCR receivers - 9kHz to 1GHz and 9kHz to 2.75GHz - which meet all of the criteria defined in CISPR16-1 in their entirety. When used in conjunction with the Schaffner BiLog® antenna, software and other equipment, the Schaffner series receivers can form the core of a totally compliant emission measuring system.

Application Software

The complexity of RF EMC tests along with the lengthy and repetitive nature of testing make it vital that some control and reporting software is used. Schaffner emission and immunity software is now virtually industry standard with hundreds of users world-wide. The software is designed to ensure that users, whatever their knowledge can use the system at their own level. Entry level users can simply choose from predefined tests but, as they gain more knowledge, the user can adapt the software to his own way of working. Backed by a dedicated team of software and RF engineers, the software is being developed continually to add more functionality and to track changes in the standards.

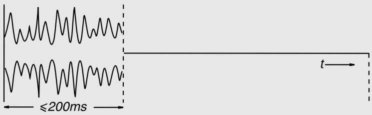
Discontinuous interference analysis — CISPR 14-1 (EN55014-1)

Domestic appliances, power tools and certain other products need to be measured for discontinuous interference in the frequency range of 150kHz to 30MHz. Because the interference generated by such products is aperiodic, the limits are relaxed compared to continuous limits.

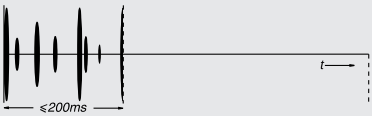
The CISPR 14-1 standard was designed to allow products' interference levels to be suppressed according to annoyance levels. Hence, emissions must be measured for their amplitude, duration and repetition rate, to determine whether the interference is discontinuous - a 'click' or continuous, as defined in the standard.

Once the discontinuous interference has been quantified, corrected limits can be applied. Such a process is complex, difficult and prone to errors if measurements are made manually. For accurate and repeatable results, automated analysis is necessary.

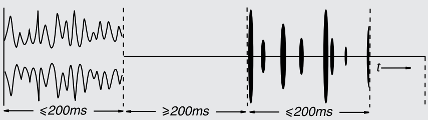
Definition of a 'Click'



One click
Disturbance not longer than 200 ms consisting of a continuous series of impulses and observed at the intermediate frequency output of the measuring receiver.



One click
Individual impulses shorter than 200 ms, spaced closer than 200 ms not continuing for more than 200 ms and observed at the intermediate frequency output of the measuring receiver.



Two clicks
Two disturbances neither exceeding 200 ms, spaced by a minimum of 200 ms and observed at the intermediate frequency output of the measuring receiver.

DIA 1512C

The DIA 1512C is a multi-channel Discontinuous Interference Analyser conforming to all of the requirements set down in CISPR Publication 16-1 for measurements to CISPR 14-1 (EN55014-1).

DIA 1512C

Conducted testing and AMN / LISN

The AMN/LISN

Conducted emissions tests use an artificial mains network (AMN, also known as a Line Impedance Stabilising Network, LISN) as a transducer between the mains port of the EUT (Equipment Under Test) and the measuring receiver. The AMN / LISN has three functions:

- it provides a stable, defined RF impedance equivalent to 50Ω in parallel with 50µH (or 50Ω/5µH for high-current units) between the point of measurement and the ground reference plane;
- it couples the RF interference from each of the supply phase lines to the receiver, while blocking the LF mains voltage;
- it attenuates external interference already present on the incoming mains supply.

The internal circuit of the standard 50Ω/50µH AMN / LISN is shown in Figure 3.

WARNING: high current flows through the earth terminal when 230V AC is applied. This terminal must be securely bonded to the safety earth.

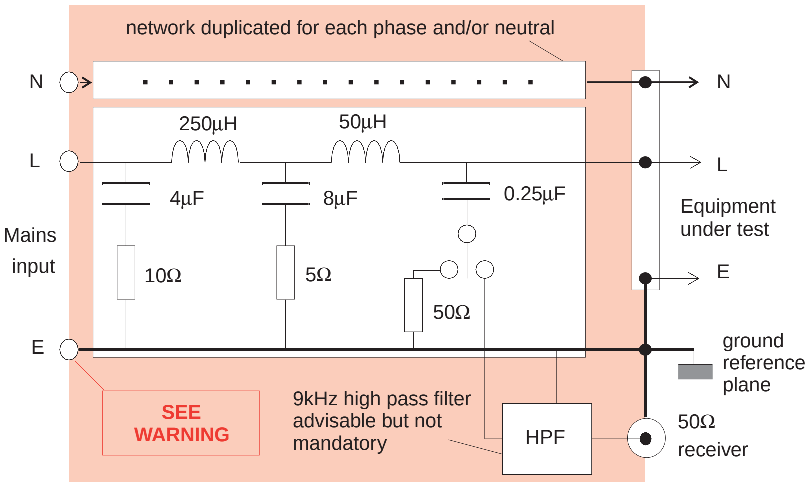


Figure 3 - Circuit of CISPR AMN / LISN

Coupling of the AMN/LISN output to the measuring receiver is typically through a high pass filter and limiter. Commercial AMN/LISNs may offer either or both of these functions. The HPF will have a cutoff frequency just below 9kHz and reduces the amplitude of low frequency mains-borne noise (50Hz and its harmonics) that is fed to the receiver, thereby avoiding potential overload problems. The limiter is a non-linear circuit which prevents high amplitude pulse transients reaching the receiver. The live and neutral lines can be a severe source of these transients, particularly those produced on turn-off of the EUT, and a limiter is highly advisable to prevent damage to the receiver input.

The AMN/LISN is required to provide a defined impedance curve ±20% between each of the phase lines and its reference earth terminal.
The shape of this curve is given in Figure 4.

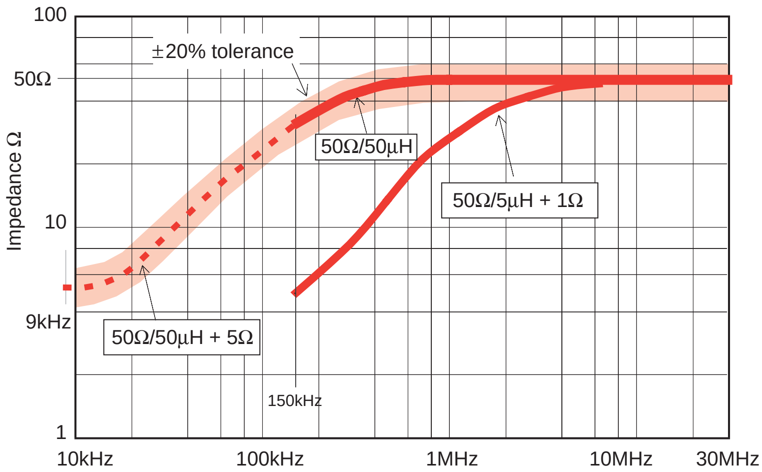


Figure 4 - Impedance curve of CISPR AMN / LISN

Ground reference plane

The ground reference plane (GRP) is an essential part of the conducted emissions test. *A proper measurement is impossible without a GRP.* Even a Class II EUT without safety earth connection must be tested over a GRP, since it provides a return path for stray capacitance from the EUT.

The GRP should be:

- at least 2m x 2m, and at least 0.5m larger than the boundary of the EUT;
- made of copper, aluminium or steel, but the thickness is not too important;
- bonded to the local supply safety earth (this is for safety only, and is not necessary for the measurement);
- bonded by a very short, low-inductive strap to the reference terminal of the AMN/LISN. A length of wire is not adequate for repeatability at the higher frequencies. The AMN/LISN should preferably be bolted directly to the GRP.

LISNs

LISNs

All Schaffner LISNs meet the requirements of CISPR 16-1 and cover the frequency range 9kHz to 30MHz. Available as single or three phase models at a variety of maximum current ratings, this range of LISNs will satisfy most applications. Models can be supplied with suitable power sockets for all world regions and can be either manually switched between phases or automatically switched by the test receiver. All models are supplied with a built in 'transient limiter' to protect the sensitive input circuitry of some receivers and spectrum analysers from switching transients on the mains.

NNB 41 LISN

MN 2050D LISN

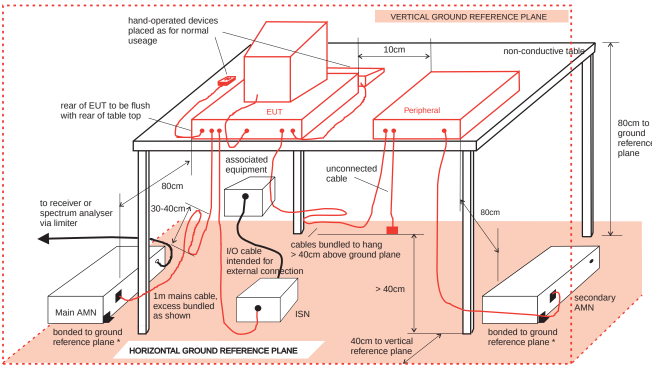
Test layout

For table-top apparatus, different standards allow the GRP to be either vertical or horizontal but all require the EUT's closest face to be maintained at a distance of 40cm from the GRP and at least 80cm from all other conductive surfaces. This is typically achieved with a wooden table either 40cm high off a conducting floor used as the GRP, or 80cm high and 40cm away from a conducting wall used as the GRP. Floor-standing EUTs should be placed on a conducting floor used as the GRP but not in electrical contact with it.

The distance between the boundary of the EUT and the closest surface of the AMN/LISN must be 80cm. The mains lead from the EUT to the AMN/LISN should preferably be 1m long and raised at least 10cm from the GRP for the whole of its length. Longer mains leads may be bundled non-inductively but this introduces considerable variations into the results and it is preferable to shorten them to the standard length. Alternatively, provide a standard wooden jig such that the bundling can be done repeatably.

Mains-powered peripherals that are necessary for the EUT's operations but which are not themselves under test should be powered from a separate AMN/LISN. Other connected leads should be terminated in their normal loads but should not extend closer than 40cm from the GRP.

An indicative test layout for conducted emissions is provided in Figure 5.



* LISNs may alternatively be bonded to vertical plane

Figure 5 - Conducted emissions test layout

The mains supply and test environment

The measurement should be well decoupled from any external disturbances. These can be coupled into the set-up either via the mains supply or by direct coupling to the leads. Although the AMN/LISN will reduce both the noise on the mains supply and variations in the supply impedance, it does not do this perfectly and a permanently installed RF filter at the mains supply to the test environment is advisable. Ambient radiated signals should also be attenuated and it is usual to perform the measurements inside a screened room, with the walls and floor of the room forming the ground reference plane. However, a fully screened room is not essential if ambient signals are at a low enough level to be tolerated.

The equivalent circuit

To understand the conducted emissions test, an equivalent circuit is useful. For a general EUT, such an equivalent circuit is shown in Figure 6. Emissions sources are separated into differential mode, which appear between live and neutral terminals, and common mode, which appear between both live and neutral together with respect to earth.

In these circumstances, "earth" may be either the safety earth connection, or stray capacitance to the GRP. Different filtering and construction techniques are required to suppress each of these two modes. The AMN/LISN measures a combination of the two modes since the measurement is made across each phase with respect to the GRP.

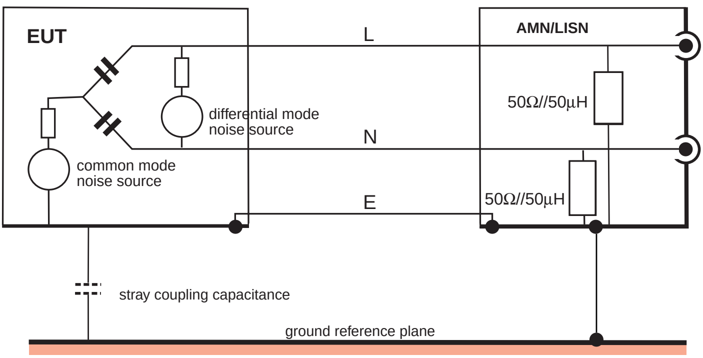
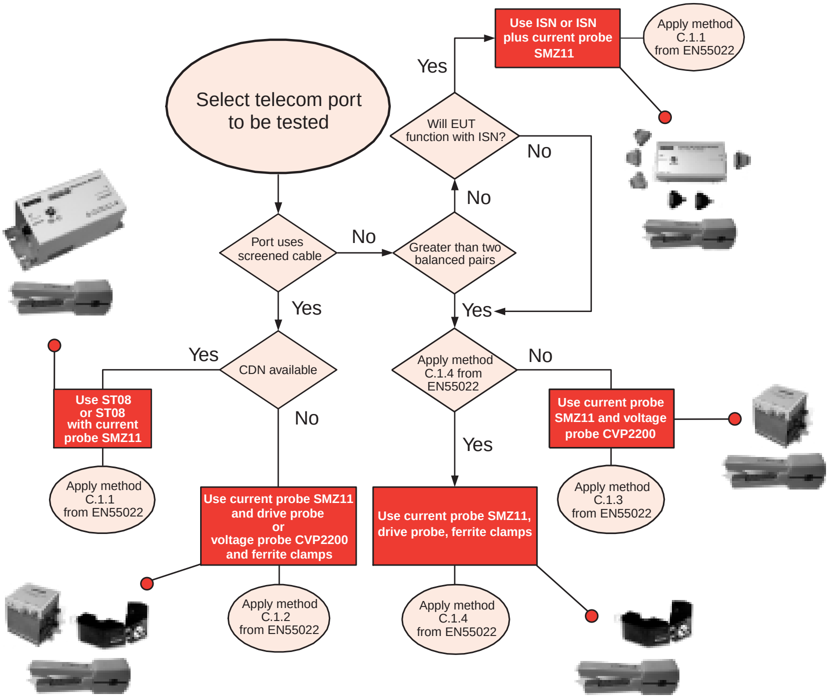


Figure 6 - General conducted emissions equivalent circuit

Telecommunications line, test components

CISPR 22 (EN 55022) requires that, in addition to the previous requirements, all telecommunications ports on IT equipment are tested for RF emissions in the frequency range 150kHz to 30MHz. Due to the variety of types of cables/connectors and the sensitivity of the EUTs to changes in the cable characteristics, a number of test methods are defined. Each test method requires a different combination of test components, connected in each case to a CISPR 16-1 compliant receiver, such as the SCR3501 or 3502.

The following flow chart (a modified version of the one produced by CISPR/G/WG1) indicates the products and methods to be used in each circumstance.

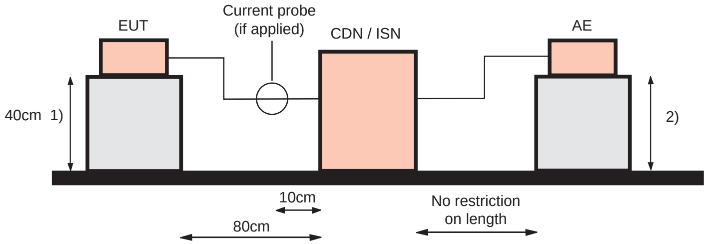


Flowchart to determine test method for telecommunications ports

Possible test setups and common mode measurements

C.1.1 Using CDNs described in IEC 61000-4-6 as CDN / ISNs

- Connect CDN / ISN (Impedance Stabilisation Network) directly to reference groundplane.
- If voltage measurement is used, measure voltage at the measurement port of the CDN / ISN, correct the reading by adding the voltage division factor of the CDN / ISN, and compare to the voltage limit.
- If current measurement is used, measure current with the current probe and compare to the current limit.
- It is not necessary to apply the voltage <u>and</u> the current limit if a CDN / ISN is used. A 50Ω load has to be connected to the measurement port of the CDN / ISN during the current measurement.



AE = Auxiliary equipment
EUT = Equipment under test

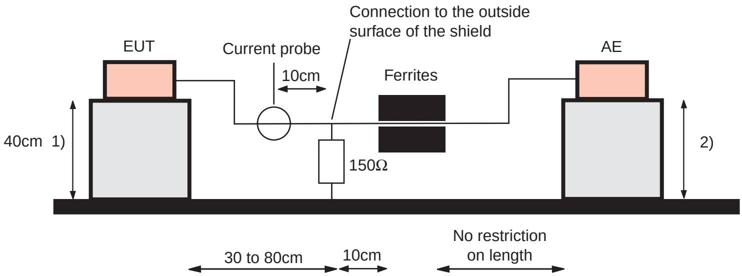
1) Distance to the reference groundplane (vertical or horizontal)
2) Distance to the reference groundplane is not critical

C.1.2 Using a 150Ω load to the outside surface of the shield ("In situ CDN/ISN")

- Break the insulation and connect a 150Ω resistor from the outside surface of the shield to ground.
- Apply a ferrite tube or clamp between 150Ω connection and AE.
- Measure current with a current probe and compare to the current limit. The common mode impedance towards the right of the 150Ω resistor shall be sufficiently large as not to affect the measurement.

Use clause C.2 to measure this impedance which should be much greater than 150Ω so as not to affect the measurement of frequencies emitted by the EUT.

- Voltage measurement is also possible either in parallel with the 150Ω resistor with a high impedance probe, or by using a "50Ω to 150Ω adaptor" described in IEC 61000-4-6 as 150Ω load, and applying the appropriate correction factor (9.6dB in case of the "50Ω to 150Ω adaptor").

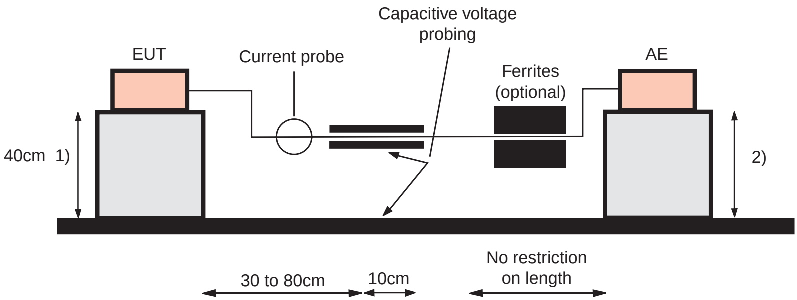


AE = Auxiliary equipment
EUT = Equipment under test

1) Distance to the reference groundplane (vertical or horizontal)
2) Distance to the reference groundplane is not critical

C.1.3 Using a combination of current probe and capacitive voltage probe

- Measure current with a current probe
- Measure voltage with a capacitive probe (size of the capacitive clamp >50cm in length, impedance of the voltage probe >1MΩ in parallel with a capacitance <5pF).
- Compare the measured voltage with the voltage limit
- Compare the measured current with the current limit
- The EUT shall meet **both** the voltage and the current limits.

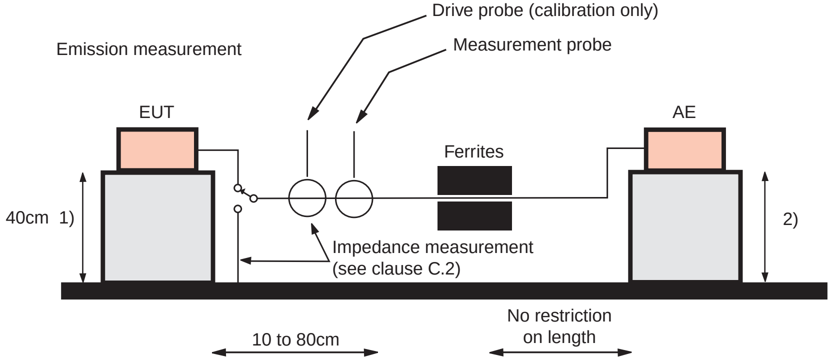


C.1.4 Using no shield connection to ground and no ISN

- Apply ferrite material
- By preliminary measurement, determine the frequencies emitted by the EUT.
- Record common mode impedance of cable, ferrite and AE by using the procedure shown in clause C.2 at frequencies emitted by the EUT. The position of the ferrite shall be adjusted until the common mode impedance is 150Ω ± 20Ω, this position shall be recorded. The ferrite shall be placed in this position during the measurement of the common mode current.

NOTE - Different types of ferrite may be required for different frequencies to achieve 150Ω ± 20Ω.

- Measure current with the current probe. The second probe in the figure is the ‘drive’ probe used in the calibration procedure used in clause C.2. This probe shall not be used during compliance measurement but is used to verify the common mode impedance.
- Compare the measured current to the current limit.



AE = Auxiliary equipment
EUT = Equipment under test

1) Distance to the reference groundplane (vertical or horizontal)
2) Distance to the reference groundplane is not critical

C.2 Measurement of cable, ferrite and AE common mode impedance

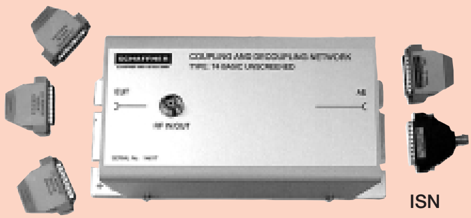
- Calibrate the "drive" and measurement probe 50Ω system. Insert a drive voltage (V1) from a signal generator into the "drive' probe and record the resulting current (I1) in the measurement probe.
- Remove the cable from the EUT and short it to the ground at the EUT end.
- Apply the same drive voltage (V1) to the cable with the same 'drive' probe.
- Measure the current with the same measurement probe and calculate the common mode impedance of the cable, ferrite and AE combination by comparing the current (I2) read by the measurement probe with that in the first step (common mode impedance = 50 x L1 / L2).
  For example, if L2 is half L1 then the common mode impedance is 100Ω.

Note: These methods and diagrams are reproduced from EN55022. For a more complete description, please refer to an original copy of the standard which should also be used as the definitive document.

CISPR 22

The new test procedures defined in CISPR 22 for telecommunications lines require the use of special Impedance Stabilisation Networks (ISNs), Probes and Coupling clamps. Schaffner can offer a kit of ISNs covering all of the common connection formats and cable types. Additionally, specially designed cpacitive clamps and inductive probes are available from Schaffner.

CVP and accessories in carry case



ISN

The voltage probe

The AMN/LISN is intended to be inserted in series with the supply to the EUT and so it must pass the full supply current. This is sometimes inconvenient or impossible, especially if the available AMN/LISN has a lower rating than the required supply current, or because the mains supply cannot be interrupted. In these cases, you can use the voltage probe, which is connected across the mains supply (each phase) to a ground reference. Its RF impedance of 1.5kΩ is high enough not to affect the EUT's emissions level but it does not stabilise the mains impedance and so, strictly speaking, the results obtained with the probe are relevant only for a particular supply installation. The circuit of the voltage probe in use is shown in Figure 7. Choice of the ground reference point is important; if a ground reference plane is used then the probe should be connected to it, but for large, in-situ EUTs it may be possible to use suitably large conductive structures, such as a machine chassis, which are connected to safety earth.

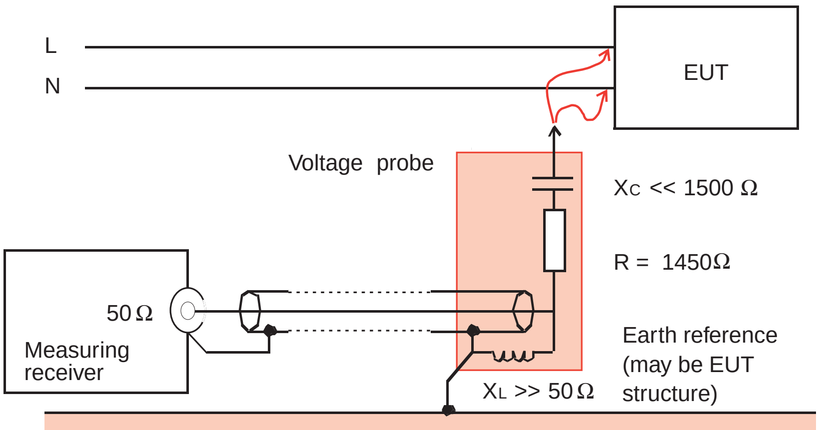


Figure 7 - Use of the voltage probe

Absorbing clamp testing

The absorbing clamp is used for disturbance power measurements on connected cables according to CISPR 13 and CISPR 14-1.

Construction of the clamp

The clamp as defined in CISPR 16-1 has three principal features which are shown in Figure 8:

- a loop of coaxial cable wound round two or three ferrite rings, which acts as a current transformer, inducing a signal into the loop from any RF current which flows through the cable under test to which the ferrite rings are coupled;
- an absorbing section made up of a further cascade of ferrite rings, located further down the cable under test away from the emitting source, whose purpose is to stabilise the RF common-mode impedance of the cable under test and reduce its dependence on the far-end termination;
- a further section of absorber over the sheath of the cable leaving the current transformer, which increases the common mode impedance of this cable and so reduces the impact of any variations in this impedance on the cable under test.

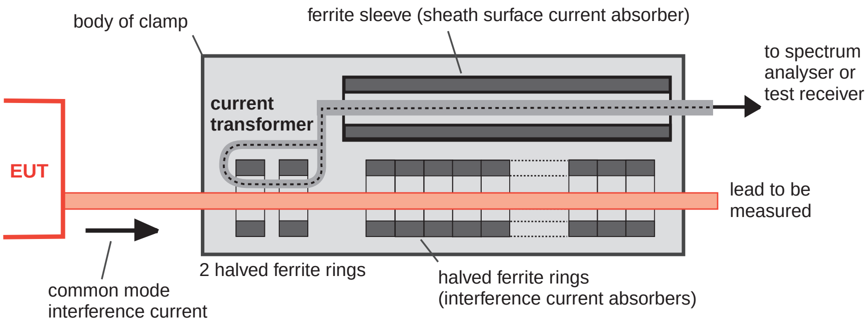
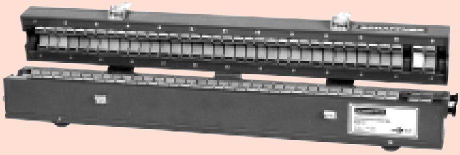


Figure 8 - Construction of the absorbing clamp

The ferrite rings are halved, and the clamp is so hinged that the cable under test can be laid through the whole assembly and the other halves brought down to enclose it completely. In use, the clamp is placed round the cable under test with the current probe facing the emitting source. The far end of the cable is connected to the mains supply or to ancillary equipment. The clamp output is connected to the measuring receiver or spectrum analyser.

Absorbing clamp **AMZ41**



Specifically designed for testing to CISPR 14, the Schaffner absorbing clamp is ruggedly built and is conveniently constructed to make this specialised test simple and quick to perform. When used in conjunction with an automatic track system and software, this test can be fully automated. Due to careful design, the correction factor virtually matches the conversion figure between dBμV and dBpW and so only a small correction factor needs to be applied during testing.

Clamp parameters

The CISPR requirement is that the clamp as a whole should present an impedance between 100 and 250Ω, not more than 20% reactive. Each clamp is provided with an insertion loss calibration curve. An example of this curve is shown in Figure 9. To create a correction factor which converts the terminal output voltage to the disturbance power present on the cable to be measured, 17dB(pW/μV) must be subtracted from this calibration:

Correction factor CF = insertion loss – 17
Power (dBpW) = indicated voltage across 50Ω (dBμV) + CF

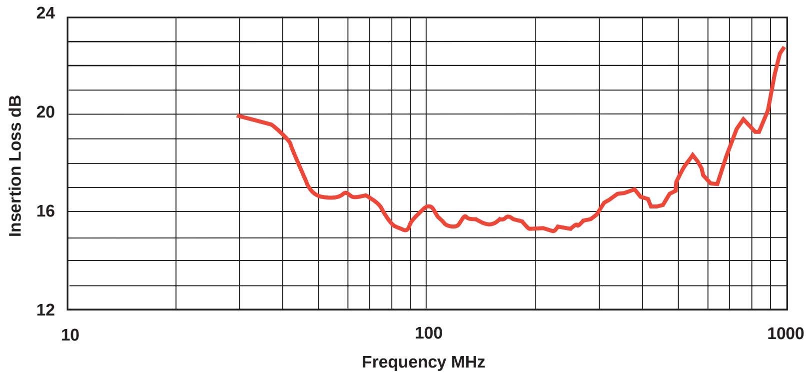


Figure 9 - Typical clamp calibration curve

Use of the clamp

To determine the maximum power that the disturbing source can deliver, the clamp is moved along the cable under test to find a peak at any given frequency. The output level varies periodically with distance, the distance between peaks being around half the wavelength of the measured frequency.

The horizontal cable is acting against the ground as a transmission line, on which current standing waves are induced, and the clamp is measuring these standing waves.
Because the maximum value may occur anywhere within half a wavelength along the cable, the clamp must be moved within this distance to find the maximum. At 30MHz, this distance is 5m, hence this is the standard length of the "racetrack" along which the clamp is run.

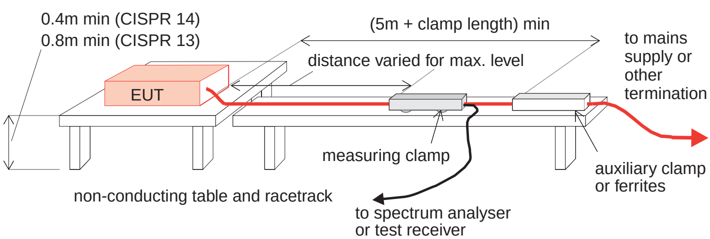


Figure 10 - Test setup for absorbing clamp

Precautions in use

For best and most repeatable use of the clamp, the following precautions in the test method and set-up are recommended:

- ensure the cable under test runs through the centre of the ferrite rings and does not droop towards the transformer at the EUT end; assuming your clamp has a centralising guide, use it.
- use an auxiliary clamp at the far end of the cable, at least 5.6m from the EUT, to minimise the influence of the termination at this end; if another clamp is not available, use at least six and preferably ten 25mm suppression-grade clip-on ferrite sleeves in series.
- for best accuracy with measurements close to the limit, connect the output cable via a 6dB attenuator pad immediately next to the clamp output – this pad can be omitted for initial scans. Remember to allow for the extra 6dB in the correction factor.
- as long as ambient signals permit it, perform the test outside a screened room and not over a ground plane, well away from other conducting objects. Keep personnel at least 1m away from the setup when measurements are being made – this implies remote movement of the clamp.
- take the output cable away from the set-up at right angles, and apply ferrite sleeves at intervals along it.

Radiated emissions testing

The open area test site

The classic radiated measurement according to CISPR 22 and CISPR 11 is performed on an open area test site (OATS). An OATS setup is shown in Figure 11 and a plan view is given in Figure 12. The minimum ground plane area as given in CISPR 22 should be regarded as indicative only; the true measure of an OATS is its calibrated normalised site attenuation (NSA, see p.29) and meeting this will normally require a larger ground plane area. Maintaining a large area free of obstructions (including wooden buildings) is also important.
The ellipse shown in Figure 12 is calculated on optical principles and ensures that a reflection from a perfectly reflecting surface located at the ellipse boundary will cause less than 6dB variation in the site attenuation. However, do not rely on the CISPR ellipse alone – only an actual NSA measurement will prove that the site is adequate.

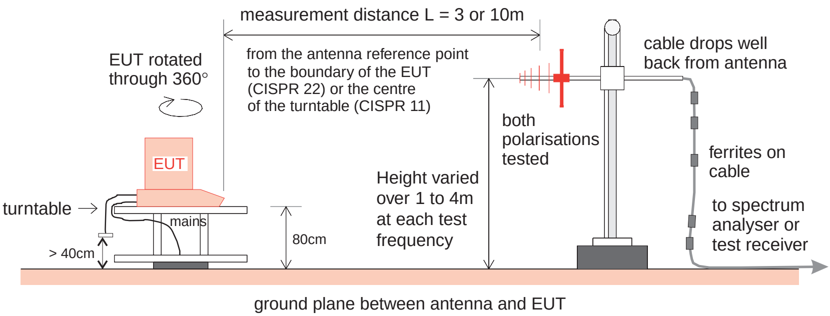


Figure 11 - Setup on the open area test site

The ground plane is necessary to regularise reflections from the ground surface and the antenna height scan deals with the nulls that inevitably result from the presence of the ground plane. The height scan is not intended to measure emissions from the EUT in the vertical direction. Only the horizontal plane of emissions, as given by the azimuth rotation of the EUT, is tested in CISPR standards.

The ground plane should be flat to within 0.15 of a wavelength at the highest frequency of use (4.5cm at 1GHz) for a 3m site, or 0.28λ (8.4cm) for 10m, and should use continuously bonded aluminium or galvanised steel sheet or fine mesh.

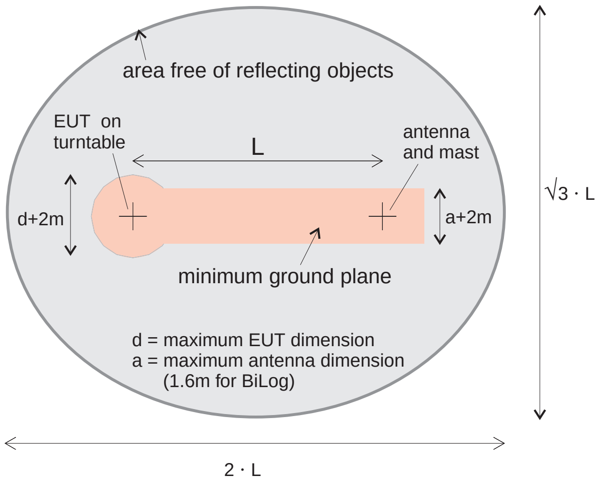


Figure 12 - Plan view of the minimum CISPR OATS

Antennas, cables and system sensitivity

The antenna is a transducer between the field quantity to be measured and the voltage input of the measuring receiver. In CISPR standards, the electric field vector is measured above 30MHz; where radiated tests are required below 30MHz, the magnetic field vector is measured. The usual broadband receiving antennas for EMC work are shown in Table 2:

Test	Frequency	Antenna
Magnetic field	9kHz–30MHz	Loop
		Large Loop Antenna (LLA)
Electric field	30MHz–300MHz	Biconical
	300MHz–2GHz	Log Periodic
	30MHz–2GHz	BiLog®
	600MHz–40GHz	Horn

Table 2 - Antennas for EMC Testing

The principal characteristic of any measuring antenna is its "antenna factor" (AF). This is a frequency-dependent parameter which converts the measured voltage at the antenna terminals to the strength of the field in which the antenna is located. A key assumption of the AF calibration is that the antenna is located in free space and – for measurements above 30MHz – in the far field of the source (see "electromagnetic fields" on page 39), so that the field is uniform across the antenna. This assumption is usually questionable in EMC tests, especially at 3m distance and heights close to the ground plane. Under these conditions, the antenna factor is modified from its free space value. However, since the basic design of antenna and the test geometry are standard, all test houses which use this design and follow the correct layout will suffer from similar effects.

The antenna factor is used to give the measured field strength E as follows:

E (dBV/m) =	**V (dBV) + AF (dB/m) + A (dB)**
where	**V is the indicated voltage on the measuring receiver**
	AF is the antenna factor
	A is the sum of all losses and gains in the path between antenna and receiver

The cable loss L is normally the dominant contributor to A but, if an antenna preamplifier or attenuator pad is used, the gain or loss of this item should also be added to A. Both A and AF are frequency dependent and their values are normally tabulated and used within the test software which interpolates between the frequencies of the tabulated values.
An example of the summation of these factors is given in Figure 13, which shows the receiver noise floor modified by typical antenna factors and losses to give an overall system noise floor. The receiver noise is taken as 6dBµV, which is the typical level below which noise will affect measurement accuracy by more than 1dB. Figure 14 shows the free space antenna factor curves of Schaffner-Chase EMC's range of measuring antennas.

Figure 13 - Using antenna factors and cable losses in a typical system

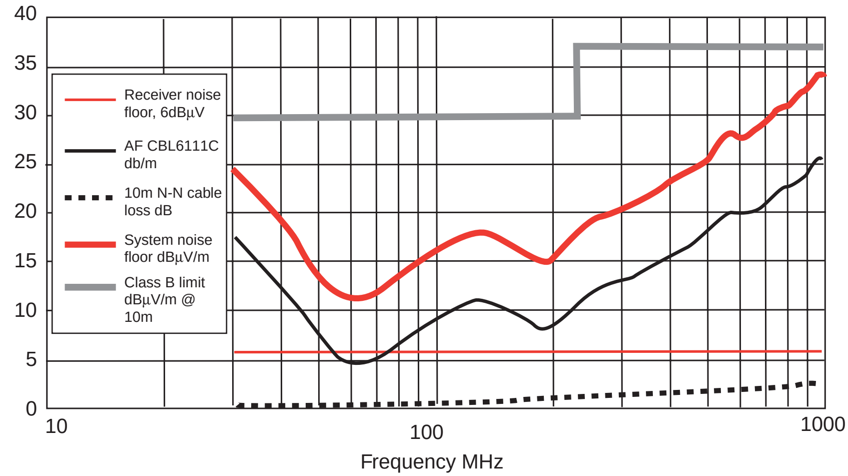
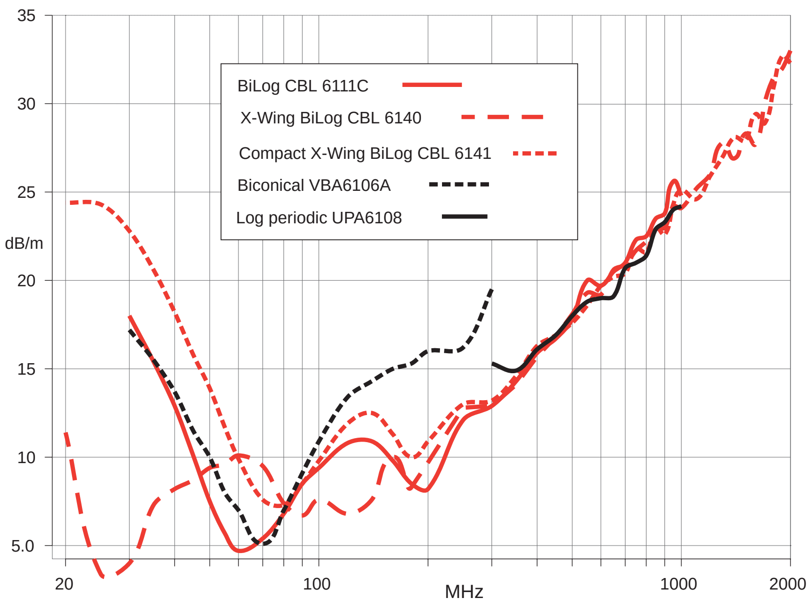
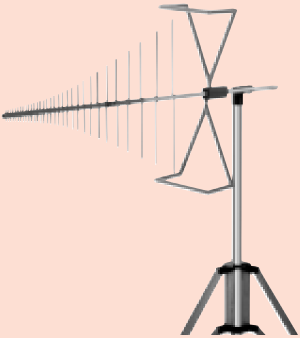


Figure 14 - Typical calibration factors of Schaffner-Chase antennas

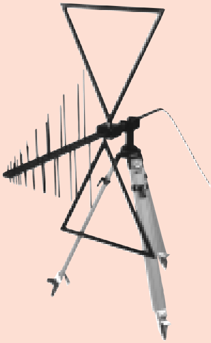


EMC test antennas

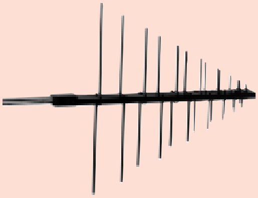
Schaffner-Chase has been manufacturing EMC test antennas for more than 15 years and has a full range of conventional test antennas, Biconical and Log Periodic. Schaffner was first to introduce the combined broadband antenna “BiLog®”, now firmly an industry standard with more than 5000 in regular use worldwide. The range has expanded to meet specific applications and frequencies. Convenient adapters have been developed to allow all Schaffner antennas to be fitted to most commercial mast and tripod systems.



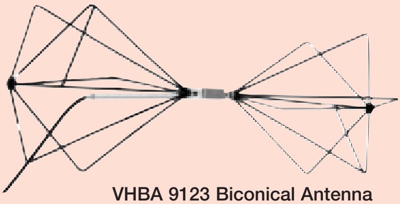
CBL 6143 ‘X-WIng’ BiLog® Antenna



CBL 6111C Classic BiLog® Antenna



UPA 6108 Log Periodic Antenna



VHBA 9123 Biconical Antenna

The problem of ambients

Any open area test site is likely to suffer from ambient signals, that is, signals which are generated in the neighbourhood and received on the site, but not emitted from the EUT. These signals can easily exceed both the EUT's emissions and the limit values at many frequencies. An emissions plot which contains ambients is hard to interpret and, more importantly, ambients which mask EUT emissions make it impossible to measure the EUT at these frequencies. There is no foolproof method whereby ambient signals can be subtracted from an emissions measurement.

Ambients can be classified in four ways:

- continuous narrowband;
- transient narrowband;
- continuous broadband;
- transient broadband.

Continuous narrowband signals (such as broadcast transmissions) can be tabulated for a given site and their frequencies avoided. It won't be possible to measure underneath them but, by reducing the measurement bandwidth from the specified 120kHz, an EUT signal that is very near to such an ambient may be distinguished. If the EUT signal is itself narrowband – that is, its level does not change when the measurement bandwidth is changed – it can be assumed that the same level would be measured in 120kHz. If the EUT signal is broadband, make measurements either side of the ambient and extrapolate.

A transient narrowband ambient allows a measurement to be made but the test engineer needs to know when the ambient signal is present. The same is true with a transient broadband signal. This information cannot be derived from a plot – an ambient will look just like an EUT emission – and must be noted at the time of the test. This means that a manual check of any suspect signals is always necessary.

Continuous broadband interference such as pulsed noise from, say, an arc welder is more difficult to deal with but a narrowband EUT emission can be extracted by using the average detector with a narrow measuring bandwidth. This should reduce the broadband level without affecting the desired narrowband signal, as long as the EUT signal is not modulated or pulsed; if it is, some error will result.

Broadband EUT emissions in the presence of broadband ambient disturbances cannot be directly measured, although if their levels are similar it may be possible to estimate the EUT level through superposition using the peak detector. However, the preferable method is to ensure that the chosen site does not suffer from broadband ambients.

Using a screened room

One way to avoid ambients altogether is to use a screened room for the radiated measurements. An untreated room, though, is almost useless for this purpose. The metallic walls of the room form a highly effective resonating structure whose resonant frequencies are given by the equation

$$F\ (\text{MHz}) = 150 \cdot \sqrt{(k/l)^2 + (m/w)^2 + (n/h)^2}$$

where l, h and w are the chamber dimensions in metres
k, m and n are any integer value, but no more than one at a time can be zero

So, for instance, the lowest resonant frequency of a chamber 6.5m x 4.2m x 3.5m occurs with k, m and n equal to 1, 1 and 0, and is at 42.5MHz.
The effect of the resonances is to severely distort the coupling characteristics between the EUT position and the measuring antenna (Figure 15). Variations exceeding ±30dB have been observed across the whole frequency range. Thus, an unlined room can only be used to observe whether or not EUT emissions exist, and to log their frequencies; it cannot be used to measure the levels of those emissions

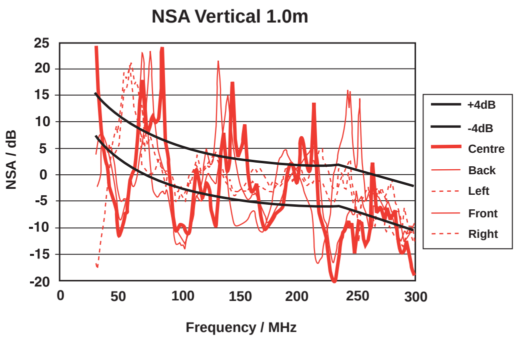


Figure 15 - Normalised site attenuation of an unlined screened room

Lining the walls and ceiling of the chamber with RF absorbing material (RAM) will damp the resonances. The quality of the absorber will determine how effective this is. Two sorts of absorber are available:

- carbon loaded pyramidal foam blocks, and
- ferrite tiles.

Ferrite tiles are thin but heavy; when fixed to the chamber walls they do not significantly affect the useable volume. They work by absorbing the magnetic field at the reflecting surface. They have a restricted bandwidth which can be optimised to achieve adequate performance from 30MHz to 1GHz, with least effect at the edges of this band. Foam pyramids are lighter but do intrude into the useable volume, especially if they have to be effective down to 30MHz. They attenuate the electric field incident on the reflecting surface. A solution which can give good performance over a wide bandwidth is a hybrid of the two types, with the ferrite providing the low frequency and the foam the high frequency absorption.
It is possible to build a fully lined "semi-anechoic" chamber ("semi-" because the floor remains untreated) which will meet the requirements for an alternative to the open area test site, discussed next under "Normalised Site Attenuation". This will allow all measurements to be made indoors without being affected by ambients or weather. However, it is expensive.

A compromise can be had with a partially lined chamber. Covering only some of the reflecting surfaces with absorber will damp the resonances sufficiently to make the chamber useable, but not enough to allow it to meet the NSA requirement. Measurements can be made inside such a chamber with an uncertainty perhaps of the order of 6–10dB. So, if this shows emissions at some frequencies within 10dB of the limit, these frequencies can be tagged and re-measured on a properly compliant open area site, with good confidence that other frequencies need not be checked. This method is now commonplace with many test houses. As shown in Figure 2 on page 3, the peak detector can be used for speed in the screened chamber, with the final spot frequency measurement made with the quasi-peak detector on the open site.

Normalised site attenuation

The principal characteristic of a radiated emissions test site is its Normalised Site Attenuation (NSA). Site attenuation is the minimum insertion loss measured between the terminals of two polarisation matched antennas on a test site, when one antenna is swept over a specified height range. This gives an attenuation value in dB at each frequency for which the measurement is performed. Transmit and receive antenna factors are subtracted from this value to give the Normalised Site Attenuation, which should be a measure only of the performance of the site, without any relation to the antennas or instrumentation.

Figure 16 shows the theoretical NSA for 3m and 10m sites in both polarisations. These theoretical figures are given in CISPR 16-1, CISPR 22, EN 50147-2 and ANSI C63.4. The common requirement of all these standards is that the measured values on an acceptable test site must deviate from these figures by no more than ±4dB.

A single position NSA measurement is satisfactory for a genuine open area test site, but it is insufficient to account for all reflections from the structure of a chamber. These reflections cause substantial variations in loss between any two paths in the chamber, separated by the nominal test distance, so that a different NSA curve can be expected from different locations. Although the receiving antenna can be fixed in position during the test, the equipment under test (EUT) in general will occupy a significant volume in the chamber – obviously the larger the EUT that is likely to be tested, the greater will be this relevant volume. For a realistic measure of the chamber's performance, the NSA throughout this volume needs to be checked.

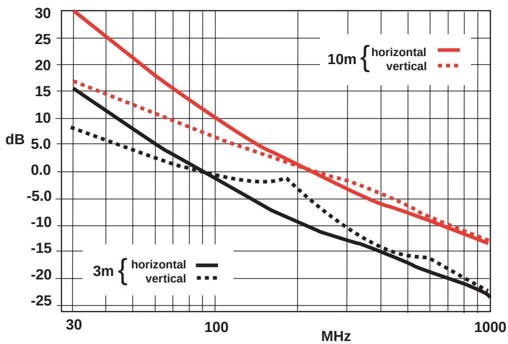


Figure 16 - Theoretical NSA for broadband antenna geometries

Therefore, the NSA chamber method defines a test volume that is traced out by the largest EUT to be tested, as it is rotated on a turntable. The NSA transmitting antenna is then positioned at five points within this volume, that is its front, rear, left side, right side and centre, as shown in Figure 17.

Five complete NSA scans are carried out and all must be within the required criterion for the chamber to be acceptable. Because the site attenuation values depend critically on distance, the receiving antenna is moved to maintain the same distance in each case. Although this may not represent the actual test set-up (where the receiving antenna position is fixed, with distance measured to centre of the EUT volume), it does allow the NSA to be characterised more accurately and does offer a good measure of the quality of the chamber

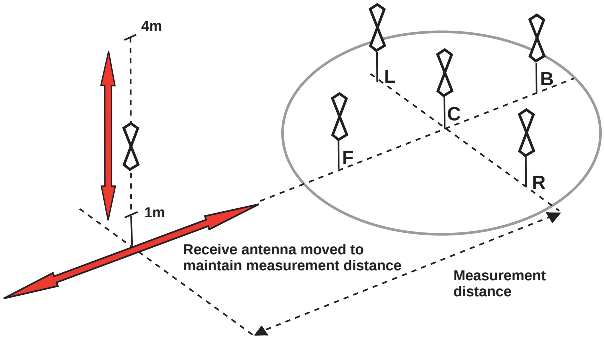


Figure 17 - NSA for chambers

Anechoic chambers

Schaffner offers a range of anechoic chambers (**Impact Series**) which can be user defined to meet varying technical and budgetary specifications. All constructed on site by our expert installation team and optionally calibrated 'on-site' by our UKAS accredited team, these chambers offer a high degree of performance accuracy and quality.

Broadband standard reference dipole

For the most accurate measurements required in test site validation and antenna calibration, it is necessary to have a tool directly related to theory. Such a tool has been developed by the UK National Physical Laboratory (NPL) which is exclusively manufactured by Schaffner and offers the lowest uncertainty available worldwide.

The BSRD6520 system (which includes two dipole antennas) can be used for assessing site quality and for calibrating antennas. The 'standard site' method explicitly requires a standard site; the 'standard antenna' method does not, but the use of a standard site is preferred because uniformity of field across the antenna is assured. The BSRD6500 system can be used for validating open area test sites, semi-anechoic rooms and fully anechoic rooms.

To speed up measurements, broadband software has been developed that reduces to four the number of dipole elements required to cover the frequency range 30MHz - 1GHz.

Emission test setups and procedures

The two main standards which define radiated emissions tests are CISPR 11 and CISPR 22. Of these, CISPR 22 gives the more detailed guidance for setting up the EUT. The guiding principle for all EUTs, whether they are individual apparatus or systems, is;

- the EUT is configured for typical use;
- within the constraints of typical use, the EUT configuration is varied in such a way as to maximise emissions.

With radiated tests, the emissions may be coupled either from the EUT itself or its connected cables, or both. All cables are suspect, whether or not they are known to carry high-frequency signals. All EUT ports which may have cables connected in normal use, should have cables connected during the test; although if there are several identical ports, it is sufficient to load only one of each type. Cables should be of the type and length specified or supplied for normal use. If this specification does not exist, the test engineer must use discretion and experience, but the actual type, length and layout must be noted in the test report. Cables should be run away from grounded objects such as cabinets or the ground plane, in order to maximise their emissions.

Table-top equipment is placed on a wooden table such that it is 0.8m above the surface of the ground plane (see Figure 11 on page 21). Floor-standing equipment is placed on the floor. In both cases the equipment must be rotatable such that emissions can be measured all around it. If this is impossible, the measuring antenna has to be moved around the EUT's periphery at the specified measuring distance, and the ground plane has to extend in all directions to cover this distance.

Earthing or grounding of the EUT is according to normal installation practice. If the EUT is only earthed through the safety earth connection of the mains supply cable, this safety earth is grounded to the ground plane at the point of connection to the supply.

EUTs which can be configured with different options, such as plug-in cards, should be tested as far as possible with all options present. Similarly, all operating modes that might be expected to maximise emissions should be tested. It is usually worthwhile to spend some time before the main test investigating the various modes and configurations to be sure that the worst cases have been found.

A typical procedural sequence for a full radiated emissions test would be the following:

- set up the EUT in a screened chamber at the chosen measurement distance
- whilst repeating a fast scan with the peak detector across the whole frequency range, vary the operating modes, layout, cable configuration, antenna polarisation and azimuth roughly in order to sure that the maximum emissions have been captured

- note the frequencies of these maximum emissions and the operating mode(s) which cause them
- transfer the set-up to an open area test site (unless the chamber is fully compliant)
- repeat the worst case operating mode(s), and for each frequency perform a height scan and azimuth rotation for each polarisation, and confirm that the cable and EUT layout is actually the worst case

Emission testing in the GTEM cell

An alternative to open sites for emissions testing is the GTEM cell (Gigahertz Transverse ElectroMagnetic). This is a development of the classic Crawford TEM cell, but with a continuously tapering geometry terminated in a hybrid broadband absorber. This design stops longitudinal resonances and removes the inherent upper frequency limit of the TEM cell. The cell is totally enclosed with an inner septum plate, which creates a transmission line matched to a 50Ω termination. The transverse electromagnetic (TEM) mode of wave propagation within the cell approximates free space conditions.

Putting an EUT within the cell between the floor and the septum couples the field generated by the EUT with the transmission line, so that a receiver connected to the apex termination will measure the voltage developed by the E-field emissions in the vertical direction. Vice versa, an E-field can be created within the cell for immunity testing, by an external generator. To avoid distortion of the field, the EUT should be no larger than a third the height of the septum.

CISPR are considering standard methods for emissions testing in TEM cells, but for the time being these are unpublished and so GTEM tests must be correlated to equivalent OATS tests. This is done by making three sets of measurements with the EUT in three orthogonal orientations. Three such scans compare favourably with the OATS measurement where both horizontal and vertical polarisations must be checked, with a turntable rotation and a height scan in each case.

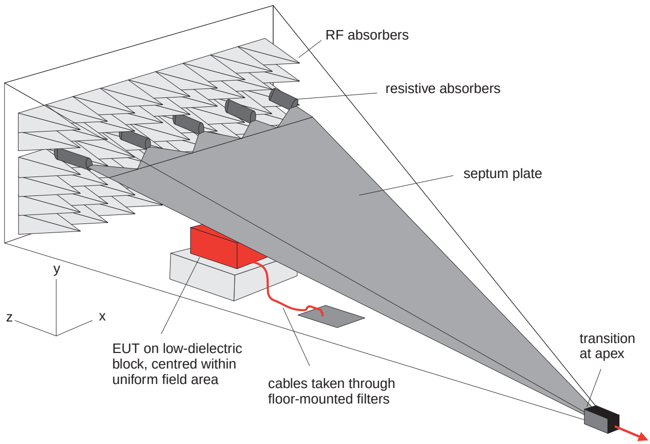
Summing the power derived from each orientation at each frequency and relating it to the geometry of an assumed isotropic EUT on an OATS should give the maximum field strength that could be measured on the OATS.

This approach assumes that;

- the EUT is electrically small (dimensions significantly less than a wavelength), so that
- the various sources within the EUT are basically in phase, and
- summation of sources does not give the EUT an effective gain (or directivity) greater than a dipole antenna.

These assumptions are a good description of many EUTs but will not hold for all. For small EUTs without cables, the GTEM is an excellent measuring tool, but EUTs with cables are not electrically small and, therefore, poorer correlation can be expected. The US FCC has accepted emissions data from GTEMS for compliance purposes, provided that GTEM-OATS comparisons supported by statistical analysis have been filed for each general type of EUT, and that cabling is arrayed and terminated identically to the previously submitted equivalence demonstration.

Despite these concerns, the GTEM has the major advantages of complete freedom from ambient signals, a predictable and largely flat response from DC to over 1GHz, and the ability to test with one transducer (no antenna) for both radiated emissions and immunity. It, therefore, remains popular with many users, and is also very well suited to manufacturers' pre-compliance and development test labs. Provided that the geometry is kept constant – best achieved with a wooden or RF-transparent jig for both EUT and cables – comparison tests for product development are straightforward and reliable.



General layout of the GTEM

GTEM test cell

A full range of eight GTEM cells are available from Schaffner, ranging in size from 250mm for very small EUT up to the very large 2 metre version capable of testing small racks of equipment. Also available is the GTEM Lite range, which offers a more economical choice for those who need to carry out standard testing without the requirement for testing at the very high frequencies offered by the classic range.

GTEM 'Classic'

GTEM 'Lite'

Near field probes

Close in to an apparatus, electric and magnetic fields are developed by its operation and these fields can give clues as to the nature of the sources within and coupling paths out of the apparatus. Currents flowing in conductors, including the shielding structure, develop magnetic fields; voltages between conductors, including the external ground reference, develop electric fields. These fields can be sensed by the appropriate type of near field probe.

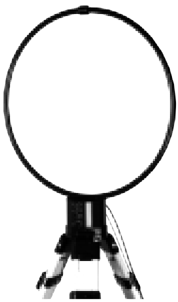
NFPS1 Near Field Probe Set

Near field probes cannot practically give a direct indication of the emissions in the far field, because the field structures in the two regions are, in general, quite different (see page 39). They are used instead to locate particular sources around the apparatus which could respond to various types of fix to reduce the overall emissions. Using a spectrum analyser and an H-field (magnetic) probe will show where substantial high frequency currents are flowing, such as on certain tracks on a PCB, or around apertures or seams in a shield. These could then benefit from a re-layout of the PCB or the application of conductive gaskets. An E-field probe, on the other hand, will show regions of high frequency voltages, such as on switching device heatsinks or microprocessors, which could be screened or earth-bonded. The E-field probe is non-directional but the H-field probe senses a maximum when its loop is aligned parallel to the current flow, thus giving extra diagnostic information.

Magnetic field emissions testing

At frequencies up to 30MHz, the magnetic component of the disturbance is measured. Two methods are available: the distant antenna method using the single-axis 0.6m loop at 3m distance, as required in CISPR 11 for induction cookers and Group 2 Class B equipment; and the three-axis "large loop antenna" (LLA), or Van Veen Loop, which surrounds the EUT, and is used in both CISPR 11 and CISPR 15 for high-frequency lamp ballasts and inverters.

Single-axis loop



HLA 6120 Loop Antenna

The classic magnetic field measurement uses a loop antenna of 60cm diameter at a fixed height of 1m from the ground to the bottom of the loop. The loop is rotated in azimuth to maximise the signal, while the EUT is also rotated. The measuring distance of 3m is taken from the centre of the loop to the centre of the turntable, with the EUT placed centrally on the turntable; or, if the EUT is not rotated but the loop is moved around it, the distance is taken to the nearest part of the EUT boundary.

A passive loop, although broadband, has an antenna factor that increases linearly with decreasing frequency in the lower frequency range. This means that, at the bottom end, it is very insensitive. Also, it has a low output impedance and is not well matched to the 50Ω receiver input impedance. These disadvantages can be overcome by adding a preamplifier to the loop output, in which case the antenna is known as an "active" loop and can be given a flat antenna factor and matched 50Ω output. It is possible that the preamplifier could be saturated by large received signals, either transient or continuous, in which case the measurement would be inaccurate and the test engineer might not know this. Therefore, an active loop must have a reliable means of indicating that it is being, or has been, overloaded during the measurement.

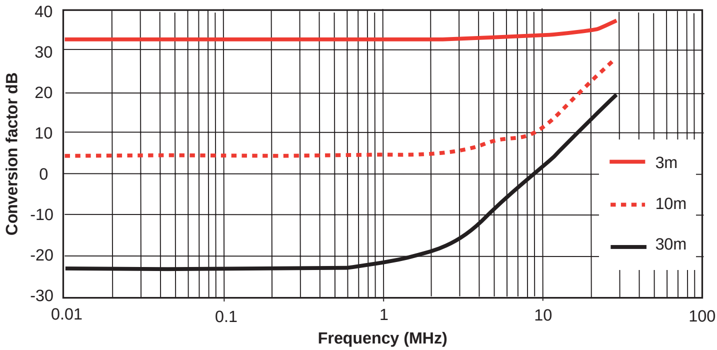
Magnetic field limits were historically and incorrectly quoted in dBμV/m, which is a measure of electric field. The assumption underlying this practice was that in the far field, the magnetic and electric components were interchangeable and related by the impedance of free space (see "electromagnetic fields", page 39). This anomaly has been corrected in the latest edition of CISPR 11, which quotes the magnetic field limits in dBμA/m.

Large loop antenna LLA

The large loop antenna is designed to surround the EUT. The standard LLA has a 2m diameter and is allowed for EUT lengths up to 1.6m – there should be at least 20cm between the EUT and the loops. Larger versions are possible and limits are provided for 2, 3 and 4m diameter LLAs. Three single-turn shielded and shorted loops of the stated diameter are mounted orthogonally to each other and the current induced in each loop by the magnetic emissions of the EUT is monitored via a current probe. Three sequential measurement sweeps are made, one for each orientation, and the limits apply to each measurement. The limits are quoted directly in terms of dBµA for each loop diameter.

The advantage of the LLA is that the test need not be performed in a screened room since it is insensitive to ambients. It should be kept at least 0.5m away from other nearby objects and walls. Figure 19 shows the general arrangement of the LLA setup, and Figure 18 shows the correlation between the current induced in a 2m LLA and the actual magnetic field at the given distances.

Figure 18 - Conversion between 2m LLA current and radiated field



Field strength (dBµV/m) = current (dBµA) + conversion factor (dBΩ/m) (from CISPR 15)

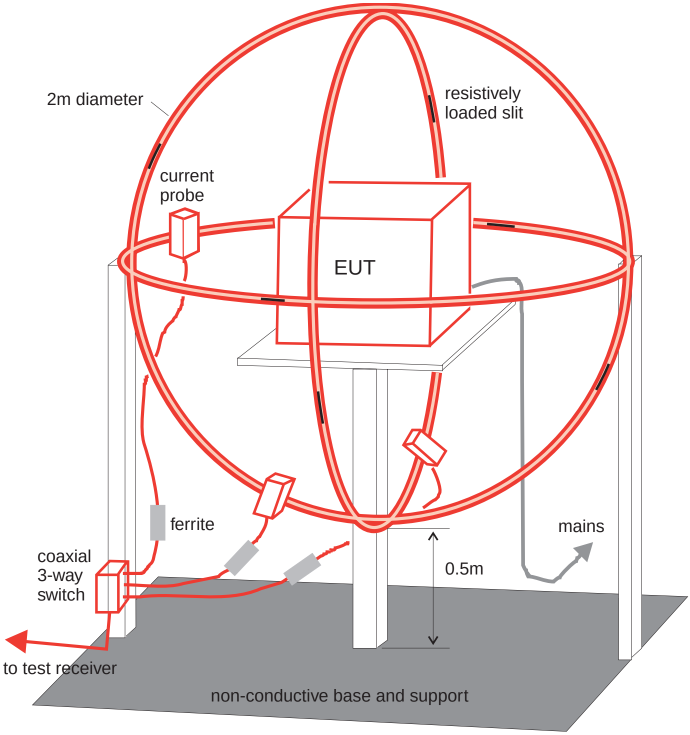
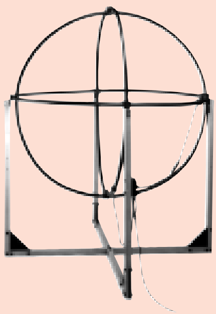


Figure 19 - Large loop antenna setup

Schaffner-Chase large loop antenna LLA 6142

Specifically designed to meet the requirements of CISPR 15 for lighting equipment testing, the Schaffner two-metre loop antenna is rugged and easy to assemble.
Each antenna is individually calibrated prior to delivery and meets the requirements of CISPR 15 so that results can be read directly from a conventional receiver such as the Schaffner SCR 3501.



Reference material

Electromagnetic fields

An electromagnetic wave propagates as a combination of electric and magnetic fields. The ratio of the electric to magnetic field strengths (E/H) is called the *wave impedance* and this depends on the nature of the source and the distance d from it. In the far field, $d > \lambda/2\pi$, the wave is known as a plane wave; the field vectors are at right angles to each other and to the direction of propagation, their amplitude decays proportionally to 1/d, and they are in phase. Its impedance is equal to the impedance of free space derived from Maxwell's wave equations, and given by

$$Z_o = \sqrt{(\mu_o/\varepsilon_o)} = 120\pi = 377\Omega$$

where μ_o is $4\pi \cdot 10^{-7}$ H/m
and ε_o is $8.84 \cdot 10^{-12}$ F/m

In the near field, $d < \lambda/2\pi$, the wave impedance is determined by the characteristics of the source. A low current, high voltage radiator (such as a dipole) will generate mainly an *electric field* of high impedance, while a high current, low voltage radiator (such as a loop) will generate mainly a *magnetic field* of low impedance. In general, the E and H fields are not in phase and they decay at a rate proportional to $1/d^2$ or $1/d^3$.

The region around $\lambda/2\pi$, or approximately one sixth of a wavelength, is the transition region between near and far fields. Figure 20 shows the transition distance as a function of frequency.

Figure 21 shows the wave impedance in the near and far field regions. In the near field, the possible values of wave impedance are bounded by the maximum and minimum values from a pure electric or magnetic dipole. In the far field, the wave impedance tends to Z_o.

If the disturbing capability of the EUT is to be measured properly, the power in its radiated fields should be known. Since the field transducer (above 30MHz) is an electric field antenna, the power is only known if the wave impedance is known.

This is why EMC radiated emissions measurements should be made in the far field, that is, >>1.6m away from the source for a minimum frequency of 30MHz. Tests with near field probes close to the source are operating in a region of unknown field characteristics and, therefore, do not give a reliable indication of the disturbing power capability.

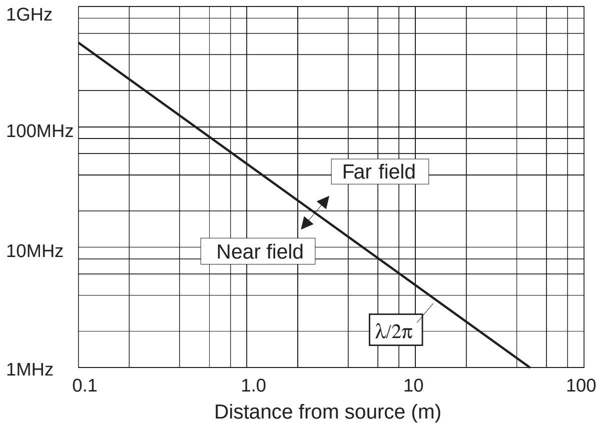


Figure 20 - The transition distance

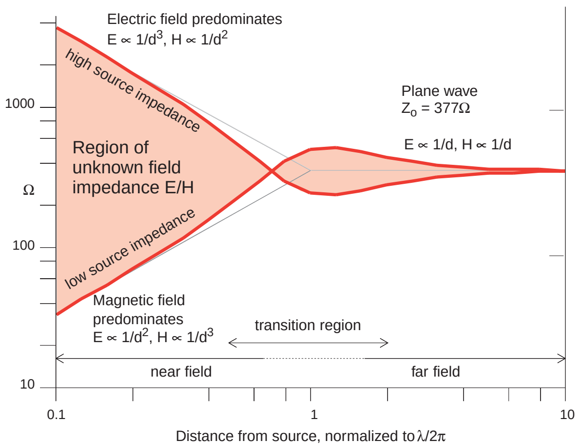


Figure 21 - The wave impedance

If radiated fields are to be measured below 30MHz, a compromise has to be made, since it rapidly becomes impractical to make a measurement in the far field. The compromise is that only magnetic fields are measured (with a loop antenna, see page 36) and the limits are given in terms of magnetic field strength. This does mean that an EUT which emits high electric fields at low frequencies is not adequately tested by a radiated measurement alone; however, the mains conducted measurement will normally show a high level in such cases.

There is another definition of the transition between near and far fields, determined by the Rayleigh range. This has to do not with the field structure according to Maxwell's equations, but with the nature of the radiation pattern from any physical antenna (or EUT) which is too large to be a point source. For the far field assumption to hold, the phase difference between the field components radiated from the extremities of the antenna must be small and, therefore, the path differences to these extremities must also be small in comparison to a wavelength. This produces a criterion that relates the wavelength and the maximum dimension of the antenna (or EUT) to the distance from it.

Using the Rayleigh criterion, the far field is defined as beyond a distance:

$$d > 2 \cdot D^2/\lambda$$

where D is the maximum dimension of the antenna

Table 3 shows a comparison of the distances for the two criteria for the near field/far field transition for various frequencies and EUT dimensions. Note how, for typical EUT dimensions, the Rayleigh range determines the far field condition above 100–200MHz.

Frequency	**Maximum dimension D (m)**	**Rayleigh $d = 2D^2/\lambda$ (m)**	**Maxwell $d = \lambda/2$ (m)**
10MHz	2	0.267	4.77
30MHz	2	0.8	1.59
100MHz	0.5	0.167	0.477
	2	2.67	0.477
300MHz	0.5	0.5	0.159
	2	8.0	0.159
1GHz	0.5	1.67	0.0477

Table3 - Comparison of Rayleigh and Maxwell transition distances

Field strength conversion

In the far field, with $Z_o = 377\Omega$

Electric field strength		Magnetic field strength			
dBµV/m	**µV/m**	**dBµA/m**	**µA/m**	**picogauss**	**picoTesla**
0	1.0	-51.5	0.00265	33.1	0.0033
5	1.78	-46.5	0.0047	58.8	0.0059
10	3.162	-41.5	0.0084	105.0	0.0105
15	5.623	-36.5	0.0149	186.2	0.0186
20	10.000	-31.5	0.0265	331.5	0.0331
				nanogauss	
25	17.8	-26.5	0.0472	0.590	0.0590
30	31.62	-21.5	0.0839	1.048	0.1048
35	56.23	-16.5	0.1492	1.865	0.1865
37	70.79	-14.5	0.1878	2.347	0.2347
40	100.00	-11.5	0.2652	3.315	0.3315
47	223.9	-4.5	0.5957	4.765	0.4765
	mV/m				
50	0.316	-1.5	0.839	10.48	1.048
60	1.000	8.5	2.652	33.15	3.315
70	3.162	18.5	8.388	104.8	10.485
80	10.00	28.5	26.525	331.5	33.156
90	316.2	38.5	83.88	1048.5	104.85
	V/m		**mA/m**	**µgauss**	**nanoTesla**
100	0.1	48.5	0.2652	3.315	0.3315
110	0.316	58.5	0.8388	10.48	1.048
120	1.0	68.5	2.652	33.15	3.315

1 Gauss = 100 microTesla = 80 Amps/metre

Class A and B radiated emission limits shown shaded

deciBels

In EMC testing, many quantities are referred to in deciBels (dBs). The dB represents a logarithmic ratio (base ten) between two quantities and is unitless. If the ratio is referred to a specific quantity this is indicated by a suffix, e.g. dBV is referred to 1V, dBm is referred to 1mW.

Originally the dB was conceived as a power ratio, given by

$$\mathbf{x\ dB = 10 \log (P_1/P_2)}$$

Power is proportional to voltage squared, hence the ratio of voltages or currents across a constant impedance is given by

$$\mathbf{x\ dB = 20 \log (V_1/V_2) \text{ or } 20 \log (I_1/I_2)}$$

Conversion between voltage in dBV and power in dBm for a given impedance Z ohms is

$$\mathbf{V(dB\mu V) = 90 + 10 \log (Z) + P(dBm)}$$

Actual voltage, current or power can be derived from the antilog of the dB value:

$$\mathbf{V = \log^{-1} (dBV/20) \text{ volts}}$$
$$\mathbf{I = \log^{-1} (dBA/20) \text{ amps}}$$
$$\mathbf{P = \log^{-1} (dBW/10) \text{ watts}}$$

Expressing values in dB means that multiplicative operations (such as attenuation and gain) are transformed into simple additions. For example, a signal of 42µV (32.5dBµV) fed via a transducer with conversion factor 0.67 (-3.5dB) and a cable with attenuation loss 0.75 (-2.5dB) into an amplifier of gain 200 (46dB) will result in an output of:

$$\mathbf{V_{out} = 32.5 - 3.5 - 2.5 + 46.0 = 72.5dB\mu V = 12.5dBmV = 4.2mV}$$

A simple rule of thumb:

When working with power, 3dB is twice, 10dB is ten times;
When working with voltage or current, 6dB is twice, 20dB is ten times.

The following tables allow you to look up a dB value for a given ratio, and also to convert from dBµV (voltage) to dBm (power) in a given impedance.

Table 4 - **dB ratios**

dB	Voltage or current ratio	Power ratio
-20	0.1	0.01
-10	0.3162	0.1
-6	0.501	0.251
-3	0.708	0.501
0	1.000	1.000
0.5	1.059	1.122
1	1.122	1.259
2	1.259	1.585
3	1.413	1.995
4	1.585	2.512
5	1.778	3.162
6	1.995	3.981
7	2.239	5.012
8	2.512	6.310
9	2.818	7.943
10	3.162	10.000
12	3.981	15.849
14	5.012	25.120
16	6.310	39.811
18	7.943	63.096
20	10.000	100.00
25	17.783	316.2
30	31.62	1000
35	56.23	3162
40	100	10,000
45	177.8	31,623
50	316.2	10^5
55	562.3	$3.162 \cdot 10^5$
60	1000	10^6
65	1778	$3.162 \cdot 10^6$
70	3162	10^7
75	5623	$3.162 \cdot 10^7$
80	10,000	10^8
85	17,783	$3.162 \cdot 10^8$
90	31,623	10^9
95	56,234	$3.162 \cdot 10^9$
100	10^5	10^{10}
110	$3.162 \cdot 10^5$	10^{11}
120	10^6	10^{12}

Table 5 - **dBµV versus dBm**

dBµV	**Power in dBm for impedance Z Ω**			
	50	**75**	**150**	**600**
-20	-127	-129	-132	-138
-10	-117	-119	-122	-128
0	**-107**	**-109**	**-112**	**-118**
10	-97	-99	-102	-108
20	-87	-89	-92	-98
30	-77	-79	-82	-88
40	-67	-69	-72	-78
50	-57	-59	-62	-68
60	-47	-49	-52	-58
70	-37	-39	-42	-48
80	-27	-29	-32	-38
90	-17	-19	-22	-28
100	-7	-9	-12	-18
110	3	1	-2	-8
120	13	11	8	2
dBV	**Power in dBW**			
0	-17	-19	-22	-28
10	-7	-9	-12	-18
20	3	1	-2	-8
30	13	11	8	2

Table 6 - **Common suffixes**

Suffix	**refers to**
dBV	1 volt
dBmV	1 millivolt
dBµV	1 microvolt
dBV/m	1 volt per metre
dBµV/m	1 microvolt per metre

Suffix	**refers to**
dBµA	1 microamp
dBW	1 watt
dBm	1 milliwatt
dBµW	1 microwatt

VSWR, VRC and return loss

These three terms describe the match presented by a source or load; they all refer to the same phenomenon but in different ways.

VSWR (Voltage Standing Wave Ratio) is the ratio of maximum to minimum voltage along a transmission line. A high VSWR implies a poor match. VSWR is always ≥1. A short circuit or open circuit load produces an infinite VSWR.

VRC (Voltage Reflection Coefficient) Γ is the inverse ratio of the sum and difference of the characteristic impedance of the transmission line (Z_0) and the load impedance (Z_L). A high VRC implies a poor match. VRC is always ≤1. A short circuit or open circuit load produces a VRC of -1 or 1 respectively.

Return loss R is simply the Voltage Reflection Coefficient expressed in dB. A low value of return loss implies a poor match.

The three parameters are related by:

$$\Gamma = \frac{Z_L - Z_0}{Z_L + Z_0} \qquad |\Gamma| = \frac{VSWR - 1}{VSWR + 1} \qquad VSWR = \frac{1 + |\Gamma|}{1 - |\Gamma|} \qquad R = -20\log(|\Gamma|)$$

Table 7 - **VSWR and VRC versus return loss**

Return Loss R dB	VSWR	VRC Γ
1	17.391	0.891
2	8.724	0.794
3	5.848	0.708
4	4.419	0.631
5	3.570	0.562
6	3.010	0.501
10	1.925	0.316
15	1.432	0.177
20	1.222	0.100
25	1.119	0.056
30	1.065	0.032
35	1.036	0.018
40	1.020	0.010
50	1.006	0.003

Mismatch error

No passive antenna presents a perfect 50Ω match to its connected cable. All antennas present a mismatch at their terminals (poor VSWR) which varies with frequency. The same is true of test receivers and spectrum analysers, to a lesser extent. This creates an additional uncertainty in the voltage measured at the far end of the cable, according to Figure 22.

Impedance mismatch can be improved by fitting an attenuator to the antenna. The effect of the attenuator is to reduce the reflected signal, but at the expense of an overall loss of signal. The improvement, in terms of matched VSWR versus original VSWR for typical attenuator values, is given in Figure 23.

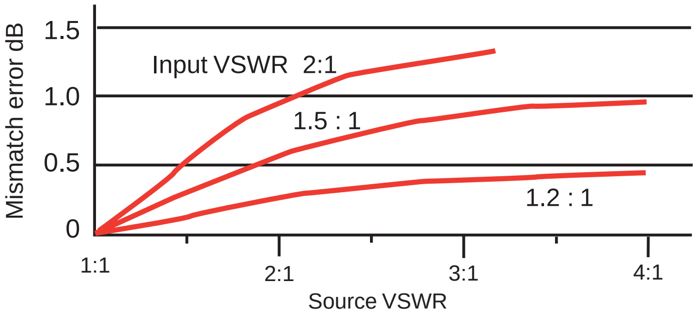


Figure 22 - Mismatch error

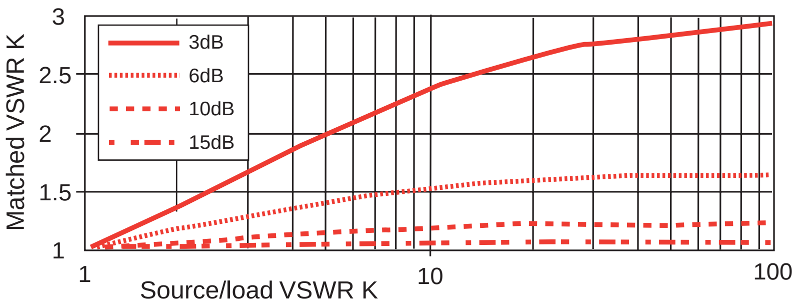


Figure 23 - Improvement of matching with an attenuator

Fourier envelopes

A trapezoidal waveform (i.e. a square wave with finite rise and fall times) consists of the fundamental frequency and a series of harmonics, in the frequency domain. The amplitudes of each harmonic component are given by;

$$V_n = 2A \cdot \frac{(T+t_r)}{P} \cdot \frac{\sin(n\pi f_o T)}{(n\pi f_o T)} \cdot \frac{\sin(n\pi f_o t_r)}{(n\pi f_o t_r)}$$

where f_0 is the fundamental frequency, n is the harmonic number and the other terms are as shown in the diagram in Figure 24.

The harmonic amplitudes follow a sinx/x function, whose envelope of maximum values can be given by a simple straight line graph as shown in Figure 24. Above a breakpoint defined by the risetime, the harmonic amplitudes decay at a rate of 40dB per decade, or proportionally to $1/f^2$.

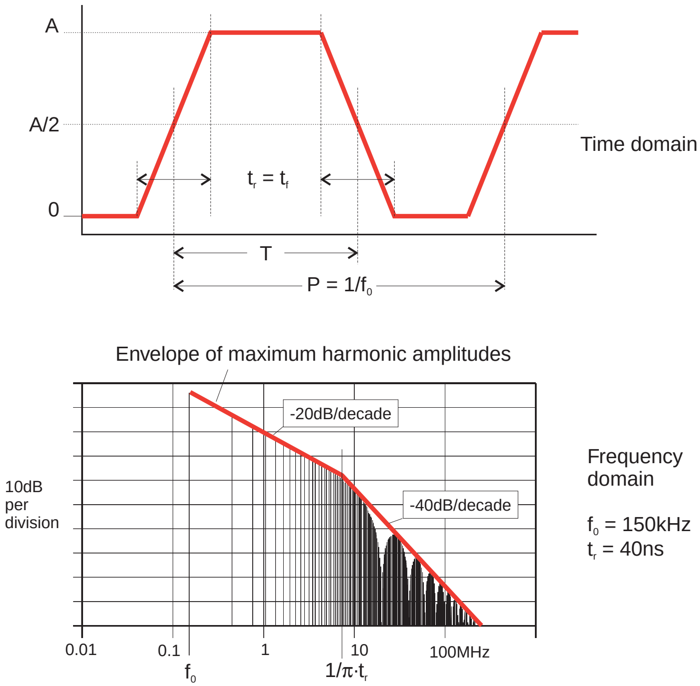


Figure 24 - Trapezoidal waveform and harmonic envelope

Title/scope	EN	CISPR/IEC	Refers to
Generic standards			
Residential, commercial & light industry	EN 50081-1	IEC 61000-6-3	EN 55022
Industrial	EN 50081-2	IEC 61000-6-4	EN 55011
Product standards - CISPR-based			
Industrial, scientific & medical equipment	EN 55011	CISPR 11	-
Broadcast receivers and associated equipment	EN 55013	CISPR 13	-
Household appliances, electric tools & similar	EN 55014-1	CISPR 14-1	-
Electrical lighting and similar equipment	EN 55015	CISPR 15	-
Information technology equipment	EN 55022	CISPR 22	-
Protection of receivers used on board vehicles	EN 55025	CISPR 25	-
Product standards - IEC-based			
Low voltage switchgear and controlgear assys.	EN 60439-1	IEC 60439-1	CISPR 22
Medical electrical equipment	EN 60601-1-2	IEC 60601-1-2	CISPR 11
Automatic electrical controls for household etc	EN 60730-1	IEC 60730-1	CISPR 22
Telecontrol equipment and systems	EN 60870-2-1	IEC 60870-2-1	CISPR 22
Marine navigation equipment	EN 60945	IEC 60945	-
Low voltage switchgear and controlgear	EN 60947-1	IEC 60947-1	CISPR 22
Low voltage DC power supplies	EN 61204-3	IEC 61204-3	CISPR 22
Electrical equipment for measurement, control and laboratory use	EN 61326-1	IEC 61326-1	CISPR 11,14, 16-1, 22
RCDs for household & similar use	EN 61543	IEC 61543	CISPR 14
Adjustable speed electrical power drive systems	EN 61800-3	IEC 61800-3	CISPR 11
Product standards - non-IEC or CISPR			
Cable TV distribution systems	EN 50083-2	-	EN 55013
Home and building electronic systems	EN 50090-2-2	-	EN 55022
Uninterruptible power systems	EN 50091-2	IEC 62040-2	EN 55011
Arc welding equipment	EN 50199	-	EN 55011
Professional AV & entertainment lighting equpt	EN 55103-1	-	EN 55013, 14, 22
Lifts, escalators and passenger conveyors	EN 12015	-	EN 55011, 14
Telecommunication network equipment	EN 300 386-2	-	EN 55022
Agricultural and forestry machines	EN ISO 14982	-	-

Product and generic standards for emissions

Radio and non-emissions standards are excluded. Shaded - not harmonised for the EMC Directive

Emissions limits

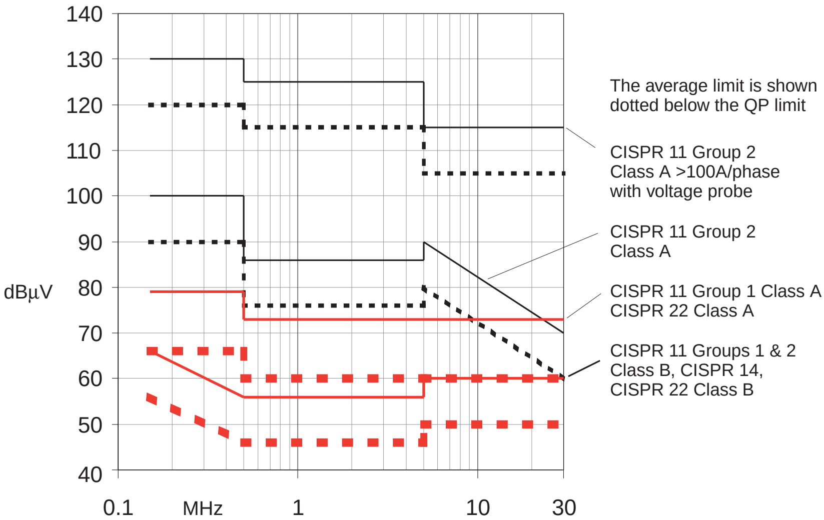


Figure 25 - Conducted emission limits on the mains port

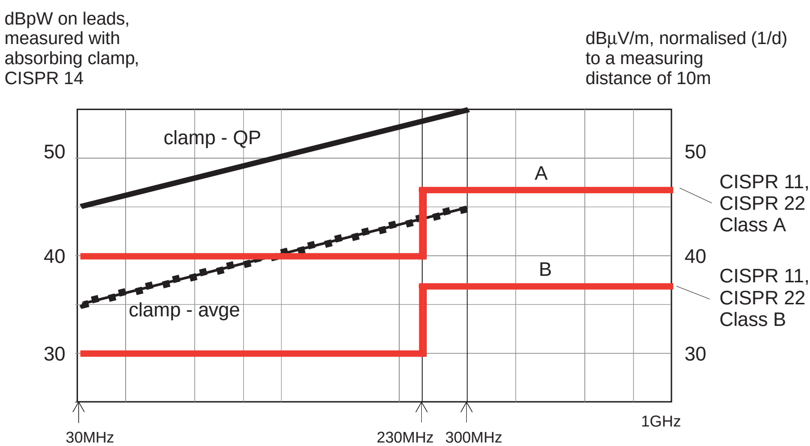


Figure 26 - Radiated and disturbance power emissions limits

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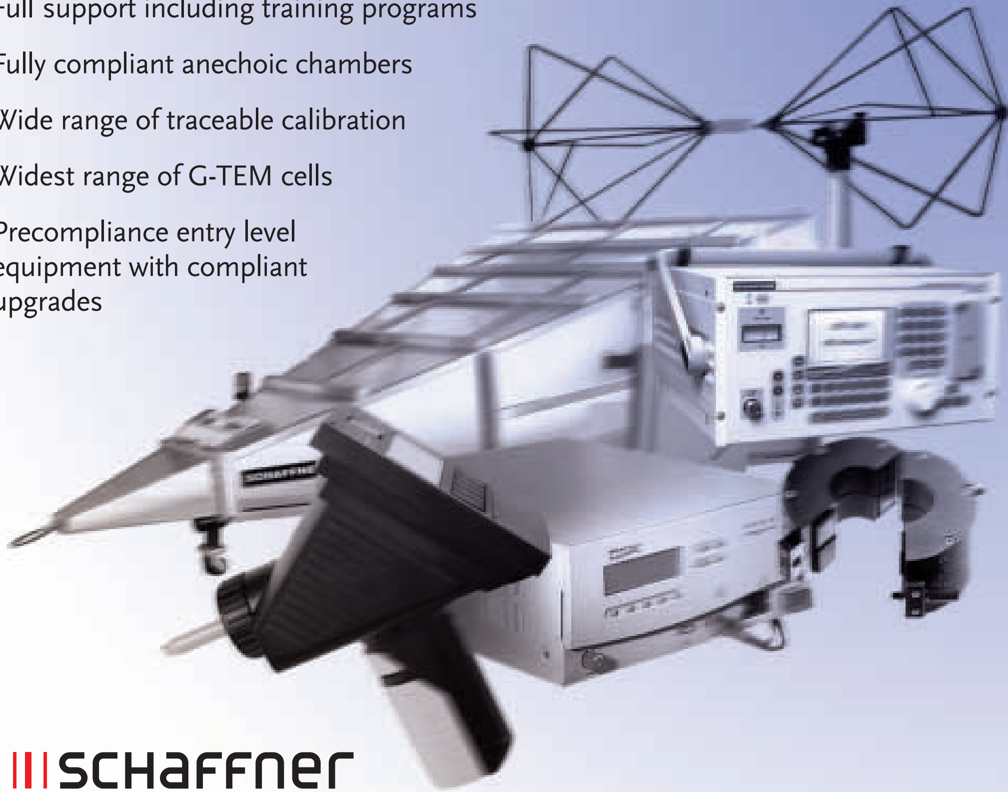
Figures and tables



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