

Conducted RF Application Note 01

Radio Frequency Testing to IEC61000-4-6

Overview

RF conducted Immunity tests are described in the basic standards IEC 1000-4-6 and ENV 50141. The reason for these tests is to determine immunity to electromagnetic fields generated by intentional RF transmitters at such frequencies that cables attached to the EUT are in resonant mode ($\lambda/4$, $\lambda/2$).

These tests are performed by direct injection of the RF signal into power, interface and communication cables connected to the EUT. Interference is generated by currents flowing through the equipment. The procedure used to inject interference signals into one cable at a time, is not representative of reality where the RF signal will act on all cables attached to the EUT simultaneously with varying amplitude and phase.

There are **two principal parameters** defined in conducted RF tests, the frequency range and the test level.

A frequency range of 150 kHz to 80 MHz is given for general applications with the possibility to extend to a maximum 230 MHz. The exact frequency range used for a test is defined in individual product standards and depends on the test object. Frequency range is chosen dependant on the size of cable and EUT. In general, if the cable and EUT length is $< \lambda/4$, the upper frequency may be increased. This rule also holds true for the start frequency which may be higher than the specified 150 kHz. Start frequencies would be increased when the cable and EUT length is $> \lambda/4$.

Test level is a slightly ambiguous term when used in relation to actual tests. The levels given in the standards refer to the calibrated signal level into an ideal impedance and with no modulation. What actually appears at the EUT during testing can be quite different depending upon the impedance characteristics of the EUT. Defined as volts RMS into a 150Ω matched load, the nominal test level chosen is entirely at the users discretion, but should reflect the electromagnetic environment expected for normal operation of the equipment. The basic standards suggest levels of 1V, 3V and 10V. In reality, because of the long time necessary to complete a test from 150 kHz to 230 MHz, a very high test level may be selected for the first test covering the whole frequency range and then a lower test level selected to cover smaller frequency ranges sensitive areas highlighted by the first test.

The basic equipment required for an RF conducted immunity test is :

1. RF Signal Generator
2. Amplifier
3. 6 dB attenuator (this is used to reduce mismatch between the amplifier and CDNs)
4. Coupling / Decoupling Units
5. Ground Reference Plane

In addition, the following would make testing much easier and quicker :
Software to control all aspects of the test and calibration
RF Measurement unit (for calibration) with remote control interface

1. What kind of signal generator do I need ?

To perform basic conducted RF tests, you will need a signal generator with frequency range 150 kHz to 230 MHz, capable of Amplitude Modulation (AM) with a 1 kHz sine wave up to 80% modulation depth.

It is possible to run these tests manually, but this is extremely time consuming and laborious. A solution such as the **Haefely Test WinPAMP software**, which can control signal generators from many different manufacturers, and manage the whole test process, provides a **quick and efficient method of saving time and money**. To come under software control, a signal generator must have some kind of communications interface, most modern units have one at least. **Haefely Test WinPATS software**, requires a GPIB (IEEE) interface.

The signal generator must deliver an unmodulated signal for system levelling, which is used to determine the test level at the EUT. Modulation is used for testing to simulate the effects of radiation from different transmitters and is applied during the test time. The **WinPAMP software**, enables even generators without frequency sweep or step function to be used.

Most signal generators have a frequency range well in excess of the requirements for these tests, higher frequencies can be selected from the **WinPAMP software** together with the correct amplifier and an antenna to perform pre-qualification radiated testing

2. Why is an amplifier necessary ?

Amplifiers are only necessary to boost the signal generator output to a level suitable for performing these tests. Amplifier bandwidth must be the same or greater than the signal generator as specified above. Amplifiers are essentially passive devices from a control point of view, power is applied to the input and multiplied by the gain before being sent to the output. Obviously there are limits to the amount of power an amplifier can generate, determined by internal construction and voltage supplies. A situation can arise, where the amplifier input keeps increasing, but the output does not increase by a proportional amount. This is called „**gain compression**“. If the amplifier is operated in this region, the output will no longer be a true representation of the input. Distortion will occur. At the other end of the scale, very low inputs to the amplifier may be subjected to noise and distortion inherent in the design. Between these two limits, is the linear section of the amplifier characteristic. Ideally this should be large enough to handle all power ratings required for testing. The **Haefely Test PAMP 250 and PAMP 1000 amplifiers** are quoted as 25 and 100 Watt respectively, using only the linear section. It is quite normal to define the linear section with 1dB gain compression. At **Haefely Test** we do not do this, because it creates distortion and potential problems for the EUT.

Haefely Test amplifiers are all fitted with internal power meters to monitor power levels at the output. This is particularly useful for detecting sudden changes in power level caused by resonances in the EM or current clamps.

3. Is the 6dB attenuator a must ?

The attenuator is used between the amplifier output and coupling unit input. Its function is to reduce returned power into the amplifier output, caused by impedance mismatch with the coupling unit. An attenuator may not be necessary if the amplifier stays within its specified limits under all load conditions encountered during testing (refer to VSWR in the glossary).

The 6dB attenuator creates an effective 12dB path for signals reflected back into the amplifier output 12dB is a power reduction of approximately 16 times. A 25 Watt amplifier would receive return power of 1.5 Watt from a worst case short circuit condition.

The attenuator must be capable of withstanding the RF power delivered by the amplifier. It is intended to protect the rather expensive hardware and has no direct relation to the test process, except that of course it reduces the signal level entering the coupling units. This must be compensated for by higher power from the signal generator. **Haefely Test WinPAMP software**, takes care of all these adjustments automatically.

4. How is the signal injected ?

The purpose of these tests is to inject RF signals into electrical networks. To achieve this, the RF signal needs to be connected so that it can transfer maximum energy into the EUT and be protected from voltages currents and control signals present in the EUT cables. This can be achieved in several ways dependant upon the network type and its associated cabling.

Because of the **Haefely Test PAMP systems** open architecture, any available type of coupling can be used. It is important to remember that for each type of coupler used, a system levelling must be performed to maintain a correct signal level at the EUT (refer to application note 05).

The **Haefely Test WinPAMP system software** contains automatic routines and a data base to perform and store levelling files for instant recall to greatly reduce non productive test time.

Direct Injection Coupling/Decoupling Networks

Direct injection Coupling/Decoupling Networks, are the most efficient method of coupling the RF signal into a network. They are designed to be a good match with the amplifier output across the full frequency range.

Direct injection CDNs break into cabling and are placed between the EUT and either its supply or communication equipment sending signals to it.

Direct injection CDNs are particularly useful in power networks or where it is possible to access individual wires in a multiple wire cable.

There are many different types of direct injection CDN dependant upon the test network.

The following selection chart should help in choosing the correct CDN for your application.

CDN type	For use in -	Number of wires
M1	earth cables	1
M2	single phase power systems	2
M3	single phase power systems	3
M4	three phase power systems	4
M5	three phase power systems	5
S1	screened coaxial cables	1
AF2	unscreened non balanced cables	2
AF4	unscreened non balanced cables	4
AF8	unscreened non balanced cables	8
T2	unscreened balanced twisted pairs	2 (1 pair)
T4	unscreened balanced twisted pairs	4 (2 pairs)
T8	unscreened balanced twisted pairs	8 (4 pairs)

It is important to remember, that although testing is described on one cable at a time, other cables connected to the EUT must be in their active state. If CDNs are inserted in cables not being subjected to test signals, unused inputs on the CDN must be terminated with 50Ω.

Electro Magnetic Clamps

Electro Magnetic (EM) coupling clamps consist of ferrite rings placed around the test cable. Coupling is both inductive and capacitive. They are used in situations where it is not possible or inconvenient to break into individual cables of the test network. Because of their mechanical dimensions, EM coupling clamps can only be used in applications where the distance between EUT and its auxiliary/power equipment is more than 1 metre.

EM coupling clamps are not as efficient as CDNs, therefore a higher signal level is required from the test system.

Because, EM coupling clamps are only for signal coupling, the test signal will equally be available at the EUT and any equipment connected to the same network. This means any equipment other than the EUT connected to the network will also be tested unless a special decoupling clamp is used. Use of the EM coupling and decoupling clamps together requires at least 2 metres between EUT and any other unit in the network. If an EM decoupling clamp is used together with the EM coupling clamp, the power required from the test system increases again. This is because the EM decoupling clamp is designed to absorb RF signals and as a consequence absorbs some of the signal intended for the EUT.

Ask for further information on the [EM101 Coupling Clamp](#)
[FTC 101 Decoupling Clamp](#)

Bulk Current Injection Clamps

In the case where a CDN cannot be used and the distance between EUT and other units in the network is too small for use of the EM clamp, then bulk current injection clamps can be used.

Bulk current injection clamps use inductive coupling, treating EUT cables as the secondary in a transformer, coupling is therefore dependant upon the number of times the cable is passed through the clamp. These clamps are the least efficient method of coupling, consequently they require a very high signal level from the test system and adequate protection against reflected power, caused by impedance changes to the amplifier output. The extra power required, usually means a high power amplifier of 100 watts or more.

In the case of both EM and bulk current clamps, it is important to monitor current induced by the test signal voltage. A current probe between the EUT and injection clamp should be used to ensure that the short circuit current does not exceed $U_0/150\Omega$.

For example using a test voltage of 3 V, the current should not exceed $3/150 = 0.02A$

Current drawn by the EUT may change dependant on frequency characteristics of the coupling unit. A test system should be capable of detecting changes and adjusting the signal source to bring the EUT current back within its specified limits. Any changes to signal level must be recorded on the test report.

5. These are RF tests, why a ground reference plane ?

The ground reference plane is necessary for both RF and electrical safety reasons.

The EUT input is defined as having a common mode impedance of 150Ω between signal or signal screens and the reference plane.

Because elements in the coupling/decoupling Networks are attached to power voltages, resulting current flow can be a safety hazard if the CDN is not properly grounded.

Glossary

Useful Terms and notations associated with RF testing.

Many of the terms described below will be used in further application notes on the subject of RF conducted immunity.

VSWR	Voltage Standing Wave Ratio, is a ratio of energy transmitted to a load and energy reflected from the load as a result of imperfect matching. An ideal condition is when all of the power is transferred to the load VSWR = 1:1
λ	used to denote wavelength, f (frequency) = $1/\lambda$
λ/4	one quarter wavelength, a cable of this length is an effective antenna
Levelling	a term used for system calibration using an ideal load impedance.
AM	Amplitude Modulation is used to superimpose a signal onto a carrier wave by the method of changing the carrier wave amplitude.
FM	Frequency Modulation is used to superimpose a signal onto a carrier wave by the method of changing the carrier wave frequency.
Coupling Network	Electrical circuit for transferring energy between networks with the minimum loss
Decoupling Network	Electrical circuit that attenuates the RF signal so that it does not cause undue interference to equipment other than the EUT .
CDN	Comprises a coupling and decoupling network for single or three phase mains and signal applications
EM Clamp	Device for injecting RF fields into a cable using capacitive and inductive techniques
EMF	ElectroMotive Force, voltage at the terminals of an ideal voltage source