EMC mains line filtering- A technical overview

EMC - Electromagnetic Compatibility

With the rapid development of electrical products and wide application in Europe, the integrity of performance is becoming more important. The high level of complexity is making modern equipment extremely sensitive, combined with spurious electromagnetic signals from atmospheric and astronomical electrical events, plus man-made electromagnetic disturbances are increasing in significance as a source of interference.

It is vital, therefore, to recognise the damage this can impose on electronic equipment where malfunctions of any sort can lead to loss of life, damage to property or a series of unplanned events which can cause loss of information and revenue.

In the drive to increase the reliability of electronic and electrical equipment, certain minimum objectives of compatibility within the electromagnetic environment have been set and formalised by agreement into specifications issued by international bodies

The situation in the EC is that the EMC directive 89/336/EEC, issued by the council of the European countries, came into force on 1 January 1996. This directive covers public mains electricity supply networks and any equipment connected to them as well as radio communications and telecommunication systems and, in order to meet the requirements of the directive, methods of preventing gratuitous coupling of spurious signals into and out of equipment must be derived and made available to equipment manufacturers.

In order to see how to prevent the inadvertent coupling of unwanted signals, which may be produced remotely on an apparently random basis, it may be useful to consider how the electrical coupling may take place.

The most pervasive coupling conductive and propagative media are electrical supply lines and free space. The spurious coupling effects of these are usually considered separately under the headings of 'conducted interference' and 'radiated interference'. Each of the two have their own legal limits set out in international specifications as discussed below.

There are two operating conditions which must be considered in bringing equipment in-line with the directives requirements. These are:

1. **Emission**: In this condition, equipment which is functioning normally must be monitored during its normal operating cycle and any voltage or current interference measured to ensure that they do not exceed the levels called upon by the directive. If found to exceed these levels, the equipment must be fitted with suppression to reduce the interference to below the mandatory levels.
2. **Immunity**: In this condition, equipment is set up to operate normally and is subject to 'incident interference' of different types at specified levels. Should the equipment malfunction under the required conditions then its immunity to the 'incident interference' must be increased by adding suppression components to the point where the equipment is made immune to the mandatory interference levels.

In meeting both the 'immunity' and 'emission' requirements, it has become standard practice to fit each piece of equipment or apparatus with its own suppression components and to this end manufacturers and suppliers in the EMC field have developed a set of standard ranges of suppressors for a wide range of applications.

The European Regulations - A Brief Outline

The agreed European regulations most frequently encountered may be summarised as follows:

Emissions:

EN55022, Level 'B':	For residential, commercial light industrial, IT: called up by EN50081-1
EN55011, Level 'A':	Industrial: called up by EN50081-2.
EN60555:	Flicker and harmonic distortion: called up by EN50081-1 and -2.

Immunity:

IEC 1004-2	Electrostatic discharge
IEC 1004-3	EM Radiation
IEC 1004-4	Electrical fast transient burst
IEC 1004-5	Electrical surge

The specifications in EN55022 and EN55011 specify the total amount of noise permitted over a given frequency range. This range extends from 150KHz to 1000MHz.

Taking into consideration the nature and propagation modes of the RFI noise spectra it has been agreed to divide the test frequency range into two parts.

Viz. 150KHz to 30MHz for conducted interference and
30MHz to 1000MHz for radiated interference.

The frequency band for conducted interference is examined for interference voltages which are expressed in dB relative to 1μV. The frequency band for radiated interference is examined for interference voltages which are measured in v/metre in a 120KHz bandwidth and are expressed in dB relative to 1μV.

The dB levels are obtained from the measured noise levels using the relationship:

$$\text{Noise level (dB)} = 20 \log_{10} V2/V1$$

where V2 is the measured noise level and V1 is the reference level of 1μV.

Figure 1 **European conducted emission limits**

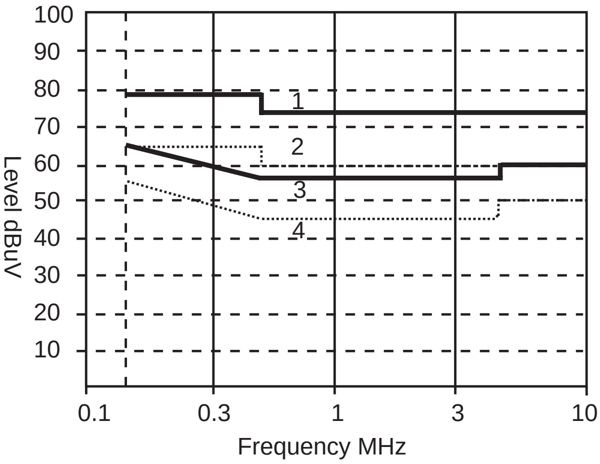
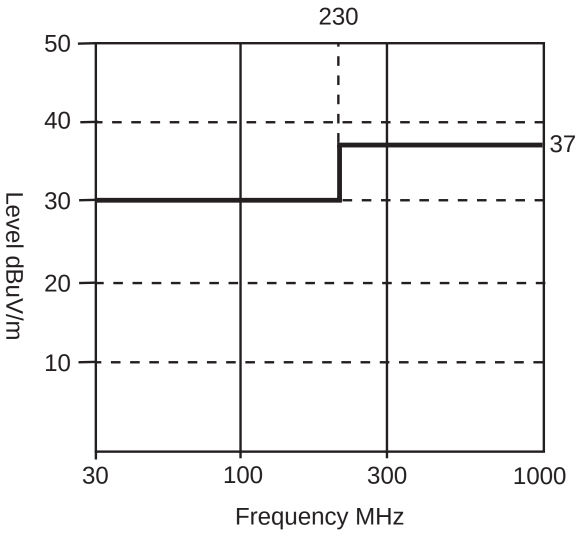


Figure 2 **European radiated emission limits**



In order to ensure continuity of measurements, the conducted emissions are measured with a standard receiver with defined time constraints, impedance and attenuators against a standard mains supply line impedance stabilisation network, the radiated measurements are made using standard receivers with calibrated antennae against a specified ground plane in an open site of set minimum size and distances.

The actual interference level limits are as shown where the axes are chosen for convenience to have dB and log frequency scales.

The flicker and harmonic distortion specification set out in EN60555 sets limits on the amount of flicker caused by voltage dips and distortion of the main current supply up to the 40th harmonic (2KHz) in terms of amps.

Immunity: Immunity to interference levels is covered by the IEC1004 series regulations. The main areas of interest being the conducted electrical fast transient and electrical surge requirements of Parts 4 and 5 with the electrostatic discharge (Part 2) and electromagnetic radiated energy (Part 3) being the complementary parts.

Principles of line filtering

The function of a line filter is to permit the flow of supply currents in the range 0 to 400Hz and to prevent the flow of undesired frequencies which in general extend from 10KHz to 1GHz.

This is achieved by adopting basic low pass filter configurations using shunt capacitors and series inductors to attenuate high frequencies. The low pass filter is effective in either direction and thus can be used to prevent excessive emissions from an equipment and limit the flow into the equipment of spurious signals on the mains lines. Because of unknown parameters such as the source impedance of the unwanted signals, it may be difficult to predict the precise behaviour of a filter in a given equipment, hence direct measurements under standard conditions are made using prescribed procedures and apparatus to confirm the performance of a line filter. Resistors are incorporated into the filter for damping resonances as well as providing safety discharge paths; non-linear devices such as metal oxide varistors and zener diode combinations are used to deal with voltage transients.

Suppression components may be required in the earth conductor as well as the current carrying conductors to achieve satisfactory performance.

All components used must be rated for the application in accordance with international standards and care must be taken to avoid generating spurious magnetic fields which can cause mechanical vibration, noise and local heating.

Filter configuration

Mains filters for suppression are made up essentially from combinations of capacitors and inductors where the network is designed to give the required amount of suppression without interfering with the flow of supply current; the greater the suppression required, the more complex the filter network.

The simplest configuration is a single capacitor used in the decoupling manner as a shunt element as shown in Figure 3a, Figure 3b shows a practical version of this suppressor as a delta connection of capacitors, where the L to N capacitor is X rated and L to E and N to E capacitors are Y rated for the supply voltage and frequency in question in accordance with international safety requirements.

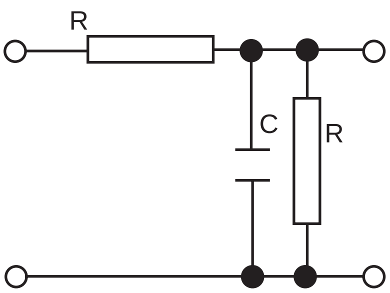
Capacitors used are of the self healing type and are either of conventional leaded style or where high performance is required in Tempest or GHz plus applications, axial feed-through types are used.

Because of the limits placed on the size of capacitors to earth in Figure 3b by leakage current safety requirements, it is usually necessary to introduce inductive elements to achieve the required level of suppression. There are five main styles of inductor which may be chosen from for various modes and types of interference as follows:

- Multiple wound flux cancelling - asymmetric mode
- Single wound saturating general thyristor - suppression
- Single wound or multiple wound flux aiding - symmetric mode
- Low inductance aircore or open loop - general vhf suppression
- Earth line chokes - single wound - asymmetric mode.

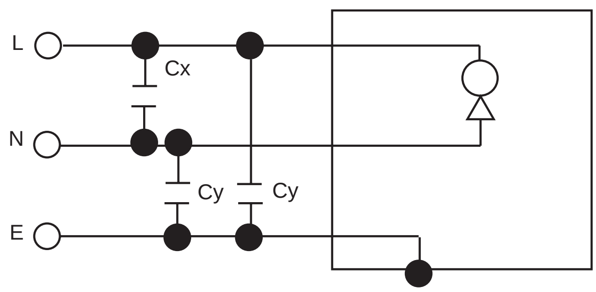
Filter configuration are built up by optimising combinations of various styles of inductor with the appropriate capacitors and other components to give a comprehensive selection of suppression levels and other features to cover the range of electronic equipment currently manufactured to various specification requirements.

Figure 3a



Simplest single capacitor filter configuration

Figure 3b

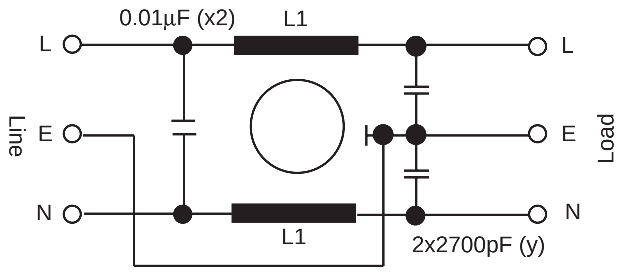


Configuration applied to mains powered equipment

Typical filter configurations

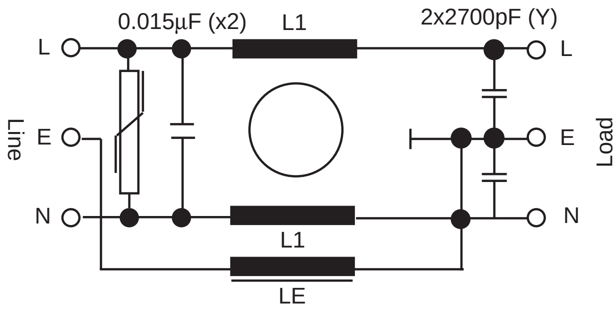
Four typical configurations are detailed below:

Figure 4a



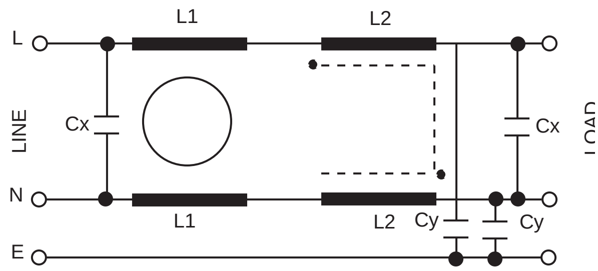
Simplest transient protection filter using double wound flux cancelling inductors L1, L1

Figure 4b



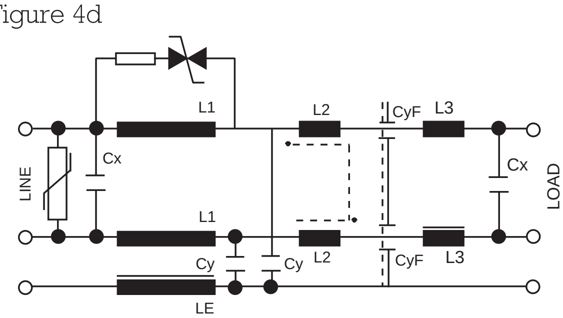
Enhanced performance transient protection filter including earth line choke LE

Figure 4c



General purpose high performances e.g. motor drive suppressor using flux cancelling inductors L1, L1 series aiding inductors L2, L2

Figure 4d



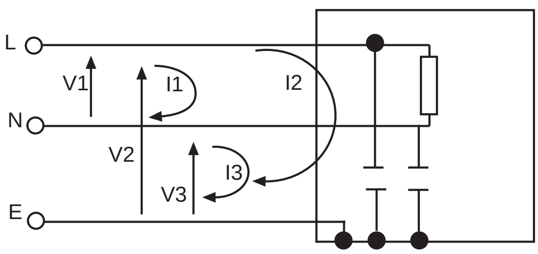
High performance tempest type using UHF chokes L3, feedthrough capacitors, internal screens with MOV and zener diode transient suppression

Mode of interference

In the general case of Figure 5 an equipment is supplied with power by lines L and N, E is the protective safety earth connected to the equipments metallic housing. Three voltages can exist, and currents can flow in three loops as shown. Currents I2 and I3 will normally flow by virtue of capacitance existing in the equipments and stray coupling caused by transformers or heatsinks or intentionally introduced filter suppression components.

Conventionally voltage V1 and current I1 are defined to be of symmetrical, differential or series mode, V2, V3, I2 and 13 are of the asymmetrical, common or shunt mode. Spurious interference voltages and currents are separated into the two modes as are the corresponding attenuation characteristics of mains interference suppressors. In analysing interference in order to determine a suitable suppression network it is usual to consider the two modes separately and the performance curves of standard filters which are given as separate plots for the two modes.

Figure 5



Equipment supplied by mains showing symmetrical and asymmetrical mode voltages and currents

Types and sources of interference

The two main types of interference are those produced continuously by repetitive switching of voltages or currents, and those produced intermittently by switches and contactors making and breaking voltage surges and electrostatic or atmospheric discharges. The former type can be investigated using a frequency domain approach while the latter could be considered a time domain problem but, because of simulation and observation problems the frequency domain approach is also used for some aspects of deriving suppression networks for intermittent interference.

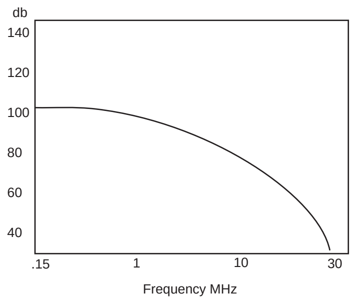
Typical continuously produced interference is characterised by a broad band spectrum of noise as is noted by observing interference produced by equipments containing mains synchronous devices such as thyristor phase controllers, or asynchronous or non-mains related switching sequences e.g. switching power supplies, variable speed drives, clocks and brush motors.

While the majority of the power switched in these equipments and consequent spurious interference produced is in the symmetric mode, capacitive and other coupling to earthed metallic parts allows interference to be transferred into the asymmetric mode where the propagation properties are such that the interference can be propagated at high impedance levels with low loss into other equipments and readily cause malfunction.

Both continuous and intermittent interference can be present in symmetrical and asymmetrical modes and in general the asymmetrical mode interference is the greater cause of problems.

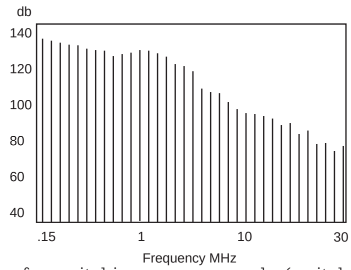
Figures 6a, 6b, 6c and 6d give typical spectra for continuous interference and wave-forms for intermittent interference.

Figure 6a



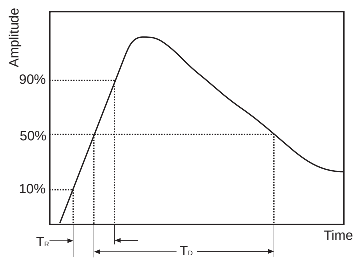
RFI spectrum envelope for thyristor lamp dimmer

Figure 6b



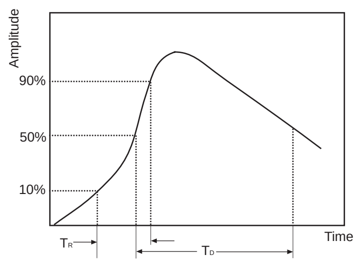
RFI spectrum for switching power supply (switching rate >10kHz)

Figure 6c



Electrical fast transient wave form. T_R=5ns T_D=50ns

Figure 6d



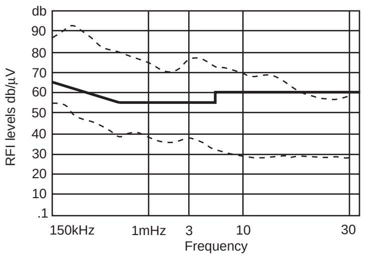
Voltage surge protection T_R=1μs T_D=50μs

An illustrative example

An equipment which emits interference onto the mains supply lines must have those emissions reduced to levels set by accepted specifications: the Directive 89/336/EEC on EMC calls for compliance for some equipments with associated specification EN55022.

An illustrative example of asymmetric mode conducted interference levels over the frequency range 150KHz to 30MHz measured on a switching power supply computer unit with and without suppression is given in Figure 7 superimposed on the appropriate EN55022 level for comparison. Because a given equipment may be operated with different systems at different sites and with supplies of differing voltages and frequencies it is often the case that more than one suppression filter should be made available for use with an equipment.

Figure 7



Showing the effect of suppression of computer supply conducted emissions to EN55022, 150kHz to 30MHz

Technical considerations (from Belling Lee)

Leakage currents

Leakage currents are measured in accordance with IEC348 (BS4743) and are given as leakage current per line.

In normal single phase use, the leakage current will be that for one line.

For three phase operation, with balanced voltages, the resultant earth leakage current will be much smaller than the value given for one line. For other voltages and frequencies, leakage current is directly proportional to voltage and frequency: 1mA leakage at 250V, 50Hz is equivalent to :

$$1\text{mA} \times \frac{120}{250} \times \frac{60}{50} = 0.576\text{mA}$$

at 120V, 60Hz.

RS Components gratefully acknowledges the help and advice of Belling Lee, BLP Components Ltd and Roxburgh Electronics Ltd in the preparation of this data sheet.

Current rating

Current rating are given for ambient temperatures Ta up to 40°C.

For temperatures above 40°C derate I^2 linearly to zero at 85°C using the formula:

$$I\,Ta = I\,rated\sqrt{\frac{85 - Ta}{45}}$$

The Ta is measured in °C

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