Technical Engineering Notes

ELECTRO MAGNETIC COMPATIBILITY (EMC)

Introduction

As a result of the vast increase in the use of information technology and communications equipment, and of domestic and industrial electronics, the electromagnetic environment is suffering extreme pollution. By the early 1980s West Germany (FTZ) and the USA (FCC) recognised the seriousness of the problem and introduced regulations limiting interference emissions from commercial and industrial products. Also, the International Special Committee on Radio Interference (CISPR), originally set up in 1934 to concentrate on test methods, began to issue recommendations and standards. Most other developed countries issued national standards based on CISPR recommendations but these standards did not have the force of law.

EU Directive

A major move towards minimising "pollution of the air waves" was taken in the European Community in 1989 by the publishing of the EMC Directive 89/336/EEC. This Directive requires harmonization of EMC requirements throughout the Community and requires Member States to introduce local laws to enforce appropriate regulations. It requires that apparatus does not generate excessive electromagnetic disturbance levels that would interfere with the proper functioning of other apparatus or radio and telecommunications equipment. Also apparatus must have adequate levels of intrinsic immunity to electromagnetic disturbances to enable it to operate as intended. The Directive is therefore concerned with both the generation of, and the susceptibility to, interference from electromagnetic and radio noise.

Transitional period

Originally it was intended that Member States standards would be harmonized, and have the backing of national laws by 1st January 1992 to coincide with the commencement of the Single European Market. Where standards were not in place there was to be a one year transitional period, i.e. to 1st January 1993 during which time existing standards could be used. However this timescale proved impractical so an Amending Directive 92/31/EEC was issued to allow an extended transitional period. Until 31st December 1995 Member States could authorize the placing on the market/and or putting into service apparatus conforming to the national regulations in force in their territory on 30th June 1992.

Scope of Directive

Any piece of equipment which is liable to cause an electromagnetic disturbance, or be affected by such disturbance is covered. Therefore every apparatus which uses a power converter comes within the scope of the Directive.

There are some specific exclusions from this Directive where reference to EMC requirements form part of another Directive. Some specific instances are

active implantable medical devices (90/385/EEC)
other medical devices (93/42/EEC)
electrical energy meters (76/891/EEC)

Components are excluded where 'component' is defined as any item which is used in the composition of an apparatus and which is not itself an apparatus with an intrinsic function intended for the final consumer. Sub-assemblies which are to be tested as part of a larger apparatus are regarded by the Commission as outside the scope of the Directive. With this interpretation it is fair to say that the majority of power converters which are to be used inside other equipment are not in themselves covered by the Directive. However most users will wish to minimise the problems they face with regard to ensuring that their total system or end product meets the requirements, so will insist that purchased sub-assemblies comply with the necessary standards.

TTE Directive (91/263/EEC)

Some overlap exists between this Directive and the EMC Directive. TTE (Telecommunications Terminal Equipment) which is not also classified as a radio transmitter must meet the EMC requirements included in the Common Technical Requirements (CTR) to which the TTE is type approved. For any EMC aspects not covered by the CTR, the equipment must comply with the EMC Directive.

If an apparatus is a TTE and a radio transmitter it is subject to the TTE Directive, the EMC Directive and local National Spectrum Management restrictions.

Relevant standards

The EMC Directive does not contain detailed specifications but refers to relevant standards. These standards are produced by CENELEC, usually following CISPR and IEC guidelines and published in the Official Journal of the European Union.

A recent list of European harmonized standards complying with the essential requirements of the Directive is as follows.

PRODUCT CATEGORY STANDARDS

European Reference Number	Harmonized Standard and Title
EN55011	CISPR11 (1990) ed 2 - Limits and methods of measurement of radio disturbance characteristics of industrial, scientific and medical (ISM) radio-frequency equipment.
EN55013	CISPR13 (1975) ed 1 + Amdt. 1 (1983) - Limits and methods of measurement of radio disturbance characteristics of broadcast receivers and associated equipment.
EN55014-1	CISPR14 (1985) ed 2 - Limits and methods of measurement of radio interference characteristics of household electrical appliances, portable tools and similar electrical apparatus.
EN55015	CISPR15 (1985) ed 3 - Limits and methods of measurement of radio interference characteristics of fluorescent lamps and luminaires.
EN55020	CISPR20 - Immunity from radio interference of broadcast receivers and associated equipment.
EN55022	CISPR22 (1985) ed 1 - Limits and methods of measurement of radio interference characteristics of information technology equipment.
EN60601-1-2	General requirements for safety. Collateral standard: Electromagnetic compatibility. Requirements and test.

Where Product Standards do not exist Generic Standards may be used. Generic Standards relate to the environmental areas in which the apparatus will be used. Product Standards take precedence over Generic Standards.

European Reference Number	
	Electromagnetic compatibility generic immunity standards
EN61000-6-1	Residential
EN61000-6-2	Industrial
	Electromagnetic compatibility generic emission standards
EN61000-6-3	Residential
EN61000-6-4	Industrial

Demonstration of compliance

Probably the best way to product certification for most electronic products and systems is by demonstration of compliance with the appropriate standards. All equipment need an EU certificate of conformity, certifying that it meets the requirements of the Directive. All separable parts of equipment, all apparatus and products have to carry an EU conformity mark consisting of the letters 'CE'. A statement of conformity must accompany each piece of apparatus which must properly identify the product category and the relevant standard, and name the signatory empowered to legally bind the manufacturer or his EU agent. This is in effect self certification by the manufacturer.

N.B.

This route to certification cannot be used for radio and telecommunications equipment. Apparatus in these categories can only be certified by an accredited test house.

Technical File

Another route towards certification is by raising a special technical file. This is mainly for special equipment categories where it is thought that current standards are either non-existent or inappropriate. The technical file must contain.

(i) The equipment identification.
(ii) A description of the procedures used to ensure conformity with the Directive.
(iii) A technical report and certificate from a recognised assessment authority.

Emission Standards

High Frequency Emission Standards

There are two types of HF emission with which these standards are concerned, mains terminal interference voltages (line conducted interference) and radiated interference field strengths. There are also two different sets of limits, one for class A equipment, and the other, more stringent for class B equipment. In general class A equipment is restricted to use in industrial or other specially designated environments. In Germany such equipment needs a special operating licence. This has to be obtained from the FTZ (Federal Telecommunications Agency) and will only be issued for fixed installations in designated industrial zones. Class B equipment is not subject to restrictions and may be used in residential, office, hospital and telecommunications environments.
Power conversion product manufacturers and users are mainly concerned with the following standards.

EN55022 (CISPR22)	European Standard for Information Technology Equipment (ITE)
FCC part 15 sub part J	U.S.A. standard for ITE

Limits for Mains Terminal Interference

FCC class A and class B limits cover the frequency spectrum from 450 kHz to 30 MHz, and as can be seen from Fig 8 the requirements are less stringent.

Limits for Radiated Interference

The standards for radiated limits are shown in Fig 9 (a) and Fig 9 (b). These are more difficult to compare than the conducted interference limits because different test distances are nominated in different standards.

Fig 9 (a) shows EN55022. The EN55022 specification is relatively simple with no requirements below 30 MHz, and the difference between class A and class B being different measurement distances, 30 m and 10 m respectively.

Fig 9 (b) shows the limits for FCC part 15 compliance. LIke EN55022 there are no requirements below 30 MHz. Class A limits are very similar to those in EN55022 although more difficult to compare, because of different measuring distances. It is fair to say that equipment meeting EN55022 class B will also meet FCC class B requirements.

Low frequency Emission Standards

Harmonics

The product category standards listed in the table in the section "Relevant standards" shows EN60555-2 as applied to household appliances and similar electrical equipment. This standard is superseded by EN61000-3-2 which covers all electrical equipment connected to AC mains supplies, and drawing up to 16A input current. CENELEC has used IEC1000-3-2 as the basic document for EN61000-3-2.

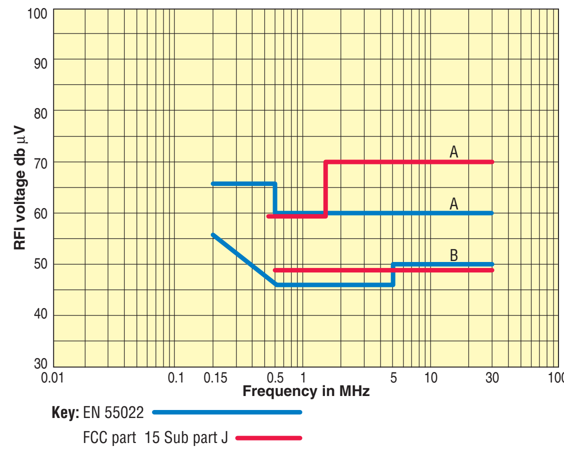

Fig 8. Limits of mains terminal interference voltage for Class A and Class B equipment for compliance with EN and FCC Standards.
(i) Above 150KHz class A limits are the same for EN & FCC limits are only spec above 450KHz.

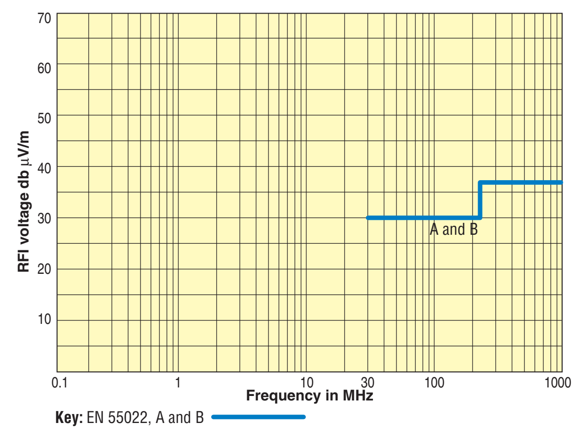

Fig 9a. Radiated RFI limits for EN55022 compliance.
Note: EN55022 class A at 30m, EN55022 class B at 10m.

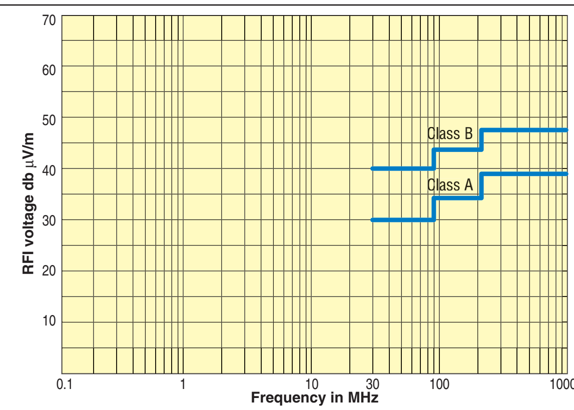

Fig 9b. Radiated RFI limits for FCC compliance. Class B limits measured at 3m, Class A limits measured at 30m.

FCC Compliance Procedures
Note: The FCC includes in RFI regulations all electronic devices and systems which generate and use timing signals at 10 kHz or above. Verification, Certification and Compliance procedures differ from the European approach. Class A (industrial, commercial and business equipment) is self tested by the manufacturer and no FCC permit is needed. Class B (residential use) testing must be performed at an FCC listed test-house and results submitted to FCC for Authorisation and certification.

In this standard equipment is classified into 4 different groups as follows:

Class A	Balanced 3 phase equipment and all equipment not in one of the other 3 classes
Class B	Portable tools
Class C	Lighting equipment including discharge lamp dimmers
Class D	Equipment up to 600W input power having a special waveshape

The diagram in Fig 10a shows the definition of special waveshape for the class D category. Equipment is in class D if the input current waveform is in the shaded zone for at least 95% of each half period. The actual limits allowed for odd harmonics for the four classes are listed in the following table.

Harmonic n	Class A Amps	ClassB Amps	ClassC Amplitude Ratio %	Class D mA/W
1	-	-	-	-
3	2.30	3.45	30l	3.4
5	1.14	1.71	10	1.9
7	0.77	1.155	7	1.0
9	0.40	0.60	5	0.5
11	0.33	0.495	3	0.35
13	0.21	0.315	3	0.30
15+	2.25/n	3.375/n	3	3.85/n

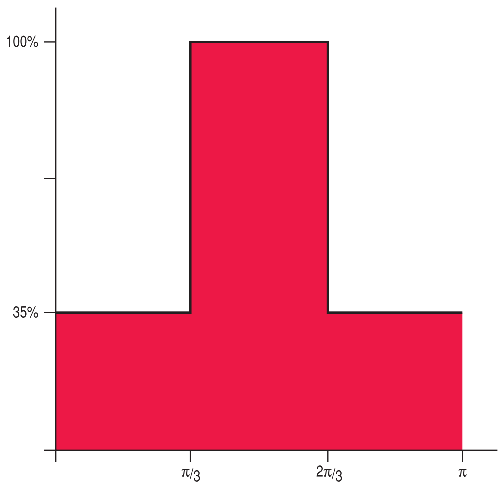

Fig 10a. Class D special waveshape EN 61000-3-2.

Harmonic limits EN 61000-3-2 Odd harmonics

Notes:
1. Below 75W no limits apply. This reduces to 50W by 5th July 1988.
2. Class A/B limits are absolute
3. Class C/D limits are proportional
4. Class D limits apply up to 600W, thereafter Class A limits apply
5. Above 1000W no limits apply for professional equipment
6. No limits apply to light dimmers up to 1000W
7. ı is the power factor defined as

real input power / input VA

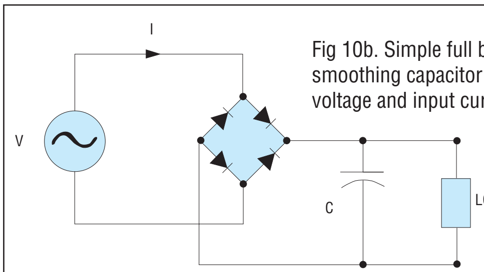

Fig 10b. Simple full bridge rectifier with smoothing capacitor and typical supply voltage and input current waveforms.

Fig 11 shows the input current waveform of a typical direct off the line full bridge rectifier with capacitor smoothing (the normal input circuit of an SMPS). Current only flows to charge the capacitor when the rectified input voltage exceeds the voltage stored. Circuit resistance is very low, only the ESR of the capacitor and forward resistance of the rectifier, so current rises very rapidly. Pulses of current with a very high odd harmonic content are drawn from the supply near each peak of the voltage waveform. The larger the stored energy in the capacitor relative to the continuous power, the shorter and peak are the current pulses. Power supplies designed for long hold-up times, and power supplies used at a low fraction of their rated power therefore have higher harmonic content (and lower power factor). The waveforms shown in Fig 11 are idealised. In a real circuit, because of finite source and circuit impedances the voltage waveform would be flat topped and the current pulses may be slightly skewed.

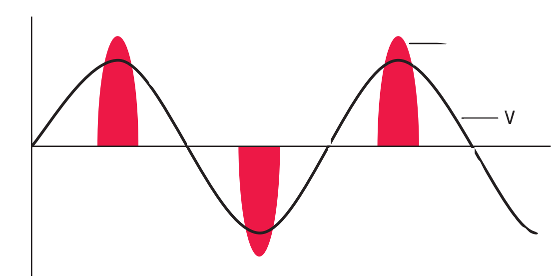

Fig 11. Typical input voltage and current waveforms for switched mode power supplies

Without some form of input waveform correction SMPS fall into class D, (class D only applies up to 600W input power, thereafter class A limits apply). Adequate correction can be achieved by using a series inductor to spread the current waveform sufficiently to move from class D to A. At low power the absolute limits of class A are much easier to meet than the relative limits of D. Above 600W, the absolute limits of class A require a filter inductor with as much copper and iron as a mains transformer of similar rating, making weight and volume advantages of SMPS questionable.

Fortunately, active input waveform correcting circuits and integrated circuit control devices are available. One of the most successful schemes uses a high frequency current mode boost preregulator which forces the input current to follow precisely the waveshape of the input voltage. A voltage control loop regulates the DC output voltage of the rectifier to a constant value above the peak of the AC waveform (typically 380-400V). Very low harmonic amplitudes can be achieved with this technique with power factors well above 0.95. One other major advantage is that universal input operation from 85V to 260V is easily obtained. The disadvantages are increased circuit complexity and cost, lower MTBF, increased space requirement, 5% efficiency reduction, and increased RFI generated.

Another scheme which has shown some promise is a hybrid active/passive approach where a series inductor is switched into the input circuit twice per mains cycle to store energy during the first part of each half cycle when the rectifiers are normally non-conducting, then releasing this energy to the capacitor later in the half cycle, this greatly reducing the peak current and widening the effective conduction angle. This technique uses an inductor less than half the size that a purely passive filter would need, and has successfully achieved power factor in excess of 0.9.

Linear power supplies with capacitor smoothing also have problems meeting the standard. Although the leakage inductance of the mains transformer is helpful, additional series inductance is normally required.

Voltage fluctuations

The standard EN61000-3-3 limits the disturbances on supply systems caused by household appliances and other domestic electrical and electronic equipment. This EN applies to all electrical equipment up to 16A input current, and has a similar calendar of implementation to EN61000-3-2. It is not thought to have significant implications for the design and utilisation of electronic power conversion equipment.

Immunity standards

The majority of users and designers of electronic equipment are familiar with malfunctions caused by susceptibility to electromagnetic disturbances, but unfamiliar with standards specifying immunity levels to ensure proper operation of equipment. This is largely because such official standards are a rarity. For specific applications designers and installers of electronic equipment have successfully dealt with such problems as mains sags and surges, electrostatic discharge, lightning strikes, RFI etc. The initiative to solve these problems has been customer or situation led, rather than an attempt to meet a recognised standard. Now, with the EMC Directive, at least within the EU this approach is no longer acceptable.

IEC801

The attempt to assess equipment immunity arose initially to safeguard the reliable operation of industrial process control equipment. This led to the publication of IEC801, defining susceptibility limits and test methods. Subsequently IEC801 has been expanded in scope, now being applied to a much wider range of electronic equipment than was first envisaged. The first products to be covered were those associated with legally enforceable metering such as petrol pumps and automatic weighing machines. Subsequently domestic electronic equipment, radio and TV receivers came with its scope. The EMC directive now spreads the net wide and brings in virtually all electronic equipment.

The problems addressed in the original publication were electrostatic discharge, RF radio transmissions and mains transients, and these were dealt with as outlined in the following brief summaries.

IEC801 part 2 defines test and measuring procedures to simulate an operator becoming electrostatically charged (due for instance to moving over a nylon carpet) then discharging into the apparatus via accessible metalwork.

Testlevels from 2 kV to 15 kV are recommended, the level used being dependent on the relative humidity and the extent of the use of man-made fibres in the vicinity of the installation.

IEC801 part 3 covers immunity to RF transmission in the band 27-500 MHz (walkie-talkie and private mobile radio bands). The equipment being tested is subjected to the RF field between a parallel plate transmission line (terminated with its characteristic impedance). An appropriate input power is applied to give the correct level of field strength and the frequency is then swept from 27-500 MHz.

IEC801 part 4. This section is of immediate importance to power conversion equipment because it is concerned with immunity to short duration mains transients. The characteristics of the transients to be applied are as follows:

risetime 5 ns +30%
duration 50 ns +30%
burst duration 15 ms
burst period 300 ms

The repetition frequency of the transients within the 15 ms burst zone is 5 kHz for transient amplitudes up to 1 kV and 2.5 kHz for transients of 2 kV and above. Transients are applied for a 1 minute period with no damage or malfunction of the equipment being tested.

EN standards

The above immunity specifications (IEC801) were the basis of the first generic immunity standard to be published, namely EN50082-1 (1992) covering residential, commercial and light industrial environments. A further two IEC801 documents have been issued, IEC801-5 (AC mains surges) and IEC801-6 (conducted RFI). To fully establish this series as general immunity requirements, rather than specific to process control, the IEC has issued the IEC1000-4 specifications and CENELEC has adopted these as the EN61000-4 series. In some instances where IEC draft documents were not yet issed, CENELEC has created ENV documents for interim use. The current situation is summarised in the following table.

Disturbance	IEC Process Control IEC801 series	New IEC general IEC1000-4	CENELEC Interim ENV	CENELEC EN61000-4
Electrostatic Discharge	801-2	1000-4-2		61000-4-2
Radiated RFI	801-3	1000-4-3	ENV50140	61000-4-3
Fast Transients	801-4	1000-4-4		61000-4-4
Mains Surges	801-5	1000-4-5	ENV50142	61000-4-5
Conducted RFI	801-6	1000-4-6	ENV50141	

In addition to the above

Disturbance	IEC	EN
Mains frequency magnetic field	IEC1000-4-8	EN61000-4-8
Pulsed magnetic field	IEC1000-4-9	EN61000-4-9
Damped oscillatory magnetic field	IEC1000-4-10	EN61000-4-10
Supply voltage dips and interruptions	IEC1000-4-11	EN61000-4-11

Product Category Standards

At present there are a few product category standards for immunity progressing such as EN55014-2 (household tools, appliances etc, EN50065-2 (signalling on low voltage installations) and EN55024 (information technology equipment. Immunity characteristics. Limits and methods of measurement).

Where there are no product specific standards in place, compliance with the EMC Directive comes under the generic standard. This will be the requirement for the majority of equipment.

EN61000-6-1 Residential, commercial and light industry
EN61000-6-2 Industrial

Criteria for compliance

These can vary dependent on the test being carried out and whether a malfunction of the equipment is considered to be safety related. Some tests will therefore require that the equipment operates normally without damage or malfunction during the test procedure. For instance, corruption of software or data in process or memory is deemed a test failure in ITE. For non-safety related functions orderly shutdown and manual reset and re-start is allowed.

Component power supplies

Such power supplies, which do not have an identifiable end use independent of the host equipment, do not come within the scope of the EMC directive as a stand alone sub assembly. CE marking of such sub assemblies will demonstrate only that they meet relevant safety requirements and accord to the LVD. However equipment manufacturers will in many instances be unwilling to make the modifications, extra filtering, shielding, input current waveshaping etc needed to incorporate non-compliant power supplies into equipment for sale in the EU. So component power supplies intended for general use will normally comply to relevant standards.

Medical Equipment

Two New Approach Directions, 90/385/EEC Active Implantable Medical Devices (AIMD) and 93/42/EEC Medical Devices Directive (MDD) exempt those specific product categories from the EMC Directive. They contain their own specific EMC requirements. Probably only the MDD will be of interest to power conversion designers and users. The EMC standards cited are IEC601-1-2, adopted by CENELEC and published as EN60601-1-2. Emission standards required follows CISPR 11 (EN55011), normally class B, with a 12dB relaxation for radiated emissions in X-ray rooms.

An important point to note for all products subject to the AIMD, and many products under the MDD (except class I). They cannot be self certified. Approvals must be carried out by Notified Test Organisations.

RFI Filtering in Power Supplies

Nearly all switched mode power converters intended for use on mains supplies are filtered to be compliant with either level A or level B RFI standards when driving steady state loads. When power units are used in “real” situations, driving active electronic circuits, especially those featuring high speed and/or high power switching, the characteristics of the interference generated can change dramatically, thereby reducing the effectiveness of the line filter. It is the final equipment as an entity, that is required to conform to the regulations, not the individual internal sub assemblies. So, specifying a power supply which meets the required RFI level does not remove the need for testing of the completed equipment for conformity.

Internal AC wiring between power unit input terminals and the equipment AC input receptacle, or between the receptacle and other AC driven units (fans, motors, lamps etc.) may well pick up interference which totally bypasses the power units line filters.

The employment of RFI compliant power units is not a guarantee of system compliance.

Design for EMC

Electronic systems must be designed from the outset with EMC considerations in mind. To ensure system conformity to the necessary standards an AC input line filter should be located in an optimum position adjacent to, or integrated with the AC input receptacle. Internal AC and DC distribution wiring should be in twisted pairs, taking the shortest possible routes, should not be bundled together in looms, and should cross other internal wiring at right angles.

The most susceptible wires need to be shielded within a grounded conductive sheath. To keep radiated noise within bounds, known sources of RFI, such as CRT's, HF ballasts and switched mode converter transformers must not be sited adjacent to vent holes or other openings in metal enclosures.

Switched Mode Power Converters

All varying electric currents and magnetic fields generate Electro Magnetic Interference. The more rapid the variation, the higher the amplitude and the broader is the frequency band of the noise emissions generated. Because they employ fast switching transitions at high power, switched mode power converters are a major source of broad band noise. In consequence they tend to incorporate comprehensive line input filters. Typically these filters are similar to those illustrated in Figs 11a and 11b for level A and Level B compliance respectively.

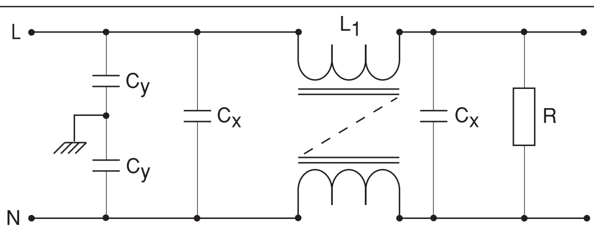

Fig 11a. Typical line filter used in SMPS for VDE 0871 level A compliance

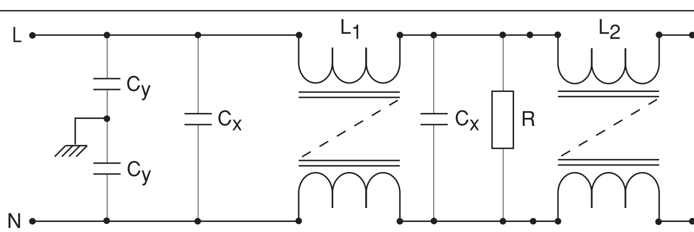

Fig 11b. Typical line filter used in SMPS for VDE 0871 level B compliance

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