Data Sheet

Suppression capacitors- A technical overview

Introduction

Most electrical and electronic equipment generates some form of Electromagnetic Inference, EMI. The high frequency EMI energy is "coupled" to the electronic circuits via cabling and other metal parts which may act as antennas.

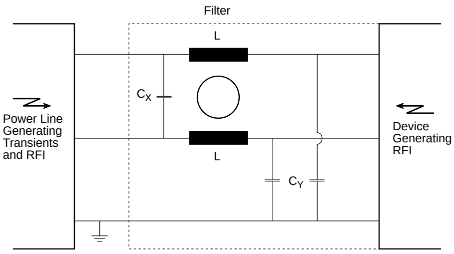
The EMC Directive states that equipment shall be immune to interference and shall not interfere with other equipment.

There are basically three different ways to control and minimise the influence of EMI:-

- Reduce the amount of EMI energy generated in the equipment
- Prevent generated EMI energy from leaving the equipment that produced it
- Protect electronic equipment from the influence of EMI energy in the environment.

The last two options can be effected by connecting a common LC network between the equipment and the mains supply, figure 1. The capacitors in the filter short-circuit the interference and the inductor blocks the interference.

Figure 1 LC network between equipment & mains supply



Electrical environment

The mains supply is theoretically a pure sinewave of 230Vac and a frequency of 50Hz. Several different studies show that frequently there are transients of several kilovolts but with short duration, figure 2. The capacitors in the filter are connected directly to the mains supply and consequently exposed to these transients. There is always a possibility that a transient with high amplitude will break down the dielectric with low insulation as a result. Since the available energy is high and released locally in the dielectric, the consequences can be serious and in the worst case lead to fire.

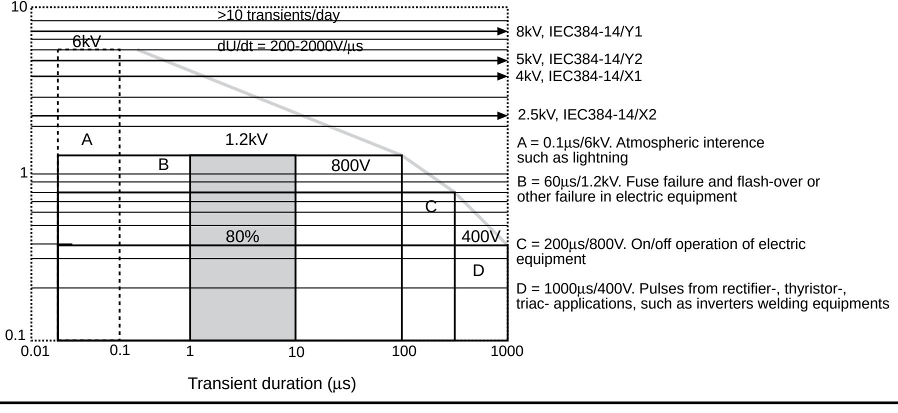
Safety consideration

BS EN132400

Capacitors intended for connection to the mains supply must in most countries be certified by a competent body like Semko, VDE UL, CSA etc. The requirements for approval have been different in the Nordic countries, Germany and Switzerland. The reason for this was differing opinion on essential safety requirements for EMI capacitors and how these should be tested and verified. For many years working groups within IEC and CENELEC tried to find test methods that were relevant to safety aspects and acceptable for all parties involved. The work ended in a second edition of IEC384-14 (1993) and a European standard EN132400 (1994) with the same title.This was followed in 1995 with BS EN132400 which is the new harmonised standard for the UK.

"Fixed capacitors for electromagnetic interference suppression and connection to the supply mains."

Figure 2 Surges on the mains network
(UNIPEDE, Union of Producers and Distributors of Electric Energy)-report:



A = 0.1µs/6kV. Atmospheric interence such as lightning

B = 60µs/1.2kV. Fuse failure and flash-over or other failure in electric equipment

C = 200µs/800V. On/off operation of electric equipment

D = 1000µs/400V. Pulses from rectifier-, thyristor-, triac- applications, such as inverters welding equipments

The capacitors are subdivided into two groups, X and Y.

X-capacitors are for use only in positions where a failure of the capacitor would not expose anybody to danger of electric shock. The capacitor is connected across the supply lines for short-circuiting interference voltages across the line conductors. The capacitor (or failure of it) is not hazardous to anyone who touches the case of the equipment. There are three sub-classes of X capacitors, as shown in Table 1.

Table 1 **X-Capacitors sub-classes**

Sub-class	Peak pulse voltage in service	IEC-664 installation category	Application	Peak impulse voltage Vp applied before endurance test
X1	>2.5 kV ≤ 5.0 kV	III	High pulse application	For C ≤ 1.0 µF $U_p = 4$ kV For C > 1.0 µF $U_p = 4/\sqrt{C}$ kV
X2	≤ 2.5 kV	II	General purpose	For C ≤ 1.0 µF $U_p = 2.5$ kV For C ≤ 1.0 µF $U_p = 2.5/\sqrt{C}$ kV
X3	≤ 1.2	-	General purpose	none

Y-capacitors are for use in positions where a failure of the capacitor could expose somebody to dangerous electric shock. There are four sub-classes of Y capacitors, as shown in table 2. The capacitance of Y capacitors must be limited to a certain value depending on the type of equipment in which the capacitor is used.

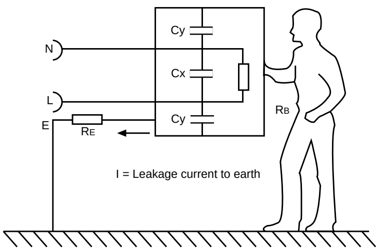
Table 2 **Y-capacitor**

Subclass	Type of insulation bridged	Rated voltage	Peak impulse voltage before endurance test
Y1	Double insulation or reinforced insulation	≤250V	8.0kV
Y2	Basic insulation or supplementary insulation	≥150V, ≤250V	5.0kV
Y3	Basic insulation or supplementary insulation	≥150V, ≤250V	none
Y4	Basic insulation or supplementary insulation	<150V	2.5kV

Note: A short circuit of a Y capacitor, or too high capacitance, is hazardous if the earth line should be open circuit or connected to earth through a too high resistance.

The national approval boards stipulate permitted current towards earth for different applications. A frequent current value for household equipment and portable tools is ≤ 0.5 mA, (Figure 3).

Figure 3 **Earth leakage on equipment**



New test (BS EN 132400)

There are often transients with amplitudes of 2 to 4 kV and a duration of 0.1 to 60 µs on the mains supply. To simulate the stress on a capacitor connected to the mains a new test Active flammability has been introduced and the endurance test modified.

Active flammability

The capacitor is connected to rated voltage through a transformer and a filter. Transients are then randomly introduced on the voltage across the capacitor. The peak voltage is equal to the impulse voltage that defines the different subclasses of X and Y capacitors (see tables 1 and 2). The capacitor is tested with 20 pulses and the requirement is that the capacitor shall not burn with a flame.

Impulse voltage test

Before the endurance test the capacitors shall be submitted to an impulse voltage according to table 1 and 2. Each of the maximum 24 impulses shall be monitored. If any three successive impulses have a waveform indicating that no self-healing takes place in the capacitor no further impulses shall be applied. If all 24 impulses have been applied and more than three have a waveform indicating that no self-healing occurred the capacitor has passed the test.

Endurance test

After the impulse voltage test the same capacitors shall be subjected to an endurance test for 1000 hours at rated temperature and with accelerated voltage.

1.7 x U_R for Y and 1·25 x U_R for X. During the test the voltage is increased every hour to 1000 Vac during 0.1s. After the test there is a voltage proof test and the capacitor's capacitance, dissipation factor and insulation are measured, changes shall be within limits.

The purpose of the new standards is to increase the performance of the EMI capacitor together with safety.

Safety performance relates to three incidents each of which could be catastrophic.

- Fire as a consequence of dielectric break-down
- Fire as a consequence of bad contact between wire, end spraying and electrodes
- Short-circuit of Y-capacitor and a risk of exposing someone to dangerous electrical shock.

Voltage rating and voltage harmonisation in Europe

Manufacturers intending to sell electrical products in Europe could encounter voltages from 207 to 253 Vac in a single-phase system and 360 to 440 Vac for three-phase systems (Table 3). They must ensure that the products will be safe in that range.

EN132400 and IEC 384-14 (1993) indicates that EMI suppression capacitors shall be chosen to have a rated voltage equal to or greater than the nominal voltage of the supply system to which they are connected. In addition, the design of the capacitor should take into account the possibility that the voltage of the system may rise by up to 10% above its nominal voltage.

Table 3. European supply voltage

Nominal supply voltage before January 1995		
UK	240 ± 6% 415 ± 6%	226-254Vac single phase system 390-440Vac three-phase system
The rest	220 ±10% 380 ±10%	198-242Vac single-phase system 342-418Vac three-phase system

Nominal supply in most of Europe from 1 January 1995		
UK	230 + 10/-6% 400 + 10/-6%	216-253Vac single phase system 376-440Vac three-phase system
The rest	230 + 6/-10% 400 + 6/-10%	207-244Vac single-phase system 360-424Vac three-phase system

Radio frequency interference

The European EMC directive prescribes Electromagnetic Compatibility for all electronic and electric equipment place on the market in Europe. A survey of the most important EMC standards is shown in table 4. (European EMC norms).

Table 4 European EMC norms

Product type	EMISSIONS			IMMUNITY
	Harmonics	Voltage fluctuation	Radio interference	All aspects
Household applications and portable tools	EN 60555-2	EN 60555-3	EN 55014 (CISPR 14)	EN 50082-1
Luminaries with charge lamps	EN 60555-2		EN 55015 (CISPR 15)	EN 50082-1
TV-receivers	EN 60555-2		EN 55013 (CISPR 13)	EN 55020
Information Technology equipment ITE	EN 6055-2		EN 55022 (CISPR 22)	EN 55024 all parts
Mains signalling equipment			EN 50065-1	(EN 50082-2)
Industrial, scientific and medical equipment designed to generate rf energy			EN 50081-2 EN 55011 (CISPR 11)	(EN 50082-2)
Industrial electronic power and control equipment			EN 50081-2	(EN 50082-2)

The immunity standards are based on IEC standards:

IEC 801-2	Electrostatic discharge requirements
IEC 801-3	Radiated electromagnetic field requirements
IEC 801-4	Electrical fast transient/burst requirements
IEC 801-5	Surge immunity requirements
IEC 801-6	Immunity to conducted disturbances induced by radio frequency fields

How radio frequency interference is generated

There are two main sources:

1. Inadvertent radio frequency interference as a secondary effect of rapid current or voltage changes in equipment, machines or installations.

Equipment	Interference generator
Household equipment	Commutator motors Thyristor switches Mechanical switches (relays)
Other equipment	Switch mode power supplies HF clock-generators Lighting equipment

2. Intended radio frequency signals

Equipment	Interference generator
Industrial	Oscillators
Scientific	Oscillators
Medical	Oscillators
TV sets	Oscillators
Cars	Ignition systems

Practical suppression examples

Motors

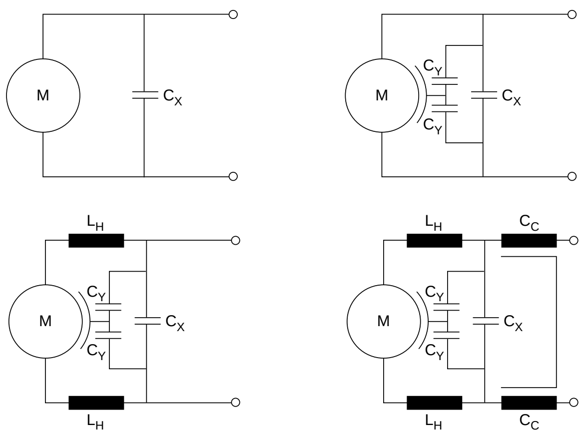
Commutating motors in for example portable tools, sewing machines, vacuum cleaners, mixers etc. generate radio interference from long waves up to VHF. With better commutation less interference is generated. However, it is difficult to achieve good commutation in motors having variable speed.

In figure 4 different ways of suppressing a motor are shown. It is very important that the suppressing capacitor is placed close to the motor so that the terminals of the capacitor can be as short as possible. Sometimes it is enough to use capacitors as suppressors but in most cases when a high level of interference is generated, chokes are also needed.

The X capacitor usually has a capacitance in the range of 0.1 μF and the Y capacitor a capacitance of 2500-5000 pF. The inductance in the high frequency coils is usually 5-50 μH.

Low frequency coils are in the range of 1-4 mH, and often of the current compensated toroid type.

Figure 4 Different ways of suppressing motors, depending upon inner impedance of the motor and the frequency of the interference

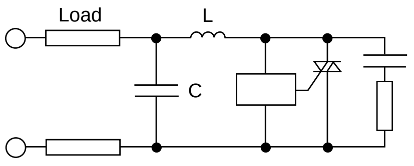


Appliances with thyristors and triacs

Thyristors always generate very high levels of interference on long and medium waves. The noise level on long wave can be as high as 1-2 V (the noise from a commutator motor is hardly more than 30 mV).

Radio interference suppression of a thyristor regulator is often made with a capacitor and a coil as shown in figure 5.

Figure 5 Suppression of a thyristor control circuit



The capacitance is often in the order of 0.1 µF and the inductance is generally 0.1 - 2 mH.

Capacitor design considerations

EMI-capacitors are connected to the mains supply and must be designed for the overvoltage, transients and high frequency signals that exist on the mains supply. These requirements can be transformed into measurable design criteria, and are considered below with reference to impregnated paper and metallised plastic film capacitors.

- High resistance to current surges
- High resistance to voltages surges
- High resistance against ionisation.

High resistance to surge current

Peak current in a capacitor during a voltage surge is proportional to the rise-time of the voltage.

$$\boxed{I_{peak} = C \text{ x } d/dt}$$

A typical capacitance value in an application is C = 0.22 µF and a typical rise time for a transient is du/dt = 2000 V/µs. This gives a peak current in the capacitor of 440 A. Even if the surge current lasts less than 1 µs it is obvious that there will be large stresses in contact areas and metallization. Performance depends on the thickness of metallization, metal and methods for spraying and welding of wire. The du/dt value is a measure of a capacitor's ability to withstand current surge. Typical values for impregnated paper and metallized plastic film are given in table 4. It is normal that the capacitor is tested with 10,000 pulses and a du/dt value five times the specification.

Table 5. du/dt values in V/µs

Dielectric	Class					
	X1		X2		Y	
	spec	test	spec	test	spec	test
Impregnated paper	600	3000	600	3000	2000	10000
Plastic film	100	500	100	500	200	100

Table 5 shows that EMI-capacitors with impregnated paper as dielectric are tested with du/dt values well above the typical rise-time for transients.

High resistance to voltage surges

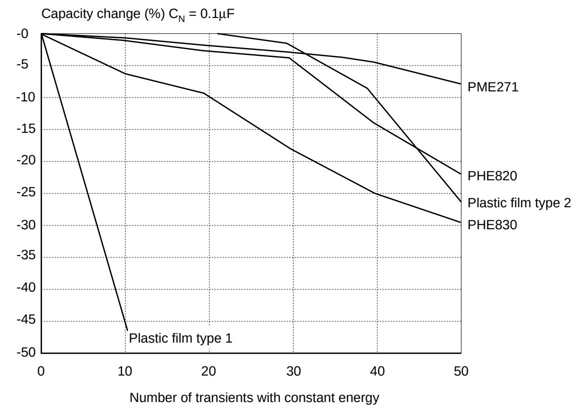
Several different studies show that frequently there are transients with an amplitude of several kilo-volts on the supply mains. In residential areas transients at 2.5 kV should be expected and in industrial areas between 3-6kV. The frequency for the highest amplitudes is between 0.3 to 1 per year. Transients at the level of 2.5kV can be expected 1 to 8 times per year.

A very important feature with metallized film capacitors is their ability to self-heal. When the dielectric breaks down there is, in principle, a channel between the electrodes that can be seen as a short circuit. The current or energy, increases very quickly, ~10ns, from zero to a very high value, 100 - 200mJ. The temperature in the channel increases to a point where the dielectric material near the channel and the electrodes evaporate.

The effect of this process is that the dielectric break-down insulates itself i.e. self-heals. The self-healing process depends on several factors such as electrode thickness, chemical composition of dielectric and process parameters during manufacturing.

Figure 6 shows the results of a test carried out by Evox Rifa, comparing impregnated paper capacitor ranges with two different structures of plastic film capacitors. The test results clearly shows that after 50 transients the decrease in capacitance value in metallized paper capacitors is less than in the other designs. None of the capacitors start to burn during the test.

Figure 6 **Effects of transients on capacitor capacity**



Clearly there has been a number of self-healings in the plastic film capacitors during the test.

High resistance to ionisation

Ionisation is normally a destructive process and EMI capacitors should not operate in that condition.

There are three areas in a capacitor where ionisation is likely to take place:

1. Air pockets in dielectric
2. Air pockets between films
3. Air pockets at the end spraying

When the field-strength in a cavity reaches a critical value there will be an electric break-down. The break-down voltage is called " Discharge inception voltage" and is a function of the gas pressure in the cavity and the size of the cavity, "Paschens law". In general the break-down voltage increases when the pressure in the cavity increases. Dielectric material responds differently to this.

Polypropylene is sensitive to ionisation. It is a soft material and it is difficult to build up a pressure to reduce the discharge inception voltage. The melting point is relatively low and there is a clear risk that the material could begin to melt and the capacitor becomes a short circuit.

Polyester is more resistant to ionisation. It is possible to build up the pressure required to suppress the ionisation.

Impregnated paper contains, if properly impregnated, no cavities - they are completely filled with epoxy. The capacitor is therefore very resistant to ionisation.

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