Radio Interference Suppression of Switch Mode Power Supplies

Switch mode power supplies generate radio interference due to the high frequency switching. This interference propagates through space by means of the electromagnetic fields or via the mains supply in the form of currents and voltages.

The legislation created limits for the levels of interference. These limits are published in the European Standards. Table 7.1 gives some of the most important limits for mobile high frequency equipment (interference class B). High frequency equipment is that which operates at a frequency in excess of 9kHz.

measurand	frequency range	limits	standard
electromagnetic interference at 10m distance	30 to 230 MHz 230 to 1000 MHz	30 dB(µV/m) 37 dB(µV/m)	EN55022 class B
current harmonics in the mains	0 to 2 kHz	see table 6.1 (PFC)	EN61000
conducted-mode interference voltages at the mains wires in repect to earth potential	0.15 to 0.5 MHz** 0.5 to 5 MHz 5 to 30 MHz	66 to 56 dB(µV) Q* 56 to 46 dB(µV) M* 56 dB(µV) Q* 46 dB(µV) M* 60 dB(µV) Q* 50 dB(µV) M*	EN55022 class B

* Q: Measured by quasi-peak detector
M: Measured by average-detector
** Linear decrease to the logarithm of the frequency

Table 7.1: Limits for mobile high frequency equipment class B

Radio interference radiation:
High frequency equipment emission radio interference is measured as radio noise field strength (µV/m) . The amount of radio interference radiation depends on the rise time of the switched currents and voltages and significantly on the layout of the printed circuit board. To keep the radio interference radiation low, three principles should be adhered to:

- Meshes, in which a switched current flows, should be as small as possible in their surrounded area to keep their electromagnetic field low.
- Nodes whose potential are in respect to earth step up and down with switching, should be as small as possilble in their volumetric space, to keep their parasitic capacitance to earth low.
- The switch mode power supply should have a metal housing.

HINT:

In addition to the reduction of the interference radiation, the first two principles are also good for keeping the conducted interferences low, which leave the power supply via the mains. It should also be noted that a high interference level results in inaccurate switching of the transistors and problems with the closed loop control circuit. This often causes audible noise.

Mains input conducted-mode interference:
Switch mode power supplies take high frequency currents out of the mains. These currents cause a voltage drop at the source impedance of the mains which can be measured at the mains terminals. According to the European Standards the interference voltages have to be measured between the mains terminals and earth. For this measurement specific radio interference test equipment is needed which includes a radio interference meter and an artificial mains network. This equipment is required to define a specific mains impedance for comparable measurments.

We distinguish between three different radio interference voltages (see Fig.7.1):

- **Unsymmetric radio interference voltage**: This is the high frequency voltage between earth and each mains terminal. Only this voltage is measured corresponding to the standards. The limits in table 7.1 are valid or this voltage only.
- **Common-mode radio interference voltage (asymmetric radio interference voltage)**: This is the sum of all unsymmetric interference voltages in respect to earth.
- **Differential-mode radio interference voltage (symmetric radio interference voltage)**: This is the high frequency voltage between the mains terminals.

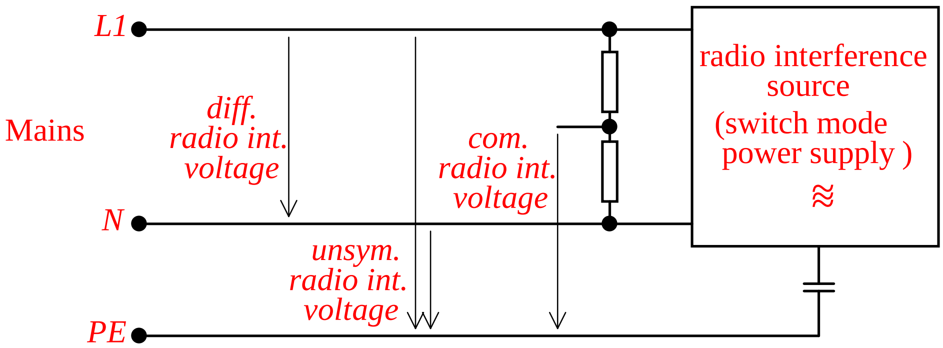

Figure 7.1: radio interference voltages at the single phase mains

Although the legislation requires only the measurement of the unsymmetric radio interference voltages, the common-mode and differential-mode interferences are decisive for the radio interference suppression. The respective suppression of common-mode and differential-mode interference needs different designs and components.

Suppression of common-mode radio interference:

Common-mode radio interference voltages at the mains terminals L_1 and N (for three phase mains L_1, L_2, L_3 and N) are common mode voltages in respect to earth potential PE, which means they are equal in magnitude and phase. The interference currents $I_{\approx}$, which are driven by this common-mode voltage, are also common-mode currents. These flow via earth (earth conductor) and back through the parasitic capacitance C_{earth}. C_{earth} is very low. Due to this, the common-mode interference voltage has a very high impedance, which means that this interference source acts like a current source. A low-pass filter to suppress the interference voltages at the mains terminals must therefore be arranged as in figure 7.2. Looking from the switch mode power supply the required low pass filter must have a shunt capacitor (Cy) and a current compensated inductor. Current compensated chokes are wound so that no magnetic field is generated by the operating current (50- or 60Hz), see figure 7.3. Due to this the choke only acts against the common-mode interference current and does not effect the operating current.

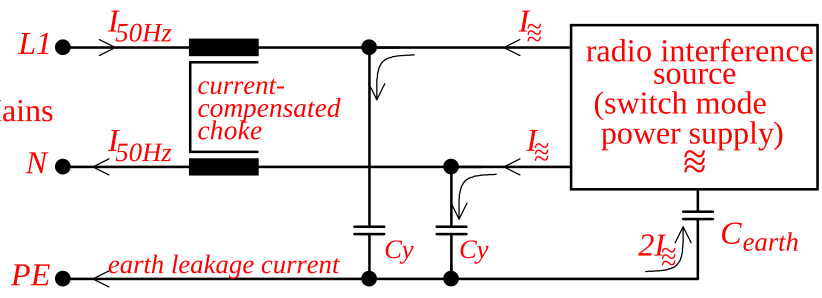

Figure 7.2: Suppression of the asymmetric (common-mode) radio interference voltages

The capacitors are called y-capacitors. Y-capacitors have to fulfil special safety requirements, because they would connect the mains phase to ground in the case of a fault. Y-capacitors may not exceed a certain capacity to ensure that the permitted maximum **earth leakage current** is not exceeded. The earth leakage current is a 50Hz-current (or 60Hz in certain countries). The maximum earth leakage current is 3.5mA (in medical equipment it is a maximum of 0.5mA). According to the standards for the measurement of earth leakage current, terminals L_1 and N have to be connected and the maximum mains voltage has to be applied between L_1 & N and PE. This means that the y-capacitors are in parallel. For the European 230V/50Hz-mains it follows that for the maximum y-capacitor:

$$Cy \leq \frac{1}{2} \times \frac{230\,\mathrm{V} + 10\%}{2\pi\, 50\,\mathrm{Hz} \times 3.5\,\mathrm{mA}} \approx 22\,\mathrm{nF}$$

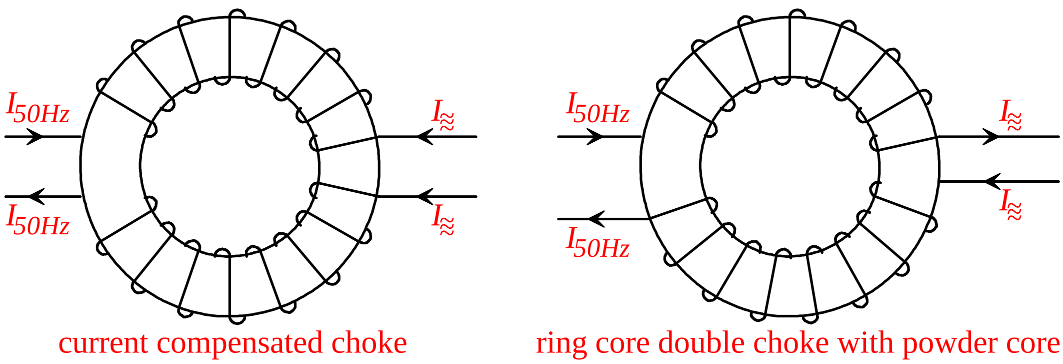

Figure 7.3: left: current compensated choke for common-mode interfernces, right: not current compensated choke (in this case a ring core double choke with powder core) for differential-mode interferences

Suppression of the differential-mode radio interference:

Differential-mode radio interference voltages are high frequency voltages between the mains terminals L_1 and N. To reduce the interference level, a LC-low-pass filter has to be inserted between the mains conductors L_1, N (figure 7.4). The differential-mode interference voltage results mainly from the pulsed current, which is taken from the switch mode power supply from the mains rectifier smoothing capacitor. Due to the impedance of the smoothing capacitor a high frequency voltage is generated between L_1 und N. This is a low impedance which means that the interference source acts as a voltage source. Looking from the switch mode power supply the interference filter must be arranged using a series choke followed by a shunt capacitor (see figure 7.4). The choke must not be a compensated choke, because differential-mode interference current and 50Hz-operating current (which is also a differential type) cause a mgnetic field within the core (see figure 7.3). To avoid saturation these chokes require an air gap. With a ring core the air gap is not visible, because the air gap is achieved due to the amount of glue used in the iron powder. Open cores are also used. With this type the magnetic field loop closes through space. Ring cores are prefered because they have a low magnetic field outside the core.

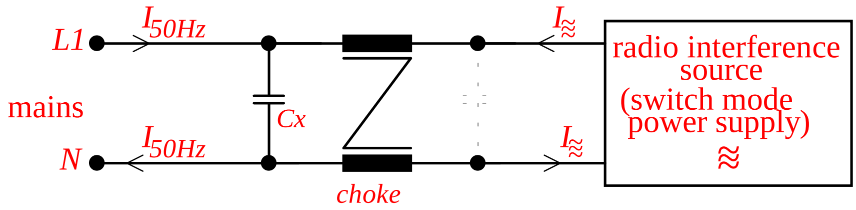

Figure 7.4: Suppression of the differential-mode interferences

The capacitors for this purpose are called **x-capacitors**. They have a lower test-voltage than y-capacitors and are not limited in their value. Foil type capacitors up to 1µF are normally used.

HINT:

Sometimes the impedance of the differential-mode interference source is approximately equal to the mains impedance. In that case a π-low-pass filter using two x-capacitors are appropriate (in figure 7.4 dotted lined).

Complete radio interference filter:

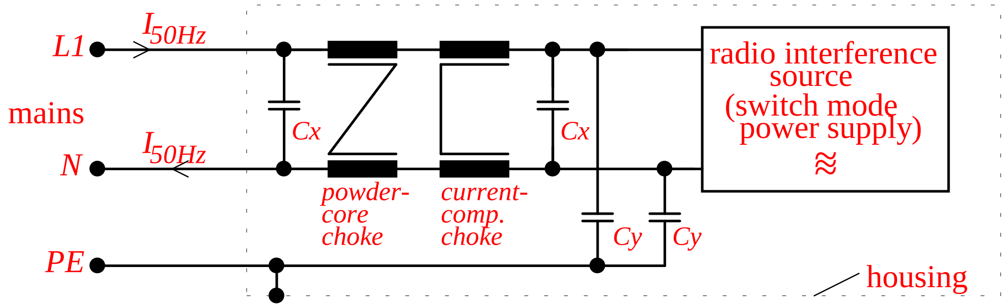

Figure 7.5: radio interference filter for common-mode and differential-mode filtering

Figure 7.5 shows a complete radio interference filter. The component values can be found iteratively and with the help of experience. With the radio interference meter only the unsymmetric interference voltages can be measured. Due to this it is not possible to differentiate between common-mode and differential-mode interference. In practice the operating frequency and several harmonics are differential-mode interference and all high frequencies, say above 5MHz, are common-mode. Often a powder core choke is not required.