POWER LINE FILTERS FOR SWITCHING POWER SUPPLIES

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Abstract. The continuous development of switching power supplies implies more efficient and inexpensive power lines filters. Passive power lines filters are now present in almost all domestics and industrial applications. One major reason for installing a filter directly at the power entry point is the suppression of the conducted emissions that would otherwise be injected directly onto the power lines. Another reason is to suppress noise entering the equipment from the power lines. This article presents a detailed description and evaluation of these "ordinary" passive filters.

Keywords: switching power supply, conducted emissions, passive power lines filter, EMI

Introduction

Power lines filters, often-called EMI filters, are present in almost all equipment, and serves two major purposes:

- First, to suppress the noise generated by the equipment, conducted emissions, which could otherwise be injected directly onto the power lines. The intensity of such emissions is regulated by government agencies in many countries in order not to cause interference with other equipment. In the USA, the Federal Communications Commission (FCC) sets the limits for various classifications of equipment, as a function of it's operating environment. The international authority in this filed is the International Electrotechnical Commission – IEC. All manufacturers must respect the rules and standards issued by IEC. The controlled equipment primarily falls into the broad category of digital devices or those that use digital techniques for any purposes.

- Second, to suppress noise entering in the equipment from the power lines. Such noise can cause malfunction of digital or digitally controlled equipment that may be susceptible to the noise frequencies present on the power lines. Due to its bilateral characteristics, the passive EMI filters serves both of these purposes. The FCC regulates the amplitude of conducted noise frequencies from 450kHz to 30MHz. In Europe, these noise levels are controlled from 10kHz (or 150kHz) to 30MHz. The range of controlled frequencies is broader for devices used in the general market than those used in specific, singular installations.

Since almost all today equipment are powered by switching power supplies operating from 20kHz to near 1MHz, the likelihood of superimposing interfering noise frequencies on the power lines is very great. Therefore, the need for an EMI filter at the power lines entry point is apparent. Although not always recognized, EMI filters also suppresses noise radiated from the power lines (that acts as an antenna). The performances of most filters are specified only up to 30MHz, but the filter will suppress noise at higher frequencies.

The performance of a filter in a particular application may be better understood from its common-mode and differential-mode equivalent circuits. The inductors and capacitors used in a filter are complex components with their effectiveness being dependent on material properties, construction, placement, and means of connection. Similar filters may not perform the same in a given application because of subtle component differences and parasitic parameters. The method used to install a filter in the equipment can have a significant effect on its performance.

EMI Noise Characterization

Any conducted noise may be resolved into two components, common (asymmetrical) and differential (symmetrical) modes. An understanding of these modes will assist in analyzing the performance of an EMI power lines filter. Common mode noise is that noise which is identical on each line with respect to ground. Differential mode noise is that part of the total noise that occurs between the two lines with no reference to ground. The common mode currents - I_{CM} are identical at any one frequency in both amplitude and phase. The differential mode current - I_{DM} is a single current in the loop consisting of the power lines.

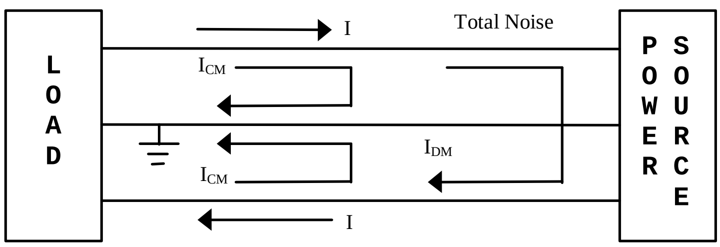


FIGURE 1. Common Mode and Differential Mode Noise Currents

The common mode currents are the same in both lines, with their return being the ground connection. The differential mode current does not flow in the ground connection. At any one frequency, the total noise current in one of the lines can be expected to be higher than that in the other line. It depends on the amplitude and phase of the component noise current at that frequency, since the total noise current in one line is the sum of the components in one case and their difference in the other.

There are several reasons, theoretical and practical, why it is difficult to predict conducted EMI:

1) Differential and common mode noises are coupled through different paths to the measured EMI. Equipment package and component layout all affect the coupling paths, but the effects are very difficult to quantify. Often, a small change in layout could lead to significant change in EMI performance.

2) The effectiveness of an EMI filter depends not only on the filter itself but also on the noise source impedance.

3) Beyond a certain frequency, the effect of parasitic elements starts to surface. This frequency is the border between “high frequency” and “low frequency”. High-frequency effects include permeability reduction of choke core, parasitic capacitance effect of the inductor and the parasitic inductance effect of the capacitors.

Low Cost Power Lines Filter

A typical power lines filter is a simply low-pass filter that provides no attenuation to the power frequency but provides large (ideal infinite) attenuation to RF energy. Consequently, an EMI power lines filter consists of series of inductors and shunt capacitors.
The inductors may take two forms. The most common inductor found in almost all low-cost filters is a single magnetic core structure wound with two coupled windings, one in series in one line and the other in series in the other line.

In the case of multiphase or split phase filters, the common core inductors must have identical windings connected in each power current carrying line. Similarly, the independent inductors would appear in each of these lines. The principles will be discussed for single-phase filters in this paper.

In order to increase the effectiveness, filters often include capacitors connected from line-to-line and others connected from line-to-ground.

A simple EMI power filter circuit diagram is shown in Figure 2:

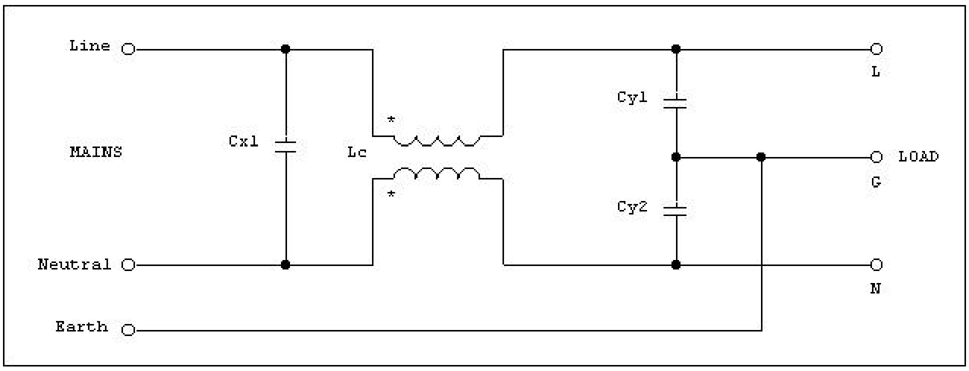


FIGURE 2. A Simple Low Cost EMI Power lines Filter
C_{x1} - Line to Line Capacitor; $C_{y1,2}$ – Line to Ground Capacitor; L_c – Common Core Inductors

On notice the presence of only one inductor (L_c) and a single line-to-line capacitor (C_{x1}). Line-to-line capacitors are usually made of metal vaporized film or film and foil. Such capacitors have a relatively high value 0.1µF to 1.0µF (their self-resonant frequency is from 1MHz to 2MHz). Thus, they are more effective against lower frequency, differential-mode noise. Line to ground capacitors must be of very low value, from 1.0nF to 10nF (ceramic capacitors with very short leads that resonate at 50MHz or more).
Any capacitor, at a frequency higher than its self-resonant frequency, is an inductor and is, therefore, a less effective EMI filter component. The impedance increases with frequency. This is important in selecting the type of the capacitor and the mounting mode into the filter.
Inductors, like capacitors, are not purely inductive. The windings, by their nature, are shunted by distributed capacitance. Depending on the inductance value, the windings geometry and the core material, coil self-resonance frequency typically occurs in the range of 150kHz to 2MHz.

High Efficiency Passive Power lines Filter

A more complex filter is presented in Figure 3. It is often called the "*total EMI filter*". The basic structure is similar with the simple EMI filter. There are some extra elements, two inductors, L_{d1} and L_{d2} and one condenser C_{x2} connected in a low pass configuration.

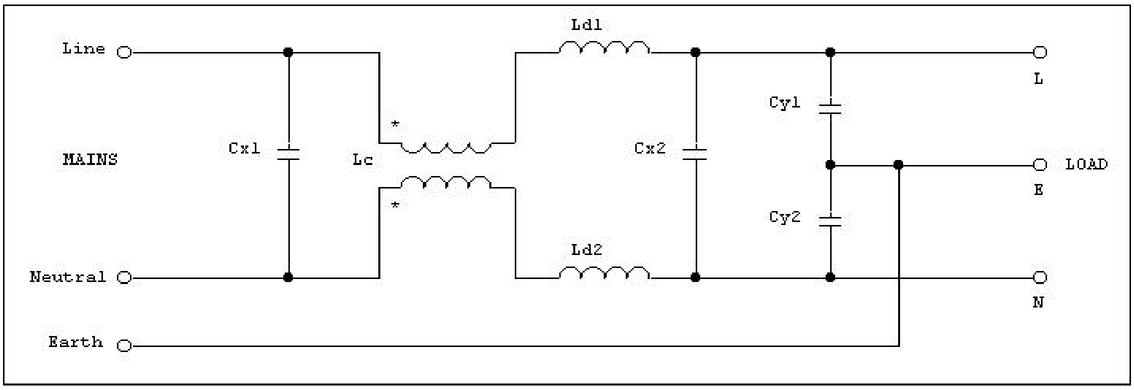


FIGURE 3. A Complete EMI Power lines Filter
C_{x1} - Line to Line Capacitor; C_{x2} – Line to Ground Capacitor; $C_{y1,2}$ - Line to Ground Capacitor;
L_c - Common Core Inductors; $L_{d1,2}$ – Independent inductors

The design of the two independent inductors L_{d1} and L_{d2} must take into account both the saturation characteristics of the core material relative to the rated current and the turns required to achieve the desired inductance. Otherwise, the core would be saturated under normal operating conditions and be ineffective as a filter component. The two windings of such a component are designed with equal number of turns, so that the magnetic forces around the core due to the power currents in these windings cancel.

An EMI filter will most often contain a bleeder resistor to discharge the line-to-line capacitors when power is interrupted (R_{x1}, $R_{y1,2}$ in Figure 5). They have no effect in filter performance. If a ground choke is included in the filter, it will suppress common, not differential, mode noise.

A Practical Approach

We made some measurements using a standard forward switching power supply based on a UC3844 specialized IC. The load was a 10 ohms resistor in series with a 10mH inductance.

For the filter, we used the more complex one (Figure 4). The condition for the filter is to meet the VDE limit (that is more than 10dB attenuation for 10Hz to 150kHz frequency range and more than 20dB for 150kHz to 30MHz range).

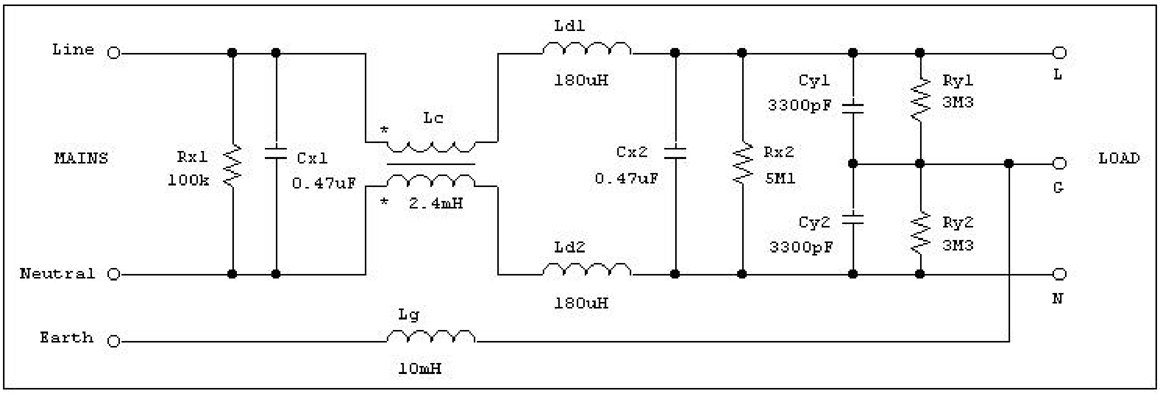


FIGURE 4. The filter used to measure the noise of a 100W forward switching power supply

$$f_{RCM} = \frac{1}{2\pi\sqrt{L_{CM}C_{CM}}} = \frac{1}{2\pi\sqrt{\left(L_c + \frac{1}{2}L_d\right)2C_y}} \cong \frac{1}{2\pi}\cdot\sqrt{\frac{1}{L_c.2C_y}} \tag{1}$$

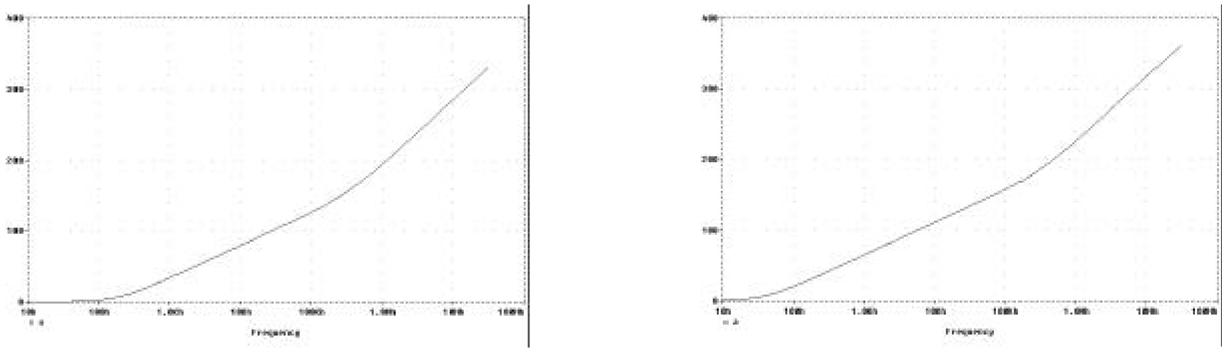
$$f_{RDM} = \frac{1}{2\pi}\cdot\frac{1}{\sqrt{L_{DM}.C_M}} = \frac{1}{2\pi}\cdot\sqrt{\frac{1}{(2L_d + L_{loss}).C_{DM}}} \tag{2}$$

where:

$$L_{CM} = L_c + 0.5.L_d\,;\; L_{DM} = 2.L_D + L_{loss} \tag{3}$$

Imposing the two frequencies, we can calculate the elements of the filter in Figure 4.

The attenuation provided by the filter for the differential-mode and common-mode are presented in Figure 5.a) and 5.b).



a) differential-mode attenuation

b) common-mode attenuation

FIGURE 5. The diagram of the differential-mode and common-mode attenuation obtained with the filter in Figure 5

Conclusions

The performance of a filter, in a particular application, may be better understood from its common-mode and differential-mode equivalent circuits. The inductors and capacitors used in a filter are complex components with their effectiveness being dependent on material properties, placement and means of construction.

Similar filters may not perform identically in a given application because of subtle component differences and parasitic parameters. Many parasitic parameters exist in any filter, which are not determined by measurements. All of these, plus the properties of the materials in the components will likely make two apparently identical filters behave differently in any given application. Power lines filters used in switching power supplies are exposed to over-voltages witch can cause damages especially to the filter capacitors.

References

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