All about EMI filters

Selecting these devices requires identifying the type and source of interference as well as applicable standards

BY MEL BERMAN
TDK-Lambda Americas
San Diego, CA
http://www.us.tdk-lambda.com/lp

All electronic equipment produced today includes EMI filtering circuits. Likewise, all switch-mode power supplies have internal EMI filters. However, there are circumstances where the EMI filters within these electronic devices require a supplemental filter to meet more stringent electrical noise regulations or to protect the device from excessive external noise sources.

Defining the noise

EMI can be in form of conducted EMI, which means the noise travels along electrical conductors, wires, printed-circuit traces, or electronic components such as transformers, inductors, capacitors, semiconductors, and resistors.

Electrical noise can also be in the form of radiated EMI (RFI), noise that travels through the air or free space as magnetic fields or radio waves. RFI is usually controlled by providing metal shielding that contains the magnetic fields or radio waves within the equipment's enclosure.

Meeting EMC standards

EMI filtering circuits are employed so the end product complies with applicable EMC standards. Among the most frequently cited EMC standards are EN55022 for IT equipment, EN55011 for industrial equipment, and, in the U.S., FCC Class A for commercial or industrial equipment or FCC Class B for residential equipment.

FCC Class B is tougher and more restrictive than Class A. For the majority of these standards, the conducted EMI frequency range is usually defined as being between 150 kHz and 30 MHz, as measured by a spectrum analyzer. In some cases, this range begins as low as 10 kHz. By comparison, RFI is usually defined to range from 30 MHz to 1 GHz.

EMI sources

Most electrical and electronic devices can generate and/or be affected by EMI. Sources are everywhere and include ac motors, fluorescent bulbs/ballasts, light dimmers, microwave ovens, microprocessors, computers, and switch-mode power supplies.

Within switch-mode power supplies, a high dc voltage is chopped or switched at a high frequency that can range from 50 kHz to 1 MHz. This high-speed switching process is intrinsic to switch-mode power supplies and provides its improved efficiency and reduced size when compared to linear power supplies.

However, as a side effect, this switching generates unwanted EMI. In fact, most conducted EMI within switch-mode power supplies originates from the main switching MOSFETs, transistors, and output rectifiers.

In either power supplies or electronic equipment, it is the function of the EMI filter to keep any internally generated noise contained within the device and to prevent any external ac line noise from entering the device. EMI filters usually comprise a network of passive electronic components including capacitors and inductors that form L-C circuits.

Since unwanted EMI is at much higher frequencies than normal signals, the EMI filter works by selectively blocking or shunting unwanted higher frequencies. Basically, the inductive part of the EMI filter is designed to act as a low-frequency pass device for the ac line frequencies and a high-frequency blocking device.

Other parts of the EMI filter use capacitors to bypass or shunt unwanted high-frequency noise away from the sensitive circuits. The net result is that the EMI filter significantly reduces or attenuates any unwanted noise signals from entering or leaving the protected electronic device.

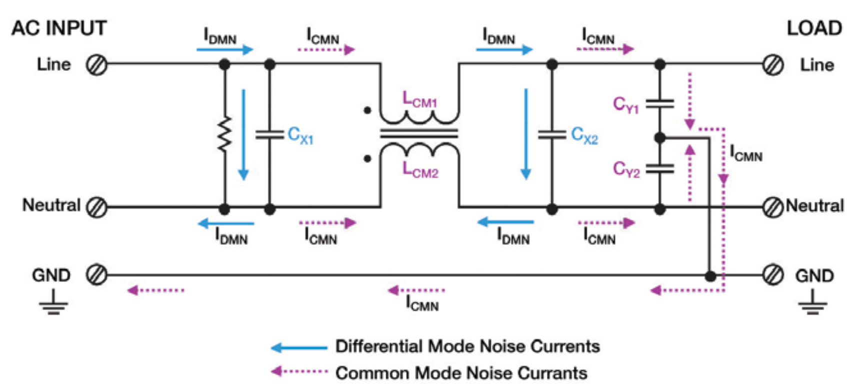

Fig. 1. The schematic shows a typical EMI filter used to suppress conducted EMI noise.

Common and differential-mode noise

Conducted EMI is divided into two main types: Common-mode noise (CMN) and differential-mode noise (DMN). CMN, a.k.a. asymmetrical noise or line-to-ground noise, exists on both sides of the ac input (line and neutral), in-phase with itself relative to ground.

The CMN current flows in the same direction on both power conductors and returns via the ground conductor. CMN can be suppressed by the use of inductors within an EMI filter that are placed in series with each power line and by Y-capacitors that are connected from both power line conductors to ground.

DMN, a.k.a. normal mode, symmetrical noise, or line-to-line noise, exists between the ac line and neutral conductors and is 180° out of phase with itself. The DMN current flows along one ac conductor and returns along the other. No DMN current flows in the ground conductor.

DMN can be suppressed using X-capacitors—within an EMI filter—connected between the power lines (line and neutral) and act as high-frequency shunts for the differential noise. In cases where DMN is very high, differential-suppression inductors may need to be added. Some hybrid inductors contain windings that suppress both common and differential-mode noise.

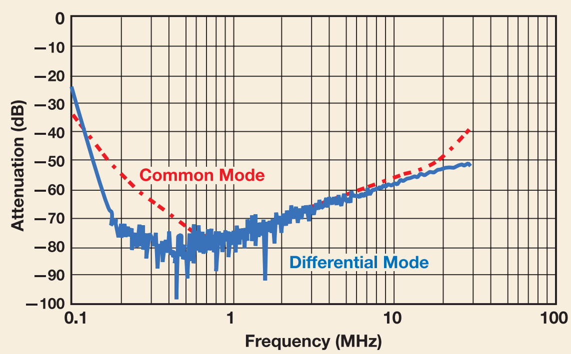

Fig. 2. This insertion-loss plot shows the attenuation versus frequency for a high-performance EMI filter.

Parasitic noise

Parasitic noise relates to the electrical noise (CMN and DMN) generated or transferred within a circuit by unexpected means. For example, switching semiconductors mounted on a PCB or heat sink with a thin insulator can contain small amounts of parasitic or stray capacitive elements.

These inadvertent stray capacitive elements at high frequencies—or with very fast switching pulse rise and fall times—facilitate the transfer or coupling of parasitic noise to other parts of the circuit or system. The same holds true for all electronic components.

For example, transformers have small amounts of capacitive elements between their windings that cannot be fully eliminated. Likewise, capacitors and printed-circuit traces have small inductive elements within them that show up at high frequencies and allow unwanted parasitic noise to be transferred from one point to another. Parasitic noise is one of the prime contributors to common- and differential-mode noise within switch-mode power supplies and many electronic OEM products.

In *Fig. 1*, CMN is suppressed by using dual-wound toroid-type inductors (L_{CM1} and L_{CM2}). These inductors are wound on a single core in such a way that they present a high impedance to the in-phase common-mode noise on each ac conductor. In addition, the Y-capacitors (C_{Y1} and C_{Y2}) shunt or bypass the high-frequency common mode noise to ground.

DMN on each ac conductor is suppressed by the two X-capacitors (C_{X1} and C_{X2}), which tend to neutralize the out-of-phase high-frequency DMN that exists between the ac power line and neutral conductors. The input resistor discharges these capacitors when the power is turned off.

When extra filtering is needed

Although all ac/dc power supplies have internal EMI filters that comply with the various EMC standards, there are cases where the circuits or systems they provide power to generate much more electrical noise than the filter can suppress by itself. In other cases, when multiple power supplies are working off the same ac power source, the small amount of noise that is not filtered or contained by each supply's internal EMI filter can combine to form an unacceptable level of noise.

In addition, there are times when the ac power line entering the power supply has so much noise on it that an additional EMI filter is required. This incoming noise can be in the form of a spike or burst of energy. It can be generated from natural causes—such as a lightning storm—or be man-made by someone operating a piece of industrial equipment containing large motors, actuators, solenoids, etc.

In all of these cases, it may be necessary to install an external or auxiliary EMI filter to bring the electrical noise down to acceptable levels. These EMI considerations apply to the design and installation of all electronic products or systems.

Standard external EMI filters typically have single-stage L-C circuits, similar to those in Fig. 1. For higher-performance EMI filtering, two-stage L-C circuits may be required. And, if electrical spikes from motors or lightning strikes are a potential problem, EMI filters with high voltage pulse attenuation should be used.

EMI filter specs

Many specs and ratings must be considered when selecting EMI filters. These include case size, I/O connections, mounting type, safety agency approvals, operating voltage, operating current (ac or dc amps), leakage current, isolation resistance, withstand test voltages, high-voltage pulse or spike attenuation, operating temperature range, dc resistance, and insertion loss.

For medical applications, the installed leakage current and withstand test voltages of the final assembly are important parameters for meeting the EMC requirements relative to patient safety.

Insertion loss information (see *Fig. 2*) for an EMI filter is usually presented in the form of graphs, plots, or tables that show how well the EMI filter attenuates or suppresses the conducted differential and common-mode noise within its operating range.

Testing for EMC compliance

As mentioned previously, the usual frequency range specified in most EMC standards for conducted EMI emissions is from 150 kHz to 30 MHz. To confirm that an electronic device meets the limits of a specific standard, it must be tested with a spectrum analyzer and a line impedance stabilization network (LISN).

Ac power is routed through the LISN to the device under test. The LISN standardizes the measurement impedance to 50 Ω and provides an isolated RF output to a spectrum analyzer, which provides a plot of the conducted emissions coming from the device.