Applications of EMI/EMC Line Filters

All electronic equipment produced today includes EMI/EMC filtering circuits. Likewise, all switchmode 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.

What is an EMI filter, what does it do, and why might you need one?

EMI is an abbreviation Electromagnetic Interference and is defined as any unwanted electrical disturbance that can cause an undesirable effect on electrical or electronic equipment. EMI is commonly referred to as electrical noise that is well beyond the fundamental AC input frequency.
This electrical noise can be in the form of Conducted-EMI, which means the noise travels along electrical conductors, wires, printed circuit traces and via AC or DC electronic components including transformers, inductors, capacitors, semiconductors, resistors, etc.

Electrical noise can also be in the form of Radiated-EMI, which means the noise travels or radiates through the air or free space as magnetic fields or radio waves. In fact, Radiated-EMI is also known as Radio Frequency Interference or RFI. RFI is usually controlled by providing metal shielding that contains the magnetic fields or radio waves within the equipment's enclosure. For example, the metal case of a switchmode power supply provides good radiated EMI shielding. Many times the enclosure of electronic equipment, including EMI filters, is either made of metal or sprayed with an internal coating that provides RFI shielding.

EMC Standards and EMI Filters

EMI filtering circuits are employed so the end product complies with the applicable EMC standards. EMC is the abbreviation for Electromagnetic Compliance and refers to the ability of a device or system to function reliably in the presence of EMI (susceptibility) and to limit its internally generated EMI (emissions) to avoid affecting other equipment. EMC limits are set by standards that have been established by the FCC (Federal Communication Commission) and CISPR (Special International Committee on Radio Interference). Many of these international EMC standards have EN prefixes, which refers to the Euro Norm or European standard.

Among the most frequently cited EMC standards are: EN55022 for Information Technology Equipment (ITE), EN55011 for Industrial Equipment and, in the USA, FCC Class A for Commercial or Industrial Equipment or FCC Class B for Residential Equipment. The 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, radiated-EMI is usually defined to be in the range from 30 MHz to 1000 MHz (1 GHz).

Sources of EMI

Sources of EMI are everywhere and include AC motors, fluorescent bulbs/ballasts, light dimmers, microwave ovens, microprocessors, computers and switchmode power supplies to name a few. Most electrical and electronic devices can generate and/or be affected by EMI. Within switchmode 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 switchmode power supplies and provides its improved efficiency and reduced size when compared to linear power supplies. But, as a side effect, this switching generates unwanted EMI. In fact, most of the conducted EMI within switchmode 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/EMC filters are usually comprised of a network of passive electronic components including capacitors and inductors that form LC circuits. Since the unwanted EMI is at much higher frequencies than the normal signals, the EMI filter works by selectively blocking or shunting the 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 the 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 (e.g., electronic equipment, switchmode power supply, etc.).

Common and Differential Mode Noise

Conducted EMI is divided into two main types: Common Mode Noise (CMN) and Differential Mode Noise (DMN).

Common Mode Noise (CMN) is also known as Asymmetrical Noise or Line-to-Ground Noise. This noise exists on both sides of the AC input (Line & Neutral) and is 'in-phase' with each other relative to Ground. The common-mode-noise current flows in the same direction on both power conductors and returns via the Ground conductor. The 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.

Differential Mode Noise (DMN) is also known as Normal Mode, Symmetrical Noise, or Line-to-Line Noise. This noise exists between the AC Line and Neutral conductors and is '180° out-of-phase' with each other.

The differential-mode-noise current flows along one AC conductor and returns along the other. No DMN current flows in the Ground conductor. The DMN can be suppressed by the use of X-capacitors within an EMI filter that are connected between the power lines (Line & Neutral) and act as high frequency shunts for the differential noise. In cases where the DMN is very high, differential suppression inductors may need to be added. There are 'hybrid inductors' that contain windings that suppress both common and differential mode noise.

Parasitic Noise

You may see or hear the term Parasitic-Noise, which relates to the electrical noise (both CMN and DMN) that is generated or transferred within a circuit by unexpected means. For example, switching semiconductors mounted on a printed circuit board or on a 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 within an electronic circuit or system. Parasitic noise is one of the prime contributors to common and differential mode noise within switchmode power supplies and many electronic OEM products.

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 to effectively reduce that noise. 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 man made by operating a piece of industrial equipment containing large motors, actuators, solenoids, etc.

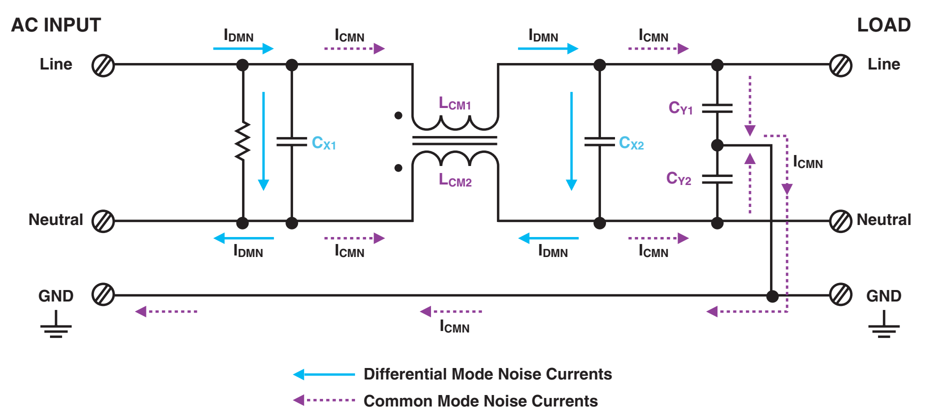
In all of these cases, it may be necessary to install an external or auxiliary EMI filter to bring the electrical noise down to acceptable levels. These EMI considerations apply to the design and installation of all electronic products or systems.

Standard external EMI/EMC filters typically have single stage LC circuits similar to what is shown in Figure 1. For higher performance EMI filtering, two stage LC circuits may be required. In addition, if electrical spikes from motors or lightning strikes are a potential problem, EMI filters with high voltage pulse attenuation should be used.

There are many EMI filter specifications and ratings that need to be considered when making a selection; these include: Case Size, I/O Connections, Mounting Type, Safety Agency Approvals, Operating Voltage, Max. 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.

The Insertion Loss information 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. See Figure 2.

Figure 1: Typical EMI Filter

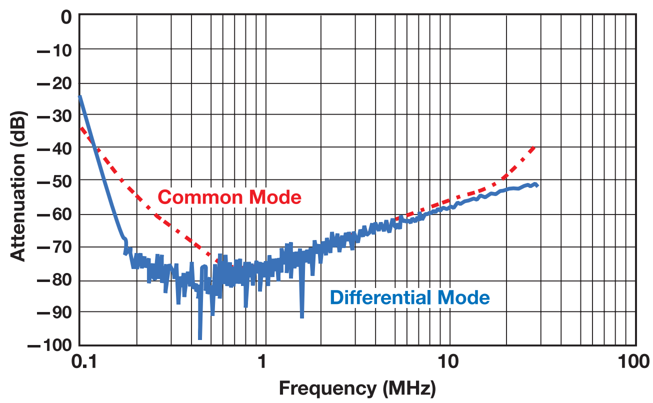


The above schematic diagram shows a typical EMI filter that is used to suppress conducted EMI noise.

The Common Mode Noise (CMN) is suppressed by using dual-wound toroid type inductors LCM1 & LCM2. 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 CY1 & CY2 shunt or bypass the high frequency common mode noise to Ground.

The Differential Mode Noise (DMN) on each AC conductor is suppressed by the two X-capacitors CX1 & CX2. These X-caps tend to neutralize the 'out-of-phase' high frequency differential mode noise that exists between the AC power Line and Neutral conductors. The input resistor discharges these capacitors when the power is turned off.

Figure 2: TDK-Lambda EMI Filter P/N RSMN-2006



Insertion Loss plot shows the Attenuation in dB versus the Frequency in MHz for a high performance TDK-Lambda EMI filter.

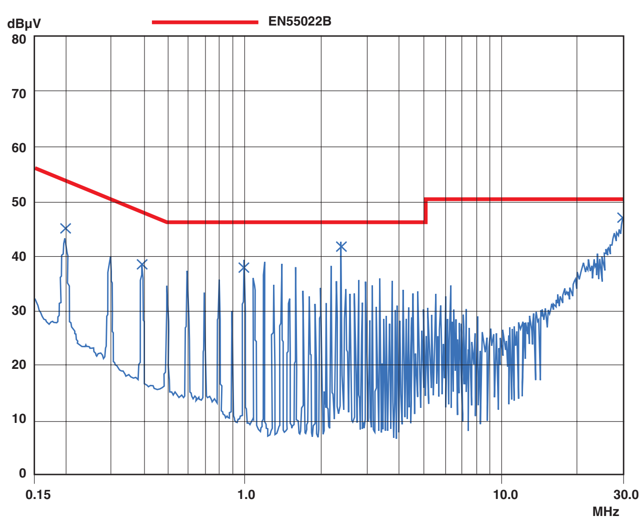
Tests for EMC Compliance

As mentioned previously, the usual frequency range specified in most EMC standards for conducted EMI emissions is from 150kHz to 30MHz. To confirm that an electronic device meets the limits of a specific standard it must be tested with a spectrum analyzer along with a special network called a LISN (Line Impedance Stabilization Network). The AC power is routed through the LISN to the device under test. The LISN standardizes the measurement impedance to 50 ohms and provides an isolated RF output to a spectrum analyzer, which in turn provides a plot of the conducted emissions coming from the device. Figure 3 below is a sample plot of a TDK-Lambda Vega Series power supply that was tested relative to conformance with the EMC standards per EN55022 Class B.

In summary, the function of the EMI/EMC filter is to keep any internally generated noise contained within the electronic equipment and to prevent any external noise from entering or affecting the equipment. EMI consists of both common mode and differential mode noise which the filter has to attenuate to levels established by local and international standards. Switchmode power supplies by their nature internally produce high levels of noise which must be carefully filtered. All electronic equipment need to have EMI filtering circuits in order to meet the EMC standards established by the FCC and/or CISPR organizations. And, in some system installations external EMI filters may be required to meet these standards.

For more information about TDK-Lambda's EMI/EMC Line Filters and our wide range of AC-DC power supplies and DC-DC converters, please visit our web site at: www.us.tdk-lambda.com/lp
Or call us at our toll free number: 1-800-LAMBDA-4.

Figure 3: Graph Of Typical Average Conducted Emissions Vega 650



This figure shows the noise emissions performance of a TDK-Lambda Vega Series switchmode power supply with an internal EMI filter relative to the limits set by (Euro-Norm) EN55022 Class B, which is more stringent than Class A. Since the measured noise levels remain below the limit line from 150 kHz through 30 MHz, this unit meets EN55022B.