Filter Location Can Affect Performance

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When designing a product to meet electromagnetic regulations, it is usual that electrical filters are employed. However, the use of these filters can sometimes cause confusion when they did not perform as expected. The reasons are not always obvious and may not be an issue with the filter itself.

Aspects which will determine the filter used include maximum current the filter must handle, maximum voltage the filter must withstand, and the performance or amount of reduction of the electrical noise the filter must prevent from transmitting through, often called the insertion loss. Passing more current than the filter is rated for can cause internal inductors to become saturated and wiring to overheat and possibly fail. Excessive voltages can breakdown the insulation on wire and inductor windings, and cause capacitors from line to line or line to ground to fail.

But what if the performance is not as good as hoped? What can be done to help? And what might be the cause?

First, it must be understood that the performance charts provided with filters are typically based on ideal 50 Ω measurements. That means that if an inductor has 20 dB of filtering, it must have about 500 Ω impedance in series. A capacitor may shunt current to ground with 5 Ω impedance to provide 20 dB of filtering. The actual performance seen in actual installations will be different since they are not ideal 50 Ω impedances. High impedance circuits may not benefit as much from the inductance, but the capacitor's performance may improve. Most filter designs are π filters which include a line-to-line capacitor, or X-Capacitor, then a common mode inductor, then a pair of line to chassis capacitors, or Y-Capacitors.

It is important to understand the difference between differential mode current and common mode currents. Differential mode means the energy is transported on one wire in one direction and will return on an adjacent wire or wires in the opposite direction. A power cord is a good example, where current flows on the phase or hot line, and comes back on neutral or return. Common mode energy is created when a voltage or current is created on two or more lines at the same time and in phase with each other. The return path for common mode energy may be on other remote wires, or other current paths such as earth or ground planes, or by radiation back to the chassis or other cables.

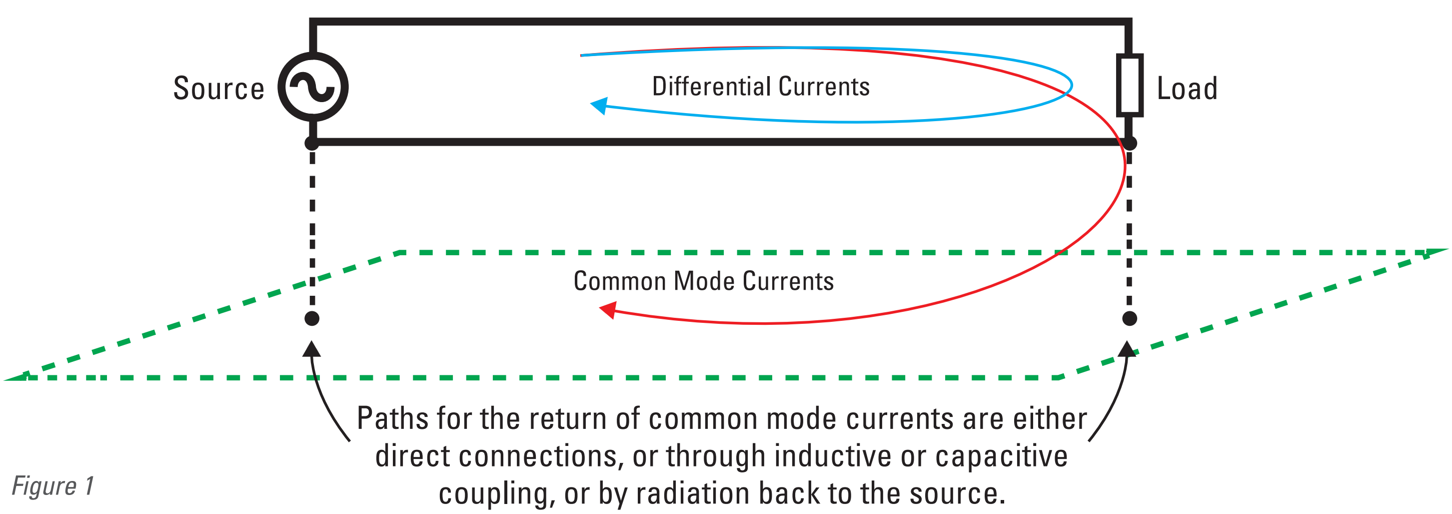

Figure 1

In Figure 1, differential mode currents are shown with the blue line. If the two wires are close together, such as a power cord, the area indicated by the blue line becomes very small, and the size of the loop which can transmit or receive energy is also very small. However, common mode currents, shown with the red line, can have very large loop areas, and become very effective radiators or receptors of external energy.

Common mode energy can be created when a device has a voltage which is created between it another object, typically the chassis. It can also come from a significant current on a trace or wire to that device and induce a magnetic field in an adjacent circuit or wire.

The energy or electrical noise to be eliminated by the filter can be generated outside of the equipment and coupled into the equipment creating a susceptible condition, or it can be generated inside and by the equipment and then transmitted outside, causing an emissions problem. Conducted emissions issues at lower frequencies, say below a few Megahertz as an example, can often be differential mode in nature while higher frequencies are more common mode. Radiated emissions is typically common mode energy, and often is radiated off cables, especially from smaller equipment. This is because wires are large antennas in comparison to a smaller device or equipment.

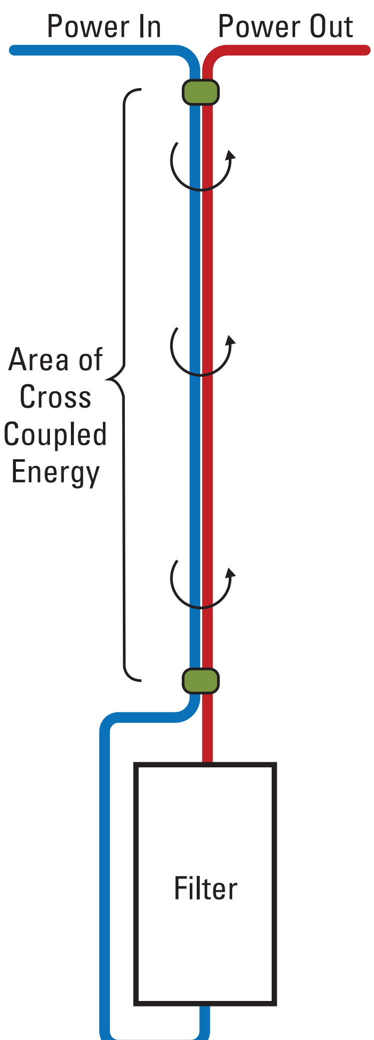

Figure 2

These same energies which are cross coupled in unwanted manners can be the cause of degraded filter performance. An example is when a filter is not placed near the entrance of the equipment, internal energy from the equipment can couple onto the wires which leave the equipment on the line side of the filter. So, if the input power and the output power to the filter are coupled together, the energy which is on one set of wires will couple onto the adjacent wires. This will effectively bypass the filter, rendering it ineffective. An example of this is shown in Figure 2.

If the unwanted energy is mainly due to high currents, the result will be inductive coupling due to the induced magnetic fields. If the energy is voltage based, such as voltage transients or spikes from a high impedance source, the coupling will be capacitive in nature. In addition, it is highly recommended that the Data/Signal Cables should not be run in **parallel**, as this can cause inductive coupling. The greater the distance, the lesser the coupling.

To cross couple energy onto lines which are intended to be filtered does not require such a close coupling of cables. Assume that a cable which comes into a piece of equipment does not connect directly to the filter. The cable may be allowed to run parallel to circuit board or other electronics, and to the back of the equipment where a secondary power switch or breaker is located. From this point the power is then routed to a filter, and onto the circuit board. Is this a problem?

Potentially yes. If the cable is coming from an electrically noisy location, say an industrial location where significant radio frequency energy is being generated, that energy may have coupled onto the cable. This energy, converted to currents, is then allowed to be routed into the equipment and parallel to a circuit board where that energy can either inductively or capacitively cross couple into sensitive circuits, which may upset their normal operation. Conversely, the circuit board may have radio frequency generators such as microprocessors or radio frequency transmitters, or if it has large magnetic sources, such as transformers or non-toroid inductors. The cable leaves the circuit board and is routed to the filter. However, the cable is then routed next to the circuit board before leaving the equipment. While next to the circuit board, energy can cross couple again back onto the cable which is intended to be filtered. This process effectively bypasses the filter.

Here, the use of IEC Input Filter Modules might be beneficial. This is an input module style filter and is designed to be placed in the metallic wall of the equipment, creating an automatic separation of the input from the output. But this alone does not guarantee success. If the chassis of the equipment is non-conductive or the chassis metallic structure is not well bonded together, fields on one side of the chassis can couple directly to the other side with little or no attenuation.

From basic electronics, it is said that to complete a circuit, the currents must return to the source. In other words, currents must close the loop. This is true in cross coupled electrical energy as well. Since the source of the energy creates currents in cables, it becomes necessary for that current to return to the source which first generated it. This is where filters can help.

Referring to Figure 1 - If the energy is differential mode, an X-Capacitor can help pass some energy from one line to the next prior to leaving or entering the equipment. In the case of common mode noise, Y-Capacitors provide a path for high frequency currents to flow from the cable back to chassis before leaving the chassis where they can contribute to radiated emissions. A common mode inductor, which is often used in filter modules, can create additional series impedance, and improve the performance of the line to ground capacitors. Filter modules are typically designed to be mounted to the chassis directly. It is then important to have a low impedance path from the chassis to the circuit board or other location where noise was generated. This is either done at the circuit board by direct connection to the chassis, or through capacitors at the mounting locations for the circuit board.

If it is possible, filters placed close to the noise source can improve the electromagnetic profile of a circuit board. The reason is that the sooner you can return undesirable currents which are generated by the noise source, the less ability that noise will have to cross couple and interfere with other electronics. For this purpose, circuit board mounted signal line filters may be beneficial. They may be mounted near an electrically active part of the circuit, or they may be close to a connector, where they can provide protection from incoming noise as well and remove unwanted noise from the lines which are leaving the circuit board.

Location of filters plays a vital role in the ability of the filter to function at peak performance. Circuit board filters can help remove and return energy to the source before it can couple to unwanted circuits or cables. IEC Inlet EMI Filters are very beneficial at providing protection against incoming noise, as well as filtering noise generated by the equipment. Placing these inlet filters into metallic chasses and enclosures can provide improved isolation of noise from inside to outside of the equipment. These filters can also include integrated On/Off switches as well as either single line or double line fuses, making them very beneficial when space is at a premium.

When greater filtration is required, or higher current or three phase equipment is used, power line modules can be the best solution. These modules come in single and dual stages to provide a high degree of insertion loss for noise filtration. They are best used as close to the point of penetration into the equipment as possible. This will provide the greatest protection from unintentional cross coupled energy to or from the filtered lines. When using these modules, assure that the case of the filter is mounted to a metal surface which has a low impedance connection with the chassis and circuit board. In doing so, this provides the line to chassis capacitors to work the best in returning energy back to the source.

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