# Contributing Factors of Filter Performance

WHITEPAPER

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# Contributing Factors of Filter Performance

Passive electrical filter design consists of inductors and capacitors in various configurations, and possibly using resistors to discharge capacitors or dampen circuit resonance. In an ideal world, inductors increase impedance with higher frequency, and capacitors decrease impedance with higher frequency, while resistor values do not change. However, this is not the case in real applications. The limiting factors of real-world components has to be understood to recognize the limitations of the filter.

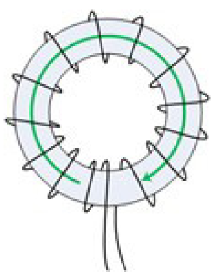
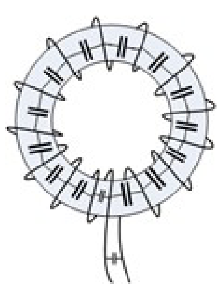


Figure 1

Consider a toroidal wound inductor as shown in Figure 1. The wire windings create a magnetic field in the core material. We may consider the limitations of the core material since materials will respond to frequencies in different manners. There may be considerations of saturation when excessive current or windings overwhelm the capacity of the material to handle the induced magnetic fields.

Figure 2


The windings themselves have attributes we must consider. The wire is has its own inductance which can contribute to additional impedance of the inductor. The wire has resistance which can cause heating. And each winding, when placed against or near the next, will have capacitance to the adjacent winding as indicated in Figure 2, which is also termed as parasitic capacitance or stray capacitance. This one aspect can degrade the high frequency performance of this inductor significantly. Adding additional windings may increase the overall inductance, but can limit the impedance created at high frequency, thus defeating the purpose of adding the windings.

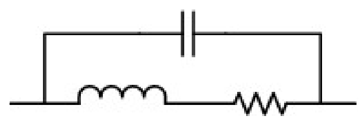
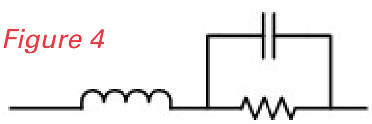


Figure 3

An electrical model of an inductor for circuit analysis can be represented as in Figure 3. Here the inductor is in series with the resistance of the wire and the lossy aspects of the core material. Across the whole inductor is the capacitance created by the proximity of the wires to each other. The best way to improve high frequency performance of inductors is to maximize the spacing between the input and output wires and minimize the wire-to-wire contact. Multilayer wound inductors are not best for high frequency applications.

Figure 4


Similar to this would be the model for a resistor as seen in Figure 4. In the case of a classic leaded resistor, each lead would have a degree of inductance, and when installed into a circuit board, the leads may be bent close together. This increases the capacitance across the resistor. It is common for the impedance of a resistor to begin to drop at some frequency where the capacitance will dominate, before rising when the lead inductance begins to dominate.

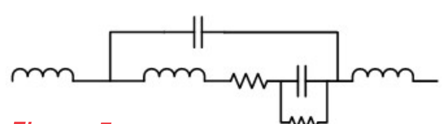


Figure 5

The most difficult to understand may be the parasites involved in a capacitor, as indicated in Figure 5. In this drawing, the capacitor itself is indicated in the middle right of the drawing. The parallel resistor is from the leakage through the dielectric material. Next to this is the series resistor and inductor, which accounts for internal wiring to the plates of the capacitor. These components are internal to the capacitor. Across this will be the capacitance of the leads or traces from one side of the capacitor to the other, and also the lead or trace inductance on either side. These last components are the parasitic components outside of the capacitor body. The result of the complex analysis is that capacitors at low frequency may behave well, but at higher frequency, where these parasitic components become dominant, the capacitor can have significant swings in impedance.

Using surface mounted components can minimize the inductance found in the leads of the component and improve high frequency performance in that regard. However, other parasitic aspects are not necessarily improved, and other issues arise with the smaller format components such as limitations in the operating voltage, Capacitance and breakdown voltage.

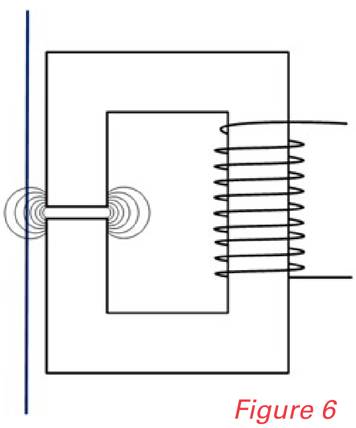


*Figure 6*

It is not only on a component level that aspects of parasitics, which can result in cross coupled energy, create issues. In Figure 6 an inductor or transformer is wound on a magnetic core which has a gap. A trace or wire is routed near that gap. The magnetic fields which bloom from the gap can induce a current into that trace or wire and causing interference internally or an emission problem if it is routed out of the equipment. In this case, the issue is called inductive coupling.

Similar issues may be caused by metal components which have induced voltages on them, such as heat sinks for transistors. Cabling with significant voltages can also induce a coupled voltage onto other wires or circuits. This issue is typically called capacitive coupling.

These sources are not always obvious to find. Commonly used are DC-DC converters on circuit boards to provide required power, such as 3.3 VDC or 5 VDC supplies, as needed to components. These converters have internal transformers, which may be open core transformers. Open core transformers can have uncontrolled magnetic fields, which may cross couple significant energy into sensitive circuits.

Thus, the use of quality filters becomes important. But a good filter must be in the proper location and used in the best manner possible. The location for the filter must be where any coupled energy to the power lines or signal lines is before it reaches the filter. Assume a cable is routed from the circuit board edge connector to the filter before leaving the equipment enclosure. The appropriate usage of Filter (Filter Location, Cable routing and grounding), makes the Filters more effective. The filter needs to be as close to the enclosure penetration as possible. Filters must be always mounted on conductive or paint free surface to get the effective results. If the enclosure is all metal, and all the metal is well bonded together, then the use of a filter which can be mounted into the penetration should work very well. IEC Inlet Filters are excellent choices for this purpose.

The reason this work so well is that since they are metallic enclosures themselves, the IEC Inlet Filter maintain the shielding of the enclosure. Wires which pass from inside to outside are filtered at the point of penetration, which can help remove energy from passing through that location. Assume an unwanted current is induced onto the power line inside the equipment. The signal will reach this filter component, which has capacitance from line to chassis. Since the chassis can provide a low impedance path back to the circuit board, the current will then return to the source. This avoids the energy passing outside of the chassis where it might radiate or be found as conducted emissions during a compliance test. Hence it is recommended that always the Filter to be placed very close to the source to get the effective result.

Likewise, energy outside the enclosure is also filtered before it can enter the enclosure, where energy may couple into sensitive circuits, causing interference.

Some equipment may not have an IEC input power plug, may be high current, high voltage, or three phase equipment, or equipment may not have a metallic chassis. In theses cases, the use of a filter module is likely necessary. These modules should be located near the entrance of the equipment, or as close as possible, to provide a barrier of electrical noise from propagating either out of or into the equipment. These modules also use line to chassis/ground capacitance to help return currents to the source. In doing so, it is important to mount the filter onto conductive surfaces to provide that low impedance path back to the source. Remember that if the source is outside of the equipment, then the return must be connected to the ground wire and likely any external metallic chassis or framework.

Printed circuit board (PCB) mounted filters are typically low current devices with common mode inductance which allows the passage of differential mode signals. These devices may also have line to line and line to ground capacitance. The line to ground capacitance may be connected to a signal ground plane where the energy can return to the source. However, if using these filters on data lines, care must be taken if they employ line to line capacitance. These capacitors may filter the desired signal in the data line. These filters are best used on DC level signals, or low frequency signals, power sources, or lines where noise must be removed or blocked, and the line does not have high frequency information being used.

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.

Ohmite AF Series filters are IEC Inlet style. They can include power (on/off) switch, a safety fuse (either on one or two lines), or both a switch and fuses. The models come in current ratings from 1 to 15 amperes and are rated up to 250 VAC. Medical versions are also available with limited capacitance from line to chassis as required for medical safety.

The filter modules available from Ohmite come in a very wide variety of styles. They are available in current ratings from 1 ampere up to 150 Amperes for single phase, and 1000 amperes for three phase power. Voltage ratings are up to 250 VAC for single phase, and up to 600 VAC for three phase models. Multiple stage versions are available for greater insertion loss. All come with aluminum enclosures to provide conductivity for bypass capacitors, and for strength and safety of the enclosures. As such, these filters can be valuable when placed on powerlines to motors and motor controllers, generators and power conversion equipment, loads, and a wide variety of military, aerospace, automotive electronics, and many other industries. For medical applications, medical grade filters are also available.

Ohmite AP Series filters are PCB mountable in line filters capable of up to 6 amperes and 250 VAC. These modules use a plastic housing to avoid potential electrical short circuit, and at 1 ounce, will limit the weight of a circuit board mounting.

When used in proper locations, and when the filter size and ratings are appropriate for their application, Ohmite filters can provide excellent protection from external interference, and minimize electrical emissions to nearby equipment.

**Ohmite Manufacturing Company**

27501 Bella Vista Parkway
Warrenville, IL 60555
P: 866-964-6483
F: 847-574-7522
E: sales@ohmite.com

**www.ohmite.com**

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