4 Easy Steps to Select the Correct EMI Filter

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TABLE OF CONTENTS

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There is much information that is already available and has been presented in webinars from Schaffner that discuss the various basic filter parameters and specifications that need or should be considered in determining the proper power line filter for your project, so we won't go over them again here. **However, if you do need to refresh your memory, please refer to References 1, 2, and 3 mentioned at the end of this article.** Now, let's continue on to the next design phase.

What this article will do is to assist you in taking all of this information/data that you have gathered and see how to actually use the information to select a potential, correct filter for your application in a straight forward step-by-step process. It is not just all "technical" data that we need to know now, but also answers to just plain, ordinary questions about your hardware. The combination of all of this information/data will be to "dwindle" down all potential filter choices to, hopefully, a manageable few, thus saving test time and schedule time in meeting your equipment's requirements.

Following these basic steps will make it easier to find the best filter that will meet your equipment's specification. Keep in mind, however, that there are other filter parameters that are not mentioned in this article, but are no less important parameters for your filter to meet. These basic first few steps will narrow down the filter choices to a reasonable few. After this, then you must continue to use all the other requirements to finally narrow the filter down to the "one"!

Step 1 – Basic Information

- **Input Voltage**: 120 VAC, 240 VAC, 480VAC or DC voltage (specify voltage)
- **Input Current**: Steady-state and maximum inrush value (if available or known)
- **Frequency**: 50 Hz, 60 Hz, 400 Hz
- **Number of Phases**: 1, 2, or 3

Step 2 – Supplemental Information

A. A description of what equipment you are filtering and what components make up this equipment such as any AC/DC converters (linear or switching), variable speed motors/controllers, microprocessors, RF modules, I/O interfaces, cabling, etc. Along with this information, include, as much as possible, the basic clock/switching frequencies, radio frequency/harmonic spectrum bands, signal rise/fall times, and, if available, the conducted emission profiles of the equipment/components
B. What type of equipment: military/aerospace, medical, solar, lighting, factory/industrial, information technology, etc. along with any other appropriate agency standards or specifications needed to meet qualifications such as MIL-STD's for Military/Aerospace or European EN standards or UL/CSA standards for North America
C. Type of filter desired: PCB type, chassis mounting, bulkhead mounting
D. How will the filter be grounded
E. Any physical size restrictions or requirements, leakage, temperature
F. Type of terminals/connection requirement: fast-on, wires, screw terminals

Figure 1. Fast On Terminals

Figure 2. Screw Terminals

Step 3 – Attenuation/Insertion Loss

Since this is such a crucial parameter for defining the filter, let's spend a little more time on this. We will present a couple of options to define the level of attenuation or insertion loss.

A. **Best Option:** If possible, provide a conducted emission scan with and/or without a filter to see the "real" noise profile over the complete frequency range such as shown in *Figure 3*.
B. **Second Option:** If a complete scan is not available, then select a minimum of four frequencies such as 150 kHz, 1 MHz, 10 MHz, and 30 MHz as an example and a level of attenuation at each of these frequencies. In the example of *Figure 3*, if the complete scan was not available to us, but we know that the noise at 300 kHz requires about 60 dB of attenuation to meet the specification.
C. **Third Option:** Specify a low level of attenuation (low being <20 dB attenuation), mid-level attenuation (mid being 20-40 dB of attenuation) or hi (hi being >40 dB attenuation). Again, using the example of *Figure 3*, one might define the attenuation desired from 150 kHz to 5 MHz as "hi" level and then from 5 MHz to 30 MHz as needing <20 dB of attenuation. If you are not sure as to what you need, then specify a high attenuation (>40 dB) filter.

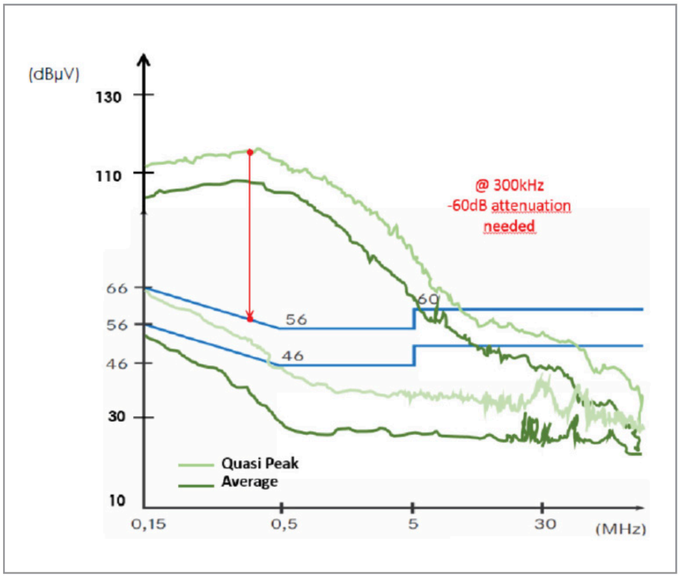

Figure 3. Typical Conducted Emission Data Scan.

Common-Mode Currents versus Differential-Mode Currents
Since this is a key filter parameter, let's spend a little more time on this topic. There is a significant difference between the two. Given a pair of transmission lines and a return path, one or the other mode will exist, usually both. Common-mode is an undesired side effect from differential-mode transmission and is most troublesome for EMC.

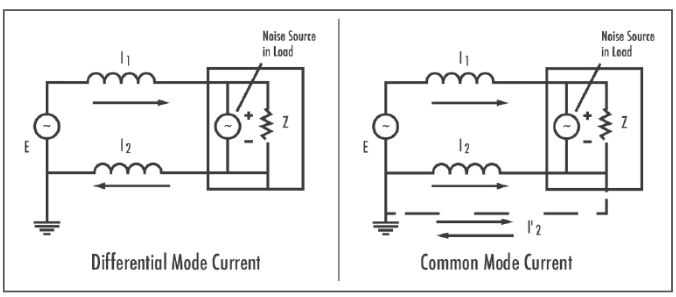

Figure 4. Common Mode and Differential Mode Current Flow (Reference 6).

When using simulation software to predict emissions, differential-mode analysis is usually the form of analysis used. One can severely under-predict anticipated emissions since numerous factors and parasitic parameters are involved in the creation of common-mode currents from differential-mode voltage sources. These parameters usually cannot be easily anticipated.

Differential-mode current, sometimes referred to as normal or symmetrical current, is the component of RF energy present on both the signal and return paths that is equal and opposite of each other (see left side of *Figure 4*). Common-mode current, sometimes referred to as longitudinal or asymmetrical current, is the component of RF energy that is present on both signal and return paths as shown in the right side of *Figure 4*. Differential-mode filtering involves placing capacitors between lines and/or an inductor in series with either the high or low side of the line *(see Figure 5)*.

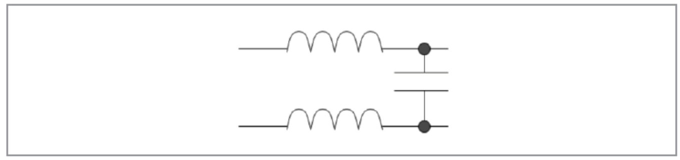

Figure 5. Differential Mode Filtering.

Common-mode filtering involves capacitors to ground and/or a common mode inductor in series with both side of the line or lines. A common-mode inductor does not affect differential-mode currents except for whatever imperfect coupling exists (i.e., leakage inductance). It is best to split the inductor evenly on both sides of the transmission line to maintain balance in the circuit (refer to *Figure 6*).

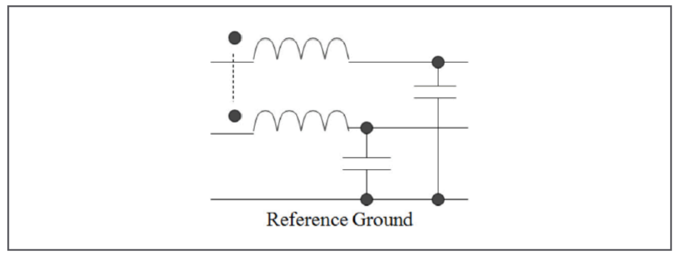

Figure 6. Common Mode Filtering.

Because of having two different noise current modes of propagation, it is important to determine which type of noise current exists so that proper filtering can be implemented for maximum efficiency and cost. This can be determined by your test lab or you can ask Schaffner for assistance in determining how to obtain this data. This is important for both common-mode and common-mode rejection ratio of the circuit. In the figure below (*Figure 7*), Curve A shows the differential mode (symmetrical) attenuation while curve B shows the common mode (asymmetrical) attenuation.

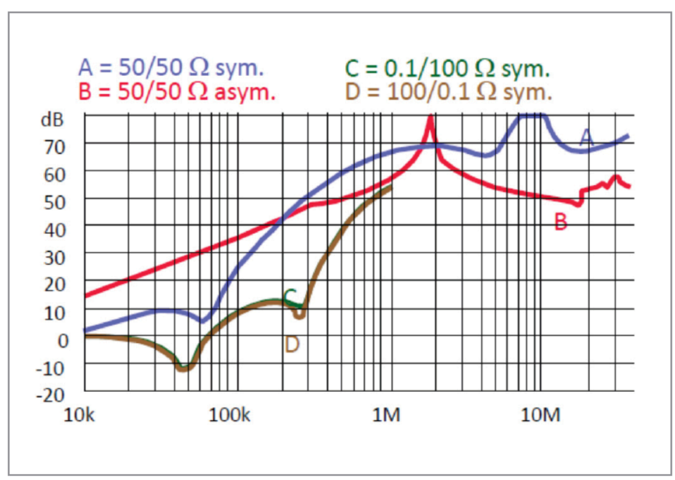

Figure 7. Typical Attenuation/Insertion loss Curves.

Another thought is to look at Curves C and D of Figure 7 in comparison to Curve A and B. It is commonplace to use a filter based solely upon the standard 50 Ohm input/50 Ohm output insertion loss as typically published by the filter manufacturer's catalog data (Curves A and B). However, in the real world, the amount of insertion loss could be different for any particular filter to yield the results of Curve C and D. Curves C and D are based on 0.1/100 and 100/0.1 ohms load/source impedances which may or may not be reflective of your equipment's impedances. So, depending upon the source/load impedances of your equipment or component, the resultant insertion loss will most likely fall somewhere in between the manufacturer's data of Curve A and B and Curves C and D. This is why the selected filter must still be tested in the actual system to verify results.

Step 4 – Resolving Other Questions

Now, at this point, one is ready to define all the other filter parameters such as leakage current, temperature/temperature rise, inrush, dielectric (Hi-pot), insulation resistance, voltage drop, overshoot, harmonic distortion and instability especially with switching power supplies and agency approvals such as UL or CSA, or CE. Designers also often forget that an EMI filter can assist in meeting immunity/transient requirements and radiated emissions as well.

Don't forget that Schaffner can also offer additional assistance in the layout area. Noise has a tendency for mutual transformation through a wire or trace by a process termed crosstalk. Crosstalk is observed where there are many wires or traces located in close proximity. Therefore, even if conducted noise is only a problem at one location, you cannot completely ignore the possibility of coupling to another location.

Layout factors to consider are the high frequency parasitic and resonance effects of the components used. Real inductors and capacitors fall short in performance when compared to theoretical models. Some of this is due to the actual inductor and capacitor elements themselves (e.g. lead inductance, winding capacitance, resistance effects, etc.) while others are caused by the circuit board layout, packaging or wiring.

Changing to a different EMI filter can affect the emission characteristic because of these parasitic and resonance effects. So, when you wish to change from a filter that passes testing, one must re-test for conducted emissions to verify that changes in parasitic/resonance effects of the new filter does not create an issue. The key point is to understand that filters are composed of inductors and capacitors with parasitic/resonance effects that cause them to interact with the source/load impedances of the equipment/components.

The filter should be placed directly at the exit point of the wire from the product. Good effective separation is essential. The separation prevents coupling of noise back into the input wires circumventing and nullifying the effects of the filter. This would be an excellent choice for an AC inlet mounted EMI filter or "power entry module (filter)."

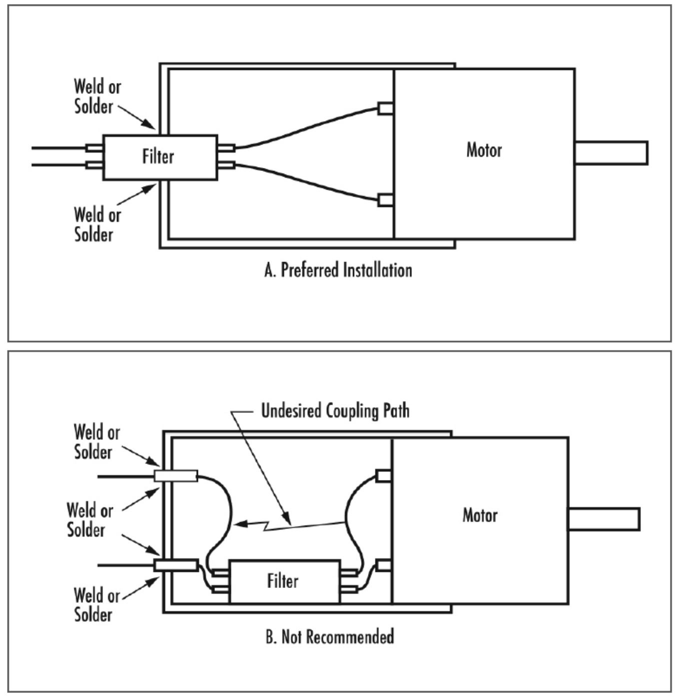

Figure 8. Lead Isolation (Reference 7).

Do not bundle or physically cross filter input and output wires. Again, with the leads physically crossing each other, it nullifies the effectiveness of the filter due crosstalk between wires.

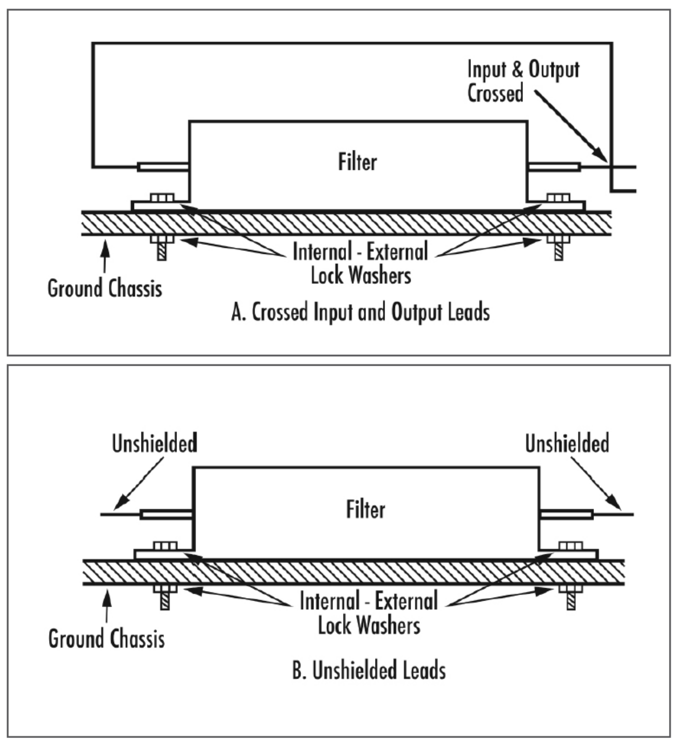

Figure 9. Separation of Input and Output Leads (Reference 7).

Provide a low impedance ground for the filter. It is imperative that the EMI filter mounting surface be clean and unpainted (e.g. conductive surface). Good filter grounding is an important factor for common mode filtering performance of the filter. A poor filter bond limits the filtering to chassis by adding series impedance, thus changing resonance effects and filtering capability of the common mode capacitors. See *Figure 10* below.

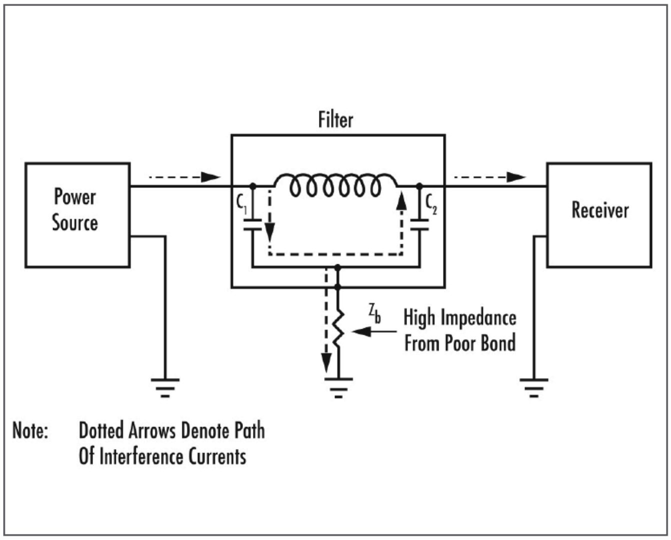

Figure 10. Effect of Poor Filter Bonding (Reference 7).

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