Selecting An AC Line Filter For Switching Power Supply Applications

by Kevin Parmenter, Chair, and James Spangler, Co-chair, PSMA Safety and Compliance Committee

Electromagnetic compliance (EMC) standards establish limits on conducted and radiated electromagnetic interference (EMI) which must be met by electronic products in order to sell those products in their targeted markets. These limits on conducted EMI apply to high-frequency signals generated within the product, or system, which are conducted onto the ac power grid. Since ac-dc switched-mode power supplies (SMPSs) connect directly to the grid, any switching noise generated by these supplies, as well as any noise generated downstream by the loads they power, must be limited sufficiently to meet the relevant EMC standards with some margin. This is where EMI line filters come in as they provide attenuation of the offending noise signals such that the systems being tested can stay within the established limits. They also serve to prevent high-frequency signals on the ac power grid from entering the product or system.

If you're designing SMPSs, you probably already know something about designing EMI line filters, as such filters are often built into the front ends of power supplies. Plus many power supply vendors offer EMI filters as distinct product lines. For those who want or need to design their own EMI filters, there is established literature on the subject. However, for the non-power supply expert trying to qualify a new product or system design for EMC, where the design does not on its own meet the conducted EMI limits, the addition of an external EMI line filter may be necessary.

The easiest path to compliance involves selecting and purchasing an off-the-shelf EMI line filter, rather than rolling you own. One of the key recommendations is to pick a filter partner up front to help you with this versus simply hoping for the best. If the filter company has a test lab and can help you with pre-compliance testing you probably have the right filter partner—if not you might want to re-evaluate your choice.

While guidelines have been written on how to select these filters (see the references), many system engineers still aren't aware that they need EMI filters. When they do learn they need one, they often select a filter without regard to their actual filtering needs, the impact of the filter on other requirements (such as leakage current), and issues such as customer support.

In this article, we'll identify some of the popular bad practices being used to choose EMI line filters, explain why they're wrong and provide a quick guide to proper filter selection that will help designers avoid the common pitfalls. We'll identify the key criteria you'll need for filter selection including rules of thumb and key specs that will guide designers to making good choices. Armed with this information, designers will be better equipped to apply the EMI selection guides and tools already available.

The Wrong Ways To Select Line Filters

As applications engineers, we've had many opportunities to discuss EMI filtering with customers. Over the years, when we've asked engineers about their EMI filter requirements or practices, we've received a number of interesting answers.

The typical responses have been along these lines:

1. I need a line filter? Why?

2. I will just use what we used last time.

3. I found this one lying around the lab and used it.

4. I just found one that fit the space we have.

5. I picked this one out on the ___________ website (insert your favorite online distributor here).

Usually these approaches don't work well or at all, though sometimes engineers do get lucky and they pass testing.

The last answer is particularly relevant because these days many engineers would just assume go online and design things. But doing so without any forethought still leaves much of filter selection to chance. In particular, this approach often overlooks the need to have the capability to do pre-compliance testing in house. This investment pays dividends when you are at the final certification test lab later, so test early and test often.

The Better Approach To Filter Selection

So, what is a practical step-by-step process to properly select a line filter? The process that we'll describe here involves a combination of testing, identifying key product or application specifications, which standards you must meet, and understanding both the EMI and non-EMI related design considerations.

But before we delve into those details, here's some general advice on choosing a filter supplier. Choose one or possibly more than one but pick a leader in filtering who has resources such as a lab and test gear to help you. Some filter companies will even let you ship your product and/or bring your product to their lab for testing and support/assistance. This type of customer support can save you massive time and money. Again if they don't have this capability to bring your product to their lab for help and work collaboratively with you in the lab you might want to find a supplier that can.

The following procedure for filter selection frames each step according to the information you'll need to gather in order to specify a filter.

Step 1. What levels of emissions does your product or system produce? If possible, test the conducted emissions (and radiated) of your product or system with no line filter. This gives you a baseline of the filtering that is necessary and once the required amount of filtering is known then some physical attributes must be determined. If you can't take these measurements in your facilities, hopefully you can do so in the filter company's lab (if you heeded our above advice).

The next three steps refer mainly to your power supply's input.

Step 2. Determine the input voltage range of your product or system. The universal 85 to 264 Vac is a common range for global voltages. However, for higher power systems it could be 277 or 480 Vac, or you might even need a dc filter. In any case, choose a voltage range for the input.

Step 3. How many phases are present and what's the max current on each phase. If this is not known it would be possible to saturate the magnetics in the filter at which point the filter ceases to be a good filter.

Step 4. What's your frequency of operation? Is it 50 Hz, 60 Hz, both or possibly 400 Hz?

Step 5. Which safety and EMC standards do you need to meet? There is a plethora of them. Several of the popular standards are set by the following organizations. You will want to select the most stringent specification you must comply with and then add at least 3 dB of margin for manufacturing tolerances and variability considerations.

- UL (Underwriters Laboratories) is a safety consulting and certification organization.
- FCC (Federal Communications Commission) is an independent agency of the United States government that regulates interstate and international communications by radio, television, wire, satellite, and cable in all 50 states, the District of Columbia and U.S. territories.
- CSA (Canadian Standards Association) is a non-profit standards organization which develops standards in 57 areas.
- TUV (Technischer Überwachungsverein) are German organizations that work to validate the safety of products of all kinds to protect humans and the environment against hazards.
- VDE (Verband der Elektrotechnik) is the Association for Electrical, Electronic and Information Technologies and their related sciences, technologies and applications.
- Nemko is another testing organization for electronic equipment.

If your application is medical, you will need to meet 60601 3rd edition and 4th edition EMC. If it's industrial, then 62368 and probably FCC or CISPR 22 and/or EN55032 and perhaps the EN55035 immunity standard. If your application is military you may have to meet the following:

- MIL-PRF-15733: Performance specification filters and capacitors, radio frequency interference
- MIL-STD-202: Test Method Standard Electronic and Electrical Component Parts
- MIL-STD-220: Test Method Standard Method of Insertion Loss Measurement
- MIL-STD-461: Electromagnetic Interference Characteristics Requirements for Equipment

Step 6. Once the relevant standards are identified you can determine the required limits on EMI. But then remember to add about 3 dB of margin to these limits for production tolerances. Now that you know the spec you need to meet, and the power spectral density range from your earlier measurements, you can determine how much insertion loss is needed to achieve compliance. This is essentially the key performance parameter for your filter, but there are still more requirements to be considered.

Step 7. What is the physical size available for the filter? These are your space constraints.

Step 8. What is the maximum allowable leakage current? This will be determined by the safety specifications of the intended application. For example, at 265 Vac and 60 Hz medical applications require less than 500 µA (although it's recommended that you have some margin there for production tolerances too). This will determine the maximum value of Y capacitors that the filter can use.

Consideration must also be given to the Y capacitors present in the rest of the system. For example, if the line filter is used in front of commercial power supplies which will also have Y capacitors, the additive capacitive reactance of the Y capacitors in parallel will increase the leakage current above spec. In many cases medical filters will have no Y capacitors so the leakage current in the filter is reduced.

If you cannot use more capacitance in the filter then the alternative is to add more inductance to increase the inductive reactance, which filters the high-frequency noise. Certain applications such as medical electronics must keep the capacitance to a minimum so this generally results in higher inductance filters. The filter will want to attenuate common-mode as well as differential-mode noise and this task will require an X capacitor across the line.

Step 9. Is a capacitive or inductive input filter desired? This relates back to the previous step—the answer depends on how much leakage current can be tolerated. For example, a filter for medical applications should be inductive since there are strict limits on leakage in medical equipment usually resulting in zero-capacitance line filters.

Step 10. What are the weight and cost constraints? Are you optimizing for performance, size-weight or cost. These are all the tradeoffs that must be considered. You don't get a high attenuation, zero leakage current, zero loss, zero size, zero weight and zero cost filter all in one. Your filter supplier can help you make the tradeoff decisions in pursuit of a practical solution.

Again, the goal of this process is to reduce line-induced conducted and radiated EMI to provide opposition to the EMI in proportion with insertion loss enough to drop the EMI below conducted and radiated emissions limits. Keep in mind that EMI emissions can and do emanate from other sources in the product including LCD panels, openings in the metal enclosure (if you are using unshielded plastic you will have emissions galore anyway), and other cable and connector entry points–these may all need to be filtered as well. Having said that, the scope of this article is really meant just to cover filtering as applied at the connection of the power supply to the ac line.

Following the above procedure should enable you to select an appropriate EMI line filter for your product or system. However, you'll also need to heed certain requirements when designing and installing the filter in order to have it work as expected. Here are a few tips in this regard.

- Take care to ground the filter to the metal chassis and bond it properly to increase its effectiveness and use a safety ground connection to the chassis keeping that short to reduce parasitic inductance.
- Route wires to the filter inside the enclosure close to the chassis and if possible either shield the ac wiring if possible and/or twist the ac wiring to cancel electromagnetic fields inside the product. Ideally, you should do both as shown in the figure.

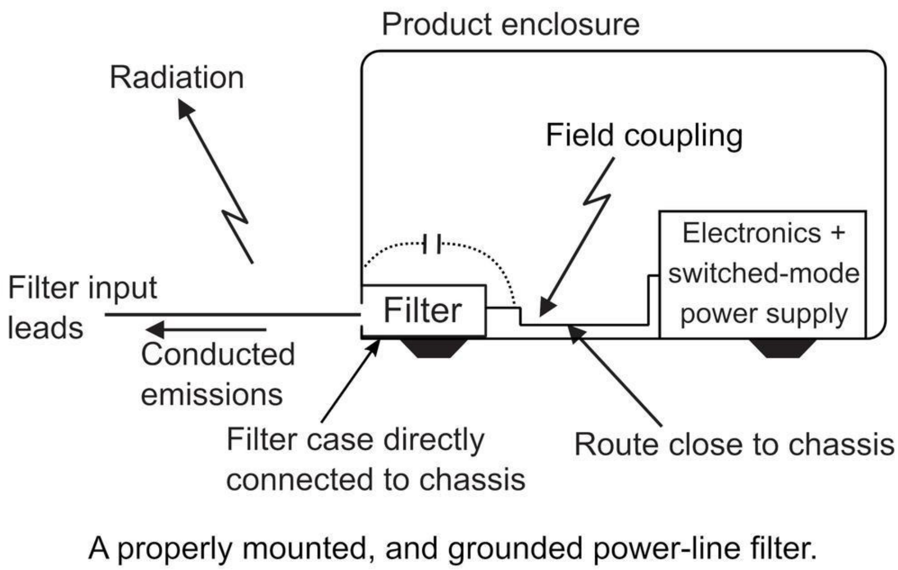

Figure. Proper placement, mounting and grounding of the line filter (Courtesy of Schurter).

- Make sure the filter is bonded securely to the chassis with heavy gauge braid or wire such that it can survive repeated 20 A+ ground bond testing. Additionally, the mounting screws of the filter–power entry module should be properly grounded to the chassis for a low impedance path for RF and to shield the RF from exiting the enclosure. These screws also provide a low impedance safety ground to the chassis in case of a fault.

References

Schurter filter products.

Mouser Electronics – Schaffner process for selecting EMI filters

Genesco Filters -selection guide – EMI-RFI filter selection criteria

About The Authors

Kevin Parmenter is an IEEE Senior Member and has over 20 years of experience in the electronics and semiconductor industry. Kevin is currently director of Field Applications Engineering North America for Taiwan Semiconductor. Previously he was vice president of applications engineering in the U.S.A. for Excelsys, an Advanced Energy company; director of Advanced Technical Marketing for Digital Power Products at Exar; and led global product applications engineering and new product definition for Freescale Semiconductors AMPD - Analog, Mixed Signal and Power Division.

Prior to that, Kevin worked for Fairchild Semiconductor in the Americas as senior director of field applications engineering and held various technical and management positions with increasing responsibility at ON Semiconductor and in the Motorola Semiconductor Products Sector. Kevin also led an applications engineering team for the start-up Primarion.

Kevin serves on he board of directors of the PSMA (Power Sources Manufacturers Association) and was the general chair of APEC 2009 (the IEEE Applied Power Electronics Conference.) Kevin has also had design engineering experience in the medical electronics and military electronics fields. He holds a BSEE and BS in Business Administration, is a member of the IEEE, and holds an Amateur Extra class FCC license (call sign KG5Q) as well as an FCC Commercial Radiotelephone License.

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For many years, he worked as a field applications engineer (FAE) for Motorola Semiconductor, On Semiconductor, Cirrus Logic, and Active Semiconductor, assisting customers in using semiconductors. He published numerous application notes and conference papers at a variety of conferences: APEC, ECCE, IAS, and PCIM. Topics included power factor correction, lighting, and automotive applications. As an FAE, he traveled internationally giving switch-mode power supply seminars in Australia, Hong Kong, Taiwan, Korea, Japan, Mexico, and Canada.

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For further reading on power supply-related safety and compliance issues, see How2Power's special section on Power Supply Safety and Compliance.