Specifying EMI Power Filters

Optimum filter selection depends on many parameters.

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INTRODUCTION

Electromagnetic interference (EMI) filters for power applications are generally passive, bilateral networks that provide filtering between the AC power grid and the equipment. This filter function provides de-emphasis or control of the frequency components (noise) of either a desired or undesired signal which would otherwise be present. The EMI filter accepts an electrical signal at its input terminal and delivers an electrical signal at its output terminal(Figure 1). There are various means of filtering, and the key characteristics and design parameters are discussed in this article.

BACKGROUND

The EMI filter plays two major roles in system design. First, the filter prevents unwanted frequency components from entering the system. These frequency components are sometimes of a voltage level that could damage or cause improper operation of the system. As a result, the reliability of the system could be compromised. For that reason, filtering is included by the equipment manufacturer, and should be required by the customer in order to insure immunity from unwanted noise.

Second, the filter prevents unwanted frequency components from leaving the system equipment and contaminating the AC power grid. This contamination could cause potential problems in operation and reliability of other equipment connected to the grid. This is the kind of filtering that is needed in order to comply with mandated standards.

A manufacturer needs to define what the filter must do (specifications). Custom filter designers/manufacturers have the design and manufacturing capability to provide filters which meet the customer's requirements.

FILTER SPECIFICATIONS

Preparation of an EMI filter specification requires thorough familiarization with all of the issues involved if good performance, timely quotes, prototype delivery, and minimum cost are to be achieved. Major items for consideration are:

- Operating current
- Insertion loss
- Leakage current
- Agency approvals
- Mechanical structuring

When designing an EMI filter, these specifications become critical areas of design criteria. Optimum component selection depends on these specifications, as well as other parameters.

By using the proper combination of passive components, an optimium filter can be designed for use in a particular system to meet the desired noise specification. The use of passive elements such as capacitors and inductors is the common approach for filter designs. Capacitors work by "shorting out" the parallel combination of the source and load impedance, while an inductor absorbs the source voltage.

To assure proper operation of equipment, there are standards and specifications which regulate the level of noise generated onto the power grid. These standards, set forth by the FCC, the EC, and the U.S. military, to name a few, limit the amount of noise allowed onto the grid. The standards thereby provide designers the assurance that, when connecting to the grid, their equipment will be minimally affected by noise. These standards are continuously being updated to reduce the amount of noise generated throughout the global market.

OPERATING CURRENT

Whether a filter is to be used at the power entry of a facility, or directly with a switching power supply, it should be understood that some switchers[1] require peak currents as high as three and a half times the rated RMS current. These high current values could easily drive a filter's magnetics into saturation with a subsequent decrease in performance. The saturation of the core material of the inductor is directly related to the current. The situation is further complicated when more than one switcher is operating at the same time. In these cases, the peak current could be the sum of the individual peaks, especially where the switchers are operating in a synchronous switching mode. This condition might not become

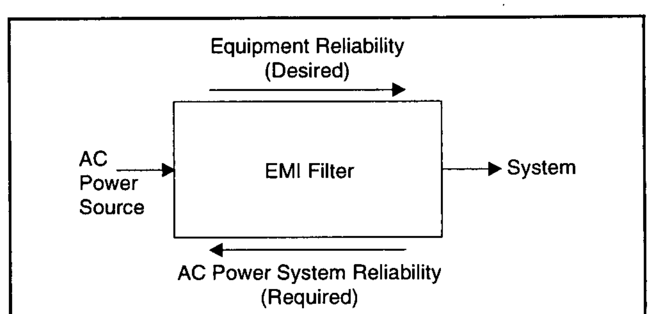

Figure 1. *EMI Filter.*

[1] While some switchers have power factor correction, a large number do not; these cause the problems cited.

See Advertisement on Page 54.

known until the system is up and running during the final compliance check. Consequently, consideration of full load current (RMS), as well as the total peak current, results in a better designed filter. Failure to account for these considerations can have a severe impact on a product release schedule. Ideally, the RMS current should be specified for heat considerations and peak current should be defined for saturation reasons whenever possible.

Equally important for knowing the peak currents drawn by the switcher(s) is determining the size and weight (for saturation reasons) of the magnetic material used in the filter inductors. The current rating of a filter provides important design input to establish the wire, inductor and terminal sizes required to meet performance and safety agency approval.

INSERTION LOSS

The insertion loss specification determines the values and topology of the passive components in order to reduce the noise amplitudes to the required levels. Insertion loss is the ratio of the amplitude of the undesired signal after filter insertion to the amplitude at the filter output terminals before insertion. Insertion loss is measured in decibels.

Knowledge about specific EMI noise sources helps to determine the design features of the filter. For example, switch mode power supplies (SMPS) produce noise products that challenge the filter designer because of the switching frequency and the associated differential and common mode EMI characteristics (see sidebar). A system profile graph of the frequency versus EMI without any filtering is probably the best data for determining the amount of the filtering needed and at what frequency. It is also important to avoid over-specifying at frequencies where not much attenuation is needed. A good example is immediately below the switcher's fundamental frequency. To over-stress requirements here results in an avalanche of negative effects such as magnetics needed, heat-rise, cost, size, weight, and of course, safety (or lack of) due to unnecessarily large line-to-ground capacitance. More importantly, it can influence other design characteristics of the filter, such as unnecessarily large leakage currents.

Another important factor is the use of standard methods of insertion loss measurement while understanding the limitations of this data. Measurement data from a screen-room measurement setup is not generally a reliable indicator of filter performance in the system where it is to be installed. The real test of a filter's performance is in the actual system environment.

CM and DM Noise

Common mode (CM) noise is characterized by the noise currents flowing in the phase-ground loop and in the neutral-ground loop.

Differential mode (DM) noise is characterized by the noise currents flowing in the phase-neutral loop. Most EMI filters are designed to attenuate both CM and DM noise products using a combined filter network.

LEAKAGE CURRENT AND AGENCY STANDARDS

Leakage current is characterized by the amount of current that could "leak" from the equipment, causing potential harm to the operator/user (see sidebar). It is this leakage current which is a major subject of the safety standards. These considerations are reflected in many U.S. agency standards, including UL 1950, and various European and Canadian standards. The filter specification should clearly indicate the standards that must be met. The filter designer/manufacturer can help provide the customer with up-to-date standards information based on the customer's product description.

Leakage Current/Agency Standards

Leakage current refers to the current (albeit small) that exists in the equipment grounding conductor (sometimes called the green wire). When the equipment is operating properly, there is no danger since any currrent "in the equipment frame" is routed through the grounding conductor and eventually back to the service entrance. The danger occurs when the grounding conductor is interrupted or broken. Then the current has no return path except through the individual who comes in contact with the equipment frame. This is a major safety concern.

Specifying liberal leakage current is important in order to select the smallest inductance needed to get the specified performance. To obtain a specified attenuation characteristic, tradeoffs exist between the capacitance and inductance elements. Furthermore, weight, cost, size and current rating are affected by these elements.

The total line-to-ground capacitance is the major factor that determines the filter leakage current, and by specifying as much leakage current as the agencies permit, greater attenuation in the reject band is achieved. The number of filter sections that may be added, in order to improve attenuation, requires more line-to-ground capacitance, which in turn causes more leakage current. At times, attenuation specifications have been impossible to achieve because of inadequate leakage allowances. Therefore, knowing all the sources of line leakage currents can result in a better leakage current specification than would be obtained by conservative estimates.

Components to be used in medical equipment are rigorously regulated. In such equipment, leakage current higher than a few microamperes is not tolerated. Filters designed for this type of equipment require circuits where dependence on line-to-ground shunt elements is replaced by high impedance series inductance. Ample attenuation is attainable in the differential mode because of the higher line-to-line capacitance available. However, in common mode, the attenuation will be quite limited due to the lack of line-to-ground capacitance forced by the leakage current restrictions.

MECHANICAL PACKAGING

The mechanical layout and structure plays a major role in the ability of the filter to remove the unwanted frequency components and meet the design and safety standards. First, the optimum approach is to have the output termination as far away from the input as possible. This helps eliminate the coupling effect of high frequency noise onto adjacent lines. Second, physical restraints are placed on the internal components because of the overall dimensional requirements. Limiting size often compromises effective costing schemes and designs. Third, the layout of passive components internally helps determine the ability of the filter to eliminate the high frequency noise. For example, undesired coupling of flux fields between inductors could cause improper performance and decreased insertion loss for the filter.

SUMMARY

Providing a custom filter designer/manufacturer with definitive specifications is the key to meeting an equipment manufacturer's performance, regulatory, cost and schedule requirements.

The filter designer/manufacturer can provide important expertise resulting in an optimum filter by exacting the proper tradeoff between cost and performance. The specification details mentioned above are the major considerations. Consultation with the filter designer/manufacturer as early as possible in the design phase will result in a better filter design.

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