EMI Filters Demystified

By

William R. “Bill” Limburg

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An EMI Filter Defined

An EMI filter is a network designed to prevent unwanted electrical conducted noise from travelling outside a specified area of a system.

There are two major classes of EMI filters:

1. Power line filters.

   These prevent internally generated electrical noise from travelling onto the power line from internal circuits in a system.

2. Signal conditioning filters.

   These prevent electrical noise from entering a system via signal lines or other non-power interfaces. This class of filters can be said to maintain signal integrity.

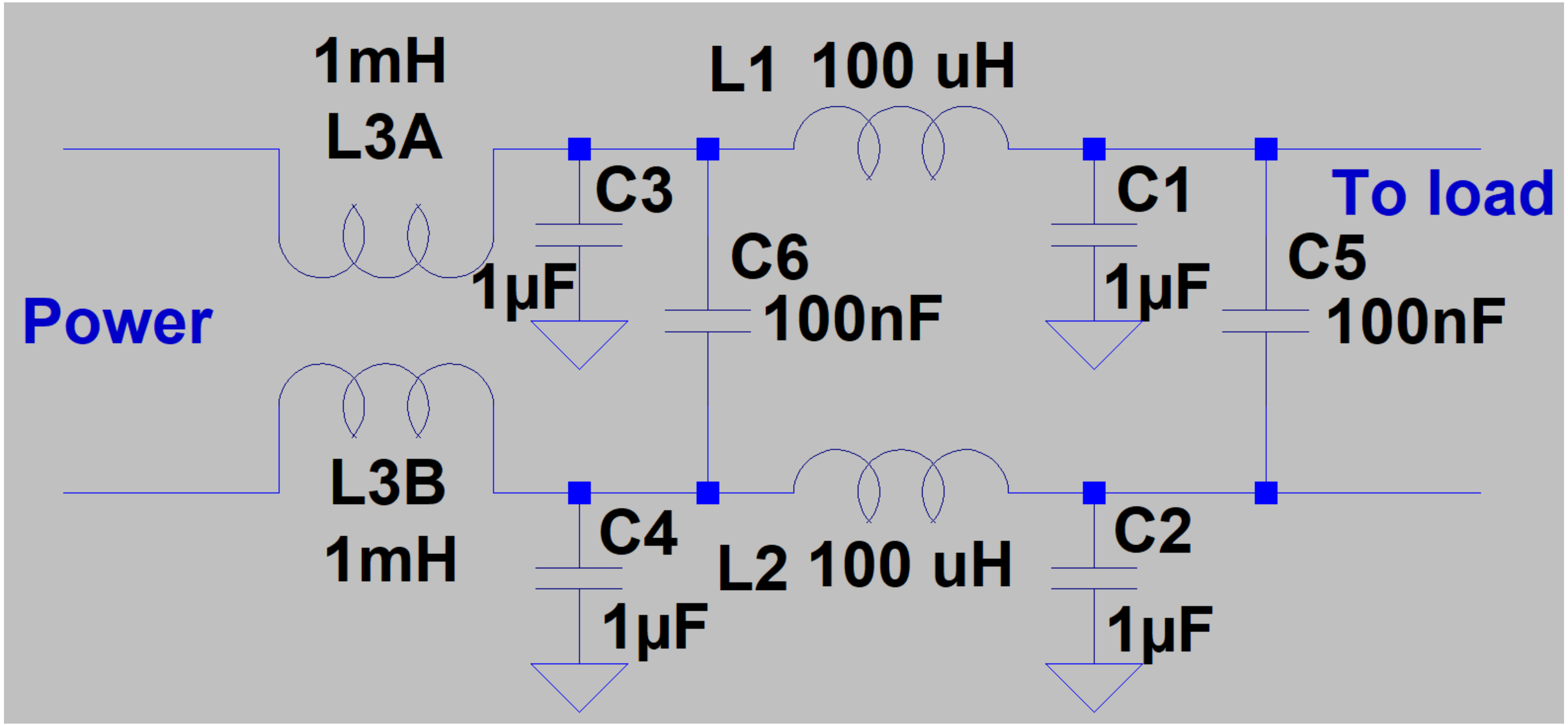
Some unique characteristics of EMI filters.

- An EMI filter typically must operate over many decades of frequency.
- An EMI filter must provide substantial attenuation to the unwanted electrical noise or disturbance while minimizing loss or distortion of the desired signal or power.
- EMI filters must be packaged and located in a way that prevents the undesired electrical noise or disturbance from bypassing the filter.

Essential Elements and Topology of a Power Line Filter

- One or two stage differential mode (line-to-line) low pass filter.
- The DM filter is comprised of at least one pair of series inductors and at least one line-to-line capacitor.
- Common-mode filter consisting of two or more line-to-chassis capacitors and a common-mode inductor. The CM inductor is located at the input end of the filter to maximize the impedance of the "outside" loop.
- One or more transient voltage suppression devices if required.

Schematic of a Typical Power Line EMI Filter



Steps in the Design of a Power Line EMI Filter

- Calculate or measure the magnitude of the expected differential mode (line-to-line) noise current as a function of frequency.
- Calculate or measure the expected common mode current (in phase on both, or all three) power lines as a function of frequency.
- Compare the emission limit to the expected noise current amplitudes as a function of frequency to determine the required attenuation the filter must have.
- Formulate the overall topology and component values for the filter.
- Design the differential-mode inductors.
- Design the common- mode inductor.
- Lay out the physical design and packaging of the filter.

Differential Mode (DM) vs Common Mode (CM) Interference Currents.

- Differential mode currents are currents which travel in opposite directions on the two conductors comprising a circuit.
- Common mode currents are currents which travel in the same direction on both conductors of a circuit. These currents therefore return on a separate third path.
- We make a distinction between these two types of interference current because they can be attenuated most efficiently by different means.

The origin of common mode currents.

- Common mode noise currents on power lines typically arise due to circuits containing high amplitude waveforms with very short rise times being capacitively coupled to the chassis of the device or system.
- Any noise current injected into the chassis of the system must return via the lowest impedance path which is usually the incoming power line.

Design of the differential mode inductor.

- The inductor must be capable of maintaining the desired minimum inductance up to the peak current at the power frequency under the maximum load condition or up to the maximum DC current.
- The magnetic material chosen for the core must have acceptable permeability up to the maximum frequency needed for useable inductance.
- The inductor winding must have low resistance to minimize power loss.
- The distributed capacitance of the winding must be low enough to enable the self resonant frequency of the inductor to be above the maximum frequency to be attenuated by the filter.

Description of a Common Mode Inductor

- A common mode inductor is a multi-winding inductor designed to have a high inductance, high self resonant frequency and low winding resistance at DC or the power frequency.
- Common mode inductors achieve these characteristics by being designed so that the magnetic flux due to the power current is cancelled by the opposing equal power currents in the two (or more) identical windings.
- Cancellation of the magnetic flux at DC or low frequencies in the core of the common mode inductor allows the use of a relatively high permeability magnetic material. This enables use of a low number of turns in each winding, thereby lowering the distributed capacity and raising the self resonant frequency.

Design of the Common Mode Inductor

- Physical layout of the windings. Bi-filar and tri-filar windings.
- Providing for adequate inter-winding insulation. Handling the high turn-to-turn potential difference.
- Keeping mechanical stress from impairing the magnetic properties of the core.
- Proper location of the common mode inductor within the filter.

Packaging and Location of a Power Line Filter

- Preventing crosstalk between the filter elements and surrounding circuits. Need for a metallic enclosure for the filter.
- Preventing the interference from bypassing the filter.
- Proper physical location of the filter in the system or device.
- Making provisions for dissipation of internally generated heat.
- Proper electrical bonding of the filter housing to the system structure

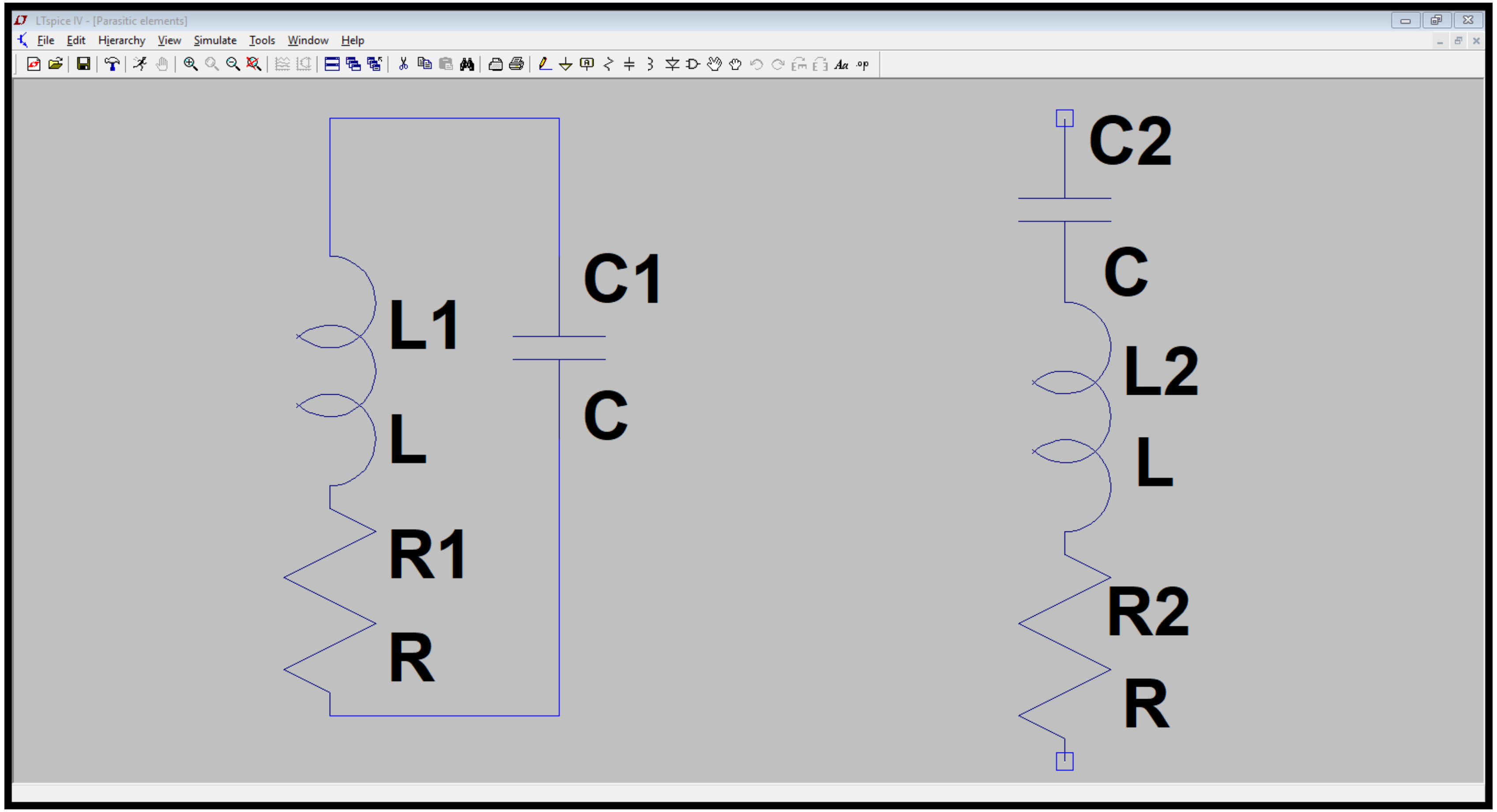
Important Considerations in the Installation of a Power Line Filter

- The most important single requirement for the installation of a power line filter is to make sure that the filter ground bus is electrically bonded to the system structure via a very low impedance path. This path must maintain its low impedance up to the highest frequency which the filter must attenuate.
- The filter should be located as close as possible to the point at which the power lines enter the system.
- Provision must be made to dissipate the heat generated within the filter. This is particularly important in high power systems.

Testing of a Power Line EMI Filter

- The standard setup for specifying the attenuation of a power line filter assumes a source and load impedance of 50 ohms.
- Filter attenuation must be measured with the filter carrying the maximum load current (at DC or the design power frequency) it is designed to handle.
- It is also desirable to measure the attenuation of the filter at lower load currents.

Parasitic Elements to be Considered



Filters Suitable for Protecting Signal and Control Lines

- Feed thru capacitors.
- Feed thru filters.
- Filter-pin connectors.
- Ferrite sleeves.
- Optical Isolators.
- Fiber optic links.

Some Unique Types of EMI Filters

- Optically coupled digital links.
- Ferrite honeycomb assemblies or “sieves”
- Feed-thru filters.
- Filter-pin connectors

Filter-pin Connectors; When they are Indispensable

- Fixing EMC design problems when the system is already designed and in production.
- Retrofitting systems already in use due to new requirements or unforeseen environmental conditions.

References:

- **EMC Made Simple** by Mark I. Montrose, 2014, Montrose Compliance Services, Inc.
- EMI Filter Design, 3rd. Edition, Richard Lee Ozenbaugh & Timothy M. Pullen, CRC Press, 2012