Electronic Design

STEVE TARANOVICH, Contributing Editor

A Starting Point for Selecting EMI Filters

Electromagnetic interference (EMI) is becoming a bigger disturbance in power electronics and other systems. Explore the many different types of EMI filters that can cut through the noise.

Electromagnetic interference (EMI) is a hazard that most electronic devices and systems must be protected from. EMI can be caused by everything from switch-mode power supplies (SMPS) and electric motors in industrial equipment to lightning, which can cause severe EMI. It also has coupling mechanisms, which means that it can be transferred from a source to a receiver through radiation, conduction, or inductive or capacitive coupling.

Many engineers use grounding or shielding to prevent EMI in the form of electromagnetic radiation or induction from disrupting electrical and electronic circuits. However, EMI suppression filters are one of the most widely used solutions for limiting EMI before it drags on the performance of the system or causes it to malfunction. EMI filters feature a wide range of configurations, capabilities, materials, footprints, and price points.

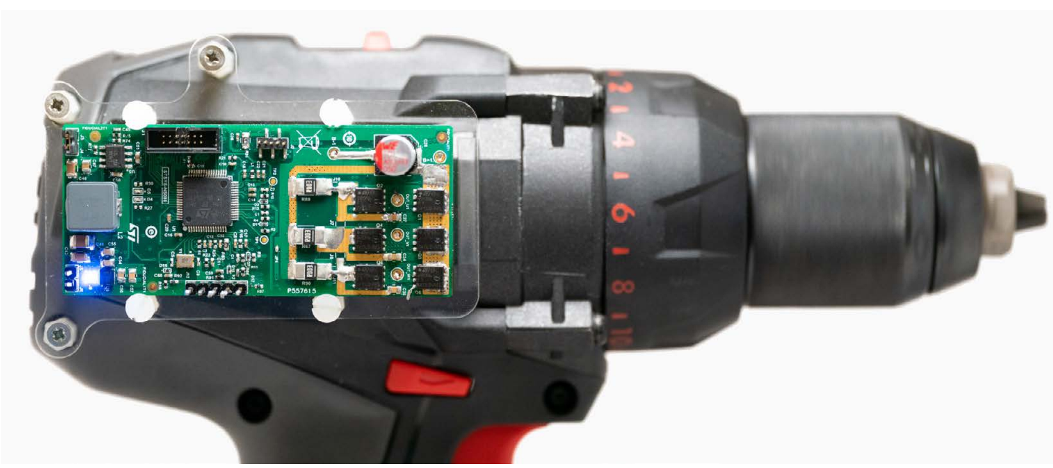
Though frequently paired with EMI shields and other forms of protection, EMI filters only extract and remove components that can cause electromagnetic noise from electric currents conducted through wiring.

This guide reviews the ins and outs of EMI in electronics and how to evaluate and select EMI filters.

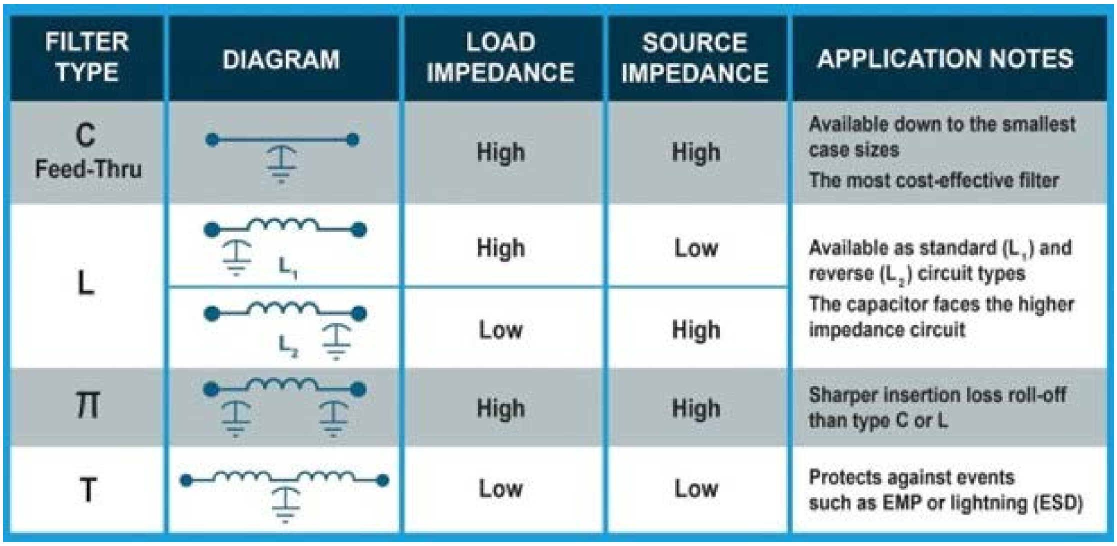
EMI: The What, Where, When, and How

Determining the type of EMI and what caused it is critical to choosing the best EMI filter to suppress it. But since it's caused when a magnetic field interacts with electric fields, there are many different sources of EMI:

- **Human-made EMI:** This EMI will occur from another manufactured electronic device when two signals are near one another, or when multiple signals travel through one device at the same frequency. The EMI can stem from the operation of switched-mode power supplies (SMPS), electric motors, and any system with electrical contacts that are opening and closing. It can also be caused by radar and radio transmissions.
- **Natural EMI:** In some cases, EMI is generated by natural phenomena, including lightning, which flashes at high currents and high voltages, and other electrical storms. EMI can also be caused by cosmic noise and solar radiation.



The electronics powering electric motors are vulnerable to noise, and so EMI filters and other forms of EMI suppression must be used. (Image credit: Würth Elektronik)



FILTER TYPE	DIAGRAM	LOAD IMPEDANCE	SOURCE IMPEDANCE	APPLICATION NOTES
C Feed-Thru		High	High	Available down to the smallest case sizes The most cost-effective filter
L	L_1	High	Low	Available as standard (L_1) and reverse (L_2) circuit types The capacitor faces the higher impedance circuit
	L_2	Low	High	
π		High	High	Sharper insertion loss roll-off than type C or L
T		Low	Low	Protects against events such as EMP or lightning (ESD)

There are several common EMI filters, and each type of EMI protection features different characteristics and circuit configurations. (Image credit: Interference Technology)

The other way to differentiate EMI is its duration:

- **Continuous EMI:** This type of EMI is constant. It comes from other electronic devices in the vicinity, such as SMPS or other circuits that emit continuous signals, or from sources in the surrounding environment.
- **Impulse EMI**: This type of EMI only lasts for a very short duration. The sources of the EMI can vary widely, but they include noise from switches, lighting, and other electronics emitting signals that can cause a disturbance in current and voltage.

The signal bandwidth also determines the type of EMI:

- **Narrowband EMI:** This EMI can stem from an oscillator or even the noise that emanates distortion from a transmitter. These are prime examples of narrowband EMI since they're mostly made up of a single frequency. The mitigation of narrowband EMI disturbances is much easier than reducing a broadband EMI disturbance.
- **Broadband EMI:** This occurs when EMI disturbances contain several different frequencies or span a wide spectrum. Broadband EMI may be man-made, such as in arc welding, or occur naturally, as is the case with solar-radiation-induced interference that affects satellite signals.

EMI is becoming more of a challenge in the future due to the enormous numbers of wireless devices and standards. Some examples are mobile phones, GPS, Wi-Fi, Bluetooth, and near-field communication (NFC).

What are the Main Coupling Mechanisms for EMI?

To prevent the problems that can occur due to EMI, it's vital to understand not only the type of EMI, but also how it gets coupled from the source to the receiver.

The EMI coupling mechanism will change depending on the route taken by the EMI as it travels from the source to the electronic device or system being affected by it. Several types of coupling can cause EMI:

- **Conduction coupling:** Also called "common impedance coupling," it occurs when EMI emissions travel along the conductor, wires, and cables that connect the source and receiver. Conduction can occur in one of two modes—common or differential.
- **Radiated coupling:** This is the most widespread type of coupling. It crops up when the source and receiver are separated by a long distance, larger than a wavelength. The EMI is radiated via vacuum or air to the receiver.
- **Capacitive coupling:** The voltage variations and coupling capacitance that occur between the source and receiver will induce unintentional currents in the receiver. This causes capacitively coupled EMI in the device or system. The frequency, distance, input impedance of the target, insulation of the target cables, and height of the cables from the ground plane are only some of the parameters that will affect capacitive EMI coupling.
- **Inductive coupling:** This happens when a conductor induces interferences in another conductor that's placed nearby, based on the principle of electromagnetic induction. This will produce what's also called magnetically coupled EMI.

Electromagnetic compatibility (EMC) can be reached if the coupling mechanism is minimized, diverted, or eliminated. Approaches to EMC include:

- **Earth ground:** In many electronic systems, signals and return currents are conducted via ground systems. In addition, these ground systems will form the references for digital and analog circuitry, thus protecting operators and equipment from lightning and other transient events that can cause EMI. When the current flows in a grounding system, it will cause differences in ground potential.

- **Shielding:** One of the main methods to combat EMI is to use shielding. Shielding regulates and decreases the coupling of radio waves, electrostatic fields, and electromagnetic fields.

How to Evaluate EMI Filters for Electronic Designs

Electronic circuitry must be protected from EMI. To select the best EMI filter for any situation, electrical and electronics engineers must carefully consider the following key characteristics of EMI filters for their designs.

One of the primary factors is filtering out the frequency. EMI filters must be properly designed to suppress the transmission of selected frequencies in any type of signal. One of the most widely used types of filters in consumer devices and other non-critical applications is the low-complexity, low-pass EMI filter. This type of filter will enable low-frequency signals to pass through, but will block higher frequency noise, as defined by its cutoff frequency, or the frequency at which the filter begins to attenuate part of the signal.

The cutoff frequency serves as the point at which the signal amplitude is 3 dB below the nominal passband value. This along with the frequency response will, unfortunately, be directly affected by a filter's inductance and capacitance values.

EMI filters are available in a wide range of different circuit configurations, from single grounded capacitors to circuits with as high as three elements. Electronics engineers must make ideal selections depending on the characteristics and requirements of the specific application, such as the device impedance.

It's also important to consider filter construction: One common feedthrough-style EMI filter construction is the donut-shaped discoidal capacitor. Other EMI filter constructions are available such as the metal ferrite containing multiple filters, filtered feedthrough array, and capacitor arrays, all of which have their pros and cons.

Experts also urge engineers to take voltage conditions into account: For optimal EMI protection, EMI filter performance must be matched to comparable capacitor performance and tested and designed for the given circuit's AC or DC voltage conditions. They also must be designed into the system in a way that minimizes current leakage.

Other Keys to EMI Filters: Reliability, Flexibility, Cost

There are also several more practical matters to keep in mind, ranging from ease of installation to testing:

- **Installation:** For optimal performance, EMI filters must be installed within an EMI shield, which in many cases takes the form of a well-grounded conductive enclosure. But engineers tend to have significant flexibility when it comes to installation.\
- **Manufacturing costs:** Careful material selection will be an important element of filter cost since functionality and prices will vary significantly based on the material. One example is the usage of palladium instead of platinum for leads or capacitor terminations. This may result in significant material cost savings. The caveat will be that this would likely make installation more difficult.
- **Inspection and testing:** Filters for mission-critical applications, such as medical devices, must be exposed to improved electrical and visual inspections, along with testing sequences to further ensure robust, long-lifetime performance.
  - Many standards for military-grade electronics have very specific instructions and performance requirements for mechanical, electrical, and thermal testing procedures, including for EMI filters.
  - Additionally, stress testing should be conducted on ceramic components because they often have a high susceptibility for crack propagation. Those with any chance of mechanical instability will usually fail early in the testing process, rooting out inferior parts that could cause performance or reliability issues in the future.

Most electronic devices and systems will be equipped with EMI filters—in one form or another. But engineers must consider the unique requirements of the specific design to choose the best one.

They must also carefully balance the voltage rating, capacitance, hermeticity, dimensions, and cost. When selecting a filter manufacturer, it's also imperative to choose one that supplies all of the inspection and testing capabilities that you need. For higher reliability, it's also worth working with manufacturers that have a track record of regulatory compliance and proven manufacturing processes.

Furthermore, system engineers and EMI filter designers must communicate and collaborate all through the entire design cycle to develop a solution that can fit into the price and performance demands of the design.