EMC/EMI Mitigation Solutions at the Design and Troubleshooting Phases of Product Development
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Electromagnetic interference (EMI) and electromagnetic compatibility (EMC) issues impacting the design and production of consumer, industrial, and aerospace/defense devices is likely to become even more pervasive and common as industrial and governmental standards and electronic device density become more stringent. This being the hard truth, electronic device product development teams are more likely to benefit from considering EMC/EMI mitigation solution technologies during product development. However, it is still very challenging, and maybe impossible, to predict all EMC/EMI issues that could prevent a product launch from failing US Federal Communications Committee (FCC), European Union European Conformity (CE), or other countries various standards and regulations.

This is where preemptive and reactionary EMC/EMI mitigation technologies, such as chokes, surge absorbers, and EMI Filters come into play. This article will provide a brief overview of EMC/EMI challenges that can occur in the product design and troubleshooting phases of product development. Furthermore, this article will describe some of the main EMC/EMI mitigation technologies, with an emphasis on EMI Filters. Lastly, the article will provide a primer on EMI Filter types.

EMI Suppression, Attenuation, and Insertion Loss

EMI suppression, or attenuation, describes the amount of EMI signal power reduced when that signal passes through an EMI mitigation device. This value is typically measured on a logarithmic scale, and represented in decibels (dB). As attenuation is typically a function of frequency, using an EMI mitigation that provides the necessary amount of attenuation to lower targeted EMI signals below the compliance testing levels is critical. This can be somewhat challenging for the inexperienced, as there are many factors, other than frequency, that will impact the attenuation of a filter.

These factors include, power operation, temperature, aging, humidity, other environmental factors, and even mechanical vibration and stresses. Hence, it may be advisable to consult with EMI experts on an appropriate mitigation technology that will provide the necessary performance under the real-world application conditions of the product.

Regulatory Compliance and Standards

There are many military, avionics, industrial, medical, scientific, and even consumer/residential operation and safety standards that may impact the design of EMI suppression solutions, beyond the EMC standards. Domain knowledge and access to a technical professional with specific knowledge of these standards is helpful in determining what measures and types of EMI mitigation solutions will be required for releasing a product to market. For example, medical equipment used for critical applications have safety and interference standards that exceed typical EMC qualification, and require separate certifications.

EMC/EMI and Product Development

Overcoming EMC/EMI issues and passing EMC testing is the gatekeeper between product design, development, and bringing a product to market. If EMC certification isn’t attained for a product, a company can face serious legal liabil-
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Also, there are often other design considerations and pressures of a design and product development team that take priority, such as competitive market pressures and actually getting a working design out of the door while facing strictly reduced design cycles. For these reasons, among others, prepackaged EMI mitigation technologies can be very important for being incorporated into a design near the end of product development, or as a last minute solution to remediate or avoid EMC testing failures.

For more information on the “Basics of EMC and Power Quality”, click here to download Schaffner’s informative whitepaper.

<table>
<thead>
<tr>
<th>Potential EMC/EMI Issues Indicator</th>
<th>Justification</th>
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<tbody>
<tr>
<td><strong>High Speed Clocks or Data Lines</strong></td>
<td>High speed digital signals, such as square waves, are constructed of a multitude of frequencies, any of which could cause radiation or coupling interactions with other circuit components.</td>
</tr>
<tr>
<td><strong>Long Unshielded Signal, Data, or Power Lines</strong></td>
<td>Long unshielded, or even poorly shielded, leads can couple external interfering signals into the device or act as an antenna for device signals to radiate as unwanted emissions.</td>
</tr>
<tr>
<td><strong>RF/Microwave or Wireless Circuitry</strong></td>
<td>RF/microwave and wireless circuitry naturally create and channel emissions, and antennas are symmetrical-capable of radiating and conducting interference.</td>
</tr>
<tr>
<td><strong>High Voltage or High Current Nodes/Lines</strong></td>
<td>High voltage or current nodes or lines in a circuit can more readily cause capacitive and inductive coupling between external and internal circuits.</td>
</tr>
<tr>
<td><strong>Switching Power Supplies are used</strong></td>
<td>Switching power supplies use high speed signal switching techniques similar to high speed data lines, but can also produce relatively fast transient changes in current and voltage. High speed and high power switching result in radiated emissions and harmonics at many frequencies of concern.</td>
</tr>
<tr>
<td><strong>Unshielded Structures</strong></td>
<td>Unshielded circuits and structures on a device could potentially be channels for emissions or interference, as they could cause unpredictable electromagnetic responses. This is even the case with dielectrics and nonconductive structures in close proximity to a circuit.</td>
</tr>
<tr>
<td><strong>High Ground Plane Impedance</strong></td>
<td>High ground plane impedances lead to voltage differences between a ground plane and the connected circuitry, which can even result in voltage gradients across a circuit board. Different aspects of a circuit experiencing different voltages results in emissions or impaired device performance which could lead to many other signal integrity and power integrity issues which impact EMC/EMI.</td>
</tr>
<tr>
<td><strong>Ground Planes are Segmented</strong></td>
<td>Ground planes which are segmented, or &quot;islands&quot;, can induce many of the same issues as having a high ground plane impedance. Multiple grounds and voltage rails may all couple capacitively, inductively, or through higher frequency radiation resulting in unpredictable products.</td>
</tr>
<tr>
<td><strong>Fast Current or Voltage Slew Rates</strong></td>
<td>High power circuits which demonstrate rapid changes in voltage or current will likely AC couple with nearby conductors, possibly causing radiated emissions well beyond the frequency of operation of the power system.</td>
</tr>
<tr>
<td><strong>Equipment Malfunction During Operation</strong></td>
<td>If an equipment regularly malfunctions when operating, even if all simulations and testing looks positive, it could be due to outside interference or inter-device interference.</td>
</tr>
<tr>
<td><strong>Other Equipment Malfunctions During Operation</strong></td>
<td>A clear sign of unwanted emissions is other electronic device malfunctioning while the target device is turned on. Though possibly less likely, some electronic device could even impact the operation of other devices when turned off if they could store and reradiate, or interact negatively with external fields and radiation.</td>
</tr>
</tbody>
</table>
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issues can first manifest during testing. Short design cycles may even prevent a useful amount of iterative testing and design improvement, and later design changes as simple as aesthetic features can render all previous EMC/EMI design considerations a moot point.

Understanding EMI Issues in the Troubleshooting Phase

The significance of EMI issues with a design often doesn’t materialize until a product is nearly complete or put through compliance testing. As many design groups don’t have the benefit of full EMC testing systems in-house, contracted organizations are employed for this. Depending on the location and schedule of EMC testing facilities, the location could be prohibitively far away from the design and manufacturing facilities to rapidly address any EMC issues. Limited scheduling availability and the expense can further reduce the availability of EMC testing, which also limits how quickly solutions can be found and implemented.

At this stage, most design and manufacturing teams are already close, or already behind, schedule and need to rapidly address the EMC/EMI issues that have surfaced. The use of semi-anechoic chambers, transverse-electromagnetic (TEM) cells, or frequency extended TEM cell (GTEM) cell, can provide illumination into the frequencies and location of radiated emissions and susceptibility issues a device may be exhibiting. Though these results are not likely to exactly match the quality or rigor of an EMC testing facility, the results of a failed EMC test could be used as a baseline to evaluate the relative effectiveness of any EMI mitigation solutions that are tested. Outside of specifically designed EMC testing equipment, other test equipment doesn’t necessarily comply with the requirements of the International Special Committee on Radio Interference (CISPR) EMI, or other, standards and this troubleshooting testing is most useful to provide relative guidance.

Another key method of testing and providing more detail into the cause of EMI emissions and susceptibility are the use of current probes and near-field/EMC probes. Current probes attached to oscilloscopes or spectrum analyzers can be used to capture the signals being conducted into the device or radiated away from the device through its power and signal cables. Near-field/EMC probes connected to an oscilloscope or spectrum analyzer can be used to more precisely locate emissions from the edges of shielding, connection points, and even specific devices/components of a product. Current probes and near-field/EMC probes can also be used to inject signals into a device to reveal immunity related issues.

Through these types of testing, the relative power levels, frequencies, and possibly even sources of radiated emissions can be compared with the EMC test facility reports and EMI mitigation techniques can be considered. On the other hand, experienced engineers that have encountered similar EMC issues with similar devices, may be familiar with EMI mitigation technologies and how best to incorporate them into the product for rapid redesign and testing. Another case is that there may be too little time, or an existing product in the field must be retrofit with a solution, and EMI mitigation solutions must be installed with little room for detailed testing and evaluation. In these situations, it could be beneficial to be familiar with common EMI mitigation solutions and how best to leverage these solutions given certain EMI challenges.

EMI Mitigation Solutions for the Design and Troubleshooting Phase

Ultimately, the goal of EMI mitigation solutions is to attenuate, or weaken, unwanted signals from radiating into, or out of, a device without negatively impacting the devices performance. Depending on the EMI mitigation technology, some may require complete redesigns, or some design changes to the actual device for them to work properly. Other EMI mitigation technologies may just require the simple addition or swapping of a component, such as a power inlet, to provide the necessary disruption of unwanted signals.

It is important to remember that EMI signal strength, frequency, and time-domain characteristics are all important factors in determining which EMI mitigation solution is the best fit for solving a particular challenge. Also, typical emissions testing is performed prior to immunity testing, and though not explicitly designed for the purpose, some EMI mitigation solutions primarily designed for emissions issues may help with immunity. The following will be a brief description of several common EMI mitigation technologies with tips on what types of EMI issues they can address.

CAPACITORS

The simplest form of an EMI filter is a simple capacitor either inline as a high pass filter or shunting to ground as a low pass filter. Shunting capacitors between the signal/power line to ground, or a pseudo ground between two differential lines, presents an attenuation that grows with the frequency of the signal. Conversely, inline capacitance presents an attenuation which grows with the reducing frequency of a signal.
The shunt capacitor will allow for DC, and very low frequency AC signals, to pass along the signal/power line while shunting higher frequency noise signals to ground. The inline capacitor will attenuate DC and low frequency AC signals, while passing higher frequency signals. The attenuation and frequency behavior of a capacitor used in these ways depends on the value of capacitance, the way it is connected, and its performance at various power levels under environmental conditions.

Though potentially effective at reducing higher frequency EMI and RFI noise and interference, this method is also prone to several drawbacks. Firstly, the frequency behavior of this type of filter is typically more susceptible to changes based on external and internal loading conditions. Also, the power and thermal stresses a capacitor may be subjected to in real world conditions limit the types of capacitors used to very reliable and robust technologies, which could be large and expensive compared to higher performing filter solutions. Lastly, the limitations of using a capacitor to attenuate target ranges of frequencies that pose specific EMI issues often requires a network of capacitors, inductors, and resistors, which is a filter. Hence, the prevalence of EMI filter technology and the variety of EMI filters.

**EMC/EMI CHOKES**

EMC/EMI Chokes, or coils, are inductors or transformers specifically designed to attenuate EMI noise. Chokes are available which can attenuate both common-mode and differential noise. Effectively, when chokes are placed inline with power lines and high current lines, they absorb a substantial portion of the common-, or differential-mode noise/interference, beyond 60 Hz and up to a few hundred hertz. If properly designed, EMC/EMI chokes won’t impact the power transfer of AC or DC power lines.

As noise caused by electronic equipment or wireless communication devices and noise generated from switched power electronics or high slew rate controllers can also introduce common-mode EMI on power lines, EMC/EMI Chokes can be used to reduce these EMI factors from either radiating or being conducted into a device from the power lines. EMC/EMI Chokes typically need to be designed into the PCB board between the power lines and the downstream circuitry. Hence, if a choke isn’t accounted for initially in a design, a redesign or modification may be required to leverage these devices. There are some EMC/EMI filter assemblies which may include a choke in the design. This can be a compact and multipurpose solution.

**EMC/EMI FILTERS**

EMC/EMI Filters are frequency dependant attenuators that are designed to be inserted between DC lines, AC power lines, or certain signal lines to prevent unwanted signals from tens of kilohertz to tens of megahertz from entering a devices as interference or exiting a devices as emissions. There are several types of EMI filters, such as IEC Inlet filters, power entry modules, single-phase filters, DC filters, 3-phase filters, and others, that are designed to accommodate various DC, AC, or signal lines and packaging styles.

Unlike EMI chokes, some EMI filters are designed to be readily installed in place of standard powerline connectors, and can be more easily designed into a device when fast turnaround is required or limited design resources are available. The versatility of EMI filter designs enable their use in EMI mitigation of many EMI issues from low-power and low-cost PCB mounting to rack mounted industrial motor drive filters. Moreover, there are EMI filters which include embedded chokes and capacitors for enhanced EMI suppression for low and high frequencies, and for common-mode and differential-mode EMI suppression.

**TYPES OF EMI SUPPRESSION FILTERS**

Typical types of EMI Filters are designed for a specific type of signal and the devices in which they will be installed. The wide variation in devices and equipment that benefit from EMI filtering necessitate a range of standard solutions, as well as an expanse of customization capability. The following are a few common types of EMI Filters.

**PCB FILTERS**

PCB filters are EMI filters that are specifically designed to be compact and cost-efficient EMI/RFI filtering solutions that can be mounted on a PCB with standard through hole soldering. When EMC is considered early on in the design phase, or when a redesign is required to pass EMC testing, a PCB filter can be built into the bill-of-materials (BOM), often helping to reduce costs and reduce the impact to product size and shape that some EMI mitigation technologies may
introduce. Multi-stage PCB filters are also available, which can provide extremely high conducted EMI attenuation in a small footprint, for applications that are restricted in device size/shape and require greater EMI protection.

THREE PHASE FILTERS
Three phase filters are similar to single phase filters, except that the filter is designed to filter all three signal/power lines for three phase power and motor systems. There are some three phase filters that also include filtering on the neutral line for applications that require it. Three phase filters are useful as mains input filters for industrial equipment, machine tools, machinery, and automation systems. Depending on the leakage performance of a filter, they may even be used with some medical devices and equipment.

DC FILTERS
DC filters are designed specifically for filtering DC power and control signal lines. This could be for protecting solar panels, photovoltaic charging/converting systems, battery charging and conditioning systems, DC motor drives, and inverter/converters. Though similar to AC EMI Filters, DC EMI Filters are optimized for passing only DC signals and are typically rated for higher DC voltages and currents. These filters are useful in preventing premature aging and protection of solar panels due to conducted emissions, such as HF stray, and leakage currents.

FEEDTHROUGH FILTERS
Feedthrough filters are designed as inline filters, which can provide increasing attenuation up to, and beyond, 1 GHz. These types of filters are often used to protect sensitive equipment within shielded assemblies, as a power line filter, line shielding for high performance computing applications, and more. Typically, feedthrough filters provide greater EMI/RFI suppression than feedthrough capacitors, especially where source impedances are below 50 Ohms.

Conclusion
EMC/EMI suppression and mitigation technologies are essential for meetings today’s rigorous compliance standards and regulations. Of the available EMI suppression technologies, EMC/EMI filters are a versatile and effective solution for a wide range of applications, and can be readily customized to target specific EMI suppression requirements during the design or troubleshooting phase of product development. There are many factors to consider when selecting an ideal EMI suppression solution, and leveraging the experience of EMC/EMI filter experts can help to accelerate and optimize the selection and integration process.
<table>
<thead>
<tr>
<th>Product Types</th>
<th>Responsible For</th>
</tr>
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<tbody>
<tr>
<td>Ecosine active</td>
<td>USA</td>
</tr>
<tr>
<td>EMC/EMI</td>
<td>Brazil</td>
</tr>
<tr>
<td>Power quality</td>
<td>Canada</td>
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<td></td>
<td>Mexico</td>
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