Mitigating Electromagnetic Interference with Filtered Connectors

SPECTRUM CONTROL

Introduction

Electromagnetic Interference (EMI) is an electromagnetic emission that causes interference in another electronic device. EMI originates from internal (i.e., switching power supplies and digital interfaces) and external (i.e., RF emitters and industrial equipment) sources. This type of disturbance can cause RF noise, which may disrupt functionality and communication between devices.

While EMI has been a major design consideration for decades, it poses a significant challenge in modern electronic systems, ranging from aircraft and unmanned vehicles to power supplies, automation equipment, and medical devices. Today's designs have densely packed circuits and high-speed components, which increase the likelihood of interference that can degrade signals and lead to compliance issues.

Importance of Limiting EMI

Controlling EMI is vital in all electronic designs

- *Power Integrity:* EMI can cause fluctuations and noise in power delivery networks, affecting device operation at high frequencies.
- *Signal Integrity:* Noise and unwanted signals can be introduced into equipment, causing data corruption, timing errors, and loss of information. This is particularly an issue in high-frequency digital and RF circuits.
- *Lower Signal-to-Noise Ratio (SNR):* Excessive EMI will lower SNR. Errors or malfunctions can become problems because equipment can't differentiate between true signals and noise.
- *Degraded Sensitivity and Accuracy:* EMI can impair the ability of sensors and measurement devices to accurately detect weak signals, so overall device performance will suffer.
- *Increased Error Rates:* In communication systems, EMI causes higher Bit Error Rates (BER), affecting data throughput and quality. Reduced Reliability and Longevity: Ongoing EMI exposure can place added stress on electronic components, reducing their life.
- *EMI emissions:* Non-compliance with EMC regulatory standards can mean costly re-designs that will prove more expensive and delay time-to-market.

A typical mitigation approach is to use EMI filters to protect these sensitive electronics. Optimal EMI filter designs address both conducted and radiated EMI. These EMI filters suppress unwanted signals, ensuring system reliability and compliance with electromagnetic compliance (EMC) standards.

Given the shrinking footprint of today's systems, filtering approaches need to evolve and address space savings and reduce component counts. While board-mount filters are a common solution. They add to space and component count. EMI-filtered connectors eliminate interference before it enters the system. A single filtered connector can replace up to 128 discrete filters and free-up board space.

EMI Filter Design

Designing high-performance EMI filters requires recognizing real-world limitations in passive components. Among the factors that need to be identified are Equivalent Series Resistance (ESR) and Equivalent Series Inductance (ESL). Both can reduce the effectiveness of highest quality capacitors, necessitating careful selection and modeling.

- *ESR*: Often referred to as parasitic resistance, ESR represents the loss of useful energy in a capacitor. The higher the ESR, the more heat is generated. In high-frequency applications, ESR can become a significant factor, as the capacitor's impedance rises. Higher ESR increases high frequency noise across the capacitor, which may decrease the effectiveness of filtering, if an inferior solution is used.
- *ESL*: The capacitor's internal structure and circuit trace length result in ESL, which is also referred to as parasitic inductance. Impedance to the ground increases when there is greater ESL, creating voltage fluctuations, common mode noise, and potential system errors. ESL contributes to the unwanted flow of current and generates EMI. In power supply related systems, ESL contributes to high ripple voltage, which can lead to noise, instability, shorter component life, and other issues

As frequency increases, ESR and ESL become larger factors, particularly above 100 MHz. Proactive steps at the design phase can mitigate these concerns.

Real-world Challenges of EMI Mitigation

While the principles of EMI filter design are well understood, engineers and system designers frequently encounter practical challenges that complicate implementation. These pain points often stem from competing design constraints and development realities.

Performance: Achieving sufficient EMI suppression without compromising system functionality is a top concern. Filters must attenuate unwanted frequencies while maintaining signal and power integrity. However, performance can vary based on component tolerances, PCB layout, and system-level interactions. Even a well-designed filter may fail to meet expectations if not properly integrated. Additionally, as electronic systems operate at higher speeds and frequencies, the bar for effective EMI mitigation continues to rise.

Footprint-Space is a premium in most modern systems, especially in aerospace, defense, and medical devices. Discrete filtering solutions often require board space that may not be available. Engineers are forced to make trade-offs between filter performance and physical size, particularly in dense, multi-function designs. This has driven demand for integrated solutions, such as filtered connectors and hybrid modules, that combine EMI mitigation with mechanical or electrical interconnects.

Lead time- Connector Express! One of the most critical, and often overlooked, pain points is timing. EMI or electromagnetic compatibility (EMC) issues are frequently discovered late in the development cycle, during system-level testing or compliance certification. At this stage, design flexibility is limited, and any corrective actions can cause costly delays. While circular connectors with embedded EMI filters offer an elegant late-stage solution, they can carry lead times of 20 to 30 weeks or more, far exceeding the schedule of many fast-moving programs. As a result, engineering teams are increasingly seeking preemptive solutions that combine performance, integration, and availability.

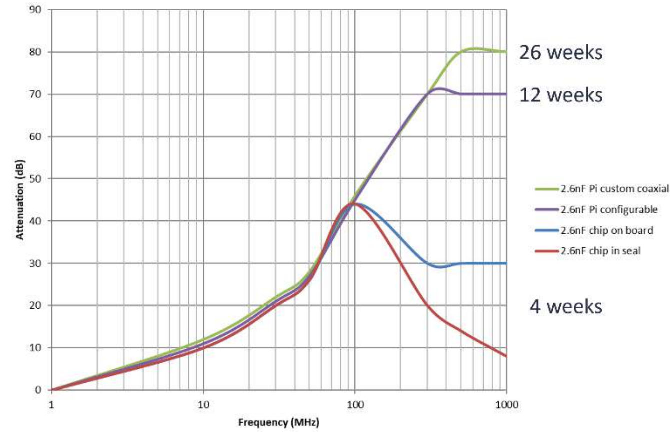
Circular Filtered Connectors

Circular connectors provide effective EMI filtering, reducing the amount of real estate required within a product enclosure. Easily installed and removed, they can transmit power and electrical signals in multi-pin designs. They are also well suited for high stress applications.

Because of their cylindrical structure, circular connectors are sealed to ensure high performance in harsh environments. They have outstanding mechanical sturdiness and a higher strength-to-weight performance, so they're well-suited for high shock and vibration environments. Today the industry offers a range of options/approaches for circular filtered connectors:

- Chip-in-seal
- Chip-on-board
- Pi-configurable
- Fully custom

The graph below plots attenuation values at various frequencies and typical delivery times for each option. The highest-performing solutions typically require 26 weeks or more from drawing/order through delivery. Chip-in-seal and chip-on-board options offer the fastest delivery but the poorest performance. The Pi-configurable solution is new to the market and is described in the following section.



Accelerating EMI Filtered Connector Availability Through a Novel Design and Manufacturing Approach

To address the long lead times typically associated with custom EMI filtered connectors Spectrum Control has developed an advanced design and manufacturing process that significantly reduces time to delivery. The first platform to benefit from this innovation is the widely used MIL-DTL-38999 circular connector series, commonly deployed in aerospace, defense, and other mission-critical environments.

At the core of this approach is a unique hybrid filtering architecture that combines planar capacitor arrays with configurable substrate filtering, an industry-first integration. This design leverages Spectrum Control's in-house planar capacitor technology, which enables full control over critical design and manufacturing parameters. Internal development of both the capacitive elements and their integration substrates allows for precise optimization of electrical performance and supply chain efficiency.

Unlike traditional designs that rely on discrete chip capacitors and suffer from parasitic effects such as high ESR and ESL, this solution minimizes those limitations through careful layout and material selection.

The substrate design employs:

- Optimized trace lengths and via placement to reduce inductive effects,
- A low-impedance return path using a continuous ground plane, and
- Low-loss tangent materials to support high-frequency filtering performance.

These enhancements bring the filtering network closer to ideal capacitor behavior, delivering robust attenuation up to and beyond 1 GHz. Furthermore, the modular nature of the substrate design allows for configurable mixed-signal filtering—enabling rapid adaptation to specific signal and power line requirements.

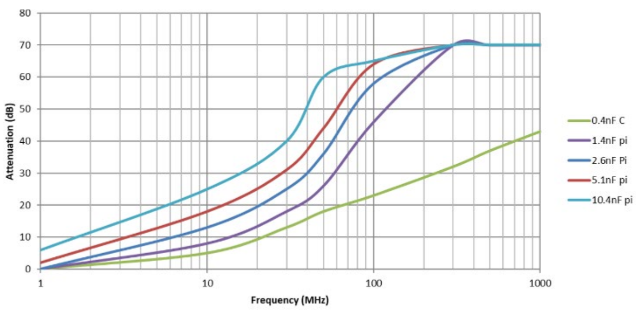
Beyond the design aspects the company has aligned its inventory and manufacturing to enable a 12-week delivery time.

- Strategic stocking of critical raw materials,
- Use of existing floor stock for common configurations,
- Standardized planar capacitor arrays matched to each insert pattern,
- Configurable substrate-based filtering networks,
- And pre-approved documentation packages for rapid design release.

The connectors are assembled in a high-volume, SOP-driven manufacturing facility, ensuring scalability and consistency. The result is a semi-custom filtered connector solution that delivers near-ideal EMI performance with roughly half the lead time of traditional custom builds.

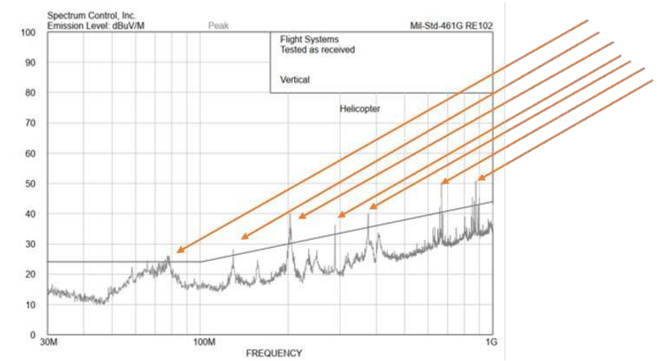
The configurable connector solution offers a choice of five filtering values for each pin, plus a ground option.

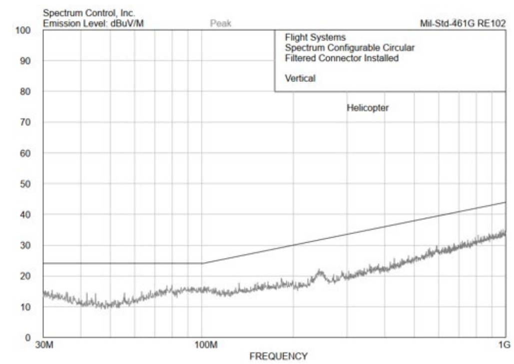
Below is the performance data for each of the available filter values.



EMC Test Data

The plots below show the EMI profile of a typical system before and after installing a 38999 configurable connector. Note the multiple spikes outside of compliance in the “before” plot and the clean emissions profile in the “after” plot.





Conclusion

Engineers must balance performance, footprint, and availability, especially as EMI issues often arise late in the development process. New, innovative compact, integrated solutions such as filtered connectors can help mitigate EMI by addressing ESR, ESL, and other factors, however they have traditionally had long lead times.

Spectrum Control is meeting the market need through its configurable filtered circular connectors. A hybrid design allows the connectors to achieve high performance in a compact, integrated solution. They are also available in 12 weeks to satisfy customer requirements in half the time of alternative filtering solutions.

Spectrum Control has protected equipment from EMI for over 70 years and utilizes that experience, as well as advanced design and manufacturing processes to develop EMI filters for modern equipment requirements. That experience and expertise lends itself to development of innovative filtering technologies.

For more information or to use our web-based tool to specify a custom 38999 connector visit spectrumcontrol.com/connector-express