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What are Filter Connectors?

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How Do Filter Connectors Solve EMI Issues?

As switching frequencies continue to increase, the Internet of Things adds connectivity to every device, and designers pack more modules into smaller spaces, the risks posed by electromagnetic interference (EMI) or radio-frequency interferences (RFI) continue to increase.

To minimize EMI problems in a complex system containing multiple electronic modules, each module must satisfy two goals: it must minimize unwanted emissions, and it must minimize susceptibility to interference from other sources. Immunity is the flip side of susceptibility which would mean that minimizing susceptibility is equivalent to maximizing immunity.

Systems designers must aim for excellent **Electromagnetic Compatibility** (EMC) between modules. EMC is a key consideration in a broad range of fields including medical electronics, automobiles, military and civil aerospace, and much more.

Since EM energy can couple between circuits by means of radiation or conduction, designers must concern themselves with EMC performance in four areas: radiated emissions, radiated susceptibility, conducted emissions, and conducted susceptibility.

What Techniques Can Reduce EMI?

Depending on the frequency spectrum of the interference (broadband, pulse or transient, ESD, etc.) and the coupling mechanism, designers can draw on many different techniques to reduce the effects of EMI. These techniques include grounding, shielding, filtering, careful PCB layout, and more.

Stopping the noise at the point at which it enters or leaves the module (at the connector) is a very effective way to reduce conducted emissions or susceptibility caused by unwanted interference propagating via a wiring harness or power cable.

If an EMC issue manifests itself early enough in the development process, the simplest approach is to add filter circuits on the PCB at the input/output pins. Figure 1 shows some common filter configurations.

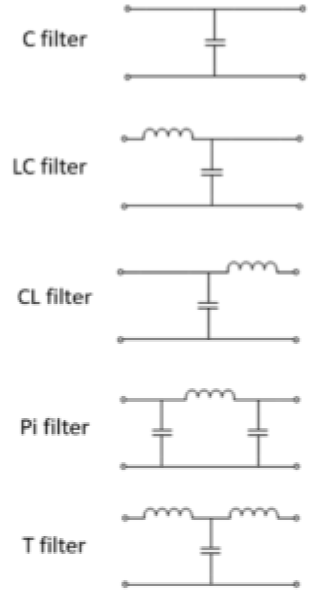

Figure 1: Common filter circuits for EMI suppression

The simplest filter is a decoupling capacitor from the signal line or pin to ground. The capacitor C combines with the output impedance of the source R_{OUT} to give a 1-pole low-pass filter with a roll-off of 20 dB per decade above the 3-dB cutoff frequency f_C given by:

$$f_C = \frac{1}{2\pi R_{OUT} C}$$

Adding an inductor gives an LC or CL filter, which provides both capacitive and inductive filtering. These filters have two frequency-dependent components and provide two-pole roll off (40 dB per decade).

$$f_C = \frac{1}{2\pi \sqrt{LC}}$$

Adding a third component gives the Pi or T configurations, so named based on their schematic appearance. These filters provide three-pole roll off (60 dB per decade). The Pi filter has capacitors on the input and output side with an inductor between them to form a CLC configuration. The Pi configuration has low input and output impedance at high frequencies as the capacitors shunt high frequencies to ground.

The T configuration is the inverse: two inductors with a center capacitor to ground in an LCL arrangement. The T filter has high impedance at high frequencies due to the series inductive chokes.

The formulas above assume ideal components, but real-world devices have additional elements that turn them into L-C-R combinations (a primary attribute plus two parasitic elements). These parasitic elements change the real component behavior compared to the ideal version and affect the filter performance.

A real-world inductor, for example, has parasitic capacitance between the inductor turns and parasitic resistance in the wire of the inductor and the leads. While a real-world capacitor has an equivalent series inductance (ESL) due to the leads and package. As the frequency increases, the ESL also increases, whereas the impedance of the capacitive element decreases with increasing frequency. At a certain frequency (the self-resonance frequency) the two quantities cancel and the capacitor has zero effective impedance. At frequencies above the self-resonance frequency, the ESL dominates and the capacitor impedance begins to increase. Precision models of real-world devices include the effects of parasitic elements.

How Can Designers Use Simulation to Compares Filter Configurations?

The designer can simulate the performance of a filter with a program such as EMI Analyst to compare the insertion losses of different filter types. The insertion loss of a filter is a measure of how much it attenuates a signal at a given frequency. This is the ratio of the signal level at the input to the filter to the signal level at the output of the filter. The insertion loss quantifies the ability of the filter to remove unwanted noise from a circuit.

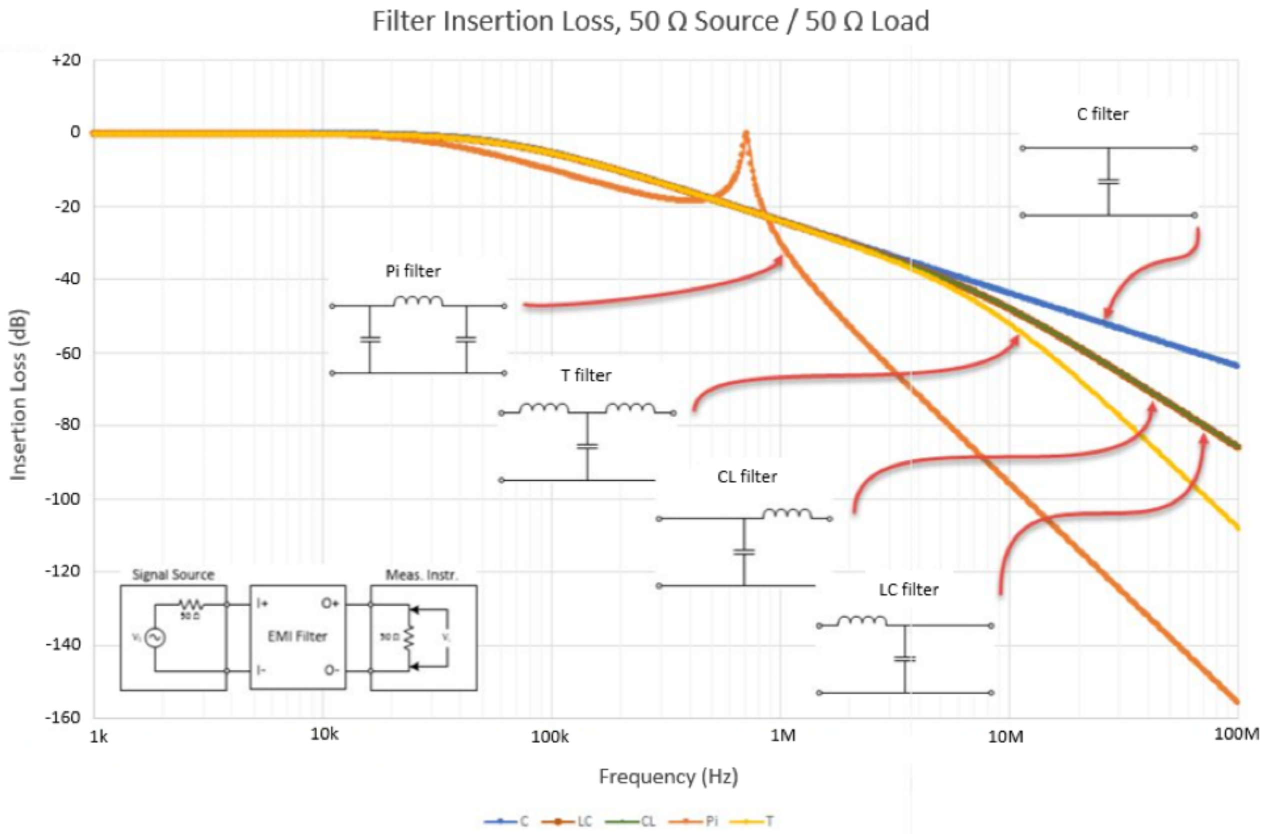

Figure 2: EMI filter performance with 50-Ω source and load impedances (Image Source: Medium.com)

A low-pass filter has low insertion loss at low frequencies and high insertion loss at high frequencies. The Bode plots in Figure 2 show the performance in a low-pass application of the four filter configurations discussed earlier. The figure shows the results in a circuit with a standard 50-Ω source and load impedance. These values are standard for radio-frequency (RF) test equipment.

Under these conditions, all four filters have similar performance at frequencies below 10kHz. At higher frequencies, the T and Pi filters give greater insertion loss than the simpler designs. All filters used 100 nF capacitors and 1 μH inductors.

The source and load impedance of a real-world system, though, can be substantially different from the standard 50-Ω model; a proper assessment should use the impedance values expected in the application.

Changing the source and load impedances gives dramatically different results than before. Figure 3 shows the performance of the same four filter types with low source impedance (10 Ω) and high load impedance (10 k Ω).

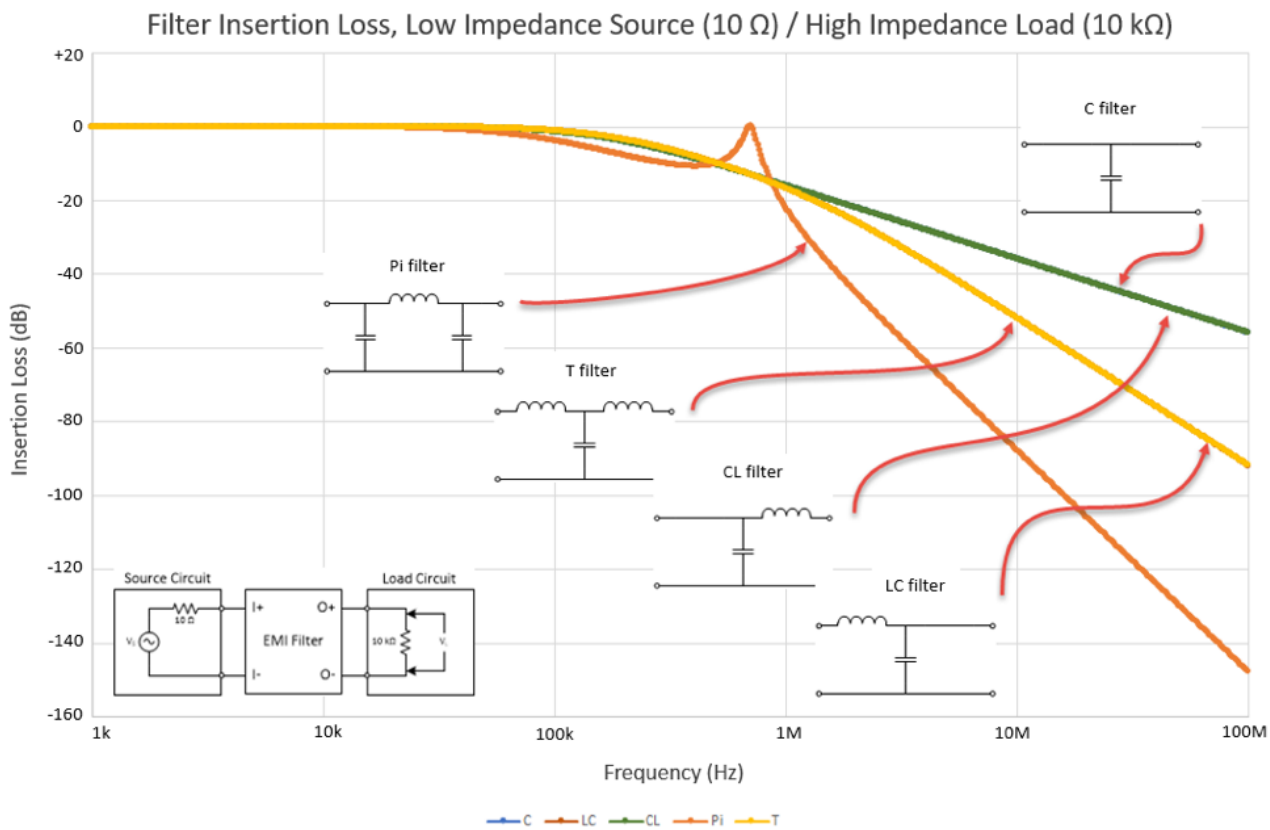

Figure 3: EMI filter performance with low-impedance source and high-impedance load (Image Source: Medium.com)

In this case, the output-side inductor has little effect; the CL filter performance curve overlaps that of the C filter, and the T filter and LC filter are equivalent.

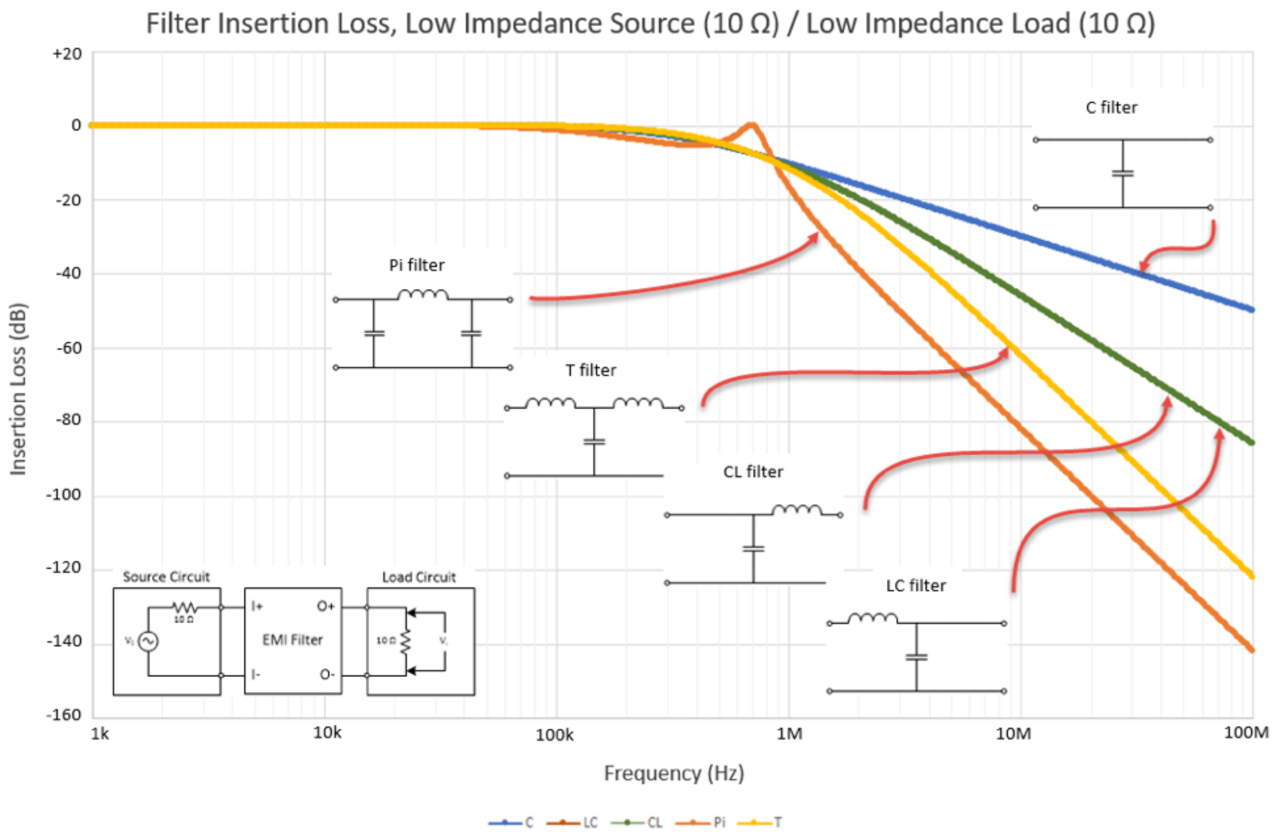

Figure 4: EMI filter performance with low-impedance source and load (Image Source: Medium.com)

Figure 4 shows the performance of the same filters in a system with low source and load impedances. Here, the CL and LC filters are equivalent.

The choice of filter clearly depends on the source and load impedance of the system. If the performance of two filters is equivalent, it makes sense to prefer the lower-cost design. The table below shows the recommended filter type for different impedance combinations.

Source Impedance	Load Impedance	Preferred Filter Type
Low	Low	T
High	Low	CL
Low	High	LC
High	High	C
Unknown or Medium	Unknown or Medium	Pi

Of course, the comparisons above used the same L and C values in all filters. The filter's job is to remove unwanted noise, but in doing so it may also attenuate a portion of the desired signal. It is important to minimize insertion loss over the frequency range of interest even though the signal can be amplified in a subsequent stage. Excessive insertion loss may result in an unacceptable degradation of system performance.

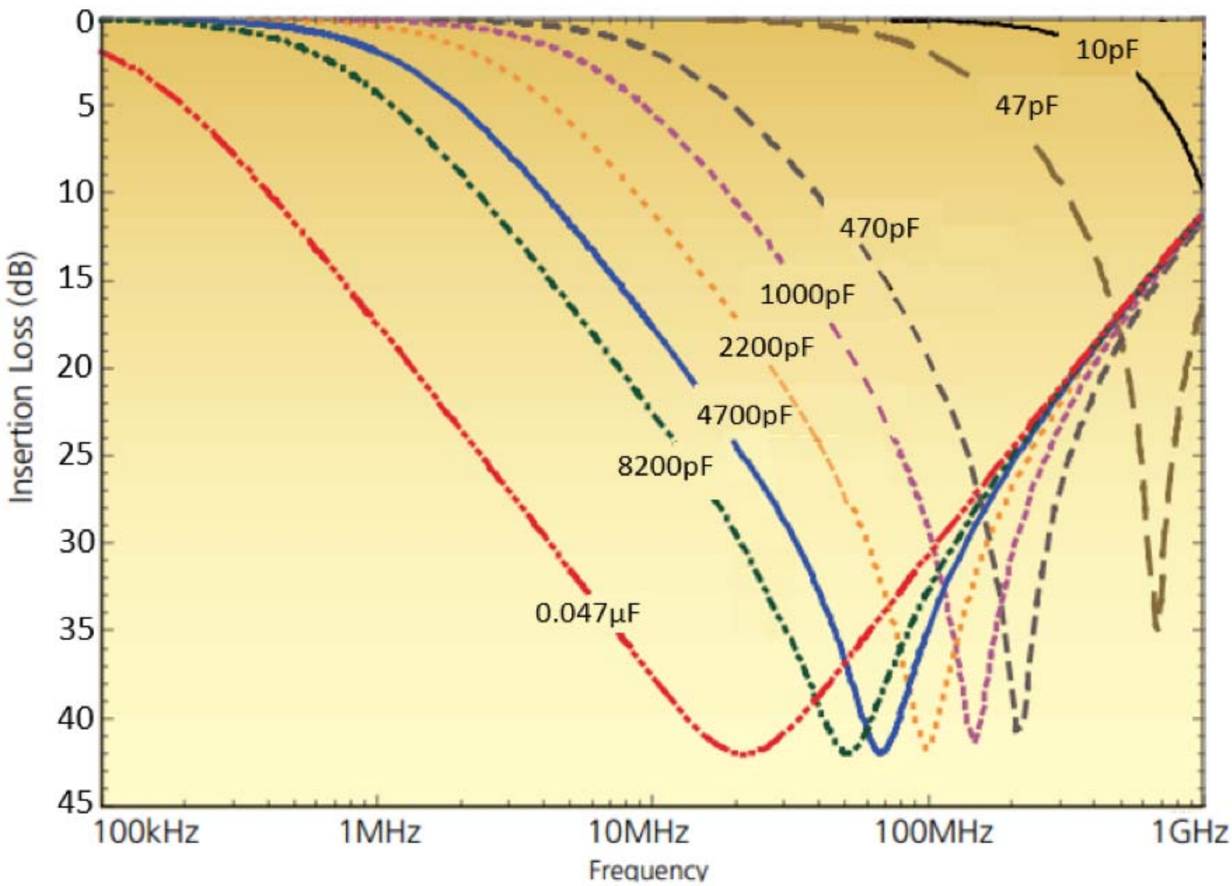

Figure 5: Typical attenuation of EMI filters vs. capacitor size. (Image Source: Quell)

Figure 5 shows the how the attenuation of a capacitive filter varies with the capacitor used: larger capacitors attenuate at lower frequencies.

How Do Filter Connectors Provide Off-board EMI Suppression?

Once the configuration has been chosen, there are several options for locating the filter components. Mounting the filter components on a PCB consumes board real estate which may pose an issue in a space-constrained design. A filter connector offers an alternative option by moving the components offboard and reducing EMI by adding EMI/RFI suppression components to a standard connector.

The filtering elements are housed within the connector. Three types of capacitors are commonly used: a multi-layer ceramic chip (MLCC) capacitor, a tubular capacitor around the connector pin, and a planar capacitor array. A planar capacitor array is a barium-titanate ceramic disc or rectangle that provides a common substrate for capacitance on each pin of a connector. Typical capacitance values range from 500 pF to 0.1 μF with pins that can also be grounded or simple feedthroughs with no added capacitance. The capacitor array also provides a continuous ground plane across the interface of the connector. Figure 6 shows examples of the two capacitor types.

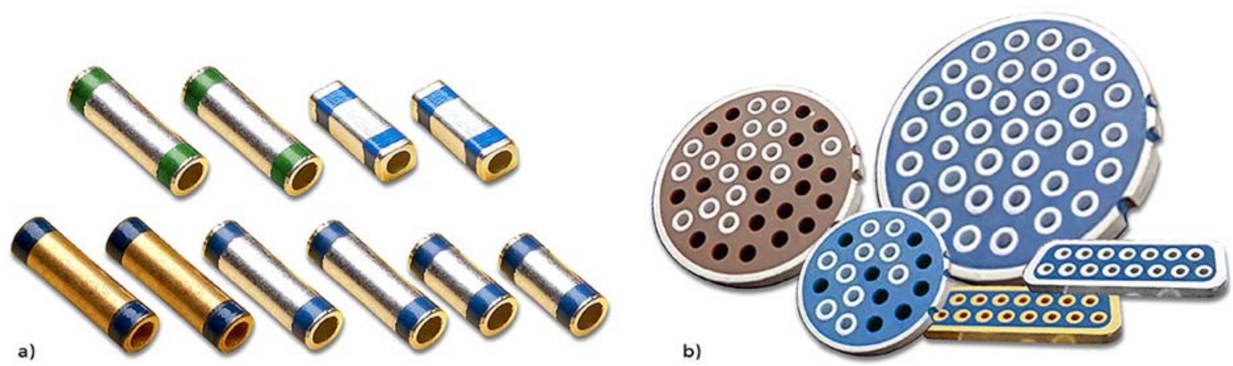

Figure 6: Examples of (a) tubular and (b) planar array capacitors (Image Source: Quell)

The ferrite inductor may either be in the form of a ferrite bead around the connector pin or a ferrite slab which all the pins pass through. Ferrite beads can provide inductance of 0.5 μH to 5 μH along with resistors of 10-100Ω in the equivalent circuit.

Demonstrated Results

Adding a filter to the connector can have dramatic results. Figure 7 shows the performance improvement to a unit undergoing the IEC-61000-4-4 fast transient/burst immunity test after adding a 5000pF capacitor on each pin.

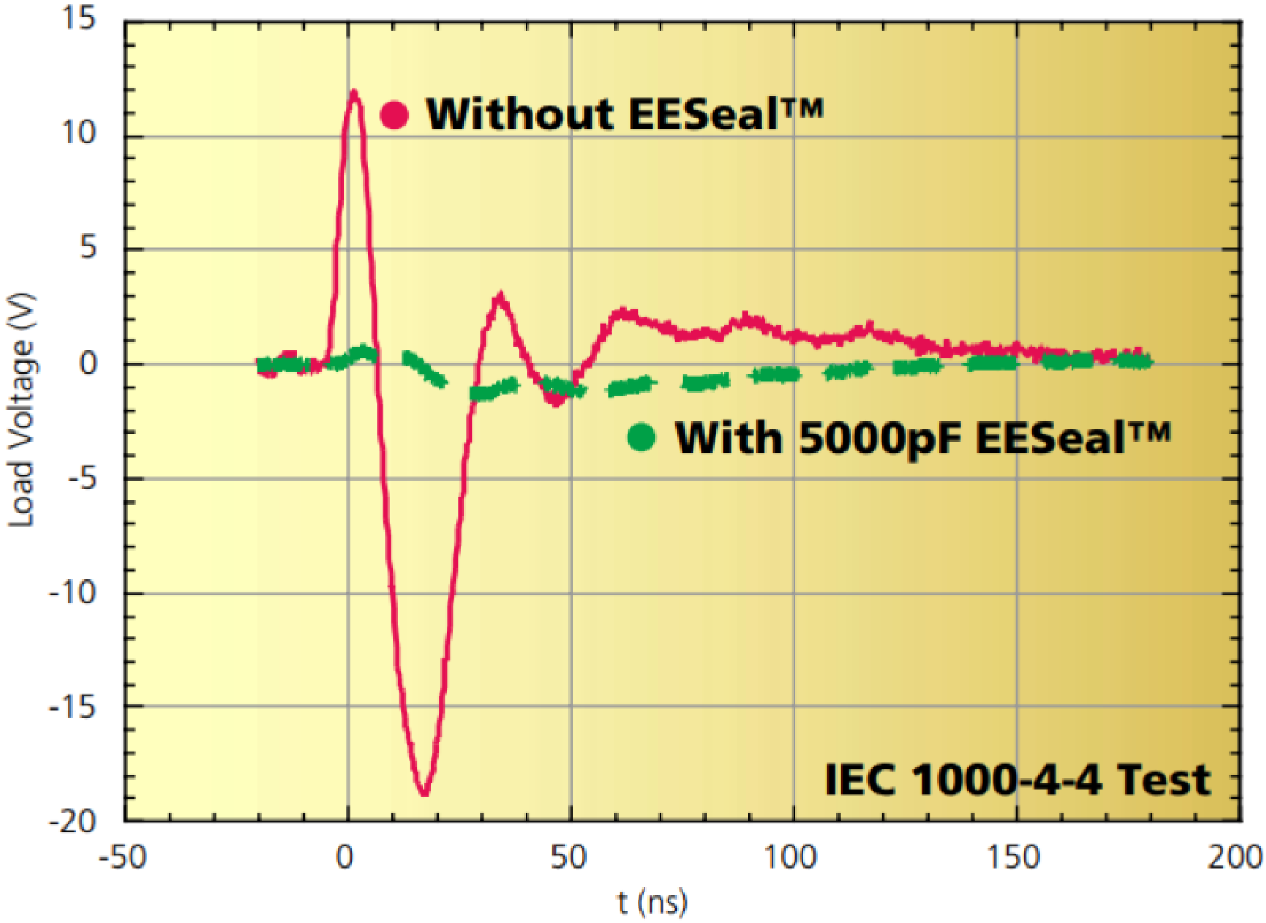

Figure 7: IEC-61000-4-4 improved test results due to adding a 5000pF capacitor to each connector pin. (Image Source: Quell)

Figure 8 shows an extract from test results on a military vehicle undergoing the RE102 Radiated Emissions test in MIL-STD-461F. Initial tests showed multiple issues over a frequency band of 2MHz – 400MHz.

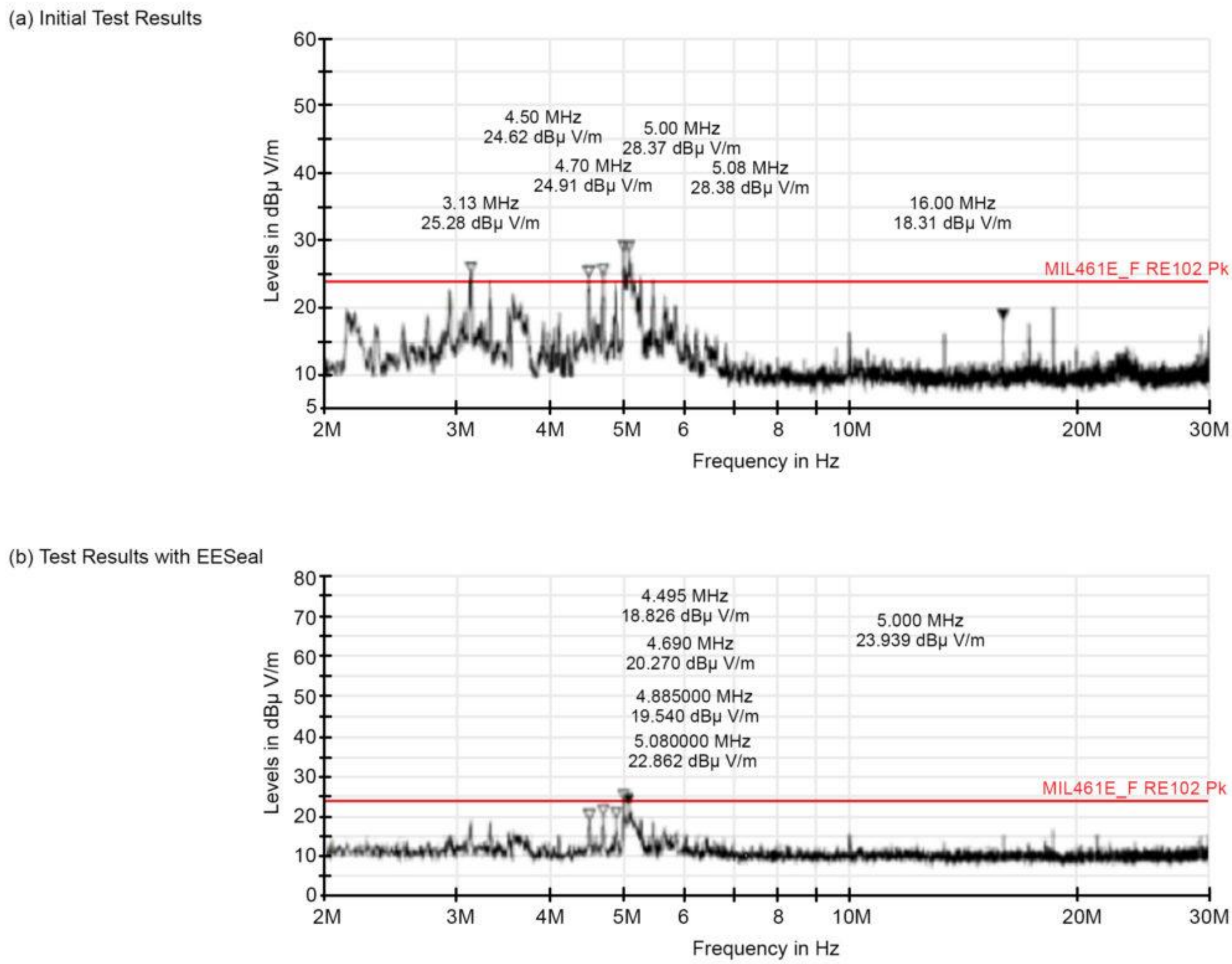

Figure 8: Before and after comparison of RE102 Radiated Emissions testing (Image Source: Quell)

Attenuation of 5-10dB was needed at numerous frequencies over a wide range. The problem was solved with a filter containing several capacitors in parallel on each pin ranging from 47pF to 2µF.

EESeal EMI Filter Inserts, Retrofit Solutions

Once the design is frozen, solutions to EMI problems become more costly. The worst case occurs when EMC issues are identified late in the development cycle, during system integration, or even after the equipment has been deployed in the field. Specifying filter connectors for all interfaces early in the design cycle may help avoid later problems. However, electromagnetic issues experienced by a design in the field may be different than those seen during development, requiring a different filter design. Additionally, the added cost and weight of multiple filter connectors can be a serious disadvantage in many designs.

Luckily, there's a better option. Quell's EESeal is a filter insert that attaches to an existing connector to transform it into a filter connector.

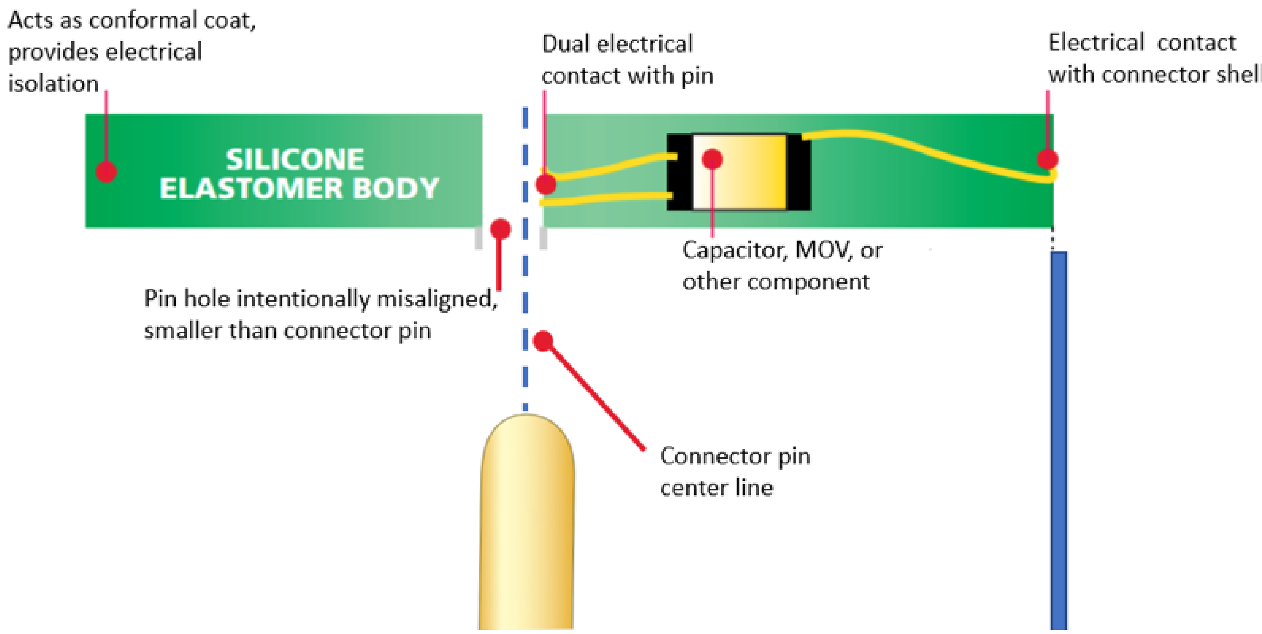

Figure 9: EESeal internal construction (Image Source: Quell)

Figure 9 shows the internal construction. EESeal technology provides EMI, RFI, transient, ESD, and grounding protections by embedding discrete filter components in an elastomeric shell. The component connects between the pin and the outer edge of the insert which shorts to the connector shell ground.

Capacitors from 1pF to 1µF are available with voltage ratings up to 1000wvdc depending on capacitance value. Most capacitors use X7R dielectric. Resistors, metal oxide varistors (MOVs), and diodes are also available and some models can include more than one component per pin. Selected pins may be a component value, shorted or open circuit. The components and wiring are fully embedded in protective material.

EESeal® is easy to install & remove in the field by non-expert personnel with no special tools. Once installed, EESeal maintains the environmental seal of the host connector and looks like a normal part of the assembly.

Figure 10: EESeal is easy to install and does not require special training or tools (Image Source: Quell)

Once installed, EESeal's interconnect system suspends, isolates, and protects discrete electrical components. The entire assembly can change shape and size in response to external forces. Individual components and interconnections move as the body changes shape while maintaining electrical and mechanical integrity.

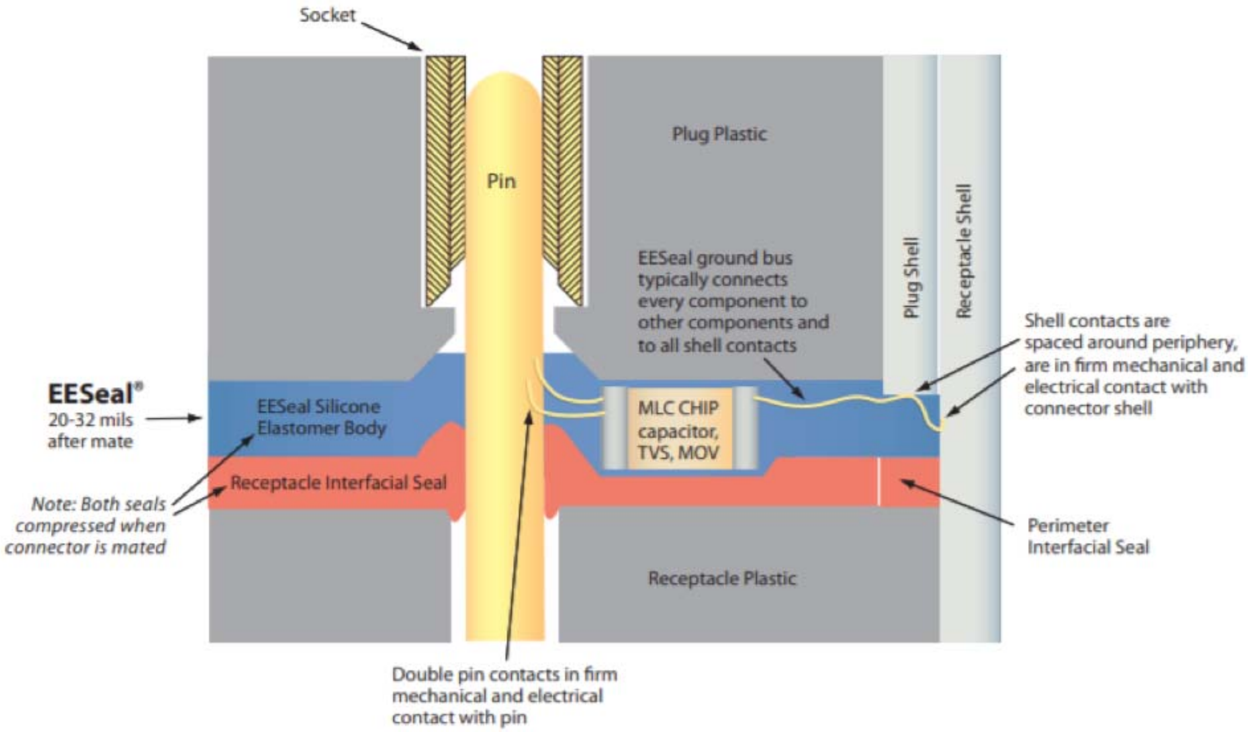

Figure 11: Cross-section of EESeal after insertion into a MIL-C-38999-type connector. (Image Source: Quell)

The body acts as conformal coat and electrical isolation for suspended components. The pin holes are intentionally misaligned to increase the pressure on the pin and are smaller than the connector pin to ensure good contact and seal. Natural compressive forces are used to create re-usable electrical contacts that can withstand pin misalignments, vibration, or wrong pin sizes.

EESeal filter inserts cover numerous connector form factors including circular MIL-C-26482, MIL-C-38999, MIL-C-5015, MIL-C-83723 connectors and receptacles, JN1003 Eurofighter plugs and receptacles, plus ARINC, DIN, LEMO, subminiature D, and custom designs.

EESeal Testing Protocols

EESeal has undergone extensive environmental and mechanical testing by independent laboratories to verify that severe environmental conditions don't affect the integrity of EESeal® FilterSeal EMI Filter Inserts or the host connectors.

Here's a summary of some of the test protocols:

Test	Protocol
Shock	MIL-STD-1344A Method 2004.1
Vibration	MIL-STD-1344A Method 2005.1
Salt Spray	Method 1001
Thermal Cycling	RTCA/DO160C: -55C to +125C, 20 cycles
Humidity Exposure	RTCA/DO160C Category A
Temperature-Altitude	MIL-STD-5400 ¶4.6.2.3 Class 1A
Durability	MIL-STD-1344A Method 2016
Fluid Immersion	MIL-STD-1344A Method 1016, Fluids a, c, d & e
Removal Re-Use Assessment	128-pin EESeal® completely removed from connector and re-inserted 12 times
Porosity	MIL-STD-1344A Method 1017
Out-gassing	ASTM E595-07

Design Procedure for Custom EMI Solutions

Quell Corporation manufacturers inserts for a multitude of combinations and EMI engineers are available to help customers solve EMI problems by determining the most appropriate solution. Once a solution is developed, they then provide free evaluation samples within a matter of days.

Only a few pieces of information are needed to get started:

- Complete connector part number
- Description of the EMI issues, preferably with scans
- Operating voltages on each pin
- Maximum data rates on each pin – RS232, Ethernet, video, etc.
- Details about special requirements – lighting pulses, etc.

The quick turnaround time for samples can result in great cost savings! For example, the military vehicle discussed in Figure 8 could remain in the EMC test chamber while the solution was validated and the staff was still on site. The vehicle passed the test and then could proceed straight to production.

Conclusion: EESeal EMI Filter Inserts Solve EMI Problems at Any Stage of the Development Cycle

EMI problems can crop up at any stage of design and designers have a range of options for solving them. Issues late in the development cycle are often the most serious because many aspects of the design have been frozen, and timescales may be short.

The EESeal filter insert provides a quick and convenient method to fix EMI problems with minimum cost and program delays.

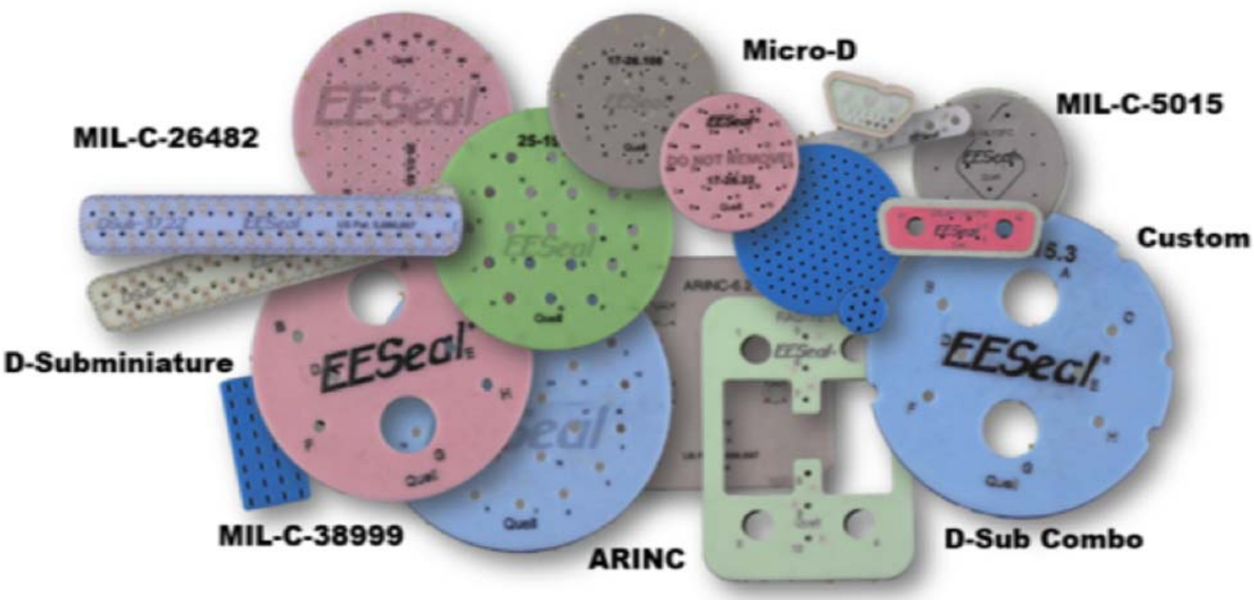

Figure 12: Adding a filter insert can solve tricky EMC problems late in the product development cycle or even after system deployment. (Image Source: Quell)

FREE SAMPLE

To request a free sample of MIL-STD 461-tested EESeal Filter Inserts, please fill out the form below.

Please choose from the following *

◯ Send a FREE generic EESeal sample and literature

◯ Send a FREE CUSTOM EESeal and literature

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Last

Company Name *

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