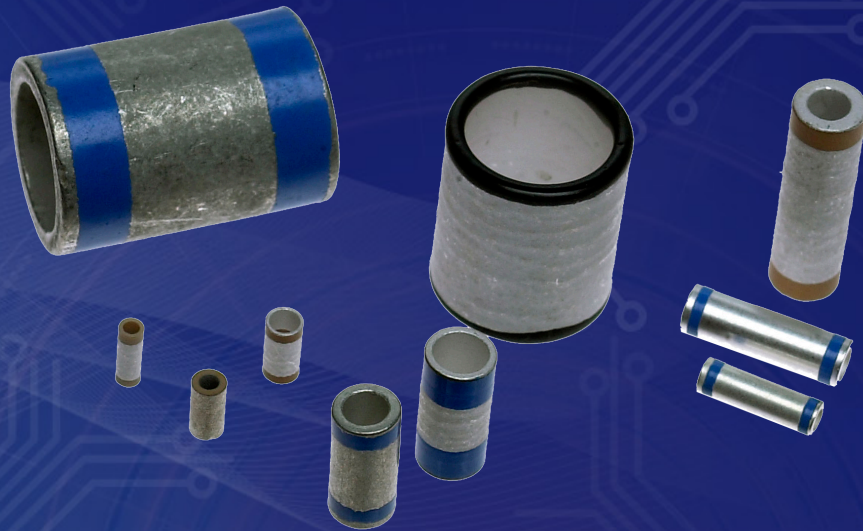




Ceramic Feedthrough Filters:

Winning the Finite EMI Fight



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CONTENTS

Introduction	01
Feedthrough Filters Defined	01
Ceramic Feedthrough Filters - Basic Requirements	02
Ceramic Feedthrough Filters - Circuit Options	04
Ceramic Feedthrough Filters - Package Options	07
Author Bio	09

Introduction

In today's world nearly all electronic devices have wireless connectivity features built into them. From laptop computers to home security systems, these devices rely on transmitting and receiving Radio Frequency (RF) or Microwave signals from one device to another. The term used to identify the energy in these transmissions is Electro-Magnetic Radiation. Electro-Magnetic Radiation is around us everywhere, all the time. The frequencies that this radiation falls into is in the 3 KHz to 300 GHz range.

When electronic devices have internal operating processes that rely on signals that are in this RF frequency spectrum, unintended results may occur if the ever-present RF or Microwave Electro-Magnetic Radiation interacts with the device. This occurrence is called Electro-Magnetic Interference, or EMI for short.

EMI is a serious concern for devices that are externally powered (ones that have a plug) or require signal wires that need to extend outside the device (signal wires that might attach to sensors or input/output devices). The wires that connect to power sources, or I/O points, can act as antennas that will allow EMI to be received (coupled onto them) and enter the device. Once inside the device, EMI can then cause the device to perform improperly.

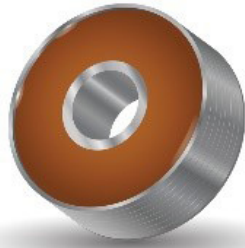
The most common way to prevent EMI from interfering with these devices is by installing Feedthrough Filters on their signal and power lines.

Feedthrough Filters Defined

A Feedthrough Filter is a component that has a capacitive element built around a central conductor. Capacitors are reactive components, meaning they conduct electrical energy at different rates based on frequency. At very high frequencies, capacitors act like a short circuit, allowing RF energy to pass through them freely. At very low frequencies, they act like an open circuit, not allowing any RF energy to pass through them. Since the capacitors are built around a center conductor that passes through the case and into the device, they are often called Low Pass Filters. This is because they allow lower frequencies to enter the device with very little loss, while shunting high frequencies through the capacitors.

Feedthrough Filters are built using a dielectric material that can be shaped into a circular form. This may be in the form of a discoidal (donut shape) or in a tubular form. These shapes allow for the center conductor to pass through and attach to them in the center. This makes the "+" connection to the capacitor element. The outer diameter of this form is the "-" connection to the capacitor element, and it is typically attached to an electrical ground point of the device.

Many different types of material can be used to make the capacitor, but the most common material today is ceramic. This is due to its ability to have relatively high dielectric constants and high working voltage capabilities.



Discoidal Capacitor Element



Tubular Capacitor Elements

Ceramic Feedthrough Filters - Basic Requirements

When reviewing the use of Low Pass Filters to prevent EMI, there are a few basic requirements that are common to all applications. These items are:

- **Cutoff Frequency**
- **Insertion Loss**
- **Power Requirements**

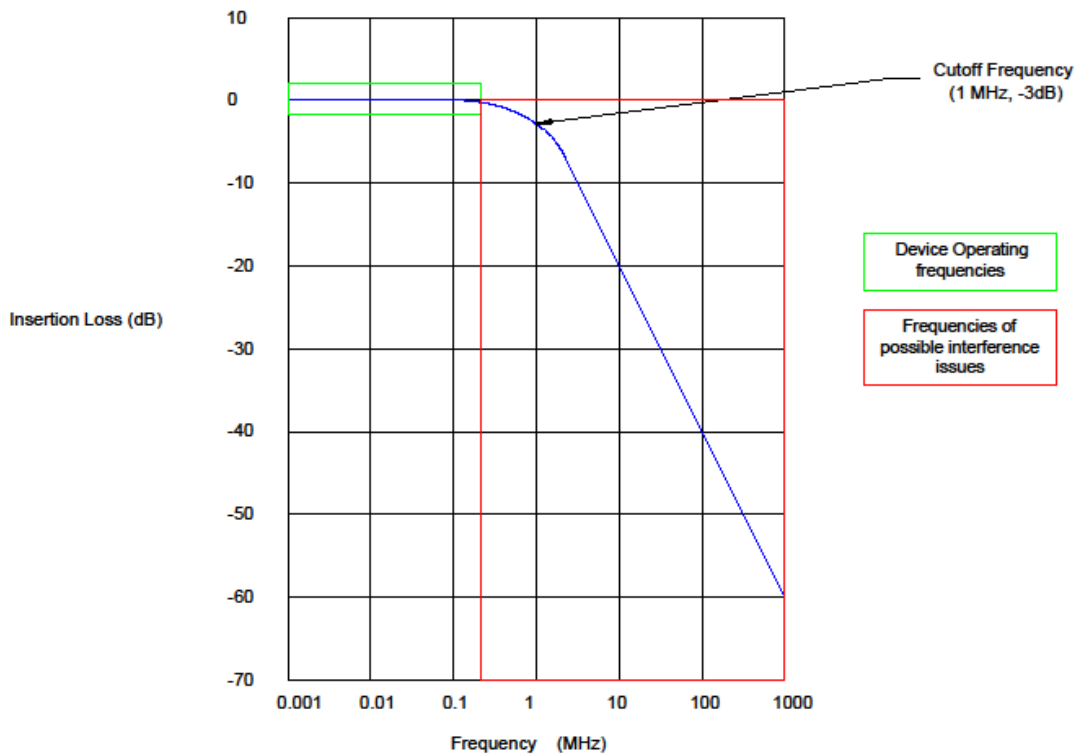
In order to incorporate a Feedthrough Filter into a design, you must be familiar with two sets of frequencies. The first set are those frequencies that the device utilizes internally for its operation. For example, if a switching power supply is used, the switching rate may be from a few Hz to over 2 MHz.

The second set are frequencies that will cause unintended operation of the device if it is exposed to Electro-Magnetic Interference. Typically, the interfering frequencies will be higher than those at which the device operates.

Cutoff Frequency

The Cutoff Frequency is the frequency at which the filter starts eliminating the unwanted EMI. This is defined as the frequency at which the filter removes $\frac{1}{2}$ of the radiation energy level, or 3 dB, which is more commonly referred to as 3 dB of Insertion Loss.

The Cutoff Frequency needs to be above the operating frequencies of the device, but it must also be low enough to eliminate as much of the higher frequencies as possible. The graph below shows a device that has internal operating frequencies of up to 300 KHz (See the green box). Within these frequencies, all I/O lines must be able to operate with minimal signal loss. The red box (above 300 KHz) represents frequencies that could potentially pose issues with EMI. For this device, the Cutoff Frequency was set at 1 MHz.



Insertion Loss

The term Insertion Loss refers to the filtering capabilities of the Feedthrough Filter at a given frequency. Mil-STD-220 is a US Military test standard that is globally recognized for the characterization of these types of filters and their Insertion Loss capabilities. Not all circuits are the same in terms of input or output impedance. This standard normalizes the measurement in a balanced 50 Ohm test system. When measured in this test system, the Insertion Loss of the Feedthrough Filter can be plotted versus frequency, which is normally shown on a Log Scale. Insertion Loss is reported in decibels (dB). The formula for Insertion Loss is shown below:

$$\text{Insertion Loss} = 10 \text{ Log}_{10} (P_{\text{out}} / P_{\text{in}})$$

P_{out} = Power level at the output of the filter

P_{in} = Power level at the input of the filter

For every 3 dB of Insertion Loss, the power level of that frequency allowed through the filter and into the device is reduced by 50%. Common Feedthrough Filters today have Insertion Loss values of 40 dB or more at 100 MHz. At 40 dB, the Feedthrough Filter is removing 99.99% of the RF energy.

Power Requirements

The other basic requirement for selecting the right Feedthrough Filter for your device is the Power Requirements (Voltage and Current). The Feedthrough Filter must be capable of operating at the input voltage of the device for power connections, or the signal voltage for signal lines. It also must have a center conductor that is large enough to handle the current level that the device requires. Most center conductors are made of copper, and standard wire gauge amperage charts can be used for design purposes.

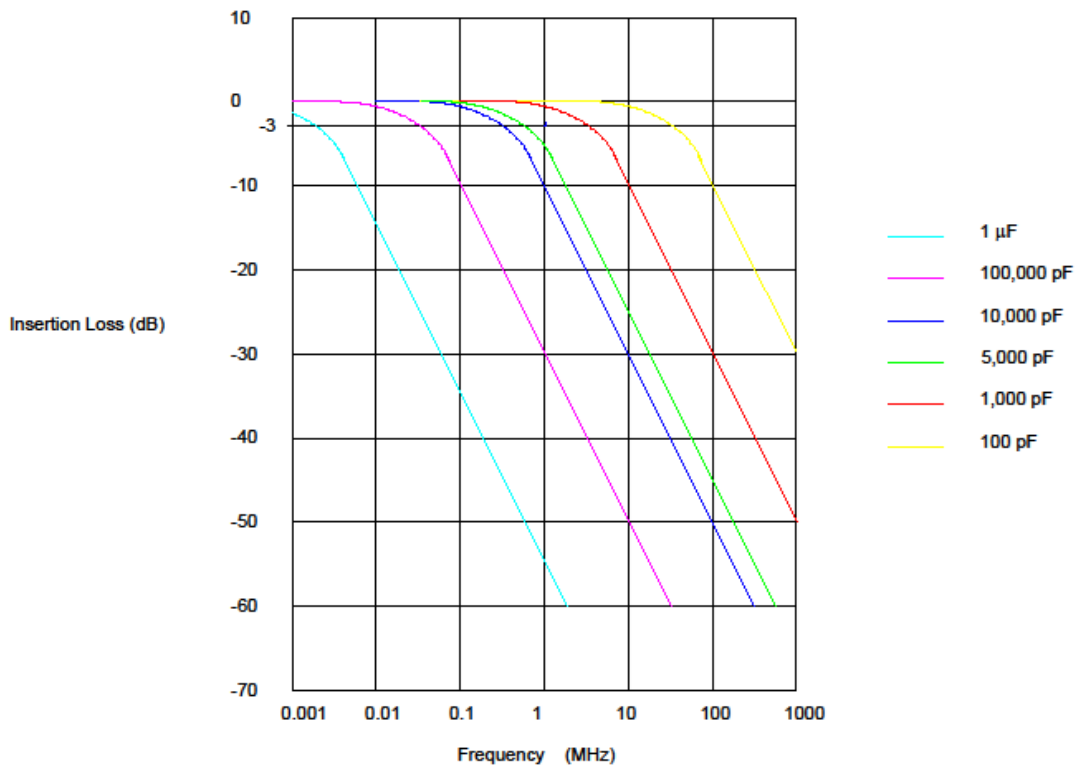
Ceramic Feedthrough Filters - Circuit Options

In Feedthrough Filtering, there are three circuit types that are common; “C”, “L”, and “π” (Pi). All three of these circuit types can be made with the discoidal or tubular type dielectrics mentioned earlier. The selection of the proper circuit for your device depends on the Insertion Loss requirements. First, set the proper Cutoff Frequency, and then determine how fast the optimal amount of Insertion Loss is needed after the Cutoff Frequency.

Setting the Cutoff Frequency

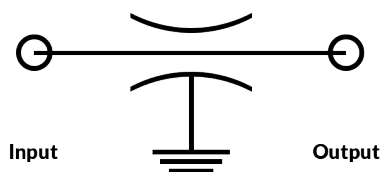
For Feedthrough Filters, the Cutoff Frequency is mainly determined by a simple variable – the total capacitance of the filter. Typical design values for capacitance versus Cutoff Frequency are shown below.

Capacitance (pF)	Dielectric Type		Cutoff Frequency
	Tubular	Discoidal	
100	Yes	Yes	50 MHz
1,000	Yes	Yes	5 MHz
5,000	Yes	Yes	700 KHz
10,000	Yes	Yes	500 KHz
50,000	No	Yes	70 KHz
100,000	No	Yes	50 KHz
1,000,000	No	Yes	3 KHz



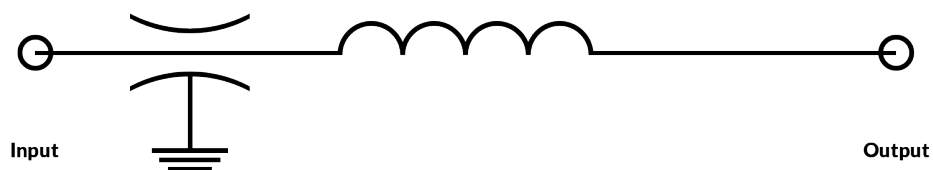
Selecting the Circuit Type

"C" Circuit



A "C" circuit is comprised of a single Feedthrough capacitor on a center conductor. This circuit type will provide an Insertion Loss slope after the Cutoff Frequency of approximately -20 dB per decade of frequency. However, as with all capacitors, there will be a point of self-resonance which will alter this slope. There will also be a frequency at which there will be a limit to the filter's ability to provide any additional Insertion Loss. The typical industry standard maximum stated Insertion Loss for "C" and the other two circuit types is around -70 dB.

"L" Circuit

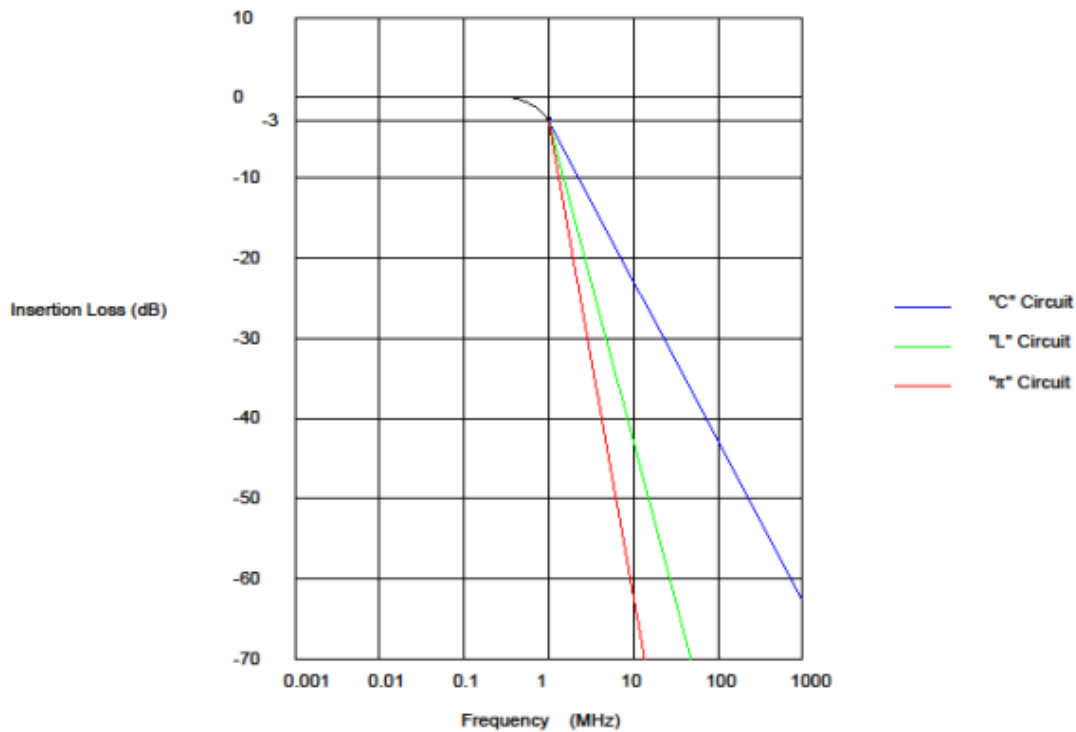


An "L" circuit adds an additional series of inductive elements to the "C" circuit. These additional elements can be an inductive coil or a slip on a ferrite shielding bead over the central conductor. By adding one of these additional elements, the Cutoff Frequency stays the same, but the slope of Insertion Loss increases by another 20 dB per decade. Self-resonance will still be present at the same frequency as if this were a "C" circuit. The magnitude that the resonance will have on limiting the Insertion Loss will be diminished.

"π" (Pi) Circuit



A "π" (Pi) circuit is two "C" circuits separated by a series of inductive elements (same as an "L" circuit with an additional "C" circuit added after the inductive element). By adding this third element, the Cutoff Frequency stays the same, but the slope of Insertion Loss increases by another 20 dB per decade over the "L" circuit (to 60 dB per decade). This circuit type eliminates nearly all the effects of self-resonance on Insertion Loss. For discoidal type dielectrics, this circuit type is made from three separate components. For tubular dielectric types, these are made with just two components, with both capacitors being made on a single dielectric tube.



Ceramic Feedthrough Filters - Package Options

Ceramic Feedthrough Filters come in a variety of package options to suit the individual needs of various applications. These range from individual component types for single line applications to multi-line products suited for applications that have many lines to protect against EMI.

Individual Line Applications

Individual Feedthrough Filters are most commonly installed directly into the case of the device. This is done by either soldering the case of a solder-in type, or bolting a bolt-in type directly into a threaded hole (or using a nut and lock washer in a clearance hole) on the case. Internally, the same installation methods can be used through partition walls or floor openings between device sections.

The various package types for individual line Feedthrough Filters is shown in the table below with their corresponding capacitance value, power ratings, and circuit types.

Individual Line Feedthrough Filters					
Type	Maximum Capacitance (pF)	Working Voltages (VDC)	Current Ratings (A)	Circuit Types	Notes
SMT	8,200	100	20	"C"	
	4,000	100	10	"π" (Pi)	
Solder-In	50,000	100	7	"C", "L"	Hermetic available
Press-In	50,000	100	7	"C"	
Bolt-In	4,000	200	1	"C"	#0 Thread
	50,000	50	10	"C", "L"	#2 - #4 Thread
	100,000	100 - 1,500	Up to 25	"C", "L", "π" (Pi)	#8 - 1/4" Thread, Hermetic available
	5,000	2,500	Up to 200	"C", "L", "π" (Pi)	5/16" - 5/8" Thread

Examples of these package types are shown below.



SMT Filters



Solder-In Filters



Press-In Filters



Bolt Style Filters

Multiple Line Applications

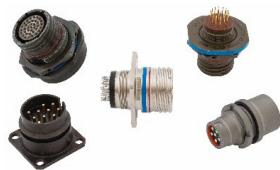
When there is a need to filter multiple I/O or power lines, multiple line components are available. Terminal Blocks, D-Sub Connectors, and Mil-Circular Connectors are commonly used on case installations. Filter Plates are commonly used for internal filtering on partition walls or floor openings between device sections. These designs are all suited to match industry standard mating connectors and hardware.

Multiple Line Feedthrough Filters					
Type	Maximum Capacitance (pF)	Working Voltages (VDC)	Current Ratings (A)	Circuit Types	Notes
Terminal Block	30,000	300	30	"C"	2 - 8 position
	5,000	300	30	"L", "π" (Pi)	
D-Sub	50,000	200	5	"C", "L", "π" (Pi)	9, 15, 25, 37, and 50 pin
Mil-Circular	50,000	200	15	"C", "L", "π" (Pi)	Mil-C-38999 and similar
Filter Plate	5,000	100 up to 500	5 up to 25	"C", "L", "π" (Pi)	Standard Bolt-in, up to 60 pin, 0.100" and 2 mm Spacings, Custom designs available
	50,000	50	10	"C", "L"	Standard Clip-In, up to 26 pin, 0.100" and 2 mm Spacings, Mini-Clip (10 position) also available

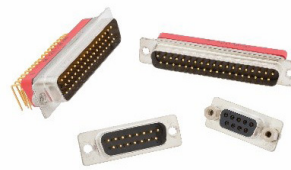
Examples of these package types are shown below.



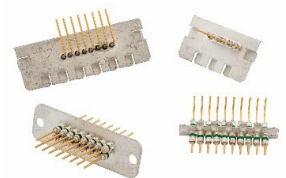
Filtered Terminal Blocks



Filtered Mil-Circular Connectors



D-Sub Connectors



Filter Plates

Author Bio



Robert Meilleur

Robert has a BSEE degree from the University of Arizona. From 1987 to 2002, he was a Design Engineer and Engineering Manager for Tusonix, Inc. In this role, he specialized in EMI/RFI filtering products and solutions. In 2002, he joined the Quantic Corry team where he became the VP of Operations.