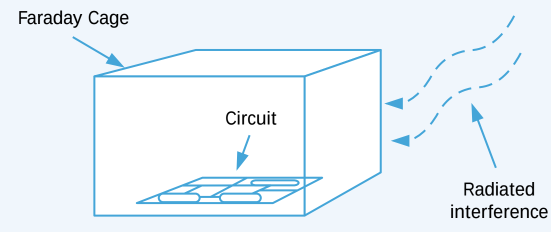
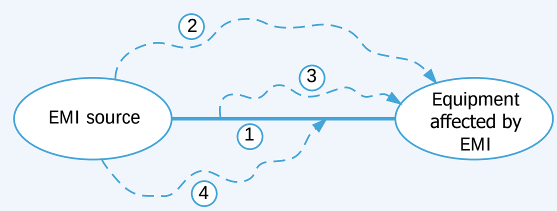
The need for EMI Filters

The use of electronic equipment is ever-increasing, with greater likelihood of interference from other pieces of equipment. Added to this, circuits with lower power levels that are more easily disturbed means that equipment is increasingly in need of protection from EMI (electromagnetic interference). To meet legislation such as the EU Directive on EMC, in addition to other international regulations such as FCC, EMI filtering is now an essential element of equipment design. Introducing screening measures, eg to the case or cables, may suffice in many instances, but some form of low-pass filtering will often be required.



Faraday Cage protects against radiated interference **Fig 1**



Modes of propagation of EMI **Fig 2**

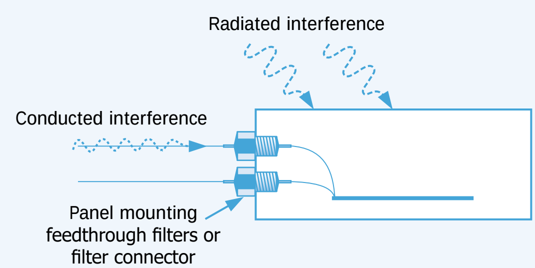
Faraday Cage

The ideal way of protecting a piece of equipment or circuit from EMI is to totally enclose it in a metal (or conductive) box. This screened enclosure is called a ‘Faraday Cage’. Radiated interference is thus prevented from adversely affecting it (Fig 1).

Input/output cabling

In reality however, most pieces of equipment require input and/or output connections, perhaps power cables or signal and control lines. The cables providing these connections can act as antennae, able to pick up interference and also to radiate it (Fig 2). Any cable or wire going in through the equipment case can introduce electrical noise, and also radiate it internally onto other wires and circuits. Similarly, it can provide a path to the outside from any noise generated internally, which can also then be radiated and may in turn adversely affect other equipment.

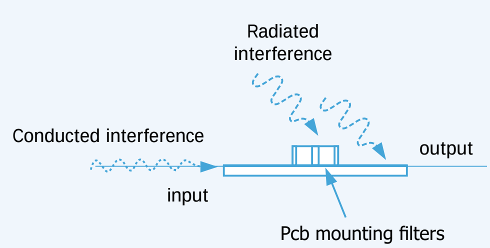
1. Interference can enter a piece of equipment directly through the cabling (conducted interference).
2. Radiated interference can travel directly to the affected equipment.
3. Interference can exit an EMI source via a cable, subsequently to be radiated from the cable and to the affected equipment.
4. Interference can be radiated from an EMI source and then picked up by a cable entering the affected equipment.



Feedthrough filters remove conducted interference and provide ultimate performance **Fig 3**

Filter location - Panel Mount filters

To prevent interference entering or leaving a piece of equipment, feedthrough EMI filters can be mounted in the wall of a shielded case. Any incoming or outgoing cables would then pass through the filters. Power or wanted signals pass through the filters unaffected, whilst higher frequency interference is removed. While the screened case protects against radiated interference, the feedthrough filters protect against conducted interference. The integrity of the equipment is thus assured (Fig 3).



Surface mount filters remove conducted interference, performance reduced due to radiated interference **Fig 4**

Filter location - Surface Mount filters

Where there is no suitable bulkhead for mounting the filters, pcb types can be used (Fig 4). While this can be an effective method of filtering, it should be noted that in general the insertion loss performance can be reduced at higher frequencies, unless additional screening measures are taken.

Good design practices such as short tracks, short connections, close proximity to input and good grounding will help improve insertion loss performance.

Explanation of common terms

Conducted Interference

Interference transmitted along a conductor/cable.

Protection is provided by a series component. If a feedthrough filter is used to remove conducted interference, and mounted in the wall of a shielded compartment, it provides effective filtering while maintaining the screening integrity. It should be noted that the filter will reduce both emissions and susceptibility.

Cut-off Frequency/3dB point

The frequency at which filters start to become effective.

Generally taken to be at the 3dB point of the attenuation curve. Anything on the line below this frequency will be unaffected. The higher the capacitance of the filter the lower the cut-off, and vice versa. It will also vary depending on source and load impedances.

EMC

ElectroMagnetic compatibility.

A situation wherein two pieces of electrical or electronic equipment are able to function in the same environment without adversely affecting, or being affected by, each other.

EMI

ElectroMagnetic interference.

A broad term covering a wide range of electrical disturbances, natural and man-made, from dc to GHz frequencies and beyond. Sources of disturbance may include radar transmitters, motors, computer clocks, lightning, electrostatic discharge and many other phenomena.

Conducted Emissions

Signals, unwanted (interference) or otherwise from a piece of equipment.

Radiated Interference

Interference transmitted in free air.

Protection is provided by shielding, but if filters are not used to protect against conducted emissions, the unfiltered lines can act as aerials radiating interference outside the shielded cage.

Susceptibility

The extent to which a piece of equipment is vulnerable to interference emitted from another piece of equipment.

ESD

Electrostatic discharge.

ESD can result in damage through excessive voltage spikes. We can offer assistance on whether our products can meet specific ESD test requirements.

Insertion Loss

At a given frequency, the insertion loss of a feedthrough suppression capacitor or filter connected into a given transmission system.

Defined as the ratio of voltages appearing across the line immediately beyond the point of insertion, before and after insertion. As measured herein, insertion loss is represented as the ratio of input voltage required to obtain constant output voltage, with and without the component, in the specified 50Ω system. This ratio is expressed in decibels (dB) as follows:

$$\text{Insertion loss} = 20 \log \frac{E_1}{E_2}$$

Where: E_1 = The output voltage of the signal generator with the component in the circuit.

E_2 = The output voltage of the signal generator with the component not in the circuit.

When testing is conducted with a network/spectrum analyser, the equipment usually maintains a constant output voltage and can be set to record the output to input voltage ratio in decibels.

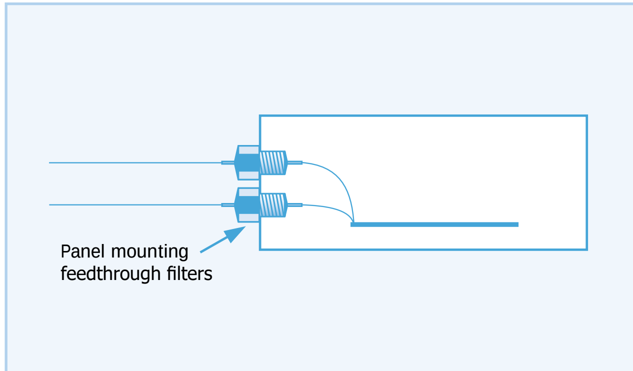
Low-pass Filter

A filter that lets through dc and low frequency signals, while attenuating (unwanted) high frequency noise.

Panel Mount Filter

A panel mounted filter that will pass the signal from one side of the wall of a shielded box (or 'Faraday Cage') to the other (it feeds the signal through the panel).

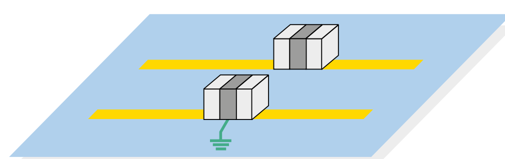
For effective operation, the filter input and output should be screened from each other, ie there should ideally be no apertures in the panel.



Surface Mount Filter

A filter that is suitable for surface mounting on PCBs.

It offers improved filtering compared to standard MLCCs, ease of assembly and savings on board space compared to a combination of discrete filter elements. Filter performance at higher frequencies is reduced compared to panel mount types, unless additional shielding measures are taken (see page 10).



Working Voltage

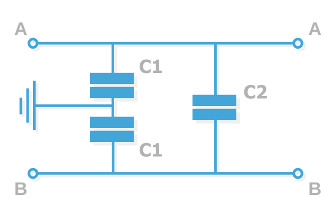
Continuous operating voltage.

This can potentially be across the entire operating temperature range.

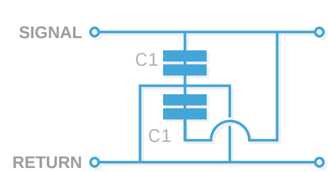
X2Y Filter

Integrated passive component with extremely low self inductance for filtering and de-coupling.

For filtering applications:



For de-coupling applications:



Insertion Loss / Filtering performance

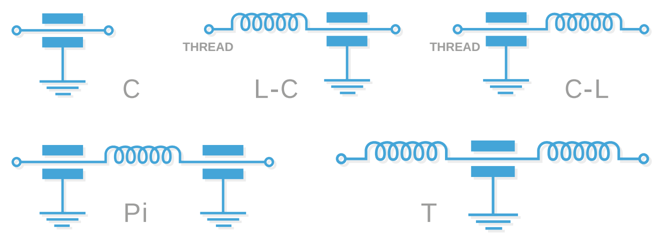
The insertion loss performance is used to aid filter selection by showing signal attenuation at any given frequency. However, it can only ever be a guide as actual performance in service will vary depending on the overall circuit characteristics.

Insertion loss is determined by:

- Electrical configuration
- Source/load impedances
- The load current (which can cause ferrite saturation)
- Ceramic dielectric materials. The capacitance change will be affected by applied voltage, temperature and the age of the part
- Earthing impedance
- Shielding integrity

Electrical Configuration

A number of different electrical configurations are available in feedthrough filters, including the common types shown opposite. A single element filter (a capacitor or an inductor) theoretically provides an insertion loss characteristic of 20dB per decade, a dual element filter (capacitor/inductor) 40dB per decade whilst a triple element filter (Pi or T configuration) theoretically yields 60dB per decade. In practise, the insertion loss curves do not exactly match the predictions, and the data sheets should be consulted for the realistic figure. The choice of electrical configuration is made primarily on the source and load impedances and may also be influenced by the level of attenuation required at various frequencies.



C Filter

This is a feedthrough capacitor with low self inductance. It shunts high frequency noise to ground and is suitable for use with a high impedance source and load.

L-C Filter

This is a feedthrough filter with an inductive element in combination with a capacitor. It is commonly used in a circuit with a low impedance source and a high impedance load (or vice versa). The inductive element should face the low impedance.

Pi Filter

This is a feedthrough filter with 2 capacitors and an inductive element between them. Ideally, it should be used where both source and load impedances are high.

T Filter

This is a feedthrough filter with 2 series inductive elements separated by one feedthrough capacitor. It is suitable for use where both source and load impedances are low.

Multi-element filters

These filters contain more than 3 elements, for example L-C-L-C-L filters. The addition of further elements increases the steepness of the insertion loss curve.

Source and Load Impedances

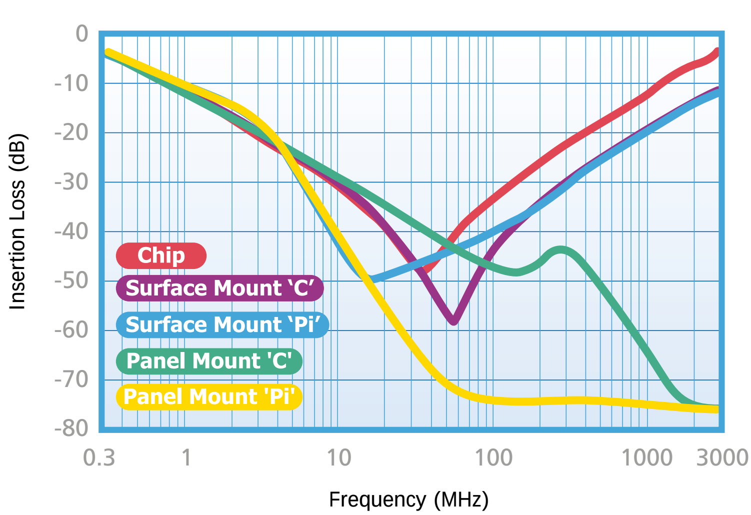
Insertion loss figures are normally published for a 50Ω source and 50Ω load circuit. In practise the impedance values will probably be very different, which could result in either an increase or decrease in insertion loss. The electrical configuration of the filter (the capacitor/inductor combination) should be chosen to optimise the filter performance for that particular source/load impedance situation. An estimate of insertion loss for source and load impedances other than 50Ω may be possible. Please contact our Sales Office.

Load Current

For filters which include ferrite inductors, the insertion loss under load current may be less than that with no load. This is because the ferrite material saturates with current. The reduction in insertion loss depends on the current and the characteristics of the particular ferrite material. In extreme cases the ferrite will become ineffective and insertion loss will appear to be the same as for a C filter. For further information contact the Sales Office.

Attenuation Curve

A plot of insertion loss versus frequency on a logarithmic scale.



Choice of ceramic dielectric material

When choosing a filter, it is important to be aware of the different performance characteristics that may be available from different categories of ceramic materials employed in their capacitors. Generally, stability of dielectric constant (and therefore filter capacitance value), with respect to some operational and environmental parameters, deteriorates with increasing dielectric constant. Specific factors which affect dielectric constant are temperature, voltage, frequency and time (ageing).

The three main classifications of ceramic dielectric employed in the manufacture of EMI filters are generally referred to as ultra stable (C0G/NP0), stable (X7R) and general purpose (Z5U, Y5V or X7W).

C0G/NP0

Most parameters for materials in this dielectric classification remain unaffected by temperature, voltage, frequency or time. Stabilities are measured in terms of parts per million but dielectric constants are relatively low (10 to 100).

X7R

This is a classification for materials which are relatively stable with respect to temperature, voltage, frequency and time. Typical dielectric constants would be of the order 2,000 to 4,000, enabling the achievement of far higher capacitance values for a given size of capacitor than can be gained from C0G/NP0 materials.

If the voltage coefficient (VC) is critical, Syfer are also able to offer parts with BX (2X1) and BZ (2C1) VC characteristics. Refer to the factory for further details.

Z5U/Y5V/X7W

These are classifications for materials which are severely restricted and performance under applied voltage may be seriously compromised.

A summary of the specifications of these materials follows. Please note that Syfer uses only the higher performance C0G/NP0 and X7R in its standard ranges.

Summary of ceramic dielectric characteristics

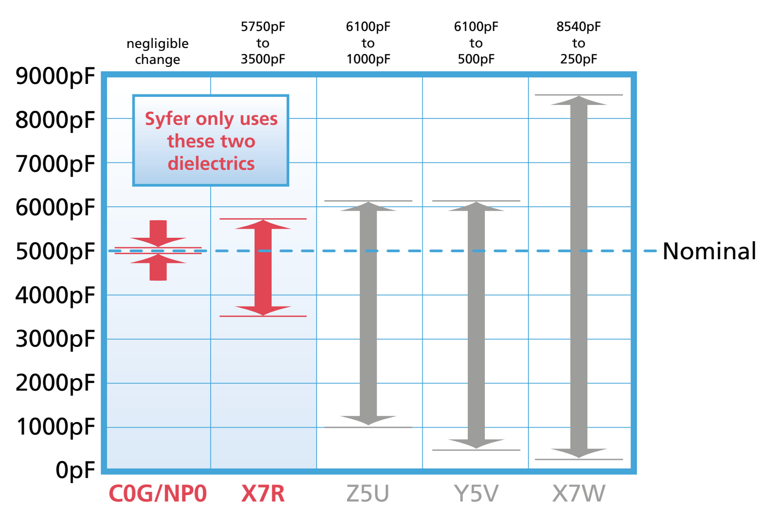
	C0G/NP0	X7R	Z5U	Y5V	X7W
EIA dielectric classification	Ultra stable	Stable	General purpose		
Rated temperature range	-55°C to +125°C	-55°C to +125°C	-10°C to +85°C	-30°C to +85°C	-55°C to +125°C
Maximum capacitance change over temperature range (no voltage applied)	0 ±30 ppm/°C	±15%	+22-56%	+22-56%	+40-90%
Ageing characteristics	Zero	<2% per time decade	6% per time decade	6% per time decade	6% per time decade

Spread of capacitance values

The capacitance of a ceramic capacitor can change as a result of a change in temperature, applied voltage and age. Please note that this potential change can lead to a significant drop in filtering performance.

Consider the typical performance of 5,000pF filter capacitors, offered in standard dielectric classifications, operating at a voltage of 100Vdc at 85°C, at an age of 10,000 hours. The final capacitance value can fall within the range of values (see chart below), taking into account the ageing process and effects of temperature and voltage as shown in the chart above.

It is clear that the capacitance can change as a result of an increase (or decrease) in temperature, applied voltage and as a result of ageing. If the capacitance has reduced, so too will the insertion loss performance.



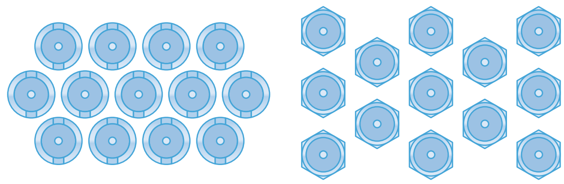
Panel Mount EMI Filters - Application considerations

Thread size or head size? What's the crucial factor in spacing

The thread size has no relevance to the mounting pitch, but can influence cost. Very small threads are harder to work with, but offer little or no gain over larger thread sizes.

If close mounting pitch is important, change instead to a round body style. Mounted using modified screwdriver blades, this style of component removes the need to allow space for mounting sockets and allow components to be mounted almost touching each other.

Syfer offer a full range of round head filter types - SFKB, SFKK, SFLM and SFUM. Special requirements can also be considered.



Schematic showing the pitch improvement that can be gained with round head filters compared to traditional hexagon heads.

Hermetic seals vs resin seals

Resin sealed filters have epoxy encapsulants injected into the cavities either side of the filter elements. The purpose of the resin is to 'ruggedise' the assembly, supporting the pins and sealing the ceramic to prevent reliability issues such as moisture ingress. Poor encapsulants can be susceptible to cracking away from the metalwork due to temperature change. This can then allow moisture ingress which can result in reliability concerns. They can also exert a force on the ceramic which can result in cracking causing electrical failure. MIL or Space specifications generally do not demand resin sealed filters be tested for immersion or accelerated damp heat testing.

Syfer resin sealed filters use a very high purity, highly filled, epoxy encapsulant with a very low co-efficient of thermal expansion – very closely matched to the expansion co-efficient of the ceramic and other materials used in the construction. These characteristics enable Syfer filters to be thermally cycled with very little stress being applied to the ceramic elements and with reduced risk of cracking allowing moisture ingress. Certain Syfer filters have successfully passed immersion and accelerated damp heat testing.

Screw mount 'hermetic' filters generally have glass to metal seals soldered into place instead of conventional resin seals. They are better than resin sealed filters in applications where outgassing is critical, or where the environment is particularly harsh. MIL or Space specifications generally do require hermetically sealed filters be tested for immersion or accelerated damp heat testing. Unless fitted with sealing rings, they will not normally provide a gas seal between either side of the mounting bulkhead – the seal is to protect the internal capacitor elements. Solder mount hermetic filters may create a gas seal between either side of the bulkhead, but this is more dependent on the sealing capabilities of the solder joint mounting the filter rather than the filter seal. Usually, solder mount filters only have a glass seal on one side of the filter body, with the other end resin sealed. Test plans are normally the same as those for resin sealed filters. Hermetically sealed solder mount filters are only normally required in applications where one end of the filter will be exposed to harsh environments, or where outgassing is critical on one side of the panel.

Please note: Knowles do not currently offer hermetic EMI filters.

Discoidal capacitor vs tubular capacitor

The original panel mount filters used single layer tubular capacitors. There is one major advantage of this type of capacitor - it lends itself to very easy Pi filter construction. For this reason, Pi filters have tended to be considered the optimum filter configuration.

As performance demands increased, higher capacitance values were required. High K, unstable (Z5U / Y5V see page 7) dielectrics and multilayer tubes began to be used. These use buried layer electrodes within the tube walls, but the reduced dielectric thickness resulted in lower voltage withstand capability. The unstable dielectrics result in poor performance over the voltage and temperature ranges.

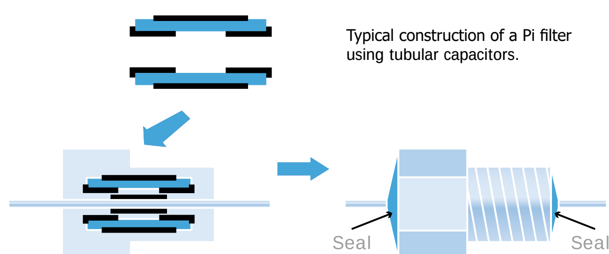
Tubular capacitors have one major flaw - the thin ceramic walls make them very prone to cracking causing electrical failures.

As MLCC chip capabilities developed, the discoidal capacitor appeared in filters. These devices use MLCC chip technology to produce a very low inductance (low ESL / low ESR) capacitor giving improved performance and higher capacitance and voltage ranges (higher capacitance per unit voltage). They are physically much stronger and robust than tubes.

Most Syfer panel mount filters use discoidal capacitors for optimum mechanical strength and high quality X7R or C0G/NP0 dielectric materials for optimum electrical performance. However, there are other dielectric materials used in the manufacture of filters.

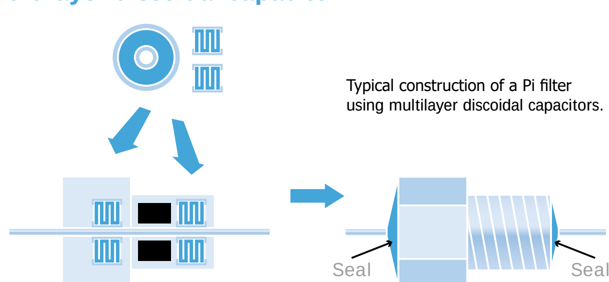
	Advantages	Disadvantages
Tube based filters	Cheap. Suited to Pi filter manufacture.	Low capacitance only, not robust – easily cracked multilayer tubes = higher capacitance but low voltage.
Disc based filters	Robust. High capacitance. C, L-C, & T circuits easy. Very high capacitance Pi filters possible. Tight tolerance possible. Vc characteristics possible.	Low capacitance Pi filters, relatively expensive.

Tubular capacitor



Typical construction of a Pi filter using tubular capacitors.

Multilayer discoidal capacitor



Typical construction of a Pi filter using multilayer discoidal capacitors.

MIL-STD-461 & EMI Filters - Common misconceptions

We routinely get filter enquiries that are typically quoting "filters must meet the requirements MIL-STD-461" or "filters must comply with MIL-STD-461". This is a complete mis-understanding of MIL-STD-461 and needs to be clarified with the customer.

The following might be useful.

The US MIL-STD-461 specification sets regulations for the control of electromagnetic interference emissions and susceptibility of equipment. It sets requirements for the levels of emissions allowed to be exported from electrical equipment and it also sets requirements as to the susceptibility levels of equipment from external noise sources. In addition it gives guidelines on measuring those features of the equipment.

A piece of electrical equipment behaves as a "source" and will generate EMI. That EMI will be transmitted by conduction and radiation, and be incident upon a receiver (which may be another piece of electrical equipment or a test fixture). The level of the electromagnetic signature of the conducted emissions is determined by the characteristics of the equipment; e.g. SMPS's may be "noisy", filament lights may be "quiet".

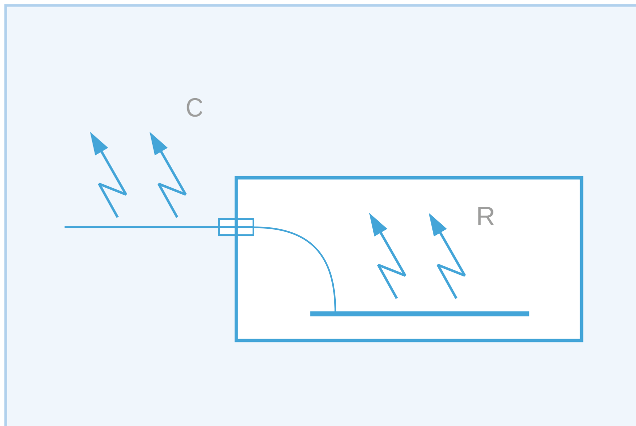
If the levels of emissions from the equipment exceed the limits set in MIL-STD-461, then they need to be attenuated by using an EMI filter. The performance of that filter across the frequency spectrum must be to allow the equipment emissions to be suppressed to a level low enough to allow the equipment to claim compliance with the limits of the specification. That filter performance requirement is determined by the electromagnetic signature of the equipment, and what limits are required to be achieved. The filter manufacturer of course can only get this information from the manufacturer of the equipment. Then the claim for compliance can normally be verified by test and measurement.

This explains why no filter manufacturer can claim that their filters "meet" MIL-STD-461; it is not the filter which "meets" the specification, but the equipment or platform. The situation might be that a filter proposed is "above specification" requirement, and the equipment conforms to MIL-STD-461 very comfortably. On the other hand, equipment in the system may be so electromagnetically noisy that a proposed filter fails to support the equipment in meeting the limits of MIL-STD-461.

Syfer are not able to guarantee that the incorporation of a particular filter into the Client's equipment will enable system compliance with the emissions limits of specification MIL-STD-461. All filter manufacturers catalogue their filter performance as insertion loss in a reference (normally 50Ω) impedance system. The filter manufacturer does not know the level of emissions associated with a piece of equipment, nor the real-world terminating impedances as presented to the filter. Hence the published filter insertion loss performance at/across a particular frequency range will not necessarily represent the equivalent attenuation of equipment emissions in application and the equipment manufacturer will need to conduct their own tests to determine the part is suitable and the filtered equipment meets the requirements of MIL-STD-461.

In summary MIL-STD-461 is an equipment specification and cannot be applied to filters. We understand some filter manufacturers may be quoting MIL-STD-461 in their literature, but this is either lack of understanding of the specification, or 'salesmanship'. It is the responsibility of the equipment manufacturer to meet MIL-STD-461, and no filter supplier can ever properly quote it.

If we have a filter enquiry where the customer refers to MIL-STD-461, we need to ask exactly what level of attenuation they require. We can then suggest part numbers based on that detail, but ultimately they will need to test parts to determine if they are suitable. Professional EMC test houses may be able to help suggesting requirements as well.



Radiated emissions 'R' are blocked by the casing design.

Conducted emissions & Radiated emissions as a result of conducted emissions 'C' are resolved by using appropriate filters in the case housing.

To define the filter, the ratio of emissions 'C' to the requirements of MIL-STD-461 must be known.

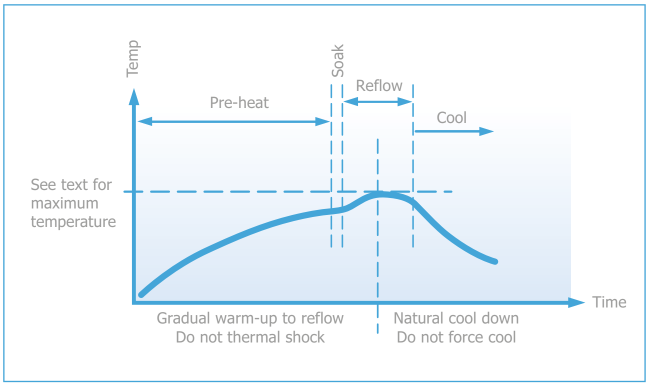
MIL-STD-461 & EMI Filters - Common misconceptions

Installation of Filters

Surface Mount and Panel Mount Solder-in filters

Solder pad layouts are included with the detailed information for each part.

Recommended soldering profile



Soldering of filters

The soldering process should be controlled such that the filter does not experience any thermal shocks which may induce thermal cracks in the ceramic dielectric.

The pre-heat temperature rise of the filter should be kept to around 2°C per second. In practice successful temperature rises tend to be in the region of 1.5°C to 4°C per second dependent upon substrate and components.

The introduction of a soak after pre-heat can be useful as it allows temperature uniformity to be established across the substrate thus preventing substrate warping. The magnitude or direction of any warping may change on cooling, imposing damaging stresses upon the filter.

E01, E03, E07 SBSP ranges are compatible with all standard solder types including lead-free, maximum temperature 260°C. For SBSG, SBSM and SFSS ranges, solder time should be minimised, and the temperature controlled to a maximum of 220°C. For SFSR, SFST and SFSU ranges the maximum temperature is 250°C.

Cooling to ambient temperature should be allowed to occur naturally. Natural cooling allows a gradual relaxation of thermal mismatch stresses in the solder joints. Draughts should be avoided. Forced air cooling can induce thermal breakage, and cleaning with cold fluids immediately after a soldering process may result in cracked filters.

Note: The use of FlexiCap™ terminations is strongly recommended to reduce the risk of mechanical cracking.

Soldering to axial wire leads

Soldering temperature

The tip temperature of the iron should not exceed 300°C.

Dwell time

Dwell time should be 3-5 seconds maximum to minimise the risk of cracking the capacitor due to thermal shock.

Heat sink

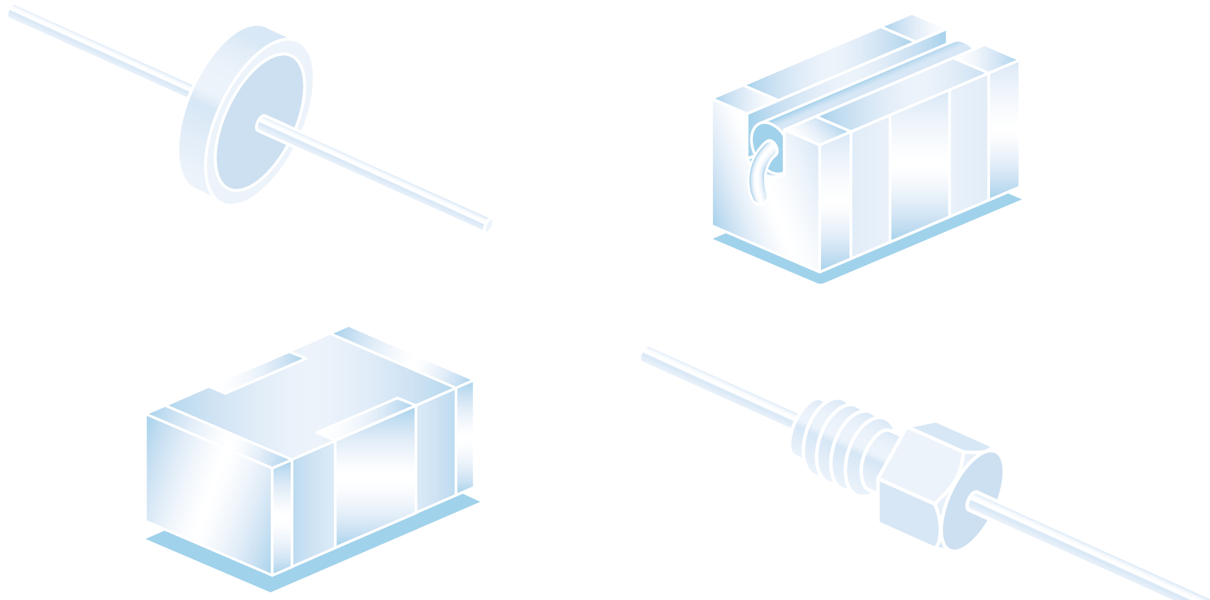
Where possible, a heat sink should be used between the solder joint and the body, especially if longer dwell times are required.

Bending or cropping of wire leads

Bending or cropping of the filter terminations should not be carried out within 4mm (0.157”) of the epoxy encapsulation, the wire should be supported when cropping.

Soldering irons should not be used for mounting surface mount filters as they can result in thermal shock damage to the chip capacitor.

A more comprehensive application note covering installation of all Syfer products is available on the Syfer website.



Installation of Filters

Resin filled screw mounted EMI Filters

General

The ceramic capacitor, which is the heart of the filter, can be damaged by thermal and mechanical shock, as well as by over-voltage. Care should be taken to minimise the risk of stress when mounting the filter to a panel and when soldering wire to the filter terminations.

Mounting to Chassis

Mounting Torque

It is important to mount the filter to the bulkhead or panel using the recommended mounting torque, otherwise damage may be caused to the capacitor due to distortion of the case. When a threaded hole is to be utilised, the maximum mounting torque should be 50% of the specified figure which relates to unthreaded holes. For details of torque figures for each filter range, please see below.

Tools

Hexagonal devices should be assembled using a suitable socket. Round bodied filters may be fitted to the panel in one of two ways (and should not be fitted using pliers or other similar tools which may damage them):

- Round bodies with slotted tops are designed to be screwed in using a simple purpose-designed tool.
- Round bodies without slotted tops are intended to be inserted into slotted holes and retained with a nut. The thread has flats machined to engage with the flats in the hole.

Grounding

To ensure the proper operation of the filters, the filter body should be adequately grounded to the panel to allow an effective path for the interference. The use of locking adhesives is not recommended, but if used should be applied after the filter has been fitted.

Minimum plate thickness

Users should be aware that the majority of these filters have an undercut between the thread and the mounting flange of the body, equal to 1.5 x the pitch of the thread. Mounting into a panel thinner than this undercut length may result in problems with thread mating and filter position. It is recommended that a panel thicker than this undercut length be used wherever possible.

Maximum plate thickness

This is specified for each filter in order that the nut can be fully engaged even when using a washer.

Soldering to axial wire leads

Soldering temperature

The tip temperature of the iron should not exceed 300°C.

Dwell time

Dwell time should be 3-5 seconds maximum to minimise the risk of cracking the capacitor due to thermal shock.

Heat sink

Where possible, a heat sink should be used between the solder joint and the body, especially if longer dwell times are required.

Bending or cropping of wire leads

Bending or cropping of the filter terminations should not be carried out within 4mm (0.157”) of the epoxy encapsulation, the wire should be supported when cropping.

RoHS Compliance

All surface mount filters, resin sealed panel mount filters and power filters can be supplied fully RoHS compliant (2011/65/EU) through material exemption. Please contact our Sales Office for further details. Care must be taken not to exceed the maximum soldering temperatures of surface mount parts.

Standard hermetic sealed panel mount filters use SnPb solders as part of their assembly and are intended for exempt applications such as aerospace or military. Substitution of the SnPb solder with Pb free solders may be possible to create a RoHS compliant part, subject to quantities – please refer to the Syfer Sales Office for more information.