EMI Filter Hints and Tips

2010

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Syfer Technology are a Dover CMP Company based in Norwich England. World leading manufacturers of ceramic passive components, their filter product range includes :-

- Multi Layer Chip Capacitors
- Feedthrough Chip Capacitors
- X2Y Chip and Panel Mount Filters
- Surface Mount C & Pi low pass Filters
- Discoidal and Planar Array capacitors and MOV Varistors
- Panel Mount C, L-C, Pi, T & multi-element low pass filters
- Very High Current Plastic Film based Panel Mount low pass filters

Todays Presentation

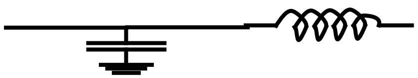
Filter hints and tips

Or

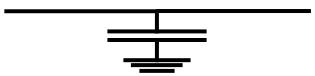
What we didn't realise our customers didn't realise about what we sold them

Low Pass Filter Theory

- A low pass filter is a network of capacitors to ground and inductors in series to filter unwanted signals



- As frequency increases, the capacitor becomes less resistive –



$$X_C = \frac{1}{2\pi f C}$$

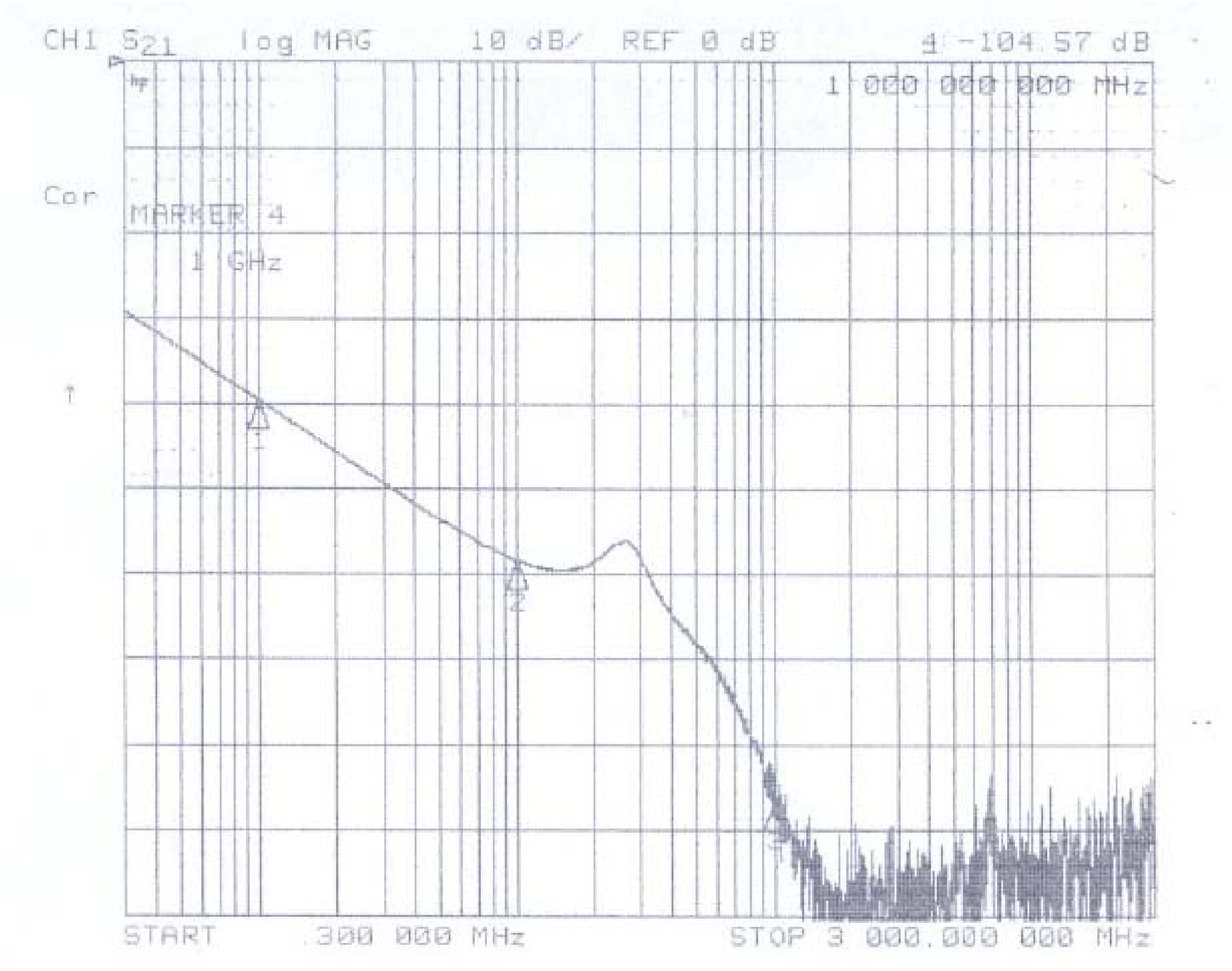
- As frequency increases, the inductor becomes more resistive

$$X_L = 2\pi f L$$

- A combination of the two elements shunts the high frequency noise to the ground

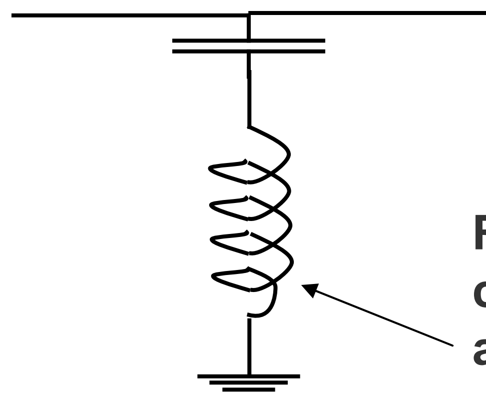
- Increasing the number of elements increases the filter performance

Low Pass Filter Response (Insertion Loss)



Low Pass Filter Theory

- **However, it is also important to remember that all capacitors have inherent inductance as well – reducing this improves the performance**



Reduce this element by changing the filter architecture

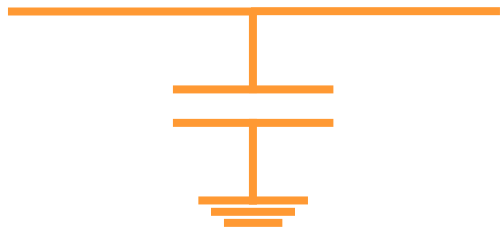
Filter Theory

- Self inductance is reduced by changing the architecture of the capacitor
- The longer and narrower the electrode path, the higher the inductance
- 3-terminal chips have lower inductance than conventional chips
- Discoidal capacitors have the lowest inductance.

Important points to remember

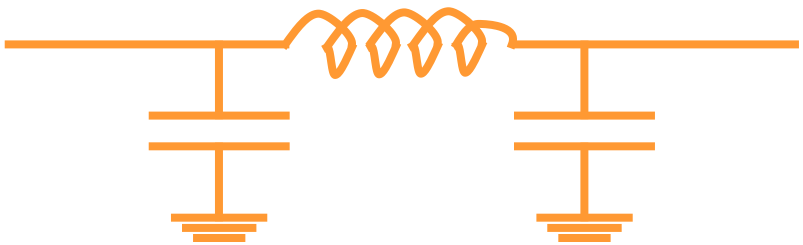
- Filter performance is (generally) quoted at room temperature, no-load (0A flowing) and in a 50Ω system
- In real life the performance is unlikely to be as good
- Ceramic capacitors are affected by the application of voltage and temperature
- Ferrite bead inductors saturate at reasonably low currents
- The real life source and load impedance is unlikely to be 50Ω

Types of Filter



‘C’ Filter

Capacitor between line and ground

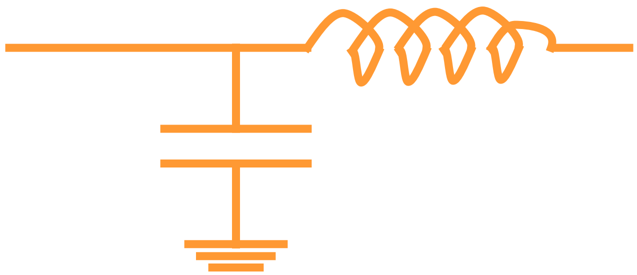


‘Pi’ Filter

Capacitors between line and ground and Inductor in line

C & Pi filters are designed for applications with high source and load impedances and are the most common panel mount feedthrough filters

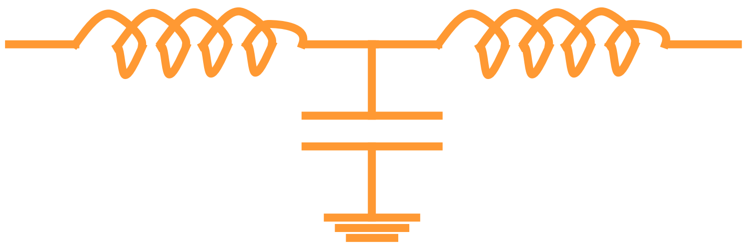
Types of Filter



'L-C' Filter

Capacitor between line and ground

Inductor in line



'T' Filter

Capacitor between line and ground

2x Inductors in line

L-C & T filters can offer performance improvements when the inductive elements 'face' a low impedance. If both source and load impedance are low then a 'T' filter is better than a Pi

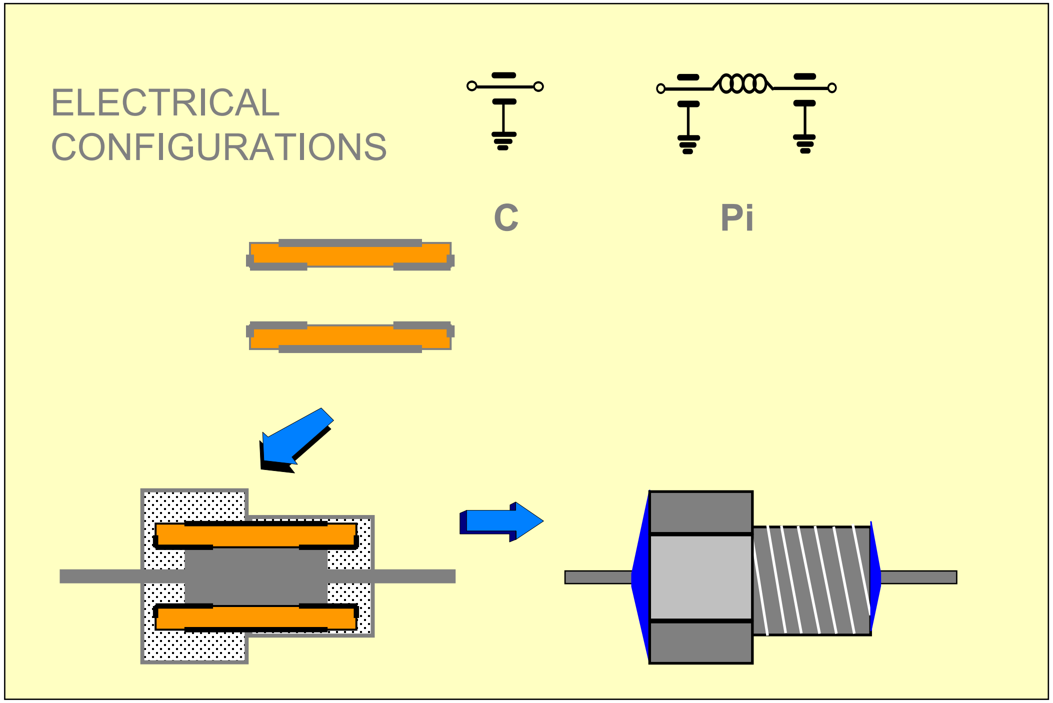
Types of Filter

- Historically, panel mount filters tend to be ‘C’ or ‘Pi’ type.
- Surface mount filters tend to be ‘C’ or ‘T’ types
- This is purely due to historical manufacturing techniques – there is little or no technical reasoning behind it!
- Many applications are probably not using the optimum filter

Panel Mounting Filters

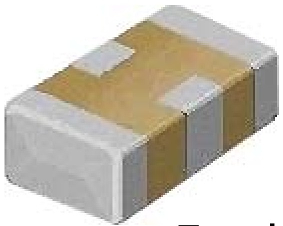
Tubular Capacitor Filter Construction

Historical build – Panel mount C & Pi filters



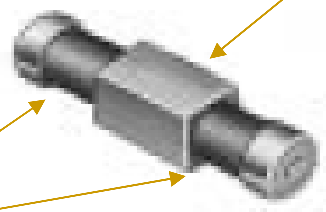
Surface Mounting Filters

Historical build – Surface mount C & T filters



Feedthrough
Chip Capacitor

‘Squoidal’

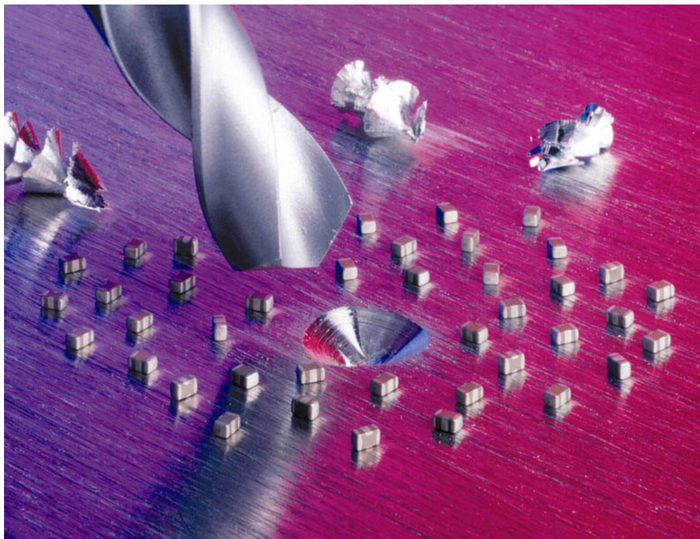


Ferrite beads

‘T’ Filter

T Filter Photo from Murata website

Surface Mount EMI filters

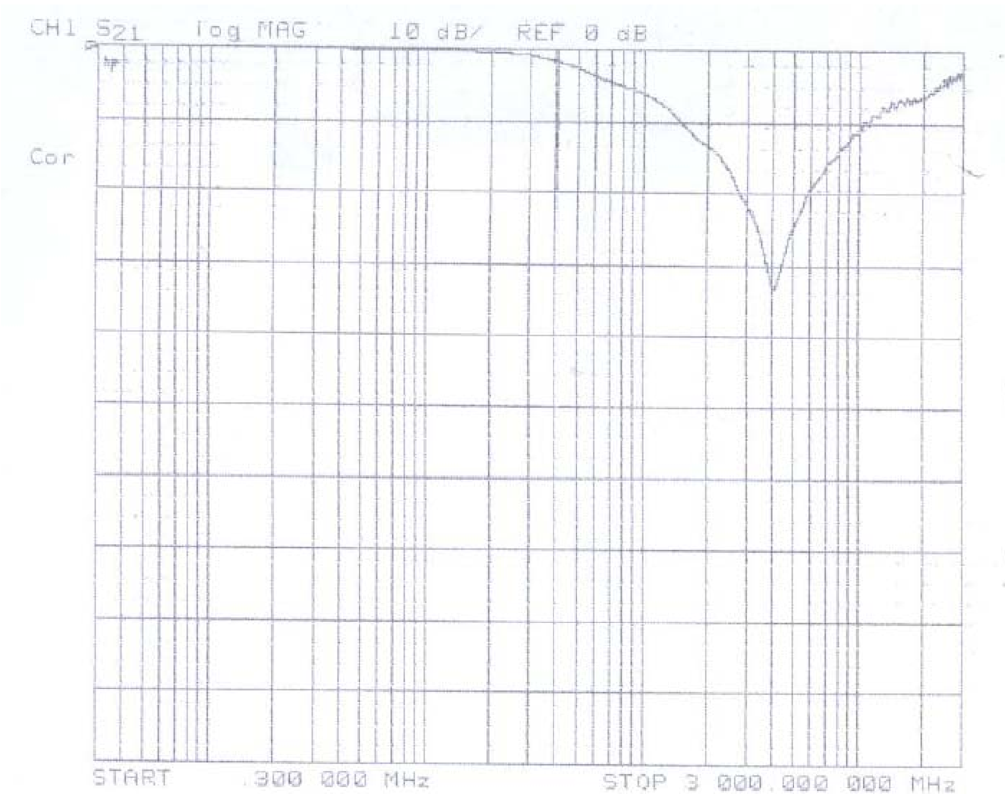


Surface Mount EMI filters

- Filtering is simply one application of a capacitor – all MLCC's can be used as filters even simple chips
- For improved performance as a filter, changes to the basic architecture are made
- 'Low pass' filters use capacitors between line and ground to conduct high frequency noise to the ground or earth and, in some products, inductors in the signal line

Surface Mount EMI filters

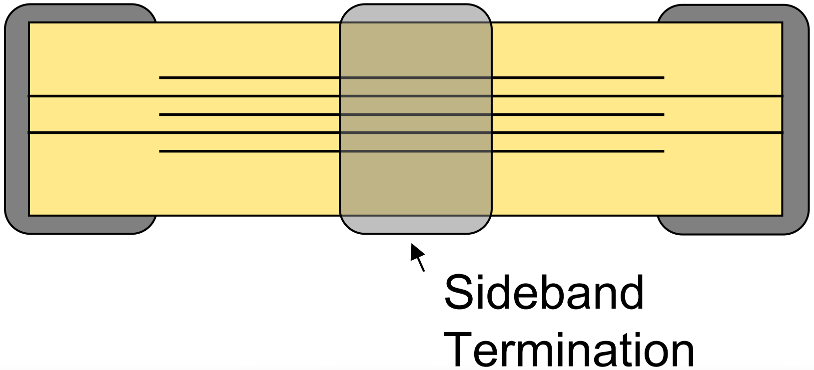
Typical SM Chip Performance Curve



100pF chip Insertion Loss shown

Surface Mount EMI filters

- **Improved performance comes from using a 3-terminal feedthrough chip**
- **Same manufacturing techniques but allows for different internal architecture**
- **The signal lines pass through the chip architecture – the end terminations being shorted together**



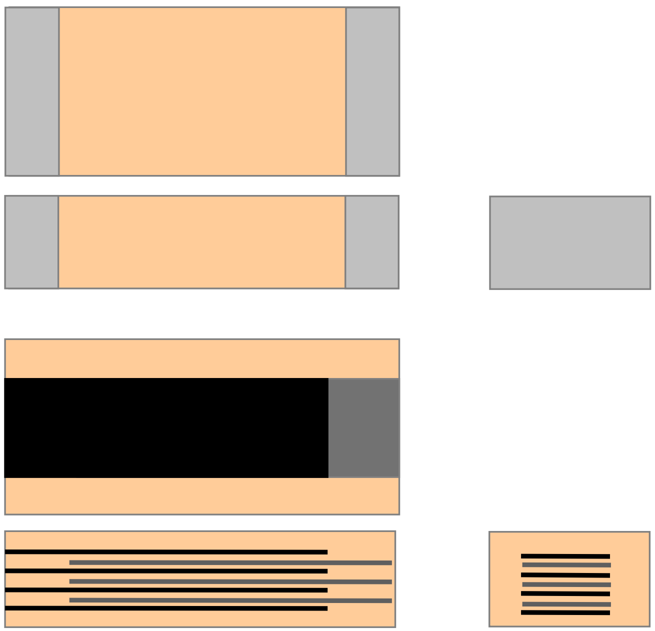
Surface Mount EMI filters

Ground inductance theory

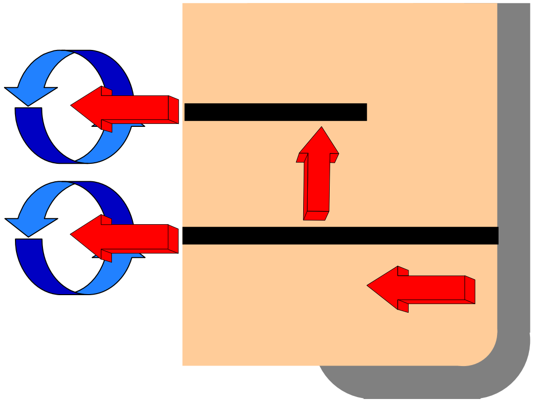
Basic Chip Capacitor Structure

External

Internal



Relatively high self inductance



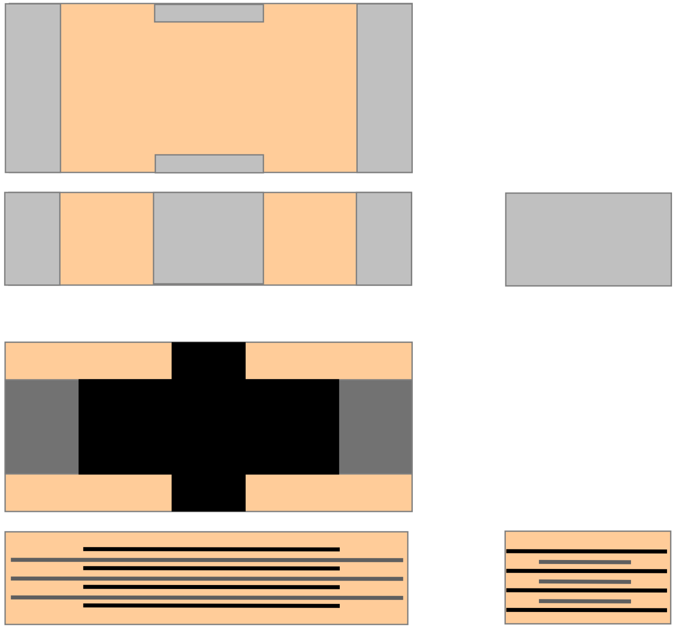
Surface Mount EMI filters

Ground inductance theory – reduced inductance

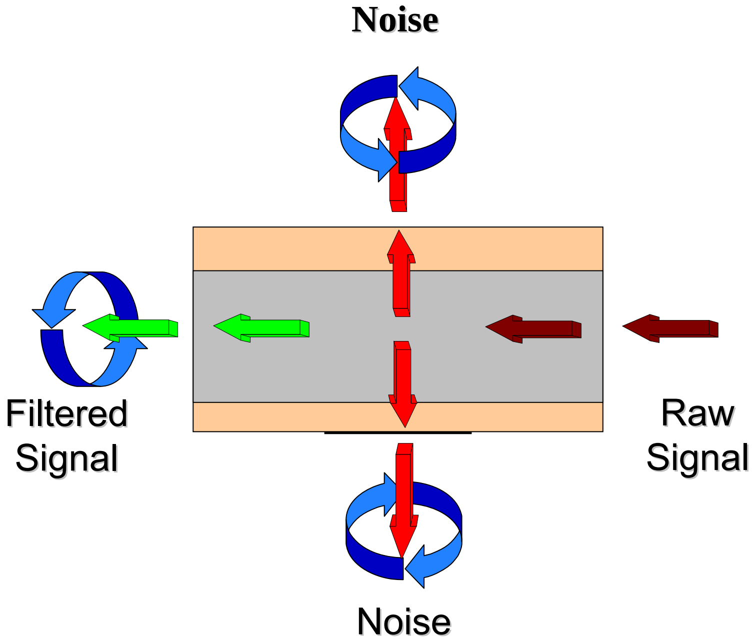
Feed Through Chip Capacitor Structure

External

Internal

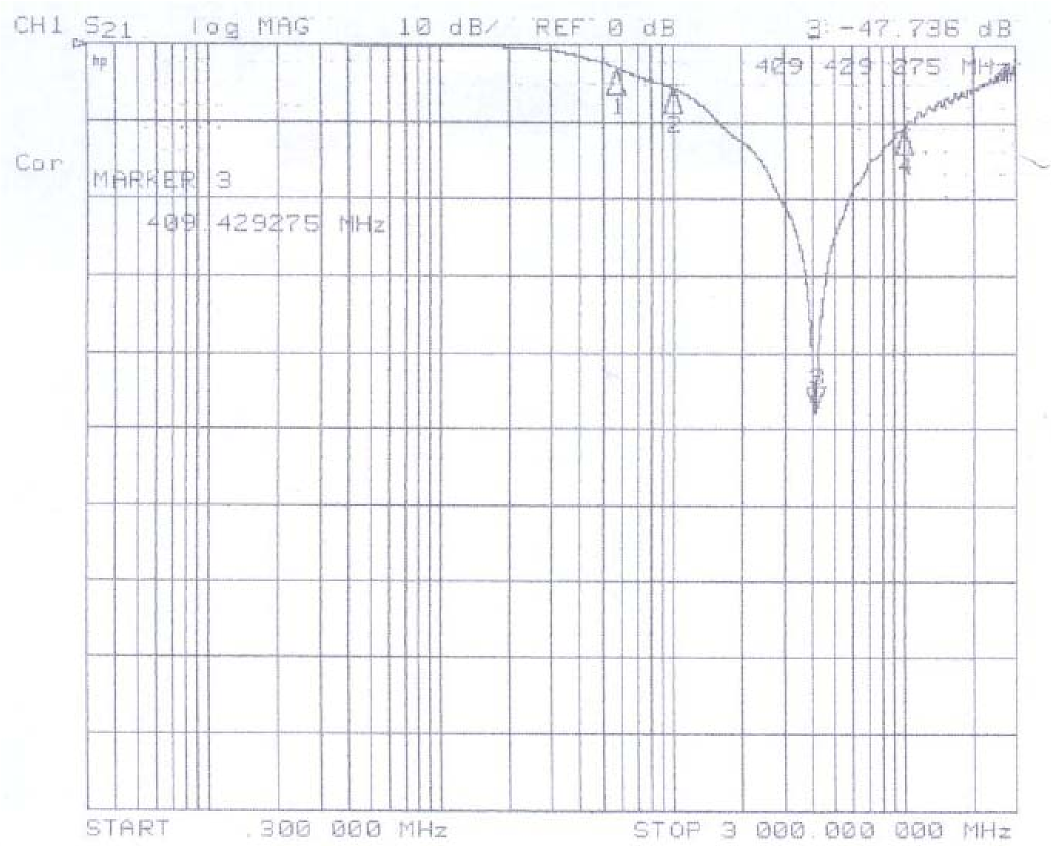


Lower self inductance



Surface Mount EMI filters

Typical Performance Curve



100pF E01 Insertion Loss shown

Surface Mount EMI filters

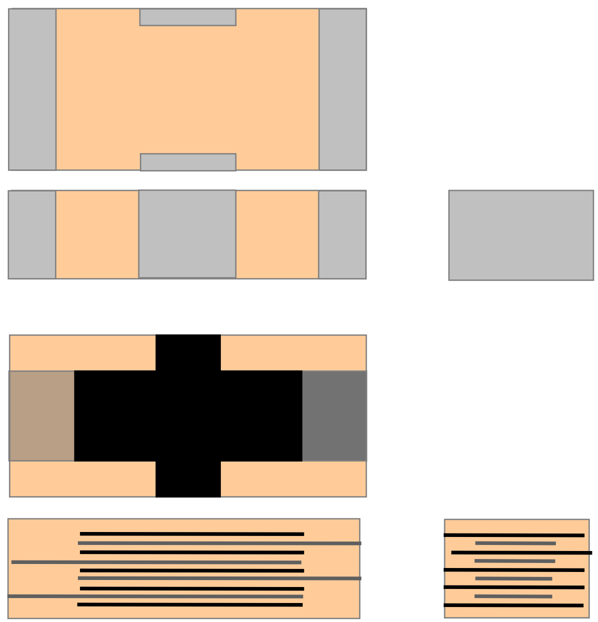
- Reducing the ground return inductance improves the performance so a 3-terminal chip offers an improvement over a conventional chip.
- The downside is that the signal must pass through the electrodes and is thus limited by the conductivity & architecture of the electrodes.
- The next improvement step is an X2Y™ chip which uses opposing current flow to cancel out internal inductances within the electrodes.
- The X2Y™ chip has 2 capacitors in a single ceramic block and is used as a bypass filter, so current does not flow through the chip and is not limited by the construction.

X2Y

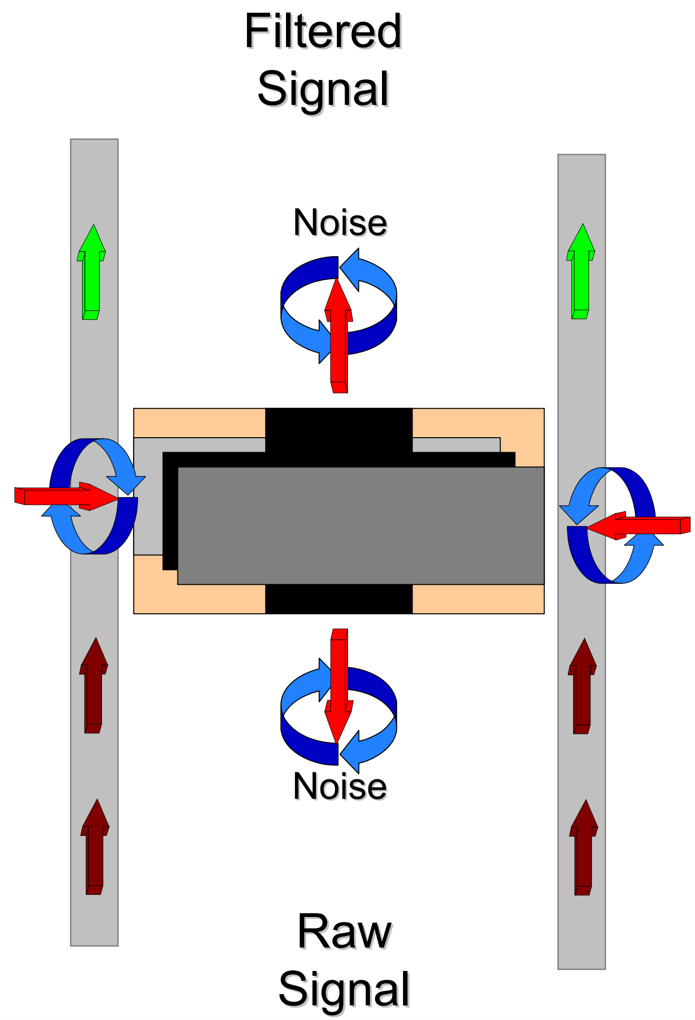
X2Y Chip Capacitor Structure

External

Internal

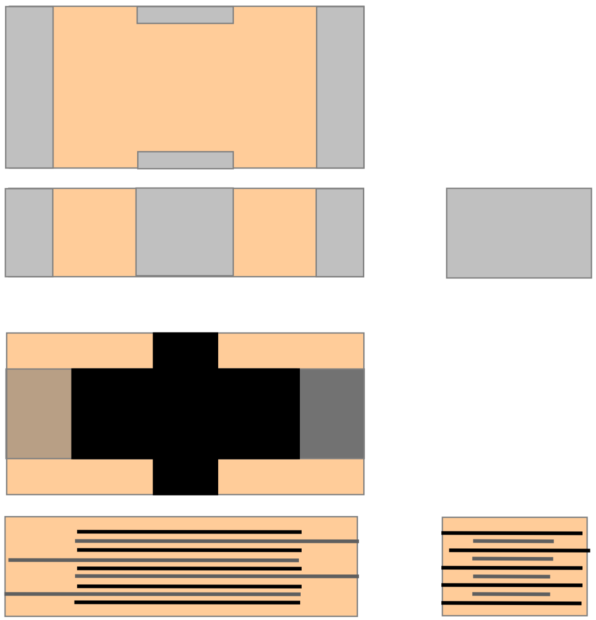


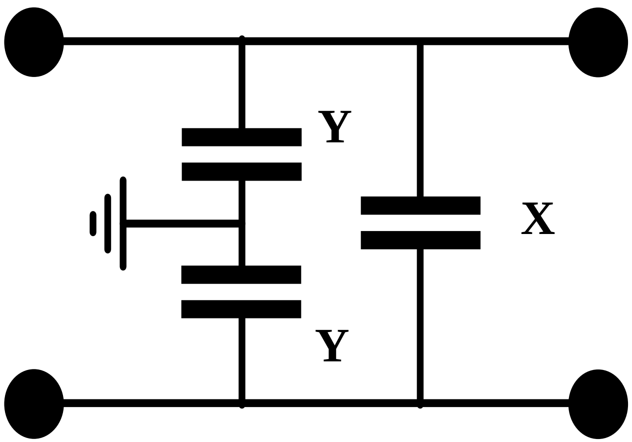
Very low self inductance



X2Y

X2Y Capacitors





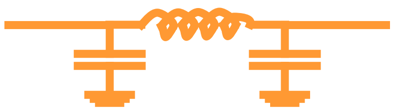
Surface Mount Pi Filters

Surface Mount EMI filters

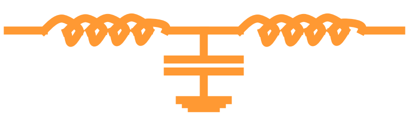
- If we accept that we've reduced the ground inductance as much as possible the next step is to increase the filtering elements

- We can add an inductor in line, with capacitors to create a Pi or a T filter

- SM Pi filters use ferrite beads to add inductance between 2 capacitors



- SM T filters use 2x ferrite beads to add inductance either side of a small capacitor

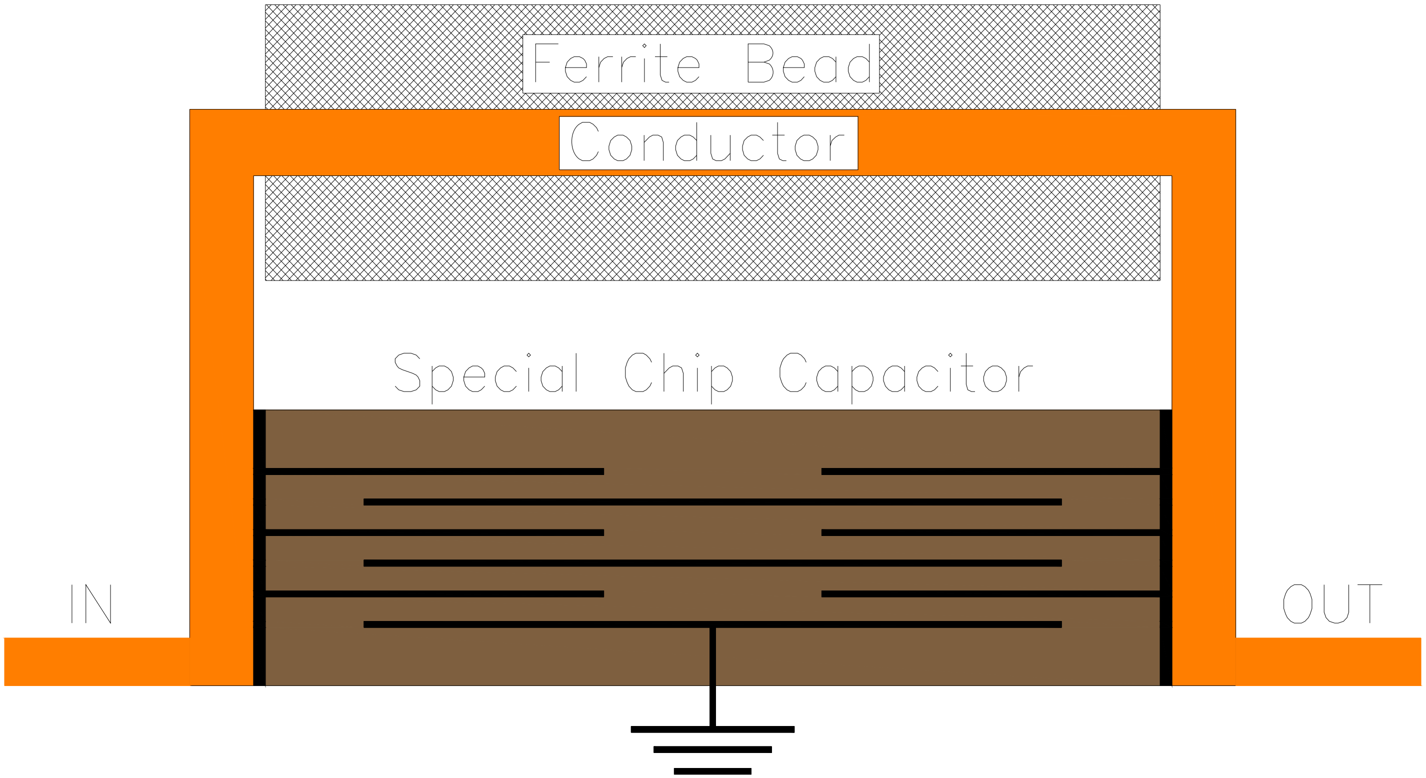


A note on Ferrite Beads

- All surface mount and small panel mount filters that have inductive elements use ferrite beads to form the inductance
- The inductance is very small – 50nH to 500nH
- Ferrites saturate with increasing current – typically the maximum before total saturation is about 6A flowing through the pin.
- Most filters quote the maximum operating current derived from the maximum the pin will carry (heating effects) and not the ferrite bead.
- When ferrites saturate, ‘T’ filters suffer more than Pi’s due to the lower capacitance values involved
- Full load insertion loss approximates the performance of a C filter

High Performance SMD Pi-Filters

Generic Construction / Theory



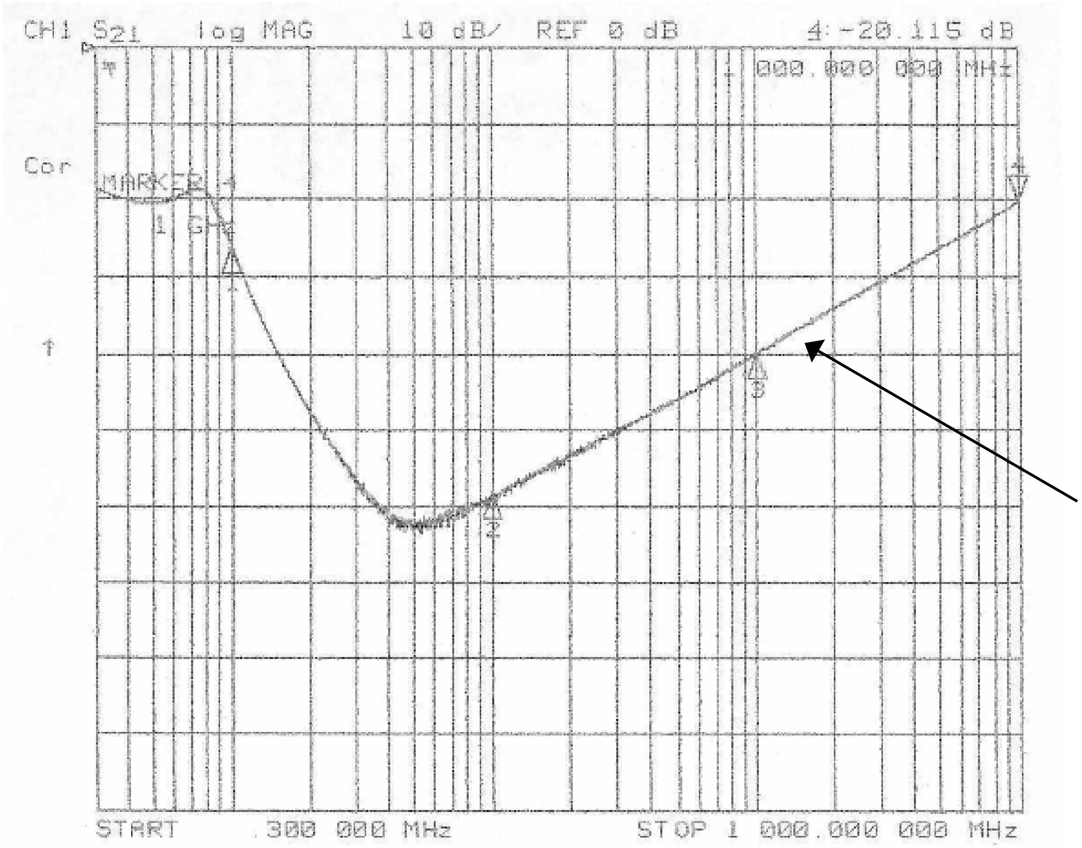
High Performance SMD Pi-Filters

Features

- Ferrite beads are used to add inductance in line
- High current ‘C’ filters are made the same way, but the ferrite bead is left out.
- An alternative option is to leave the board track under the feedthrough chip to handle the current

High Performance SMD Pi-Filters

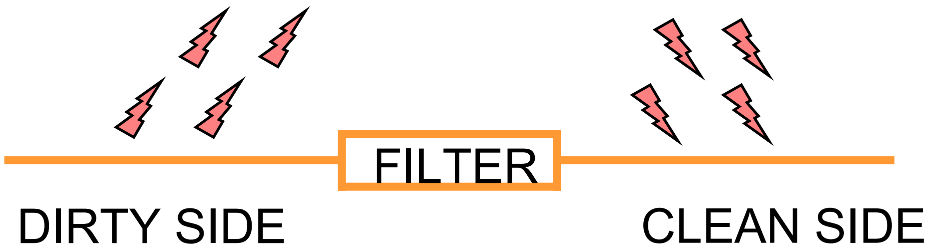
Typical Performance Curve



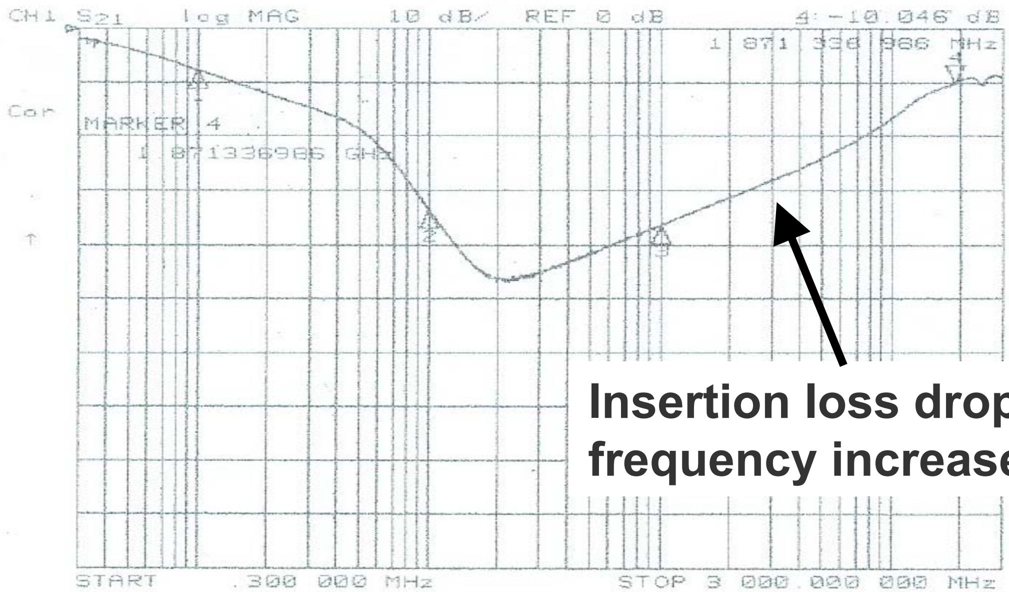
SBSGP 220nF Insertion Loss shown

Note the degradation with increasing frequency

Surface Mount EMI filters & High Frequency



All surface mount filters suffer at high frequencies



Insertion loss drops off as frequency increases

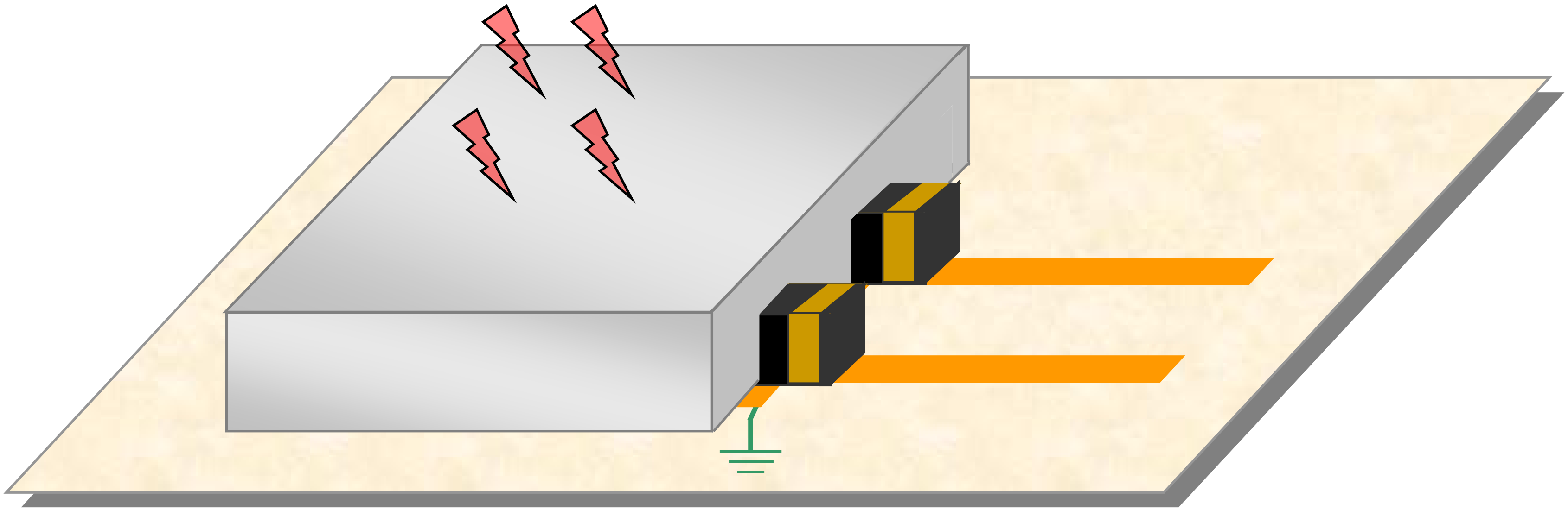
Surface Mount EMI filters & High Frequency

- Insertion loss for surface mount types is lower at higher frequencies (100'sMHz to 1GHz) above the component resonance
- You can improve this by using a shielding can on the board to form a faraday cage, or by using a special track layout in conjunction with a multilayer board
- The high frequency performance can be improved, but it is difficult to get SM parts as good as panel mount components

Surface Mount EMI filters & High Frequency

High Frequency Improvement by Use of Shielded Can

Place shielding can over clean side of circuit to act as bulkhead and faraday cage



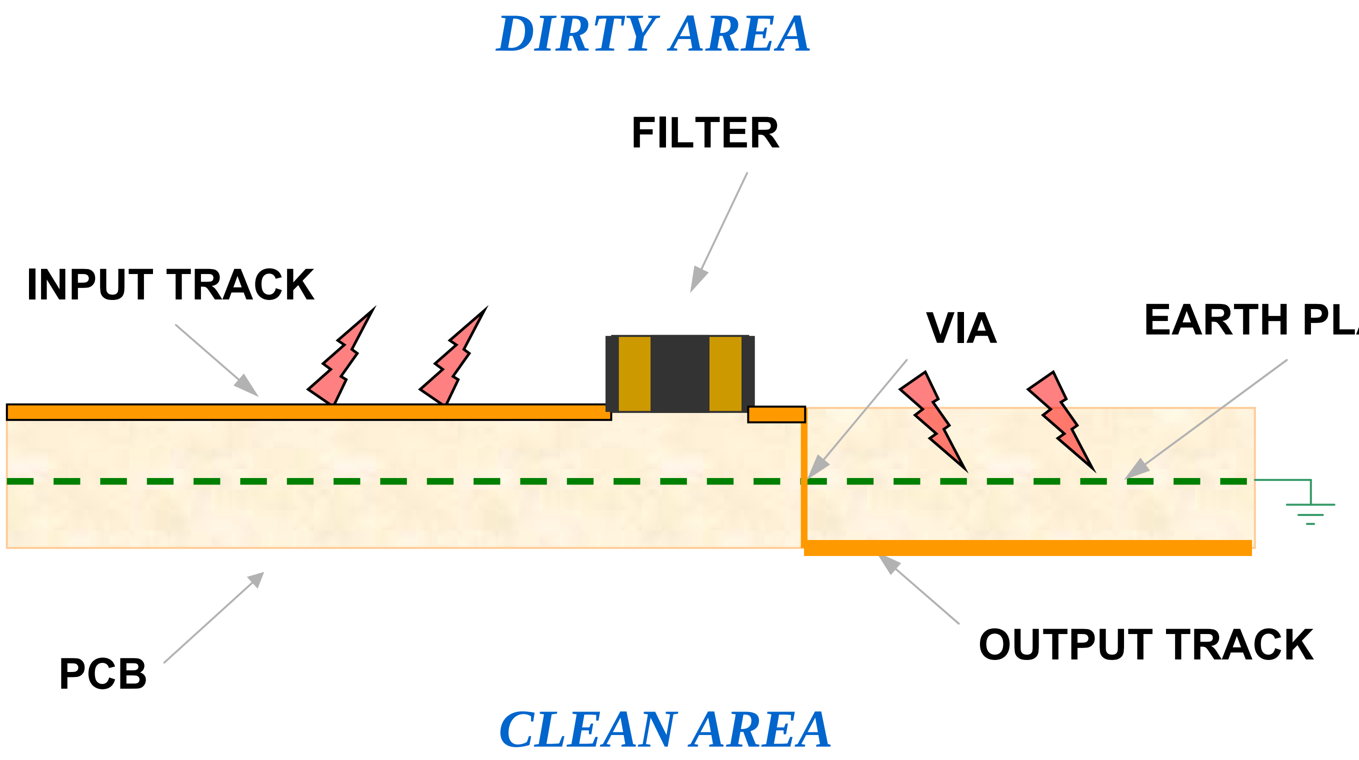
Surface Mount EMI filters & High Frequency

High Frequency Improvement by Use of Shielded Can

- Shielding can is grounded
- Can need not be attached to the filter
- Insertion loss performance is similar to that of a panel mounting type
- Best method of improving performance of SM filters
- Not very easy in practise – cost is relatively high

Surface Mount EMI filters & High Frequency

High Frequency Improvement by Use of Buried Layer Board

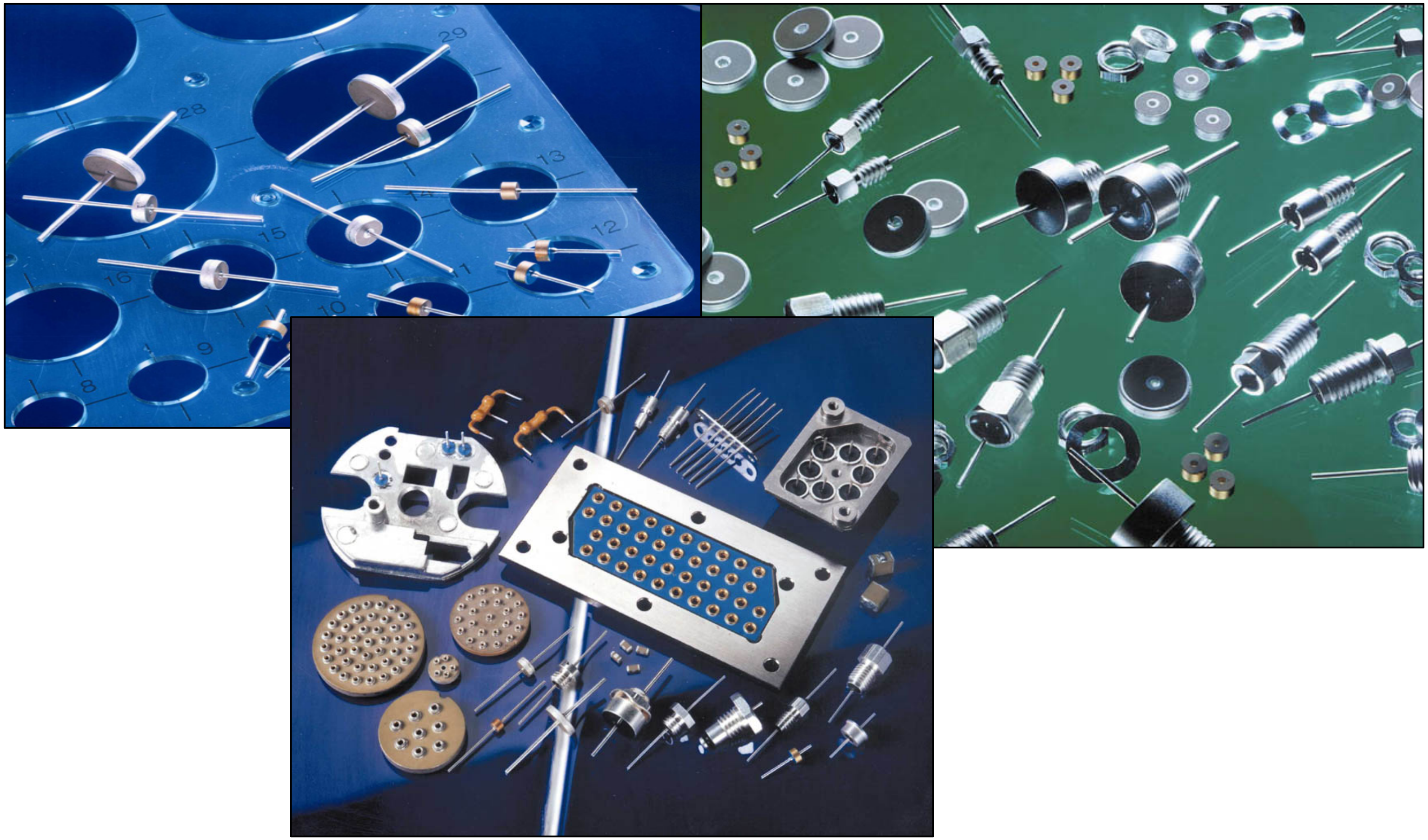


Surface Mount EMI filters & High Frequency

High Frequency Improvement by Use of Buried Layer Board

- Much more common method
- Output track is on opposite side of the pcb to the input track
- A via connects the filter to the other side of the board
- An internal ground plane provides screening between the 2 tracks
- Assembly of the filter is then standard pick-and-place
- Benefit is ease of assembly for manufacturer

Panel Mount EMI filters

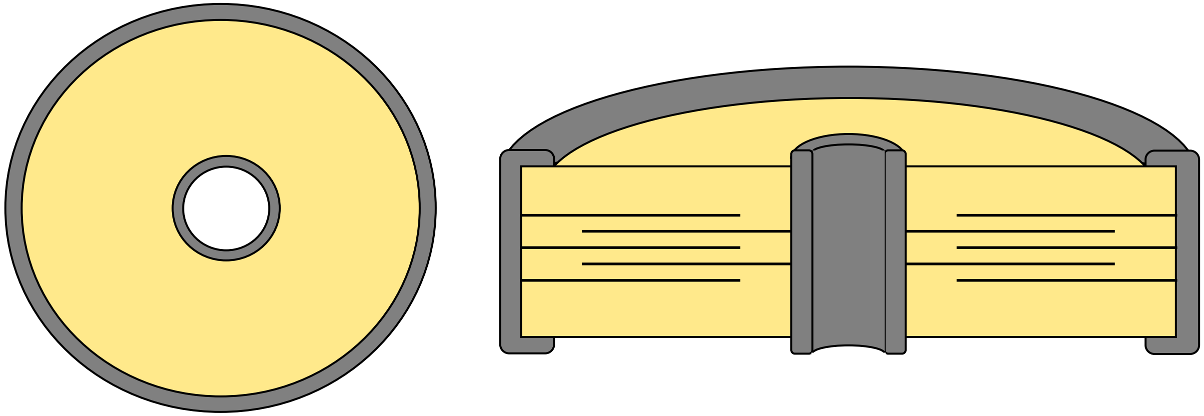


Panel Mount EMI filters

- Panel mount filters bolt or solder direct into a Faraday cage bulkhead to provide the ultimate in filtering performance at high frequencies
- These include filter connectors for multiple lines
- The heart of the filter is the disc or planar array - internal construction is as per standard MLCC's but the outside is shaped.
- The circular shape reduces self inductance and offers electrode interleaving giving optimum filtering performance
- Beware - some manufacturers use chip capacitors. These types of component have the same limitations as surface mount filters – poor high frequency performance

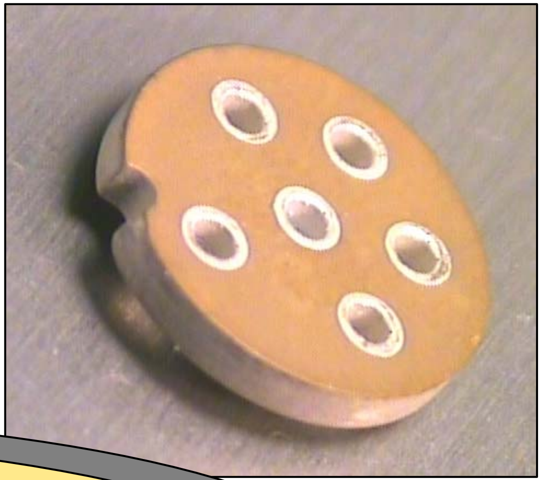
Discoidal Capacitors

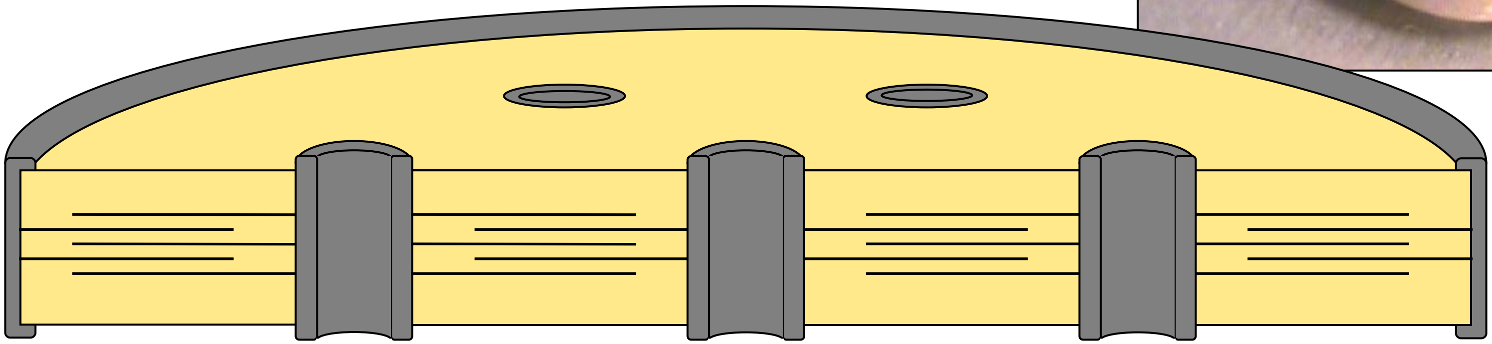
- Used for feedthrough filtering in panel mount filters and bulkheads.
- Ultimate in low inductance design
- Manufactured in the same way as chip capacitors and shaped prior to termination



Planar Arrays

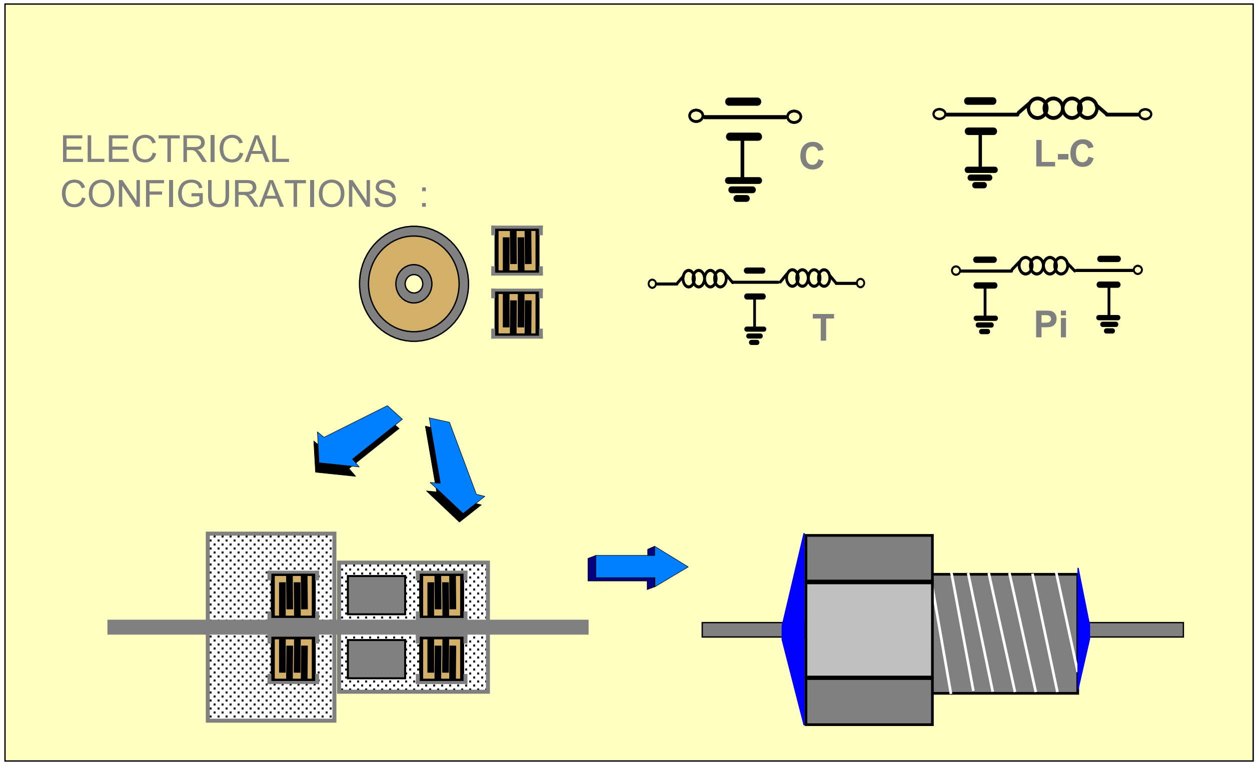
- Like many discoidals in one piece of ceramic
- Used for multi-way connectors





Panel Mounting Filters

Discoidal Capacitor Filter Construction

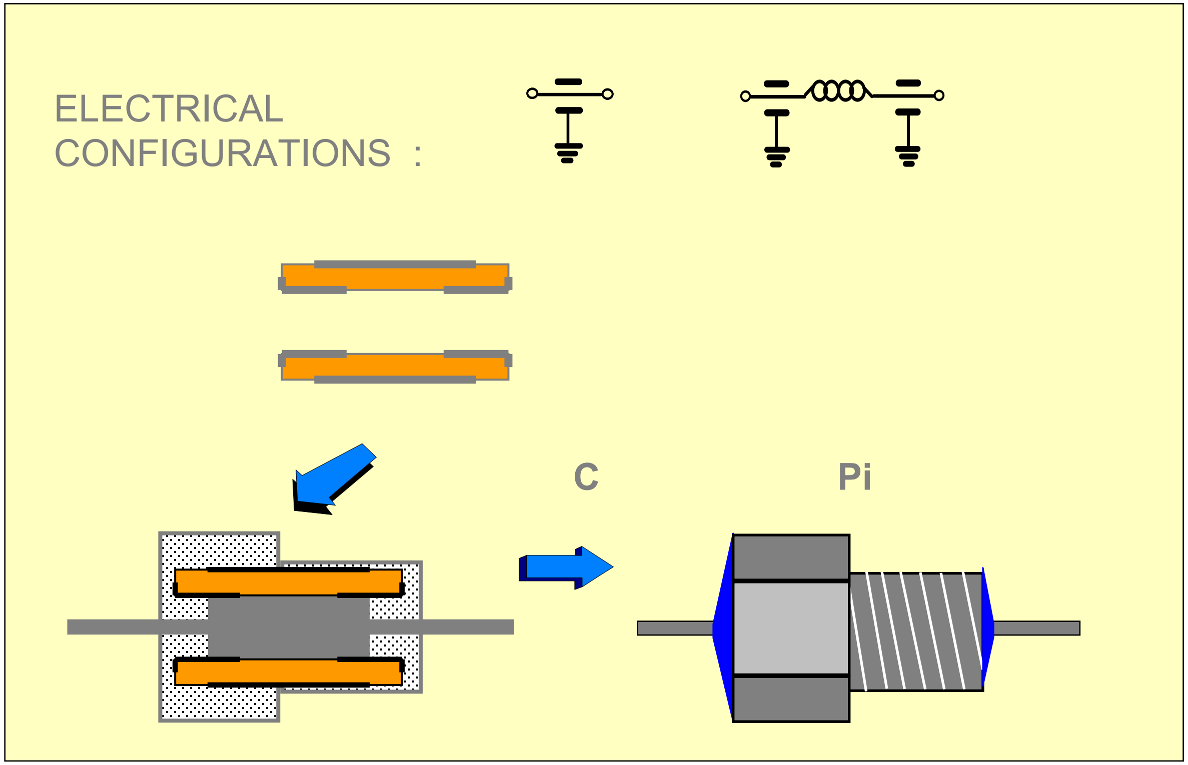


Panel Mounting Filters

- Traditionally used tubular capacitors for low value filters
- Tubes are cheaper than discs, but only available in much lower capacitance (typically 20nF maximum)
- Often the low capacitance limitation is overcome by the use of very unstable dielectrics
- Ideal for Pi filters – hence these are often offered irrespective of best solution
- Have a reputation for cracking, particularly in applications where the tube is exposed

Panel Mounting Filters

Tubular Capacitor Filter Construction



Panel Mount EMI filters

Factors to consider in filter selection

- Ferrite bead inductors saturate with current – in high current applications it is better to use a high capacitance ‘C’ filter
- Some suppliers use very poor ceramic dielectrics such as Z5U, Y5V, X7W etc. which effect performance considerably
- The grounding is critical – mounting hole diameter and tightening torque must be checked
- Filter mounting pitch is determined by the head of the filter not the thread – often more expensive small thread filters are mistakenly specified

Ceramic Dielectric Performance

Example of different Dielectric Performance

Compare 2x 1nF filters :-

1) 500V rated X7R 10nF

@ 50V & 125ºC

Actual capacitance ≈ 8.6nF

2) 50V rated Z5U 10nF

@ 50V & 125ºC

Actual capacitance ≈ 1.5nF

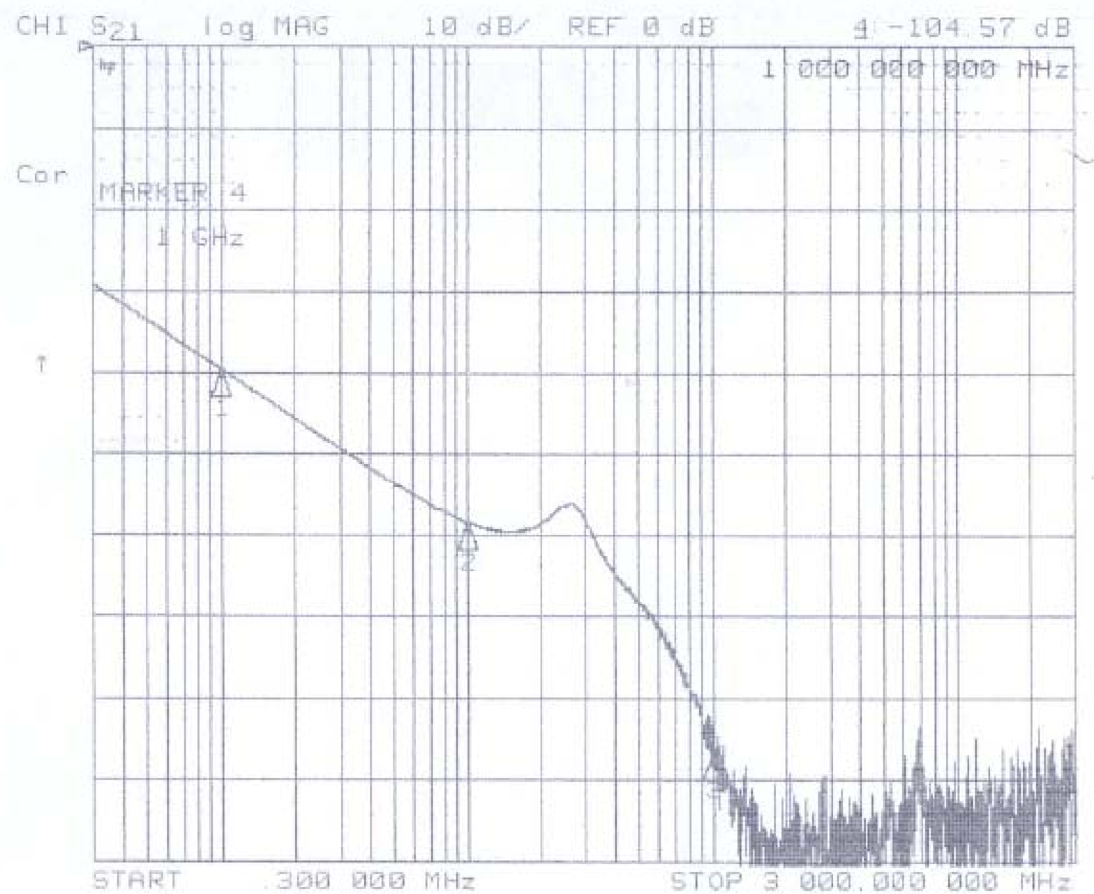
Insertion loss of 8.6nF filter @ 1MHz ≈ 3dB

Insertion loss of 1.5nF filter @ 1MHz = 0dB

Effect of Poor Grounding

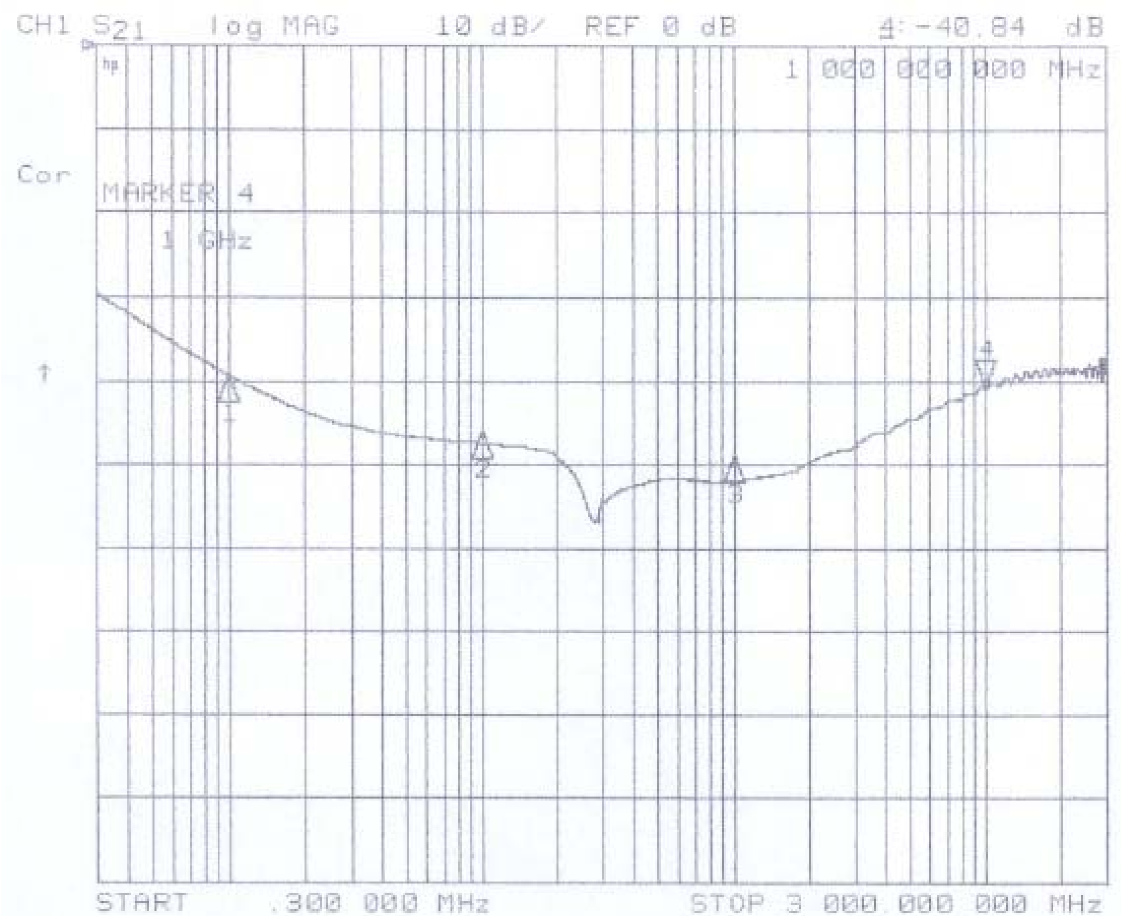
Insertion Loss Plot 1 - 680nF filter mounted in a standard test fixture with good grounding

(Tested IAW MIL-STD-220)



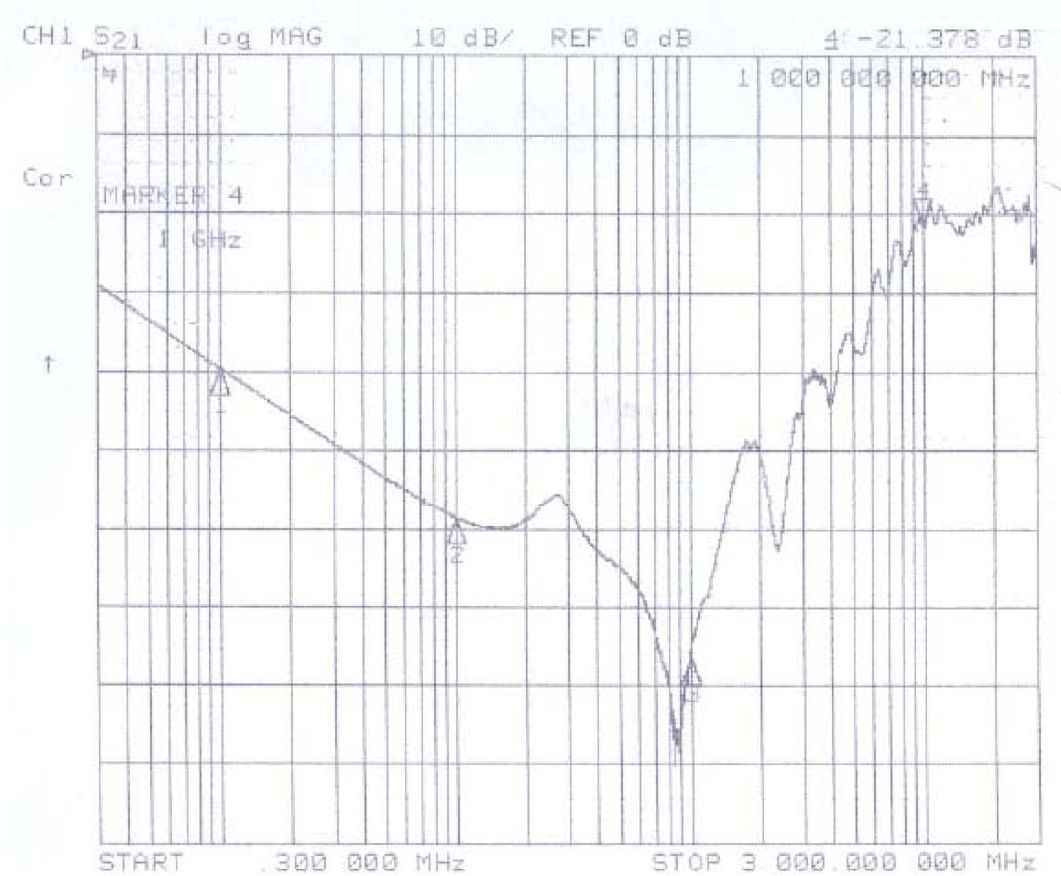
Effect of Poor Grounding

Insertion Loss Plot 2 - the same filter as in plot 1, still in the same test can, but the filter mounting nut has been slackened by ¼ turn



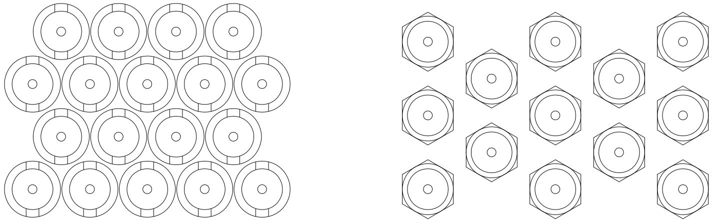
Effect of Inadequate Shielding

Insertion Loss Plot 3 - The same 680nF filter again, but this time mounted in a test fixture with too large a mounting hole meaning there's a gap which allows high frequency noise to radiate through the bulkhead to the output side



Panel Mounting Filters

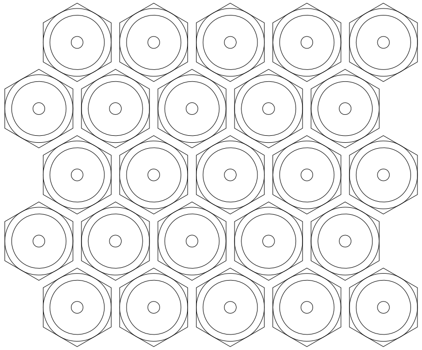
- A note on the mechanical design for installing panel mount filters
- The body thread does not define the pitch – the head of the body does
- Smaller thread filters tend to be harder to make and therefore more expensive
- For closer pitch mounting use round body styles or consider an assembly



Panel Mounting Filters

AND FINALLY

This is not possible



But it's amazing how often we see it tried

Syfer Technology

innovative

world-class

ceramic components

THANK YOU