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

Stephen Hopwood - Snr Engineer
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 – \( X_C = \frac{1}{2\pi fC} \)

- As frequency increases, the inductor becomes more resistive – \( X_L = 2\pi fL \)

- 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.
‘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

Ferrite beads

‘T’ Filter

‘Squoidal’

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

Noise

Filtered Signal

Raw Signal

Noise

Signal
Surface Mount EMI filters

Typical Performance Curve

100pF E01 Insertion Loss shown
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

Filtered Signal

Noise

Raw Signal
X2Y Capacitors
Surface Mount Pi 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

- Ferrite Bead
- Conductor
- Special Chip Capacitor

IN    OUT
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.
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
High Frequency Improvement by Use of Buried Layer Board

**DIRTY AREA**

- FILTER
- VIA
- EARTH PLANE
- OUTPUT TRACK

**CLEAN AREA**

- PCB
- INPUT TRACK
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

**ELECTRICAL CONFIGURATIONS:**

- C
- L-C
- T
- Pi
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

ELECTRICAL CONFIGURATIONS:

C Pi

Diagram showing various electrical configurations for panel mounting filters.
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 & 125°C
   Actual capacitance ≈ 8.6nF

2) 50V rated Z5U 10nF @ 50V & 125°C
   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