

ELECTRICAL FILTERS

INTEGRATED PROTECTION OF C⁴ EQUIPMENT & FACILITIES
(Command Control Communications Computer & Intelligence)

E³ LINE FILTERS

EMI LEMP NEMP HEMP TEMPEST

Electromagnetic Environmental Effects



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John Jephcott
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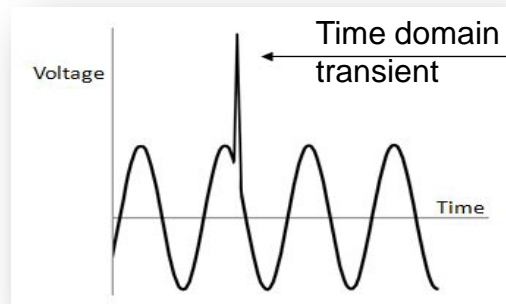
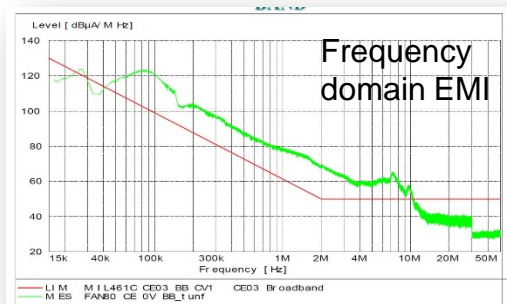
WHAT IS AN ELECTRICAL FILTER?

- A filter is an device placed into a network to control and manage the frequency components of an electrical signal
- Filter supports EMC - ability of equipment to function satisfactorily in it's electromagnetic environment
- Filters are used to block or attenuate a range of signal frequencies by use of a combination of frequency dependent impedances
- Filters may be active or passive - designed to attenuate EMI
- Circuits may be configured as low pass, high pass, band pass or band rejection
- EMI is undesired electrical origin disturbances across the full frequency spectrum - DC - EHF viz 0Hz - >100GHz
- RFI is a traditional term covering disturbances across the radio frequency spectrum - viz 150kHz – 300MHz
- **Commercial Filters**
 - Chassis mount to 30MHz+
 - 2-terminal capacitors
- **Military Filters**
 - Bulkhead mount to 40GHz+
 - Feedthrough capacitors



EQUIPMENT & FACILITY PROTECTION

- Filter is required to pass intentional (managed) power or communications signals, but attenuate unintentional (vulnerable) radiation or conductions
- The filter represents the electrical point of entry of the boundary of the protected volume, and must meet a minimum required specification
- Rugged, durable, cabinet / box style, fully gasketed to maintain the integrity and hardness of the shield EM boundary from:
 - EMI – emissions and immunity (susceptibility)
 - LEMP – multiple event protection
 - NEMP / HEMP – early, intermediate and late time multiple illumination protection
 - Tempest – infosec red area maintenance (*treated as EMI*)
 - HPM / IEMI – full spectrum DEW system protection to 100GHz
- Protection on all lines achieved by a hybrid combination of transient suppression devices and high performance EMI filters



WHY USE ELECTRICAL FILTERS

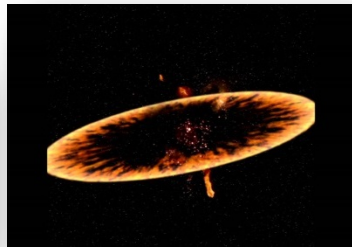
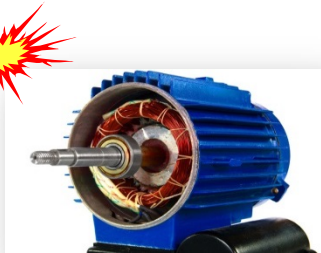
Protect against EMI, EMP (LEMP/ NEMP/ HEMP), HPM/ IEMI, TEMPEST

Keep EMI OUT of system

- Meet EMC regulations
 - CE, MIL-STD, DEF-STAN, VDE, CISPR, IEC-EN etc
- ‘Noisy’ Environment
- Interference
 - Radio Tx & Rx
- EMP Protection
 - Secondary Lightning
 - NEMP / HAEMP
 - HPM & DEW

Keep EMI IN the system

- Meet EMC regulations
 - CE, MIL-STD, DEF-STAN, VDE, CISPR, IEC-EN etc
- Interference
 - Radio Tx & Rx
- Anti-electronic eavesdropping
 - TEMPEST (*coherent EMI*)

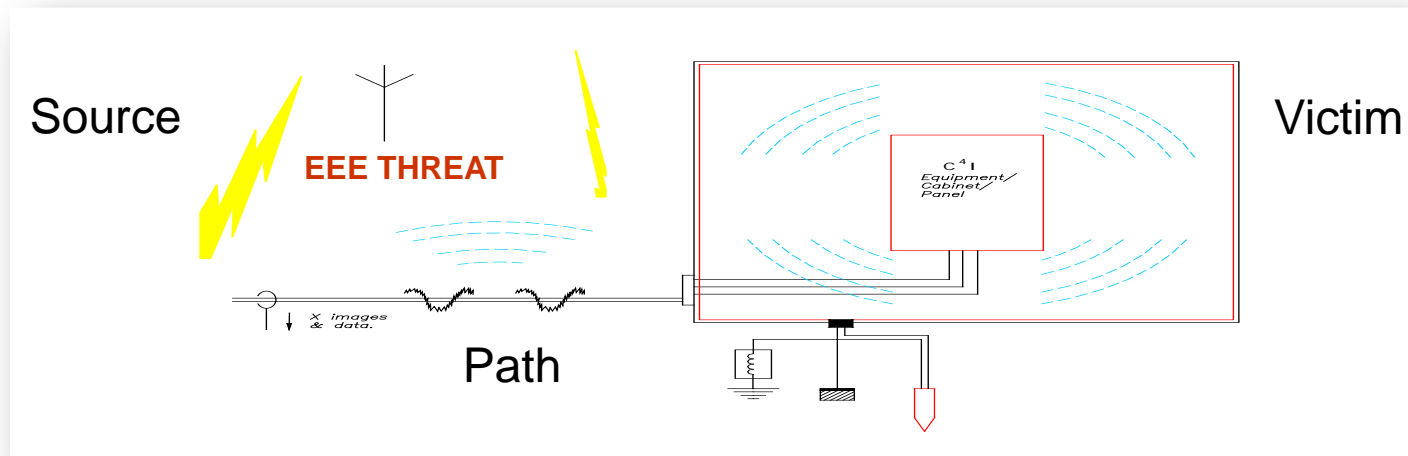


EMI - HOW DOES IT PROPAGATE

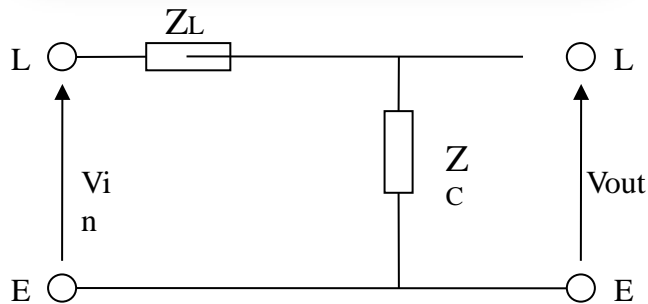
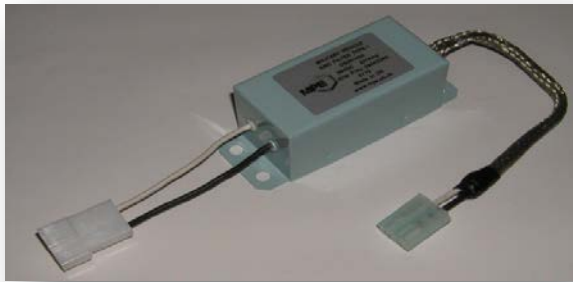
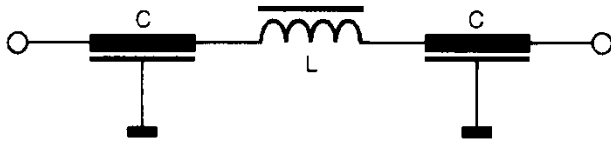
What are the aspects of EMI and how does it propagate and couple ?

	<u>Emissions</u>	<u>Susceptibility</u>
Conducted	CE	CS
Radiated	RE	RS

- CE propagation can be dominantly LF (<30MHz) - at higher frequencies the copper lines attenuate the electrical signals
- RE propagation is mainly field effects - electric & magnetic, near & far
 - The non-EMC situation may be of artificial or natural origin:
disturbing element - propagation mechanism - disturbed element



FILTER OPERATION



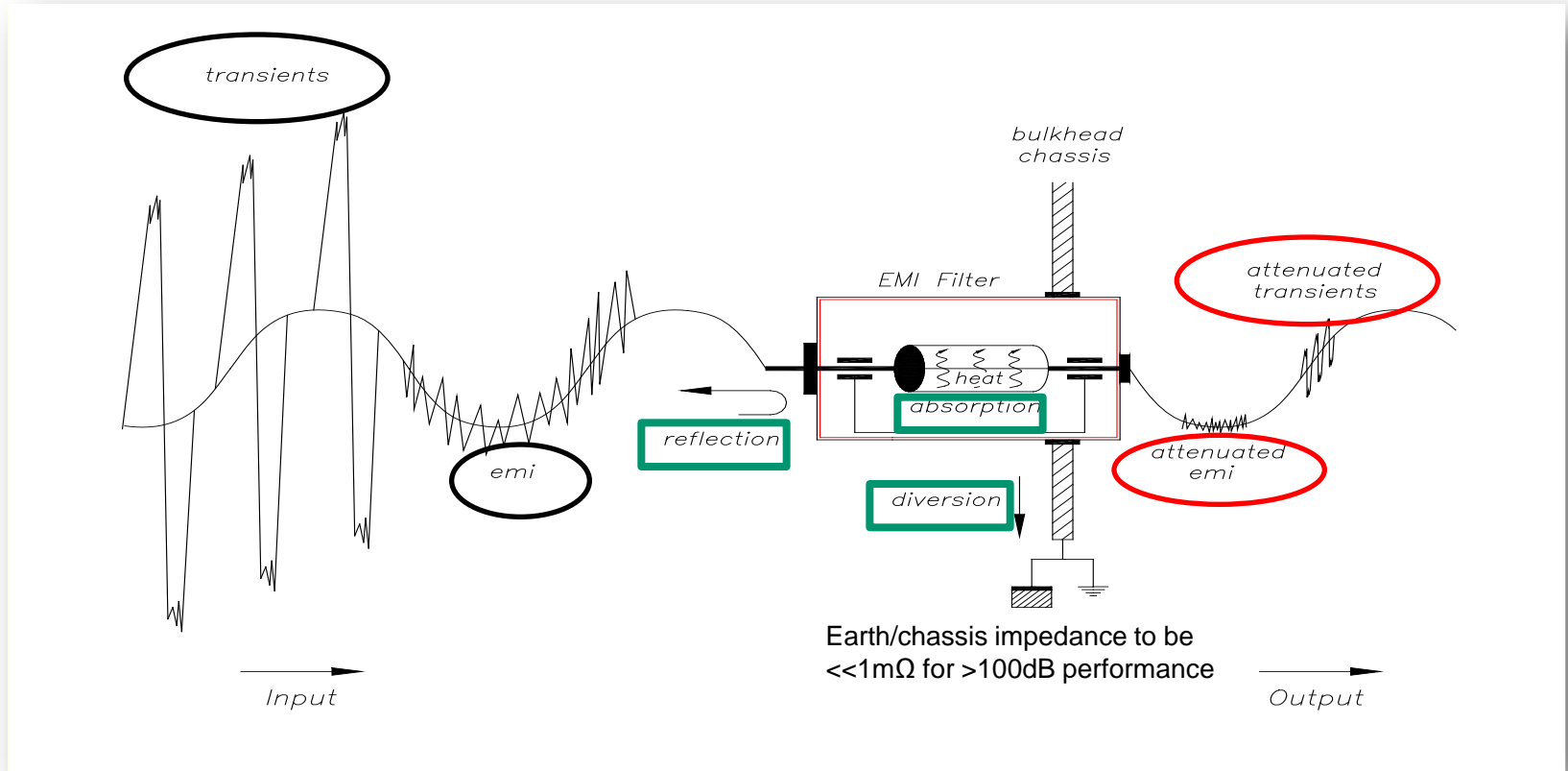
Example of voltage divider between inductor and second capacitor

$$V_{out} = V_{in} \frac{Z_C}{(Z_L + Z_C)}$$

- Low pass EMI filters are a combination of shunt capacitors and series inductors
- EMI filters are most commonly low pass filters as they are required to pass low frequencies and block/attenuate high frequencies
- Low pass filters generally have circuit type shown - a simple 3-element pi-filter with 2-capacitors and 1-inductor (*choke*)
- The number of components can be increased to improve the filter performance - performance 20dB/decade/element
- Each component forms a voltage divider with the previous element – based upon ratio of impedances
- "Insertion loss" performance predicted by classical circuit analysis (usually 50-Ohms)
- "Attenuation" determined by measurement in actual equipment impedance (non 50-Ohms)

FILTER DESIGN - LOW PASS FILTERS

HF voltage / current attenuation through EMI filter



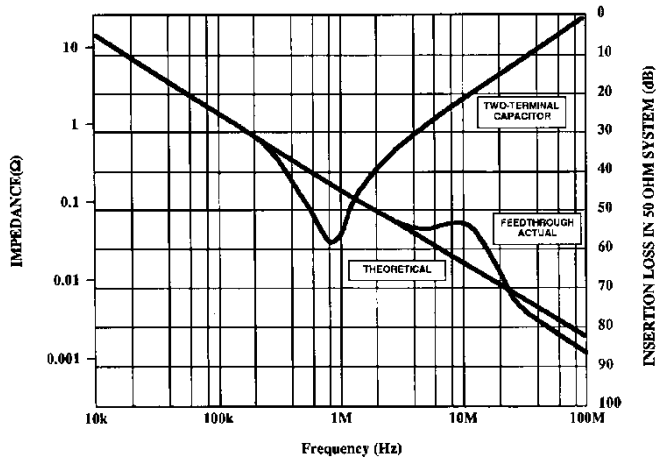
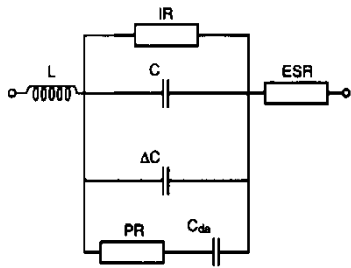
The Filter is installed on the bulkhead of a Faraday chamber, or at an architectural Red / Black zone boundary, & functions in removing transients & EMI from the equipment cables & wires by :

Reflection / Absorption / Diversion

PERFORMANCE OF PRACTICAL CAPACITOR



Capacitors may have their electrodes connected in two terminal or feedthrough configuration to determine their spectrum performance



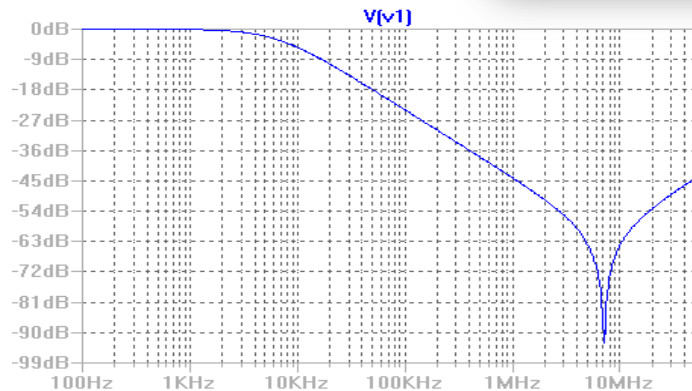
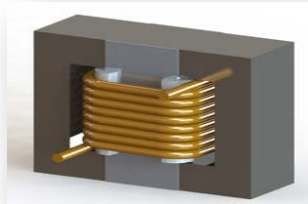
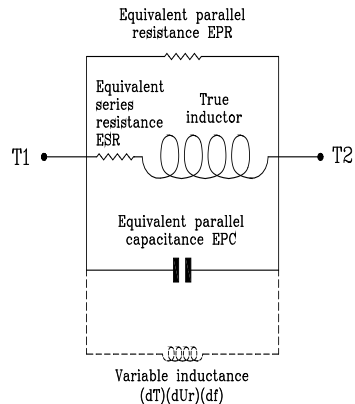
- For two terminal connected capacitors they will at some frequency go into a full series resonant condition
- For feedthrough connected capacitors the response will be ideal except for a low order parallel resonance and a limiting earth bond impedance limitation
 - Low inductance radial connection
 - No fundamental series resonant frequency

- 2-terminal capacitor performance lost above resonant frequency - longer lead lengths reduce resonant frequency
- Feedthrough capacitors always needed for good performance across HF
- Most commercial filters don't use feedthrough capacitors - most "military" filters do use feedthrough capacitors

Performance of 1 μ F feedthrough capacitor compared with two-terminal capacitor with 20mm leads

PERFORMANCE OF PRACTICAL INDUCTOR

- Act as a block/attenuate to high frequencies but pass low frequencies
- For low pass circuits inductors are connected series, input to output
- Less "perfect" response than feedthrough capacitors - resonance issues
- Less effective at high frequencies due to parasitic capacitance and inductance



Design Styles:

Common mode

- Multiple line - "bucking coil"
- No saturation if balanced
- Ferrite / Amorphous / MuMetal etc
- Used in power line filters

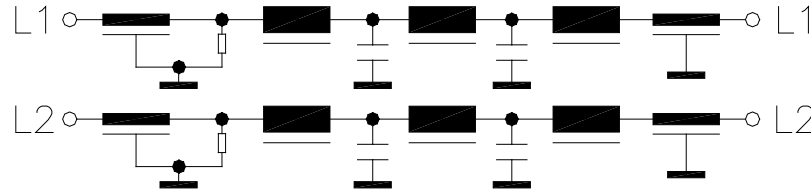


Differential mode

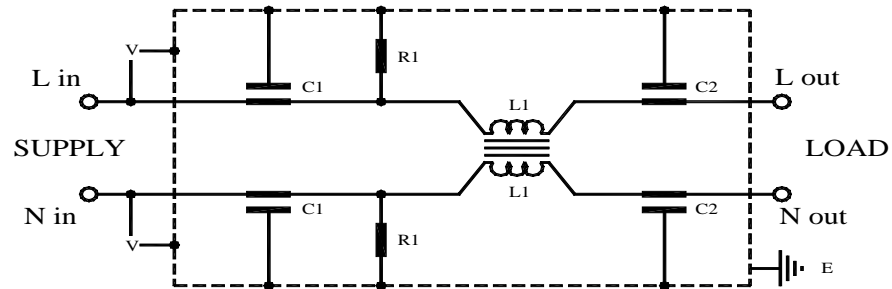
- Single line
- Saturation issues
- Iron powder / SiFe / MPP etc
- Used in telephone, data, control line filters



SINGLE LINE & COUPLED CHOKE FILTERS



- Coupled choke design optimum for most power line applications - but must ensure:
 - Load current returns through filter, imbalance causes partial or full saturation (acoustic noise, waveform distortion)
 - Filter not used on single lines
 - Product wiring disciplines to be observed; phase & neutral, supply & load, cascading etc

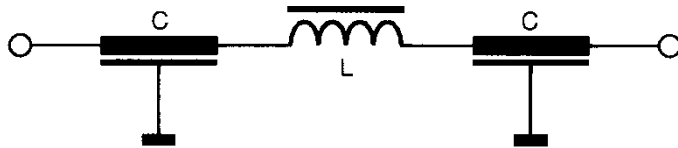


Photograph shows comparison 100Amp SP&N power filters

FILTER CIRCUIT TYPES

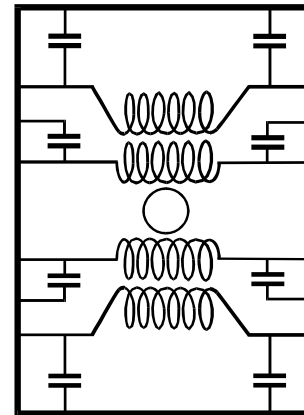
Single Line:

- Optimum for low current control, signal, telephone & data lines
- Power line designs need to account inductor saturation with current
- High performance power filters are large, have high leakage current and high heat dissipation



Multiple Line:

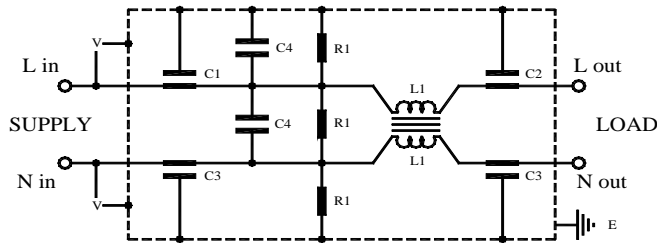
- Current compensating (common mode) inductors used to avoid saturation – line current (flux) cancels in inductor core, load current to return through filter
- High inductance (Z_L) so high performance in smaller size with less capacitance and power dissipation



LOW LEAKAGE FILTERS

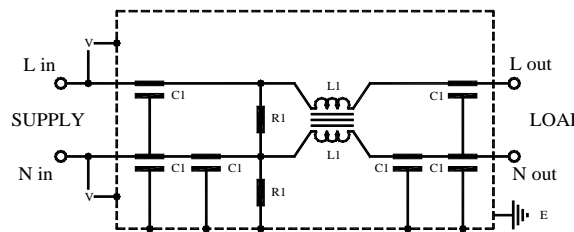
Standard filters:

- Capacitors connected directly between line and ground
- Leakage currents high; e.g. 32A SP&N Tempest filter 1.8A at 250V/50Hz
- Not compatible with RCCD's



Low leakage filters:

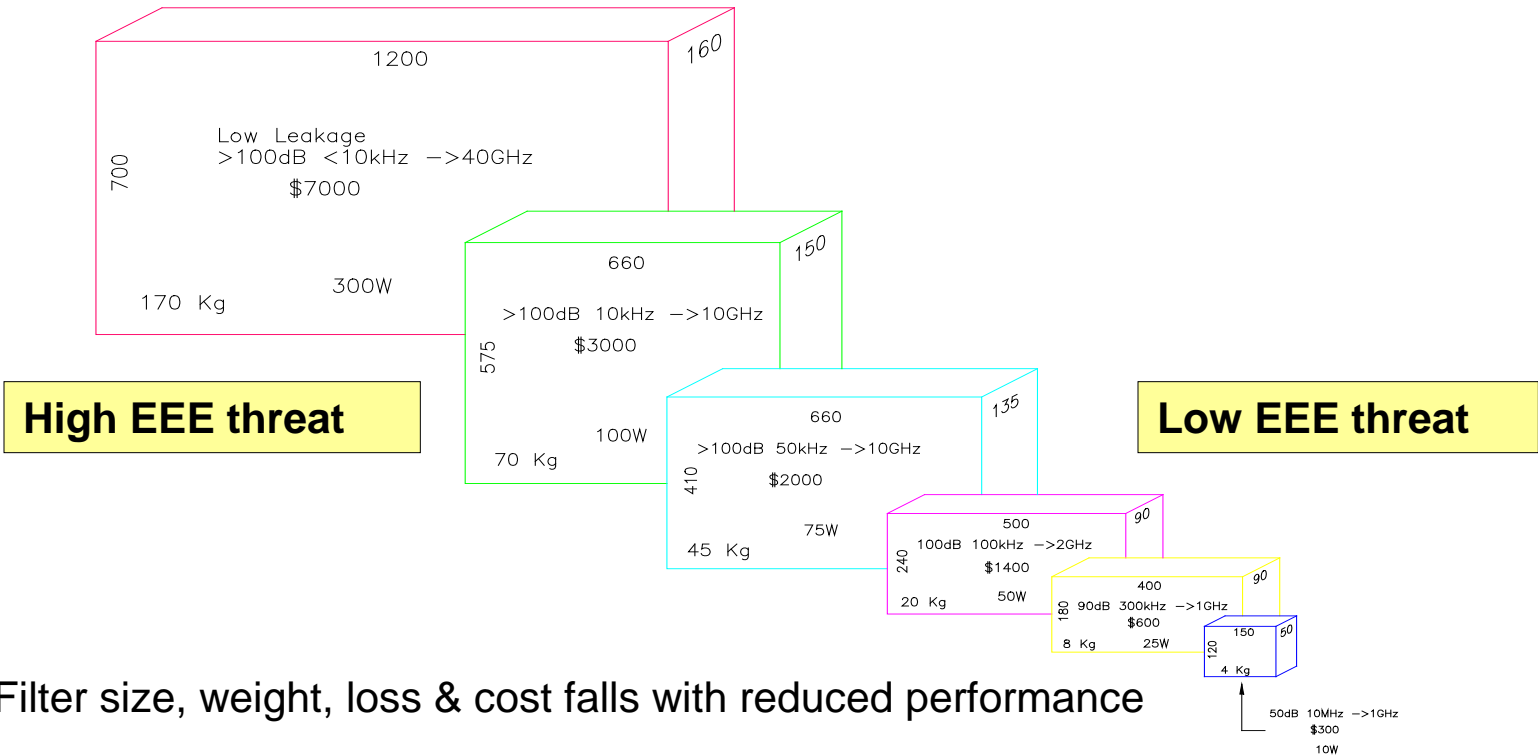
- Special circuit for mains power lines which have a neutral return
- No direct capacitance between phase line and ground – capacitive paths are Φ -N and N-E
- Leakage currents low; e.g. 32A SP&N Tempest filter 25mA at 1V/50Hz reference (inrush $>100A_{peak}$ μs period)
- Safety benefits - especially mobile/shelter
 - Lower leakage current
 - Leakage current only comes from neutral line voltage
 - If filter earth lost, case only goes to neutral potential



- Disadvantage is larger size and weight for same performance
- Not compatible with RCCD's

FILTER DESIGN - SELECTION

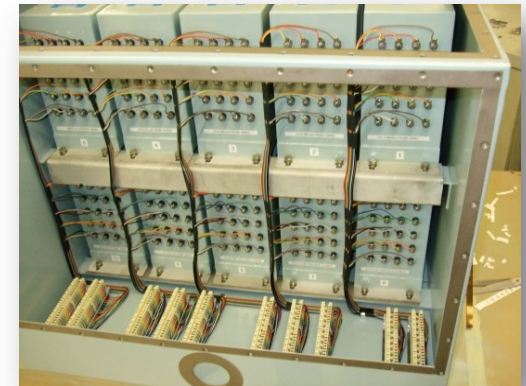
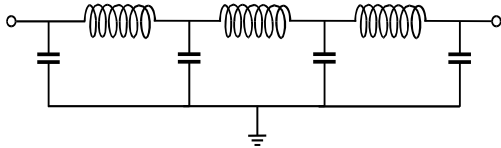
Filter size/ weight/ cost for performance specification
Comparison example : 100Amp TPN 250/440VAC power filter



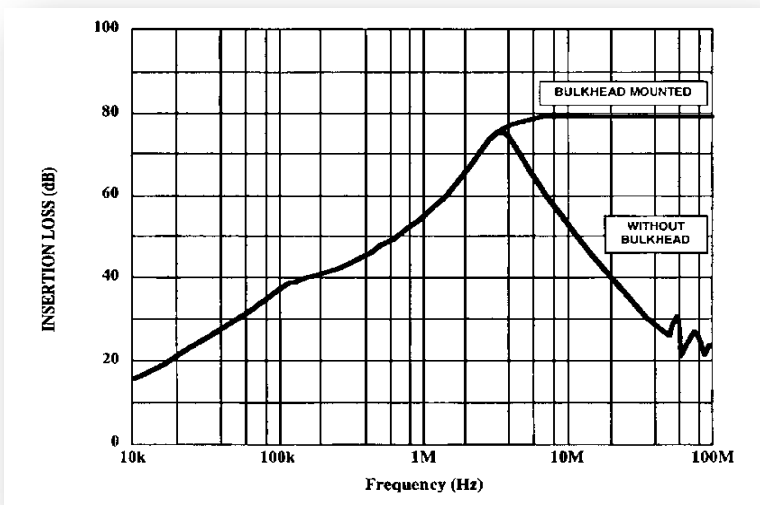
CONTROL, TELEPHONE & DATA FILTERS



- Equipment compatibility must be considered for:
 - Telephone line filters "A", "B", Brent
 - Data line filters
 - Signal filters for BMS (fire, intruder, PA, HVAC, control etc)
- Flat passband, high symmetry, matched impedance circuits with element matching to $<0.1\%$ - avoids reflections (echo) and distortion
- Normally 3-stage/7-element for rapid roll-off between pass and stop bands
- Interface equipment must be tolerant of:
 - Capacitance limitations
 - Inductance
 - DC and shunt resistance
 - Pass band and interface impedance
- For control line filters
 - DC *high cap, low resistance*
 - AC *low cap, high resistance*

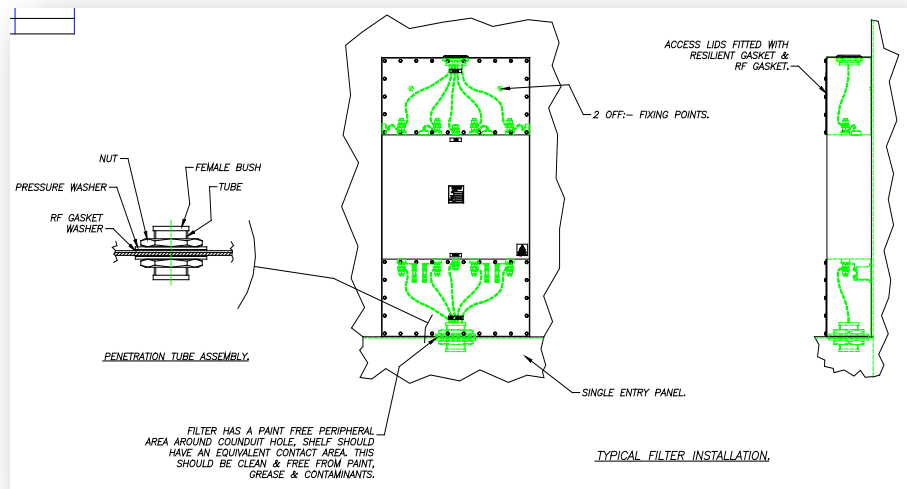


• BULKHEAD MOUNTING



- Graph compares equipment filter chassis mount versus bulkhead mount
- Bulkhead mounting provides shielding between input /output to minimise coupling
- Bulkhead can be cabinet, chamber, vault
- Similar effect on installation filters if not correctly mounted and gaskets fitted

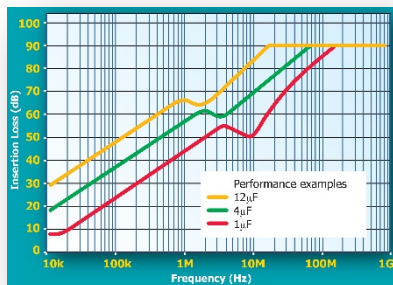
• CHASSIS MOUNTING



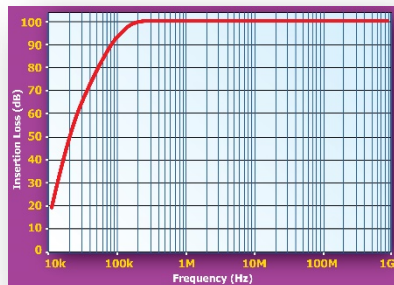
SUMMARY - MAIN SELECTION CRITERIA

Typical insertion loss performance of professional and military filters:

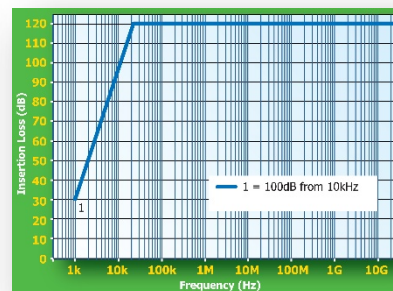
Feedthrough capacitor



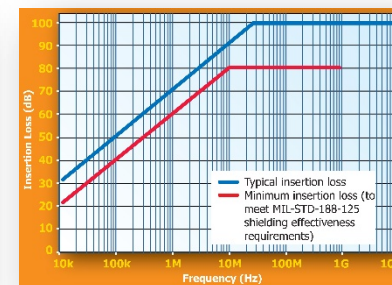
Equipment filter



Power line filter



HEMP filter



Power:

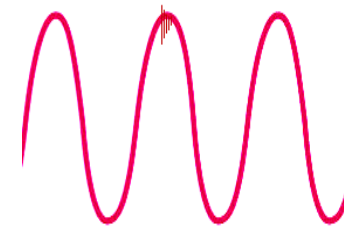
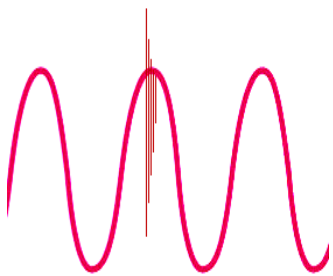
1. Desired attenuation / Insertion loss performance
2. Current rating
3. Operating voltage, AC, DC, 50-60-400Hz.
4. No of Lines (SP&N, TP&N, 2-Ph, 1-L)
5. Leakage current
6. Mechanical / Termination style
7. Environmental

Signal:

7. Frequency & Signal Waveform
8. Circuit impedance characteristics

SUMMARY - FILTER SELECTION

- The EMI filter is selected to achieve a specified performance across the frequency spectrum – level of insertion loss / attenuation at specific frequencies
- Voltage rating and number of lines (SP&N, TP&N, 2-Phase, 1-Line) must be correctly specified - DC or AC. If AC mains applied to a DC filter then it could fail catastrophically upon energisation, or very early infant mortality
- Current rating must be correctly specified. Filters may be used at lower than rated currents "without penalty" (except size, weight, cost, leakage losses). If load current exceeds filter rating then inductor temperatures will rise, at risk of catastrophic thermal runaway
- The filter specification requirement determines physical size, weight, cost and system electrical losses
- Bleeder discharge resistors can upset DC leakage detection systems
- The benefits of including a filter in an electrical system are not penalty free:
 - impose resistive and reactive loading on the supply
 - set up earth leakage currents in AC applications
 - can cause equipment compatibility problems
 - occupy space and introduce weight to apparatus
 - require periodic maintenance
 - cost money





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& would be pleased to answer any questions.....**

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