Electromagnetic Compatibility (*EMC*)

Introduction about Filters

Agenda

- *Characteristics of Filters*
  - Impedance Mismatch Effects ([2] 10-2-1)
  - Low-Pass Filters
  - High-Pass Filters
- Power Line Filter Design
  - Common-Mode Filter
  - Differential-Mode Filter
  - Combined CM and DM Filter
  - Inductor Design
- Filter Installation

Characteristic of Filters

- Filters are designed to attenuate at certain frequencies, while permitting energy at other frequencies to pass.
- Filters performance characteristics
  - *Insertion loss*： $IL(dB) = 20 \cdot \log_{10} \frac{V_1}{V_L}$
    - V_1, the output voltage of signal source without filter
    - V_L, the output voltage of signal source at the output terminals of the filter with filter
  - *Input and output impedances*
  - Attenuation in the pass-band
  - Skirt fall-off
  - Steady-state and transient voltage ratings

Characteristic of Filters

Impedance Mismatch Effects

- Filters are usually designed to operate between specified input and output impedances.
  - When source and load impedances are different from the specified impedances of the designed filter, the output response changes.
- *Impedance mismatch can result in an increase of interference level at the filer output, rather than the desired decrease.*

Characteristic of Filters

Impedance Mismatch Effects

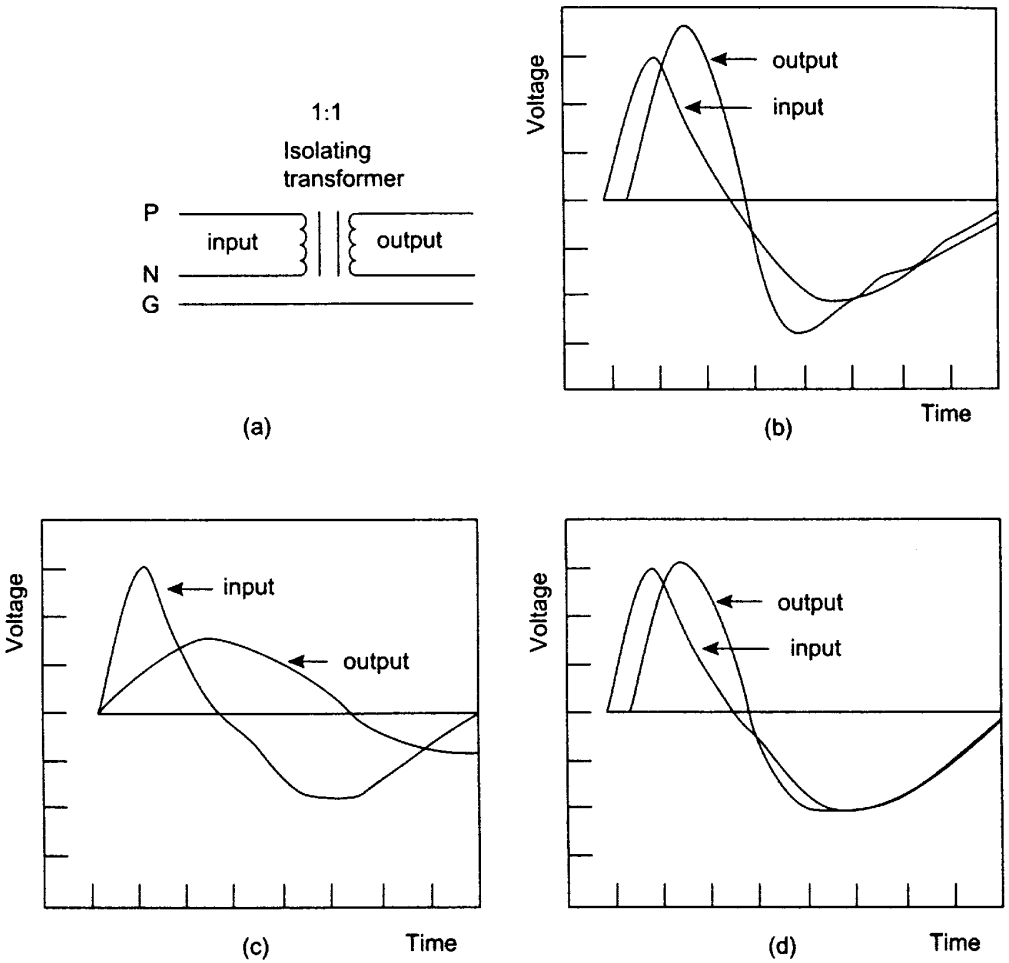
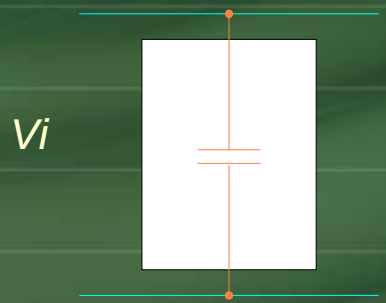


Figure 7-3 Propagation of a 6-kV peak 0.5-μs rise-time transient voltage in (a) 1:1 isolating transformer with the (b) output terminals open, (c) output terminals terminated in 150-Ω 100-W load, and (d) output terminals terminated in 1500-Ω 10-W load

Characteristic of Filters

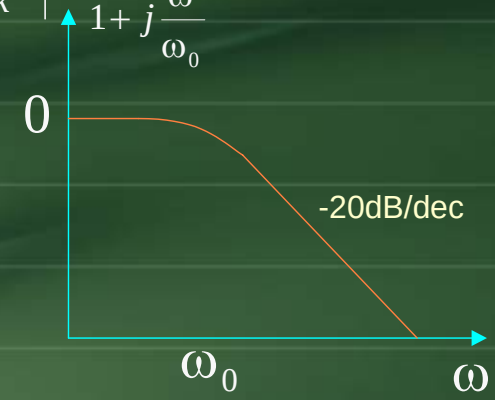
Low-Pass Filters

- Capacitor Filter

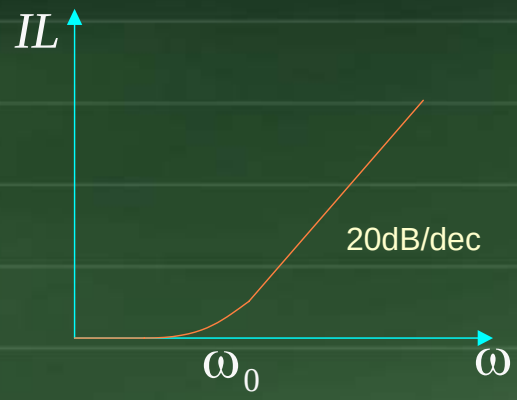


Transfer Function

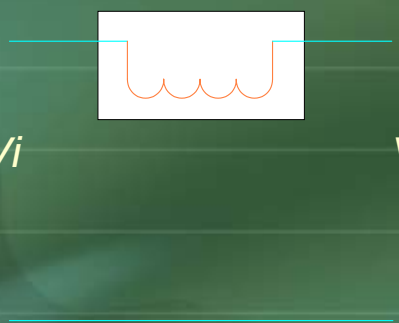
$$\left|\frac{T(\omega)}{k}\right| = \left|\frac{1}{1+j\frac{\omega}{\omega_0}}\right| (dB)$$



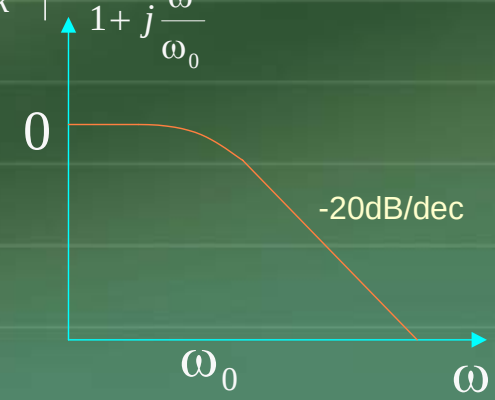
Insertion Loss

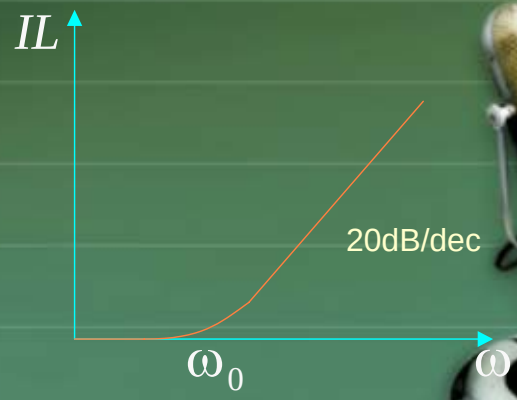


- Inductor Filter



$$\left|\frac{T(\omega)}{k}\right| = \left|\frac{1}{1+j\frac{\omega}{\omega_0}}\right| (dB)$$

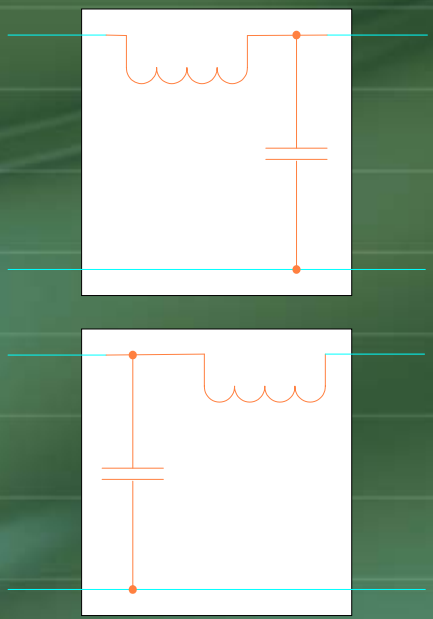


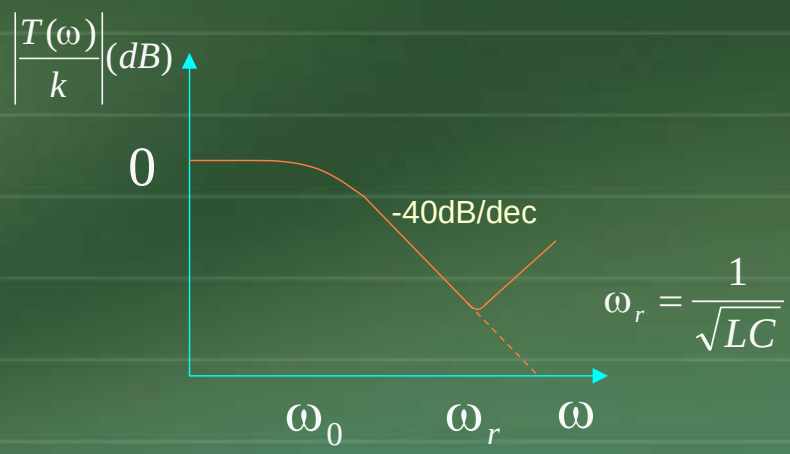


Characteristic of Filters

Low-Pass Filters

- L-Section (LC) Filter
  - More filtering than a single C or L filter at high frequency
  - Poor high frequency attenuation because of stray interturn capacitances. *It may resonate* when input signal is a transient.

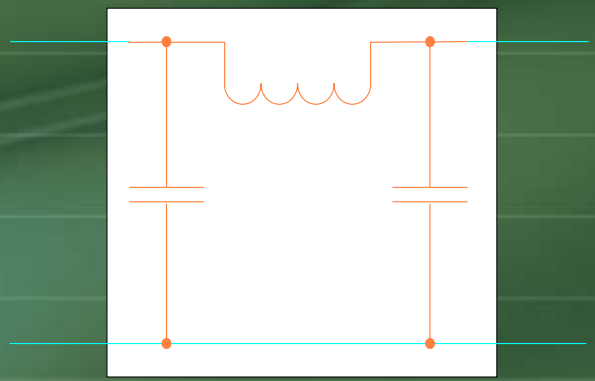


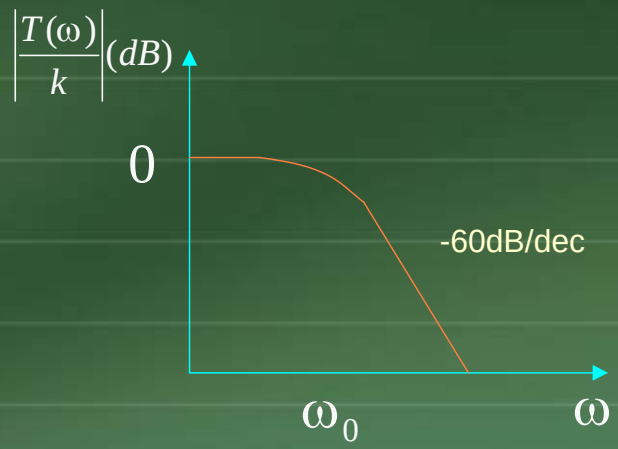


Characteristic of Filters

Low-Pass Filters

- π-Section Filter
  - The most common used in practice

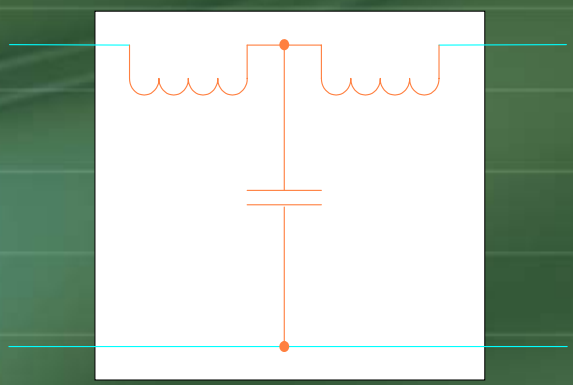


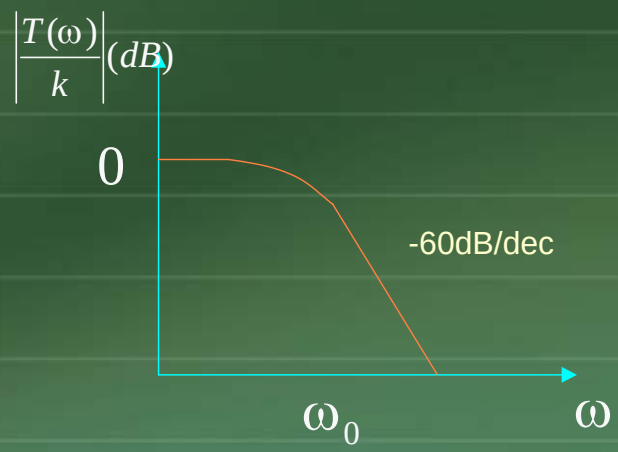


Characteristic of Filters

Low-Pass Filters

- T-Section Filter
  - Requiring two inductors increases the size of the filter, but it is more effective in reducing transient interferences than π-section filter.

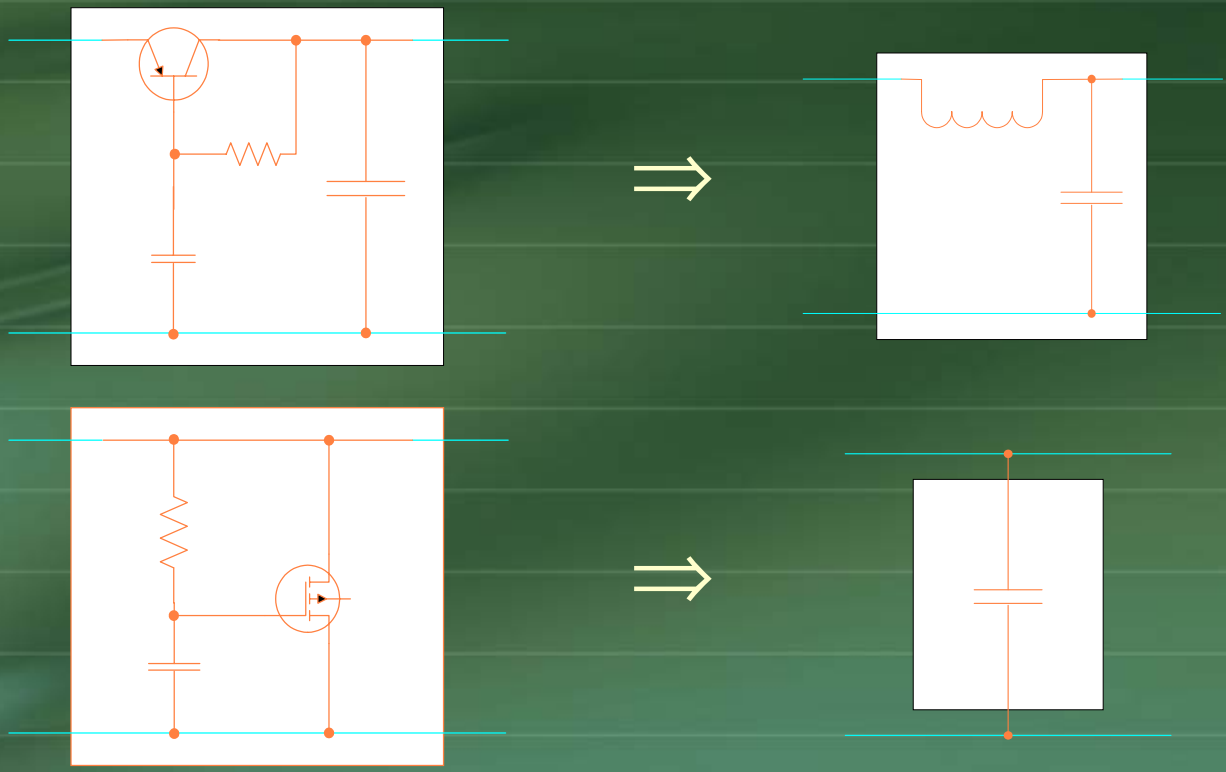




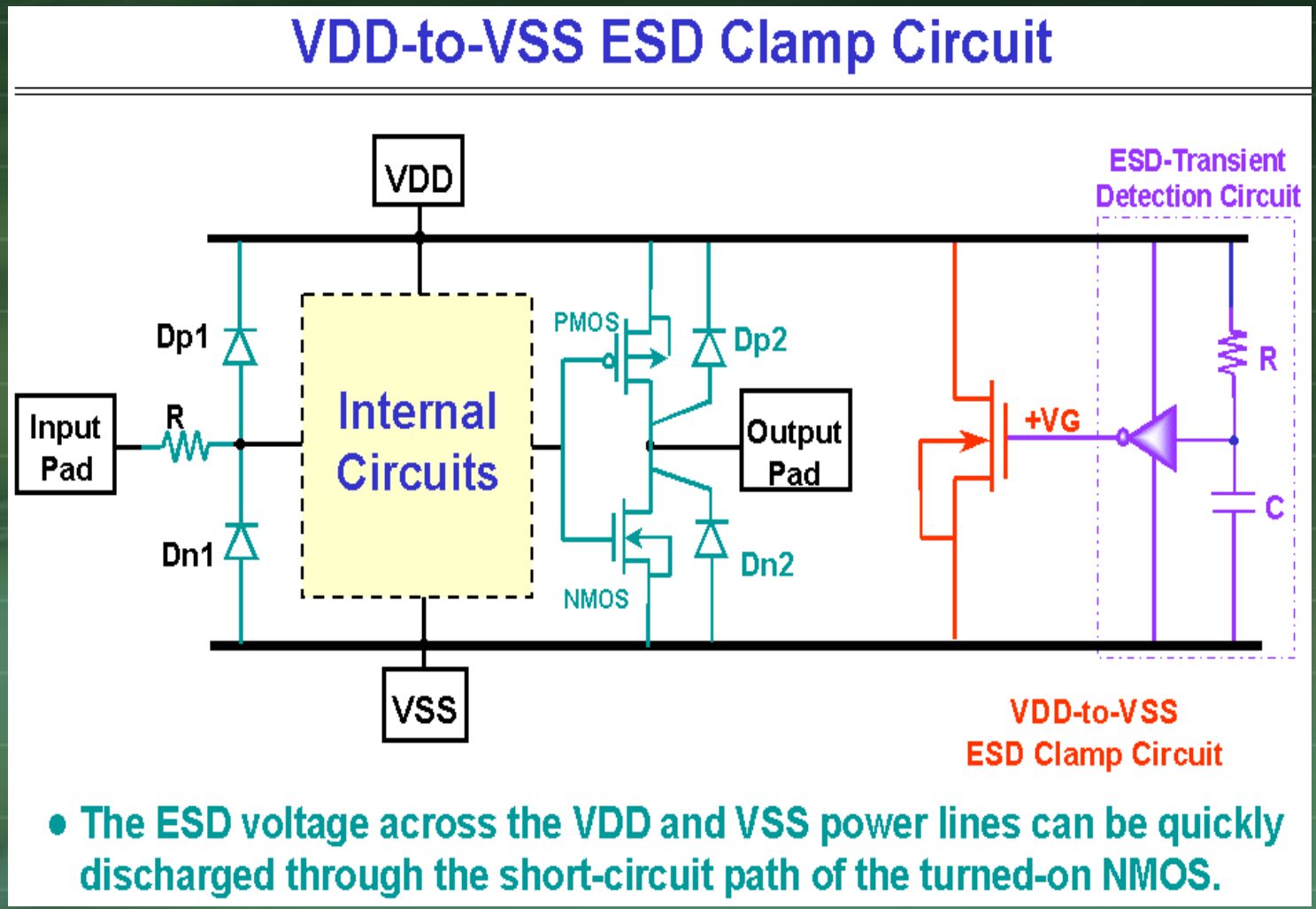
Characteristic of Filters

Low-Pass Filters

- Active Filter
  - It offers reasonable size when very low frequencies have to be filtered out.



參考資料：出自交大柯明道教授的網頁



Characteristic of Filters

Low-Pass Filters

- Guidelines to decide the type of filter [2] 10-2
  - Low impedance in both directions
    - L filter or T-Section filter
  - High impedance in both directions
    - C filter or π-Section filter
  - Mismatched impedance in both directions
    - L-Section (LC) filter

Characteristic of Filters

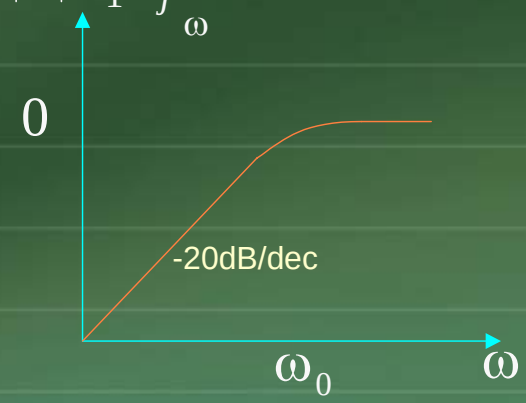
High-Pass Filters

- A standard low-pass filter transforms into a high-pass filter when each inductor is replaced with a capacitor.

$$C_{hp} = \frac{1}{L_{lp}}$$

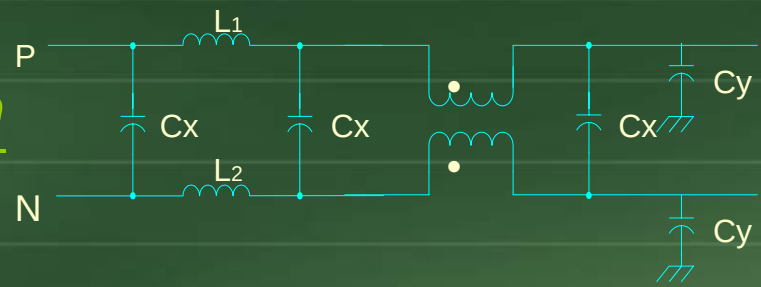
$$L_{hp} = \frac{1}{C_{lp}}$$

$$\left|\frac{T(\omega)}{k}\right| = \frac{1}{k} \cdot \left|\frac{V_o}{V_i}\right| = \left|\frac{1}{1 - j\frac{\omega_0}{\omega}}\right| (dB)$$



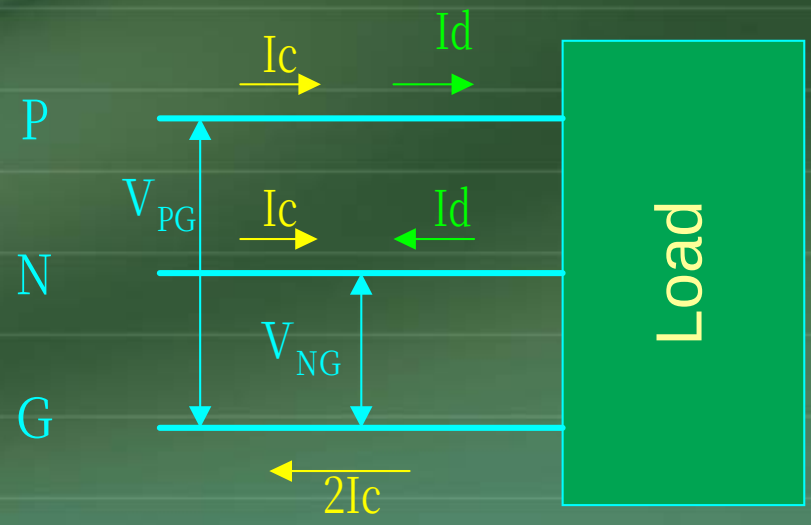
Agenda

- Characteristics of Filters
  - Impedance Mismatch Effects
  - Low-Pass Filters
  - High-Pass Filters
- *Power Line Filter Design*
  - Common-Mode Filter
  - Differential-Mode Filter
  - Combined CM and DM Filter
  - Inductor Design
- Filter Installation



Power Line Filter Design

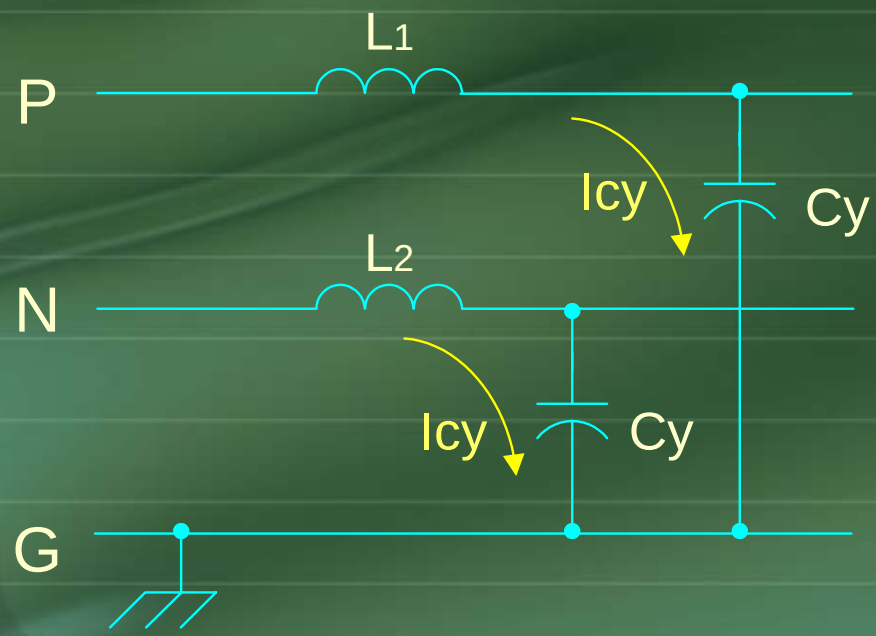
- Basic differences between a power line filter and a communication circuit filter
  - The input impedance of a power line filter is almost never impedance match because of load changing.
  - Power line filters are strongly biased by the power line current.
- Common-Mode(CM) and Differential-Mode(DM)



Power Line Filter Design

Common-Mode Filter

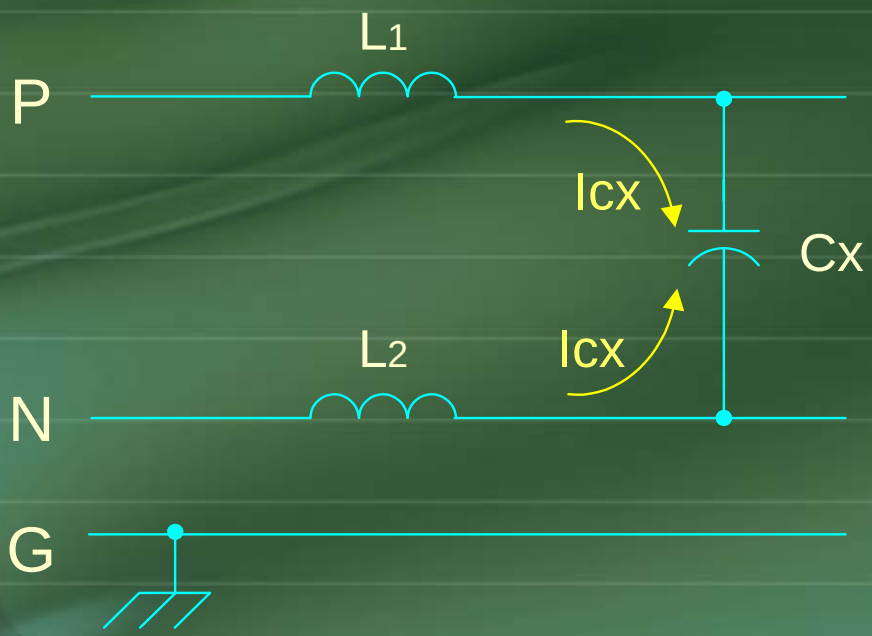
- Phase-to-ground CM filter
  - Limit Cy maximum value, so the high leakage current Ic depends on the line voltage

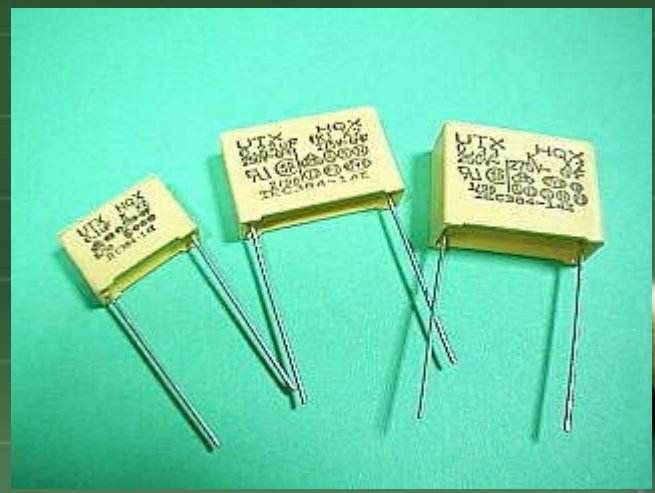


Power Line Filter Design

Common-Mode Filter

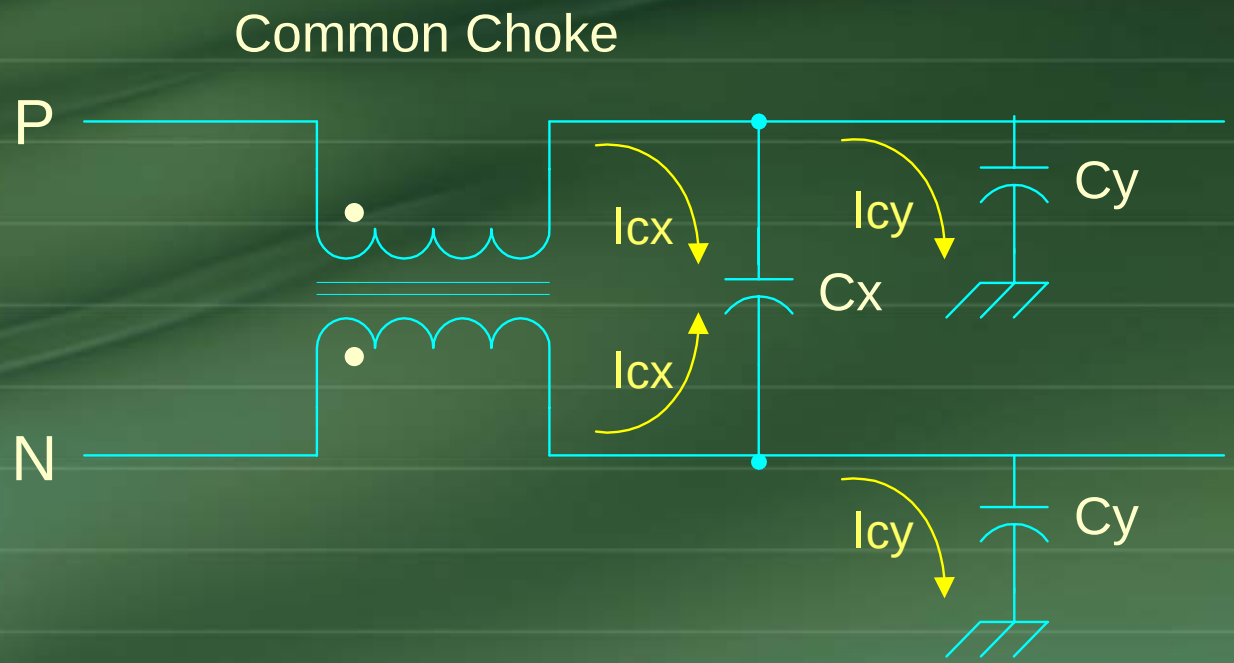
- Phase-to-phase CM filter
  - Cx must be less than 0.5uf to avoid shock hazard Icy.





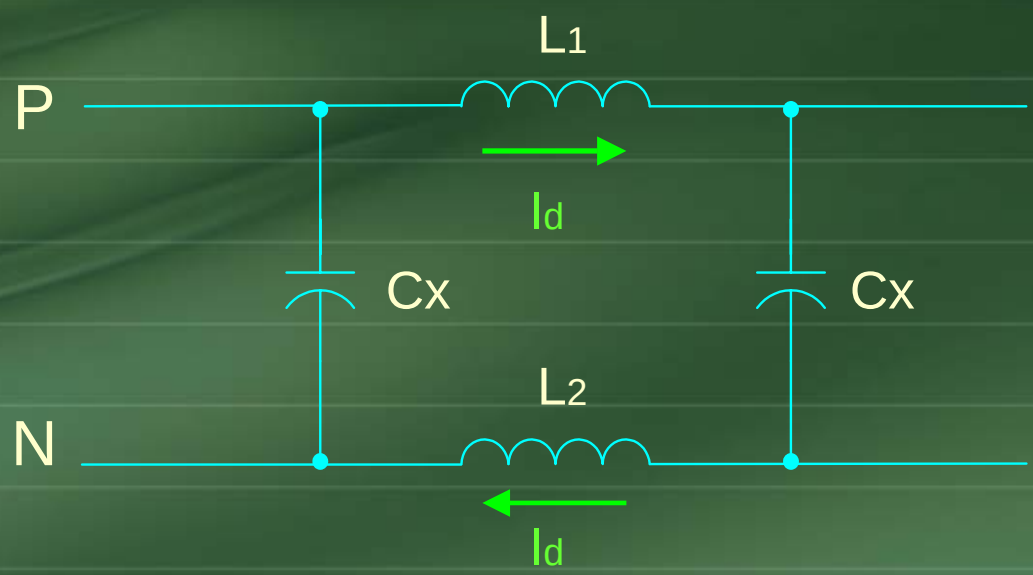
Power Line Filter Design

Common-Mode Filter



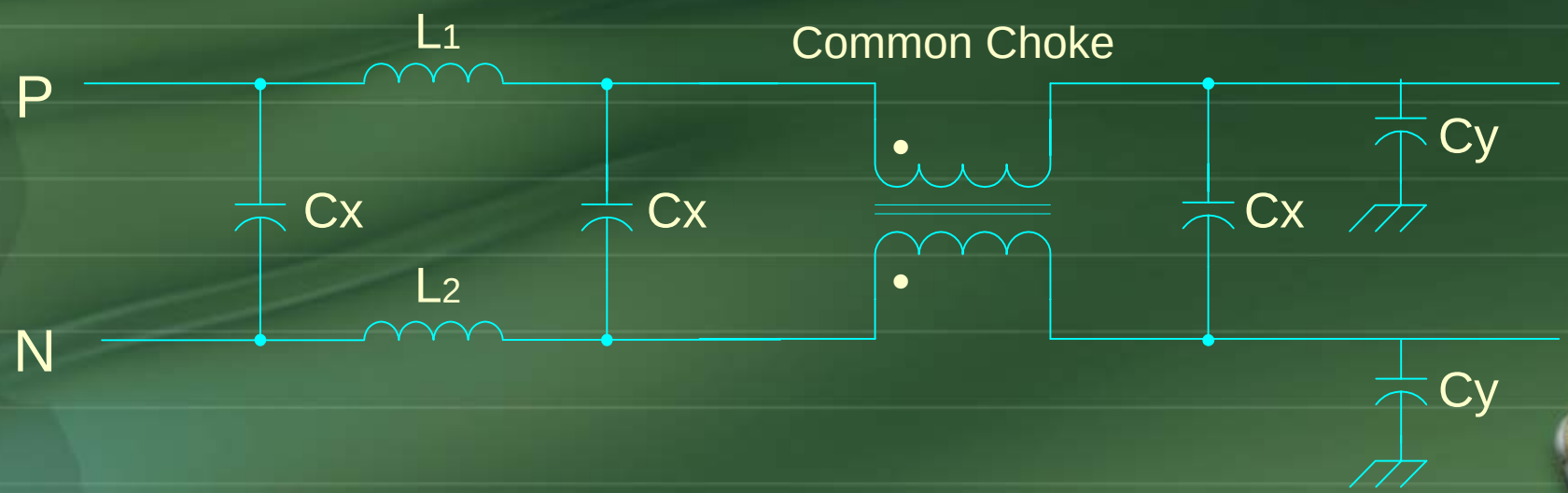
Power Line Filter Design

Differential-Mode Filter



Power Line Filter Design

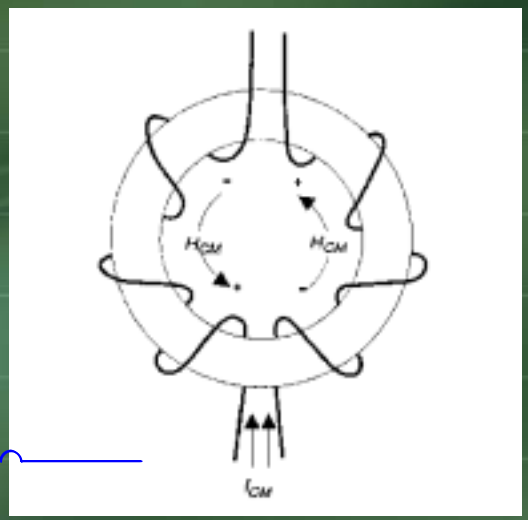
Combined CM and DM Filter

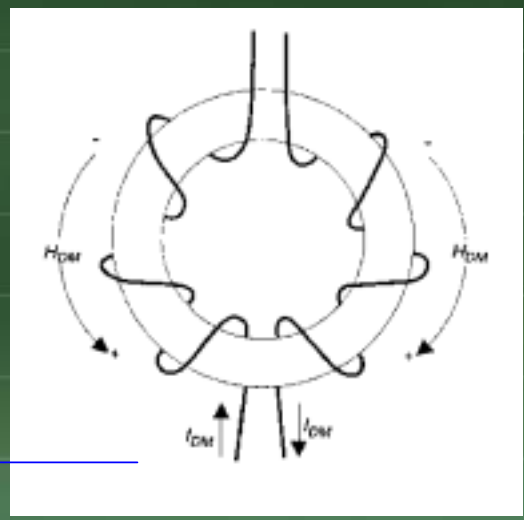


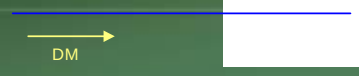
Power Line Filter Design

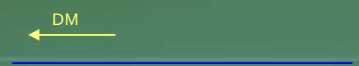
Inductor Design (Common Choke)

- CM choke is the only technique that does not require a ground to function, and by the nature of its operation does not affect the differential-mode current.
- The winding should be done with minimum inter-winding capacitance, or with minimum potential difference between adjacent windings.









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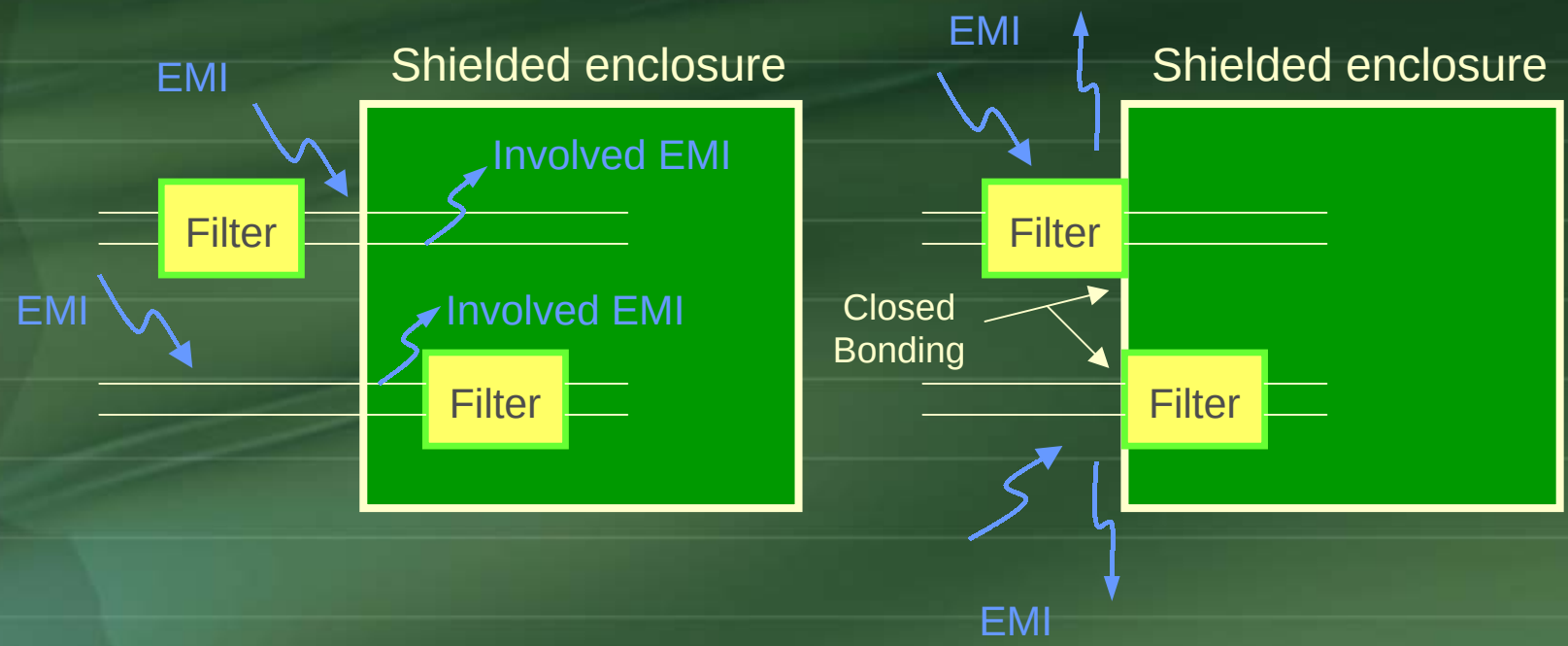
Filter Installation

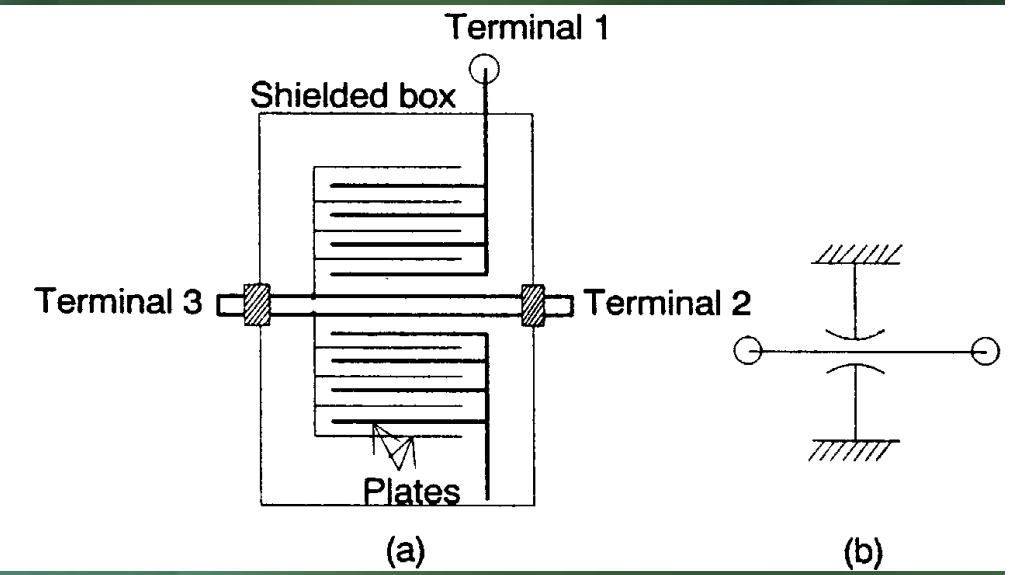


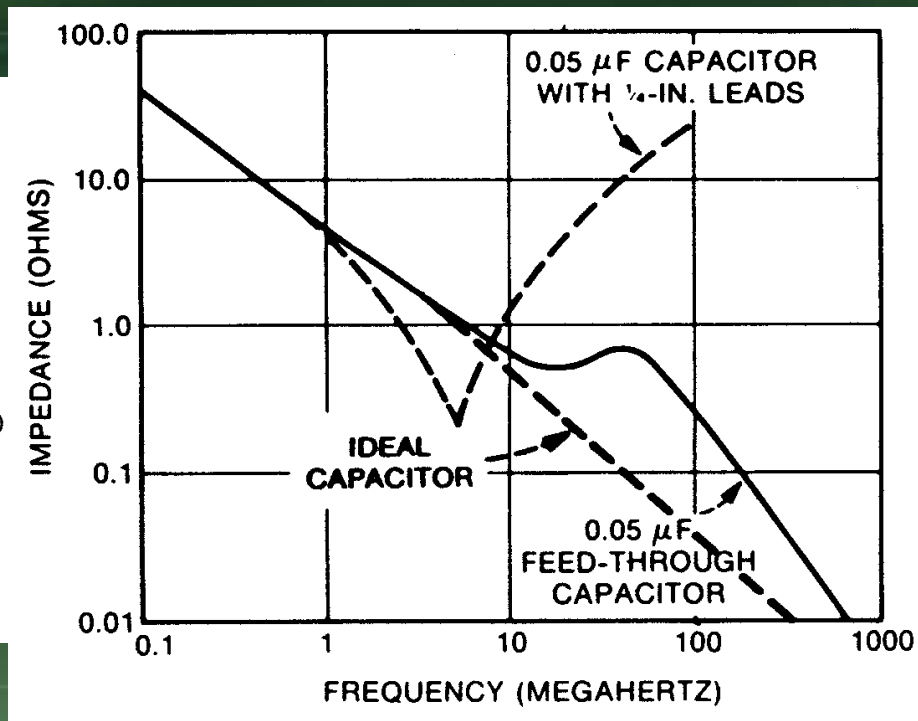
Poor filter installation

Appropriate filter installation

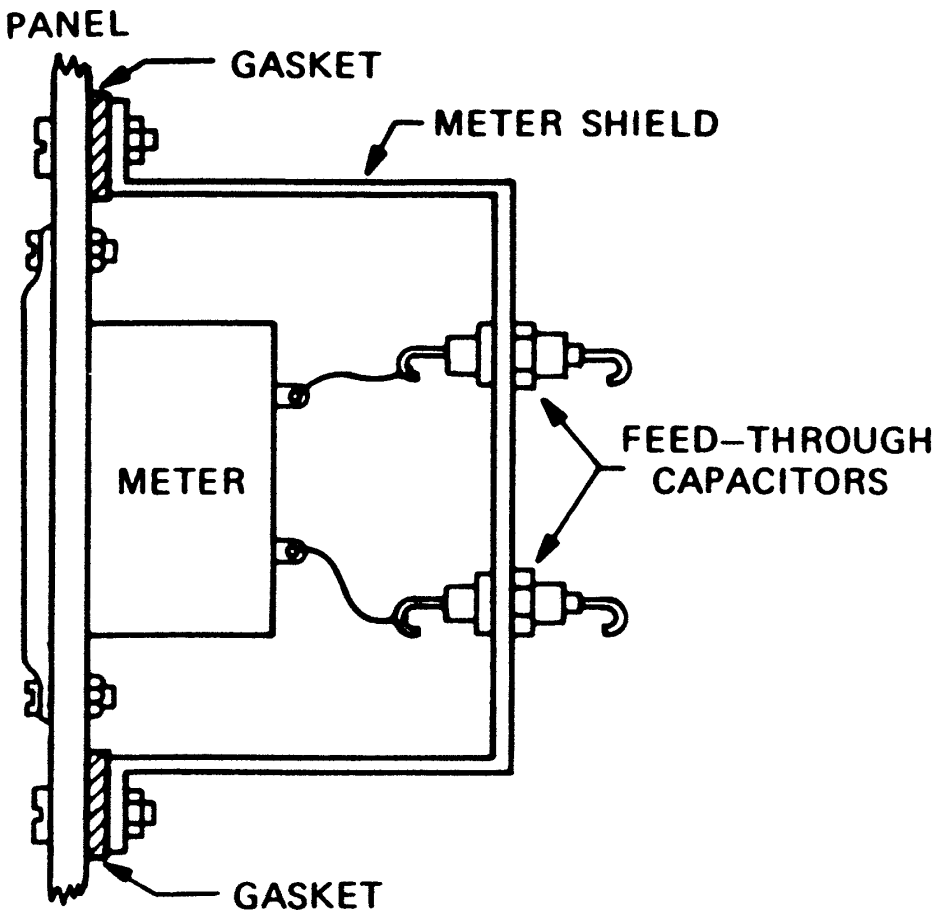
Filter Installation

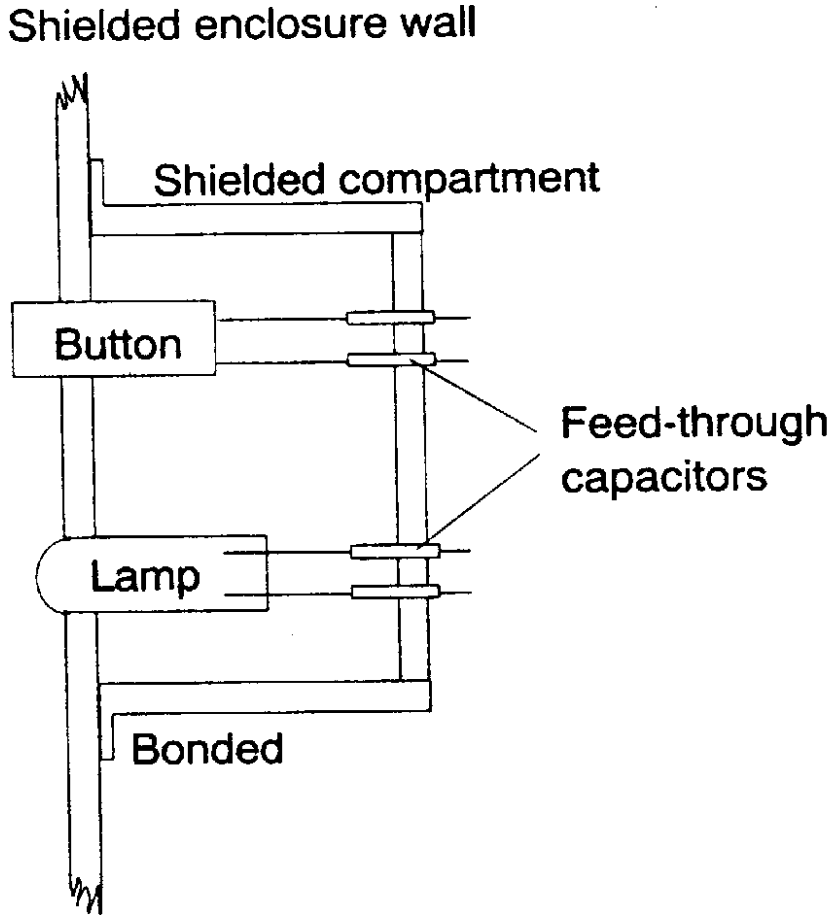
- Feed-through capacitor





Filter Installation





Summary

- What is the effect for impedance mismatch at the filer output ?
- What are LP / HP filters and their characteristics ?
- How to eliminate CM and DM noise ?
- How to design the power line filter ?