Introduction to EMI filter Design

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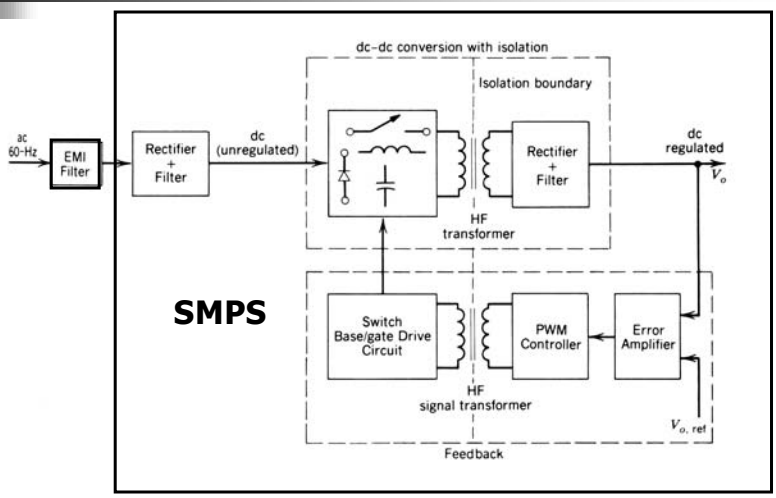
What're EMI filters ?

- EMI filter is specifically named of "filter circuits" that used to reduce the "EMI" generated by power electronics equipments.
- The EMI filter can't be used to filter out mains harmonics.

Why should be EMI filter ?

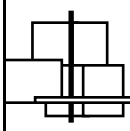
- "EMI Filter" is an important mitigation equipment for <u>suppressing undesired conducted electromagnetic interference (EMI)</u>

Where're EMI filters ?



Eyes of EMI filter designers

- **EMI filter designers** thinks in terms of attenuation, insertion loss, voltage drop and the number of filter sections required to meet the insertion loss
- **True filter houses** speak of poles, zeros, group delay, predistortion, attenuation and the order of the filter



Basic concepts

Basic concepts

- Insertion Loss
- Lump Element Low Pass Filters

Insertion Loss

What's Insertion Loss ?

- The Insertion Loss (IL_{dB}) gives the reduction in the load voltage *at the frequency of interest* due to the insertion of the filter

What's Insertion Loss ? (con't)

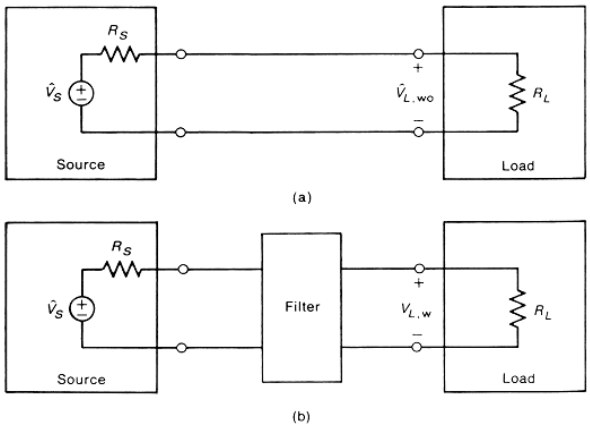
$$IL_{dB} = 20\log_{10}\left[\frac{V_{L,wo}}{V_{L,w}}\right]$$

$V_{L,wo}$ = *The output voltage of the signal source without the filter being connected in the circuit*

$V_{L,w}$ = *The output voltage of the signal source at the output terminals of the filter with the filter in the circuit*

(not transfer function)

Insertion loss (con't)



(a)

(b)

Lump element Low Pass filters

Lump Element Low-Pass Filters

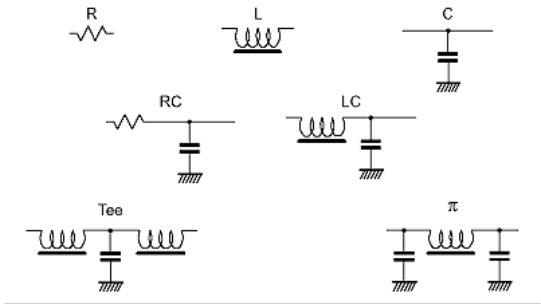
- Filtering concept
- The simple capacitive filter
- The simple Inductive filter
- Cascade LC, T, ¶ and Why should be cascaded ?
- EMI filter

Filtering concepts

- Filters are designed to attenuate at certain frequencies while permitting energy at other frequencies to pass unchanged
- The role of a filter in attenuating by providing maximum mismatch impedance at undesired frequencies while providing maximum matching impedance at desired frequencies to pass unchanged

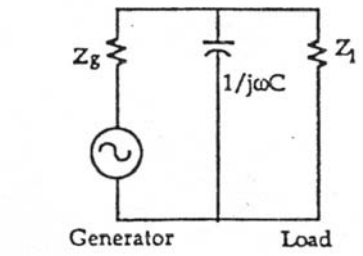
Various signal filters

Figure 3A
Different types of single-line filter



Simple capacitive filter

The simple capacitive filter



$$IL_{dB} = 20 \log_{10} \left| 1 + \frac{Z_p}{Z_C} \right|$$

Z_p = The Impedance of the parallel combination of Z_g and Z_l,

$(Z_g * Z_l)/(Z_g + Z_l)$

Z_c = The impedance of the filtering capacitor, $1/j\omega C$

The simple capacitive filter (con't)

- Capacitive is effective as a filter when

$$Z_c << Z_p$$

Therefore, Source and Load impedance connected with capacitor should be **high impedance**

- **Insertion level = 20dB/decade**
  = 6 dB/octave

The simple capacitive filter (con't)

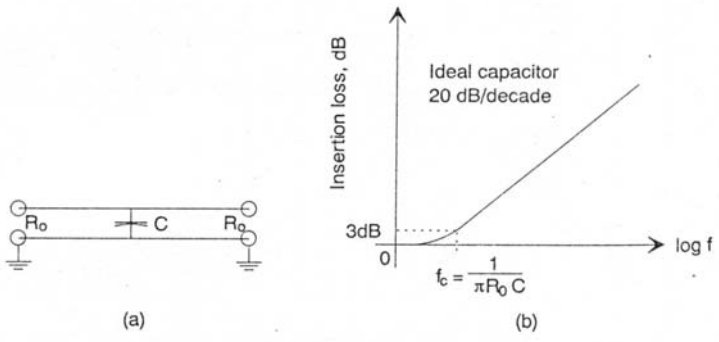


Figure 10-3 Capacitor filter and its response characteristics

The simple capacitive filter (con't)

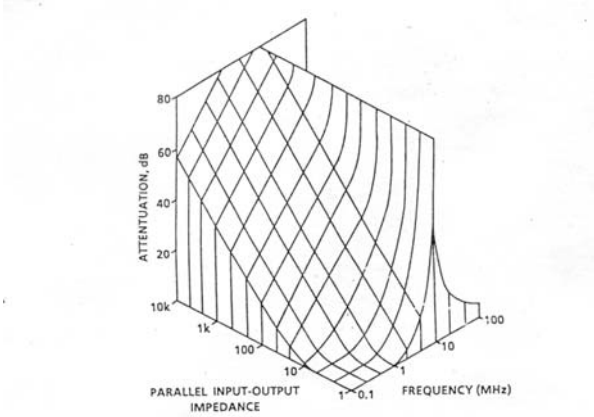
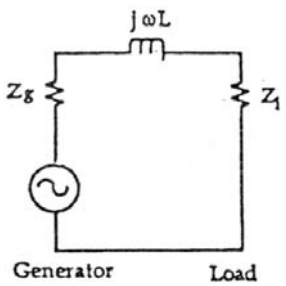


Figure 2-4. Capacitor attenuation versus frequency and Zp. (Copyright © 1991, EMC Services. All rights reserved. Printed with permission.)

Simple inductive filter

The simple inductive filter



$$IL_{dB} = 20 \log_{10} \left| 1 + \frac{Z_{ind}}{Z_{sum}} \right|$$

Z_{sum} =The Impedance of the series combination of Z_g and Z_l , (Z_g+Z_l)

Z_{ind} = The impedance of the filtering inductor, $j\omega L$

The simple Inductive filter (con't)

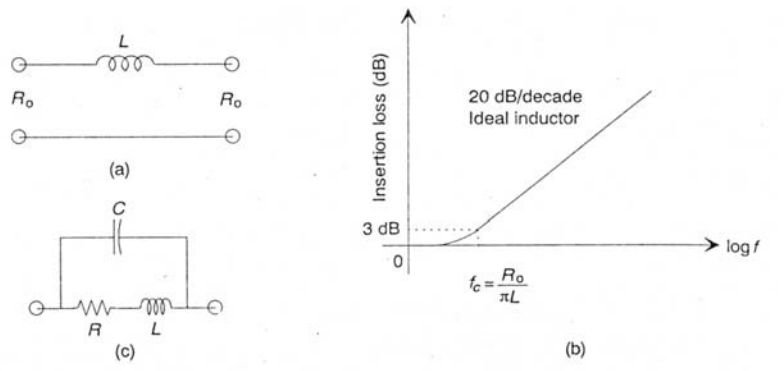
- Inductive is effective as a filter when

$$Z_{ind} >> Z_{sum}$$

Therefore, Source and Load impedance connected with inductor should be **low impedance**

- **Insertion level = 20dB/decade**
  = 6 dB/octave

The simple Inductive filter (con't)



C = parasitic capacitance
R = parasitic resistance

Figure 10-5 Inductor filter

The simple Inductive filter (con't)

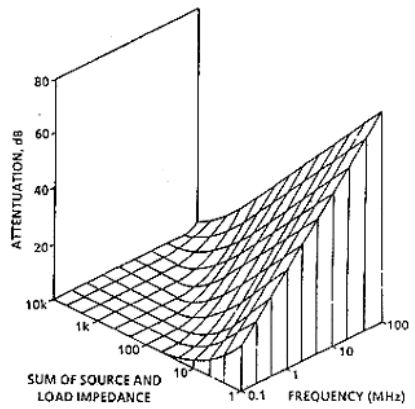


Figure 2-7. Inductor attenuation versus frequency and Z_{Sum}. (Copyright © 1991, EMC Services. All rights reserved. Printed with permission.)

Cascade filter

Cascade LC, T, ¶ and Why should be cascaded ?

- ***How should you do ?*** if Zin and Zout is dissimilar ,for example : Zin = high , Zout = low or vice versa, or when you want to increase the Insertion Loss !!

  Ans Cascade LC, T and π filters are mostly useful when the source and load impedances are very dissimilar or when you want to increase the insertion loss!!!

LC filter

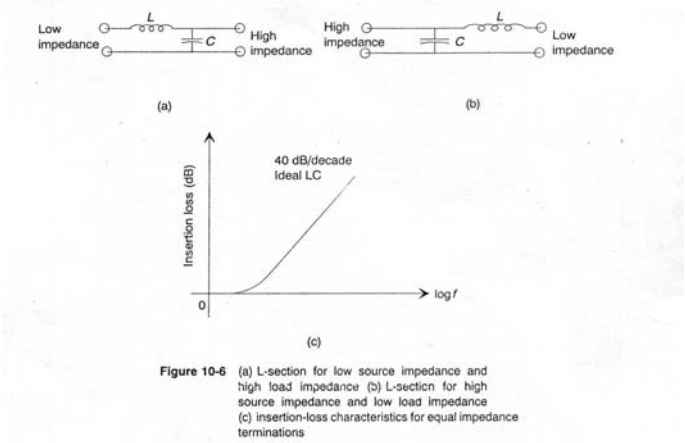


Figure 10-6 (a) L-section for low source impedance and high load impedance (b) L-section for high source impedance and low load impedance (c) insertion-loss characteristics for equal impedance terminations

¶ - filter

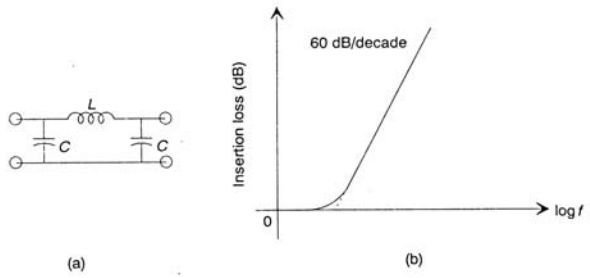


Figure 10-7 π-section filter

10-2-2-4 π-Section Filter. This configuration, which is shown in Figure 10-7(a), is the most common type used in practice. Its advantages include an ease of manufacture, higher insertion loss over a broad frequency band, and moderate space requirements.

When $Z_g = Z_L = R_0$, the insertion loss [4] is given by

T – filter

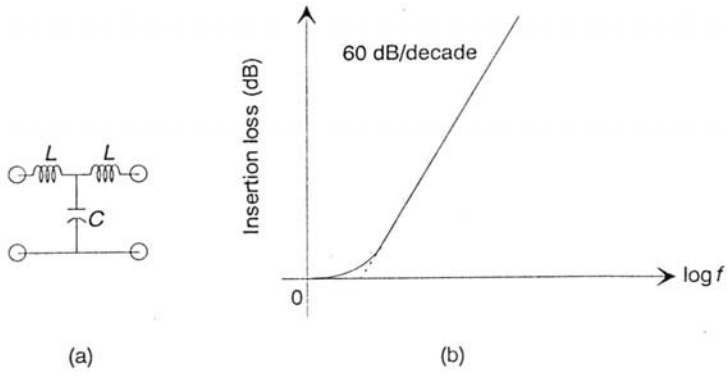


Figure 10-8 T-section low-pass filter

Conclusion for effective filtering

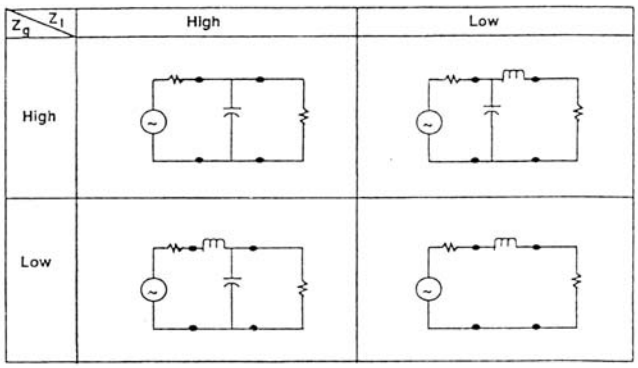


Figure 2-9. Filter selection matrix. (Copyright © 1991, EMC Services. All rights reserved. Printed with permission.)

Conclusion for effective filtering (con't)

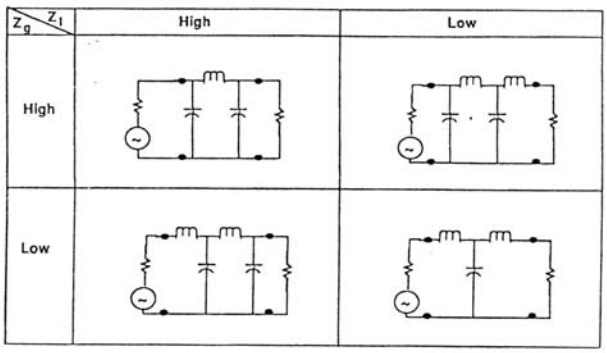


Figure 2-10. Higher order roll-off filter selection matrix. (Copyright © 1991, EMC Services. All rights reserved. Printed with permission.)

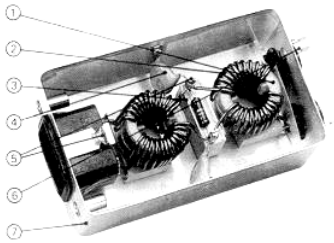
EMI FILTER

EMI filter

Construction and Design

- Toroid cover for perfect insulation, with built-in spacers to maintain creepage distance between windings. ①
- Precision balance of inductance between windings to prevent core saturation at full load. ②
- Only capacitors that comply with VDE 0565-1 are used. ③
- Low leakage current. ④
- Both crimped and soldered connections. ⑤
- Anti-rotation terminals to prevent open connections. ⑥
- Corrosion-proof case. ⑦

FIG.1



Main Idea !!!

- **Diagnosing conducted EMI noise mode**

  Two conducted noise modes :

  Differential Mode (DM) and Common Mode (CM),

  Dealt with separately in EMI filter design

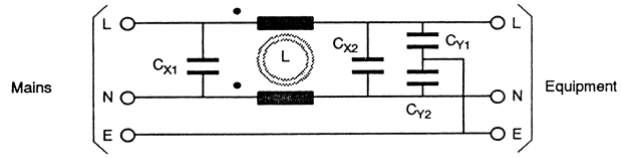
- **Methods:**

  ⌦ Differential mode rejection network

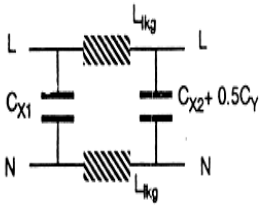
  ⌦ Current probe

  ⌦Noise separator

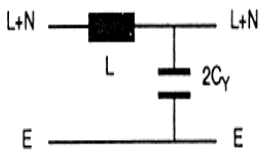
A basic of EMI filter diagram



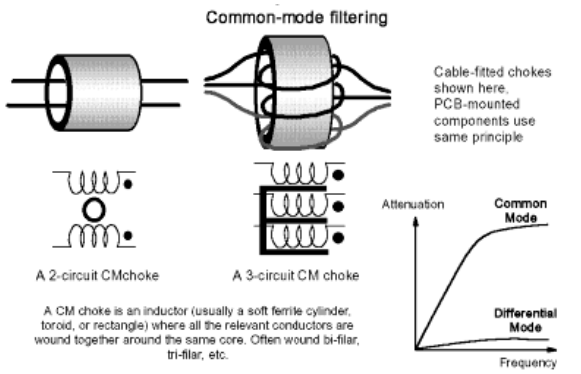
Equivalent circuit for differential mode



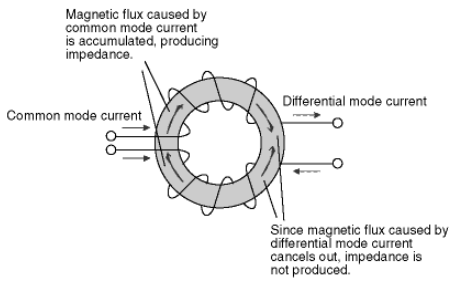
Equivalent circuit for common mode



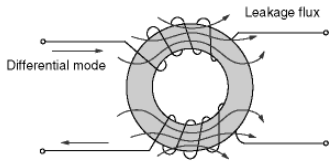
Common mode choke



Effect of the filter elements on Common and Differential mode currents



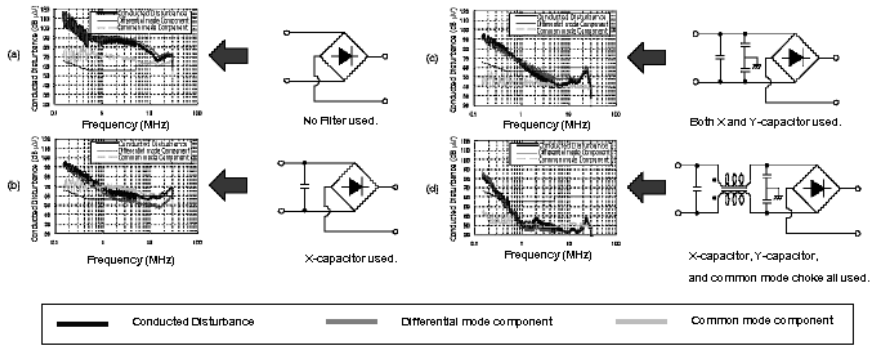
Idea Common mode choke



Since leakage flux is produced, magnetic flux caused by differential mode current does not entirely cancel out. Therefore, differential mode inductance is produced.

Actual Common mode choke

Separation of the conducted Emissions into Common and Differential mode currents



Higher performance mains EMI filters

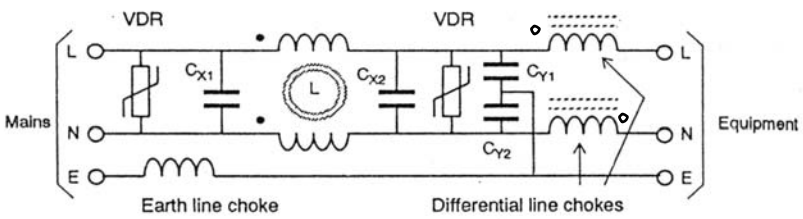
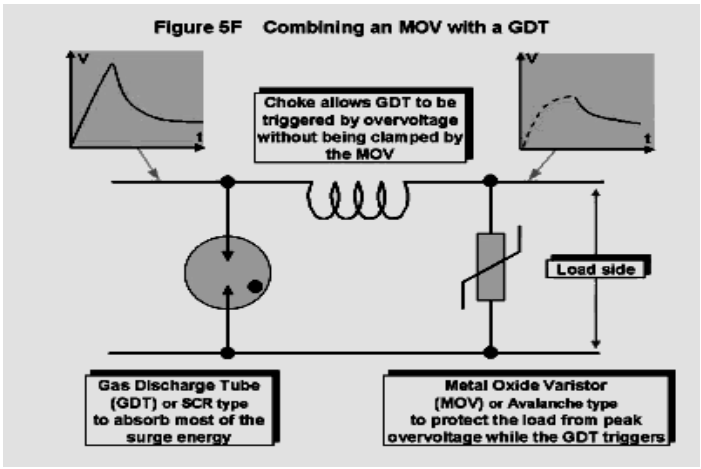
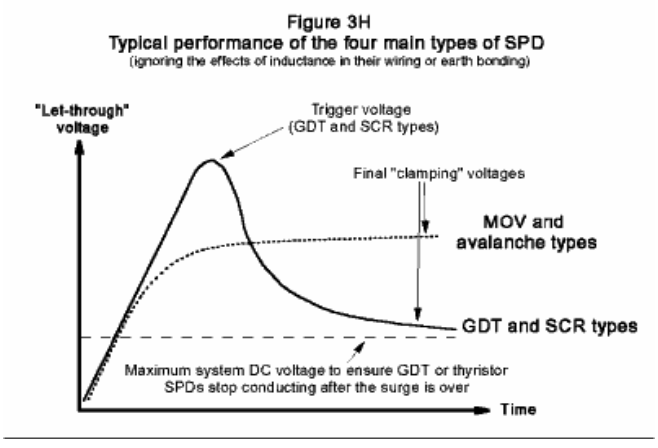


Figure 7.24 Higher performance mains filter

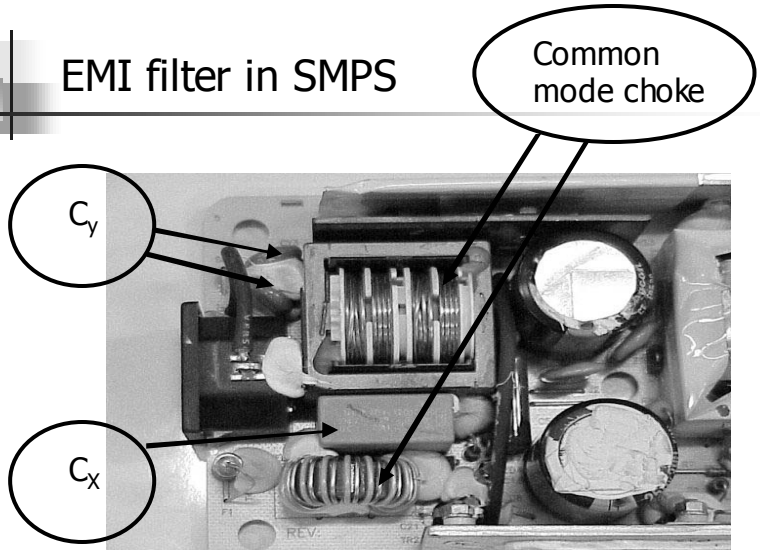
Metal Oxide Varistors (MOVs)



Metal Oxide Varistors (MOVs)



EMI filter in SMPS



Packaging of EMI filters

References

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- EMI Filter Design, Richard Lee Ozenbaugh
- Engineering Electromagnetic Compatibility, V.Prasad Kodali
- Controlling conducted emissions by design, John C. Fluke. Sr.
- Power line filter design for switched-mode power supplies, Mark J. Nave
- Handbook of electromagnetic compatibility, edit by Reinaldo Perez