Conducted EMI filter design for SMPS

Jukka-Pekka Sjöroos
Helsinki University of Technology
Power Electronics Laboratory

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Introduction

- **The threat of generating EMI from the fast switching pulses in SMPS has always been a serious concern**
- **Thus achieving the electromagnetic compatibility (EMC) has become a requirement as important as meeting the power conversion specifications**
- **EMI includes three elements**
- **Source of the electromagnetic emission**
- **Coupling path**
- **A receiver of the EMI (victim)**
- **Conducted emissions 150kHz-30MHz**
- **Common mode(CM) measured between each power line and ground**
- **Differential mode measured between power lines**
- **Radieted emissions 30MHz-1GHz**

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EMI in SMPS

- **Because of the fast switching in SMPS they generate large amount of electromagnetic interferences and that's usually the reason for SMPS not to comply the EMC standards**
- **EMI filter is usually needed in the input of the SMPS to achieve the required standards**
- **Conducted emissions 150kHz-30MHz**
  - **CM common mode emissions :**

  paracitic capacitances and the switching voltage waveform across the switch

  $$\rightarrow i_{CM} = C_{par} \frac{du}{dt}$$

  - **DM differential emissions:**

  The swiching action causes current pulses at the input

  $$\rightarrow \quad u_{switching \ \mathrm{spike}} = L \frac{di}{dt}$$

  Thus switching spikes exist as a differential mode noise source
- **Radiated emissions 30MHz-1GHZ**
  - **Magnetic and Elecric fields**

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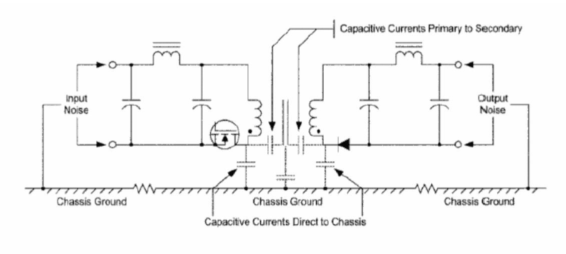
EMI in SMPS

- **Operation conditions also affects to the filter design**
- **The worst case should be always considered**
  - **Highest input voltage leads to peak du/dt value**
    → CM noise will be maximum
  - **Lowest input voltage and maximum load current would lead to peak di/dt value**
    →DM noise will be maximum

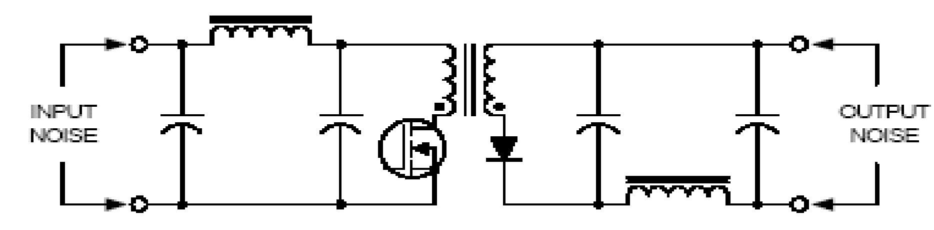
EMI in SMPS
Sources of CM noise



EMI in SMPS

Sources of DM noise

- The switching action of the power mosfet causes current pulses at the input and voltage ripple at the output



EMI in SMPS

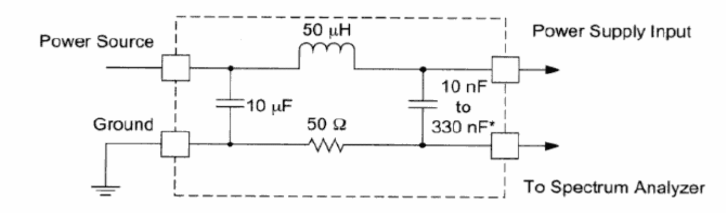
Minimizing EMI in SMPS design

- **Because of economical reasons EMC has to be considered in the early stage of the SMPS design**
- Combating CM EMI
- **The parasitic capacitances of heatsink and transformer are two major components to cause CM EMI in SMPS**
- **CM EMI can be minimized by minimizing stray capacitances between the circuit and ground**
- **Component selection**

- Combating DM EMI
- **Semiconductor devices like power mosfet are usually DM EMI sources**
- **Proper layout design can reduce DM EMI for example wires that carries a switching waveform should be as close as possible to each other**
- **Emi sensitive circuits like control circuits should not locate near circuit elements that carries the switching waveform. The goal is to prevent electromagnetic coupling between these circuits**
- **The use of RC-snubbers is to reduce ringing and protect the switch**
- **Component selection**

Measuring conducted EMI

- LISN Line Impedance Stabilization Network
- Filters the high-frequency noise signals from the input current
- Creates a standard load impedance (50Ω) at the measurement point



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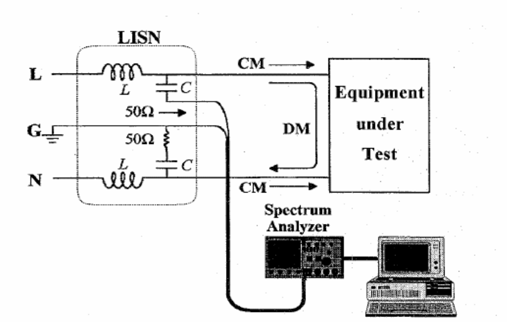
Measuring conducted EMI

Test setup for conducted EMI measurement

- **The noise voltage is measured across 50Ω resistor in the Spectrum analyzer**
- **The powerline LISN measures CM + DM**
- **The neutral return measures CM - DM**
- **CM noise sees two 50Ω resistor in parallel one in LISN and another in Spectrum analyzer 25 Ω total while DM noise sees two 50Ω resistor in series total 100 Ω**



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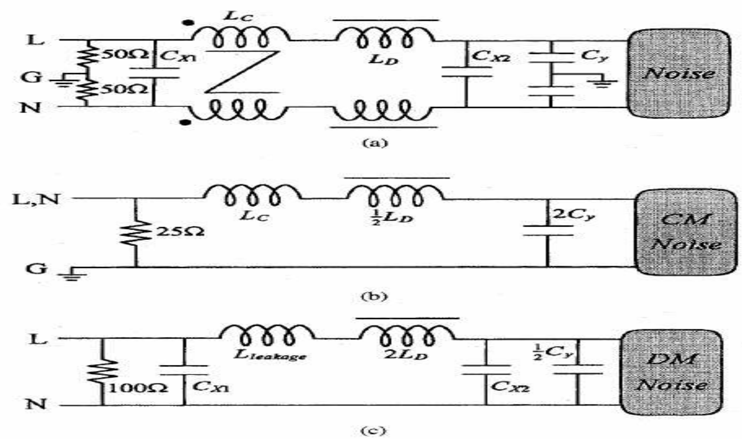
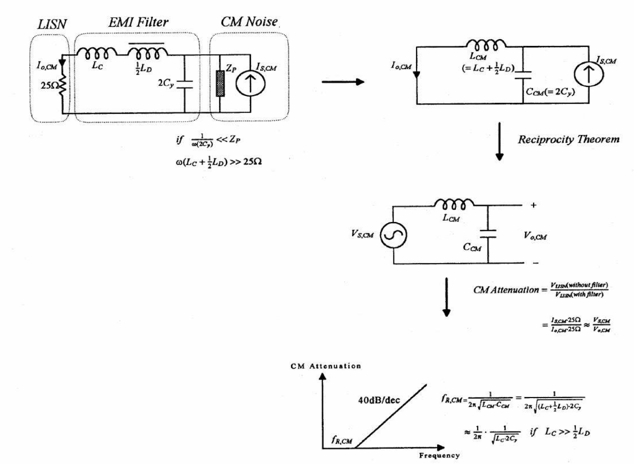
EMI filter design
Emi filter components

- Both DM and CM noises should be attenuated
- Suppressing DM noise: DM inductors and X-capacitors
- Suppressing CM noise CM inductors and Y-capacitors
- Y-capacitors and $L_{\mathbf{leakage}}$ of the CM inductor attenuates also DM noise
- DM inductors attenuates also CM noise

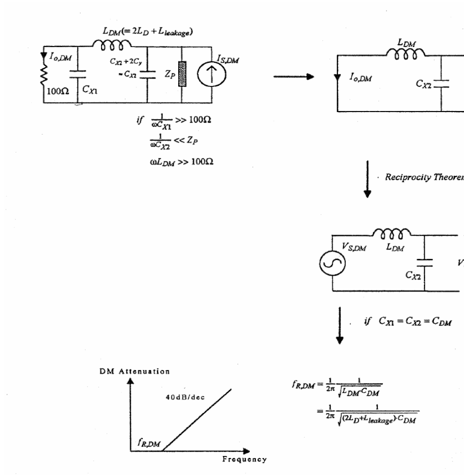
EMI filter design
Emi filter topology
CM and DM equivalent circuits



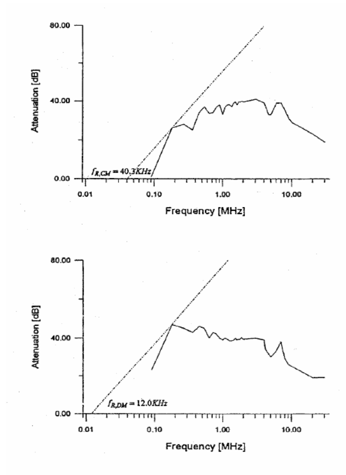
Calculating CM filter component values



Calculating DM filter component values



Determining filter corner frequencies

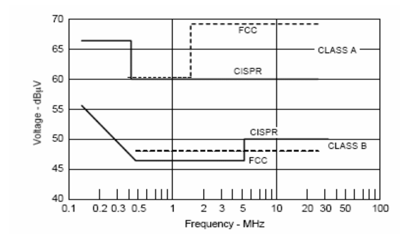


Emi filter design
Design steps

- **The goal is to meet the low frequency requirements**
- **Class A industrial and commercial applications**
- **Class B residential equipments**

- **Filter design**
- **step 1 Measure CM noise and DM noise without the filter**
- **step 2 Calculate required CM attenuation and DM attenuation**

$$(U_{req,CM})_{dB} = (U_{CM})_{dB} - (U_{\lim it})_{dB}$$
$$(U_{req,DM})_{dB} = (U_{DM})_{dB} - (U_{\lim it})_{dB}$$



Emi filter design
Design steps

- **step 3: Determine filter corner frequencys by drawing a 40db/dec slope which is tangent to the required attenuation for DM and CM**
- **Step 4: Calculate component values**

CM components:

C_y is limited to 3300pF because of safety reasons and the corner frequency $f_{R,CM}$ has been found in step 3 so we get the common mode inductor

$$L_C = \left(\frac{1}{2\pi * f_{R,CM}}\right)^2 * \frac{1}{2C_y}$$

DM components:

There is freedom of choosing differential mode inductor L_{dm}. To reduce cost and size of the filter often manufactures use only common mode inductor's leakage inductance $L_{leakage}$ as DM inductor. The corner frequency $f_{R,DM}$ has been found in step 3. Thus the DM capacitors are

$$C_{X1} = C_{X2} = C_{DM} = \left(\frac{1}{2\pi * f_{R,CM}}\right)^2 * \frac{1}{L_{leakage}}$$

Conclusions

A simple method for designing input filter for SMPS has been presented. This design method is quick and it meets the conducted emission requirements. The component selection is made according the required Insertion loss. After little modification to the layout and wire contstruction would made the filter also meet the radiated emission requirements.

Some References

- Laszlo Tihanyi, Electromagnetic Compatibility in Power electronics, IEEE Press, 1995
- Fu-Yuan Shih, Dan Y. Chen, A Procedure for Designing EMI filters for AC Line Applications, IEEE 1996
- Chia-Nan Chang, Hui-Kang Teng, Jun-Yuan Chen and Huang-Jen CHIU, Computerized conducted EMI Filter Design System Using Labview and its Application