HIGH VOLTAGE SEMINAR

BING LU
ISOLATED GATE DRIVERS

INTRODUCTION TO EMI IN POWER SUPPLY DESIGNS

Outline

- Introduction to EMI and EMC
- EMI standard and measurement method
- Differential and common mode EMI noise source, path, and spectrume
- EMI filter and design considerations
- Other EMI mitigation method

EMI and EMC

- Electromagnetic Interference
- The equipment should not interfere with other systems
  - For example: turning on AC/DC power supply should not interfere with radio operation

- Electromagnetic Compatibility
- The equipment should operate normally even with interference from the noise
  - For example: the AC/DC power supply should operate normally in noisy environment with heavy machinery

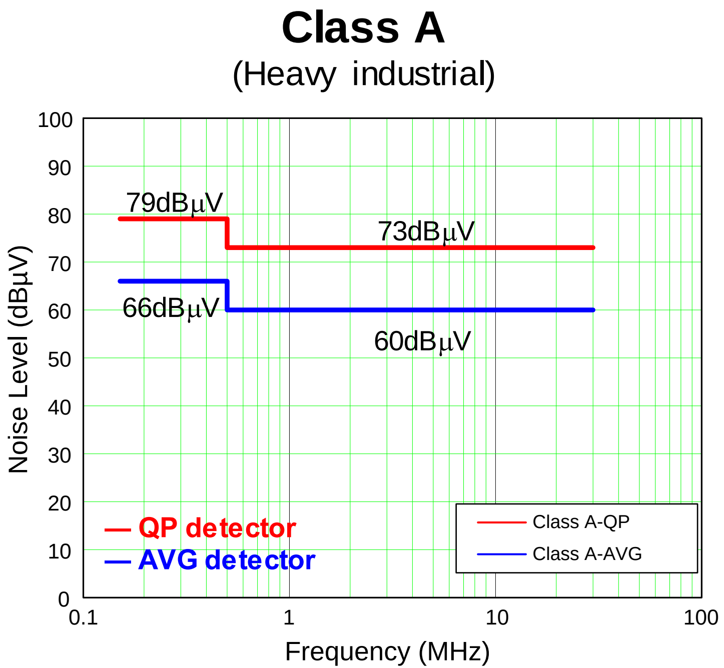
EMI challenges in power supply design

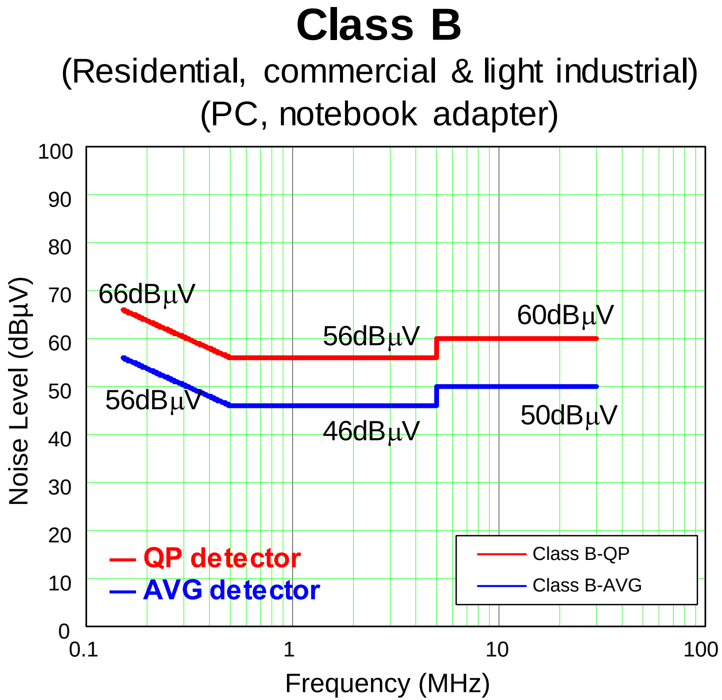
- EMI is a challenge for nearly all electronic systems
- EMI source → coupling path → receptor
  - Conducted path through cabling
  - Radiated EMI path through air
- ***Conducted EMI***: **EN55022** covers frequencies from **150kHz to 30MHz**
- ***Radiated EMI***: **EN55022** covers frequencies from **30 MHz to 1 GHz**
- Leverage IC and system-level features:
  - Careful PCB layout
  - Spread spectrum / slew-rate control
  - EMI filtering

PMP21251
Less than 90 mW Ultra-low standby power auxless AC-DC power supply

EN55022 limit lines: conducted emissions

Class A and Class B limits, quasi-peak & average, 15 0kHz–30 MHz

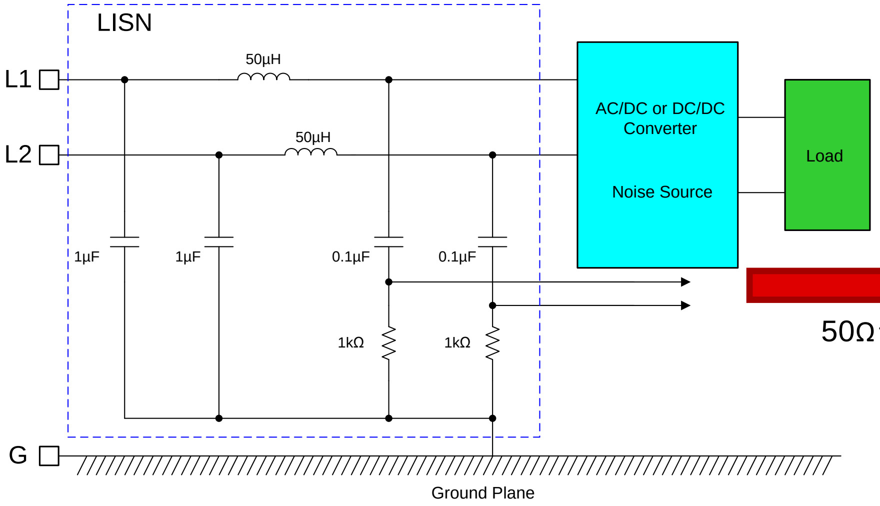




EN55022, "Information technology equipment– Radio disturbance characteristics– Limits and methods of measurement"

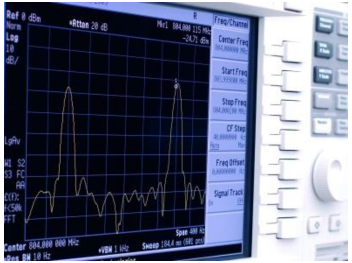
Line impedance stabilization network (LISN)

1. Stable line source impedance
2. Isolation of power source noise
3. Safe connection of measuring equipment
4. "**Total**" noise levels measured separately in **L1** and **L2**
5. Terminated into 50Ω, internal to EMI receiver



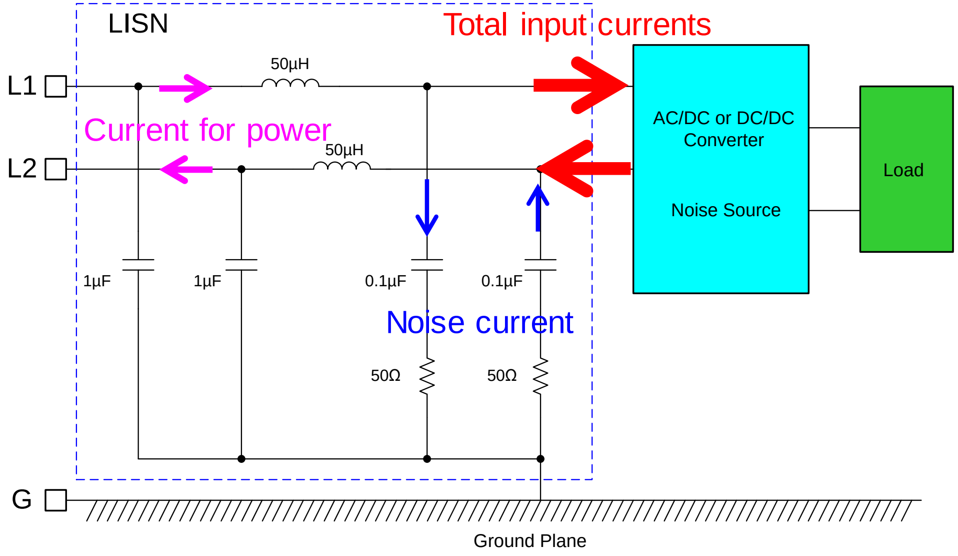
50Ω terminator provided by EMI receiver

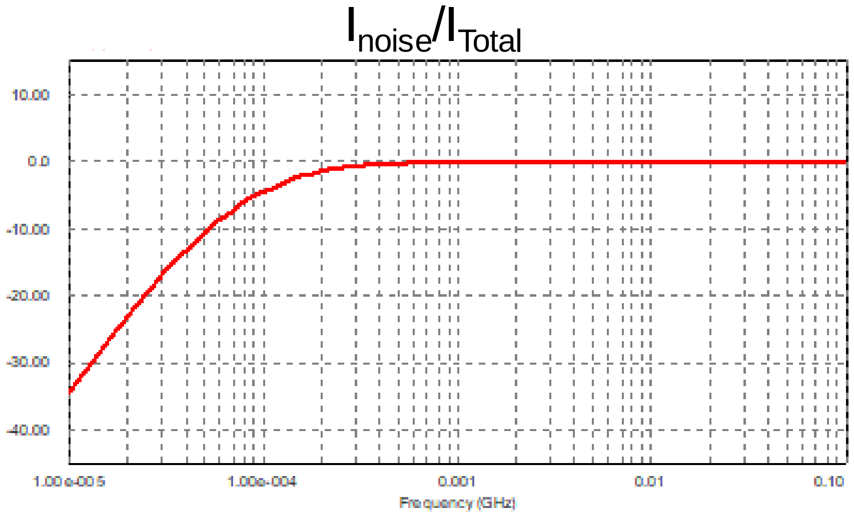
EMI receiver



** Functional equivalent circuit of a LISN, not a complete schematic **

LISN properties



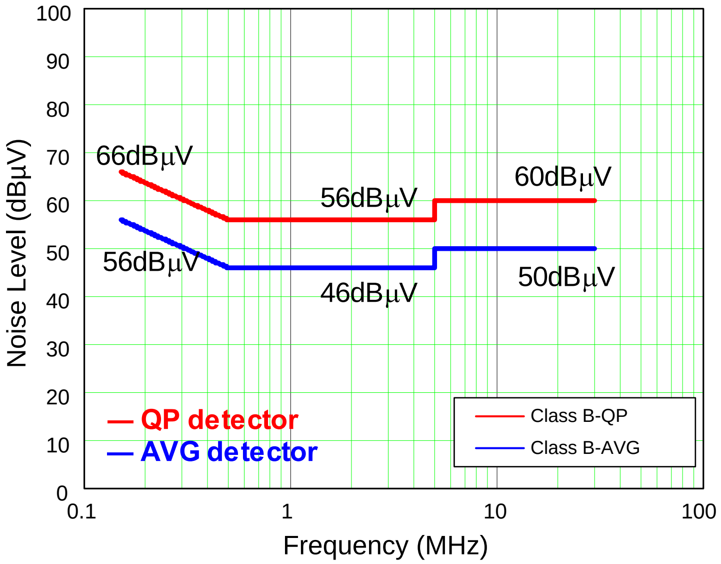


- LISN is a high-pass filter
- High frequency current (noise) is trapped by the LISN capacitor and the amplitude is measured based on the voltage across 50Ω load

EMI noise and current amplitude

QUESTION:

The **EN55022 Class B** QP conducted emission limit is **60dBμV** at 10MHz
What is the current level at the conducted emission limit in: (a) μA, (b) dBμA



ANSWER:

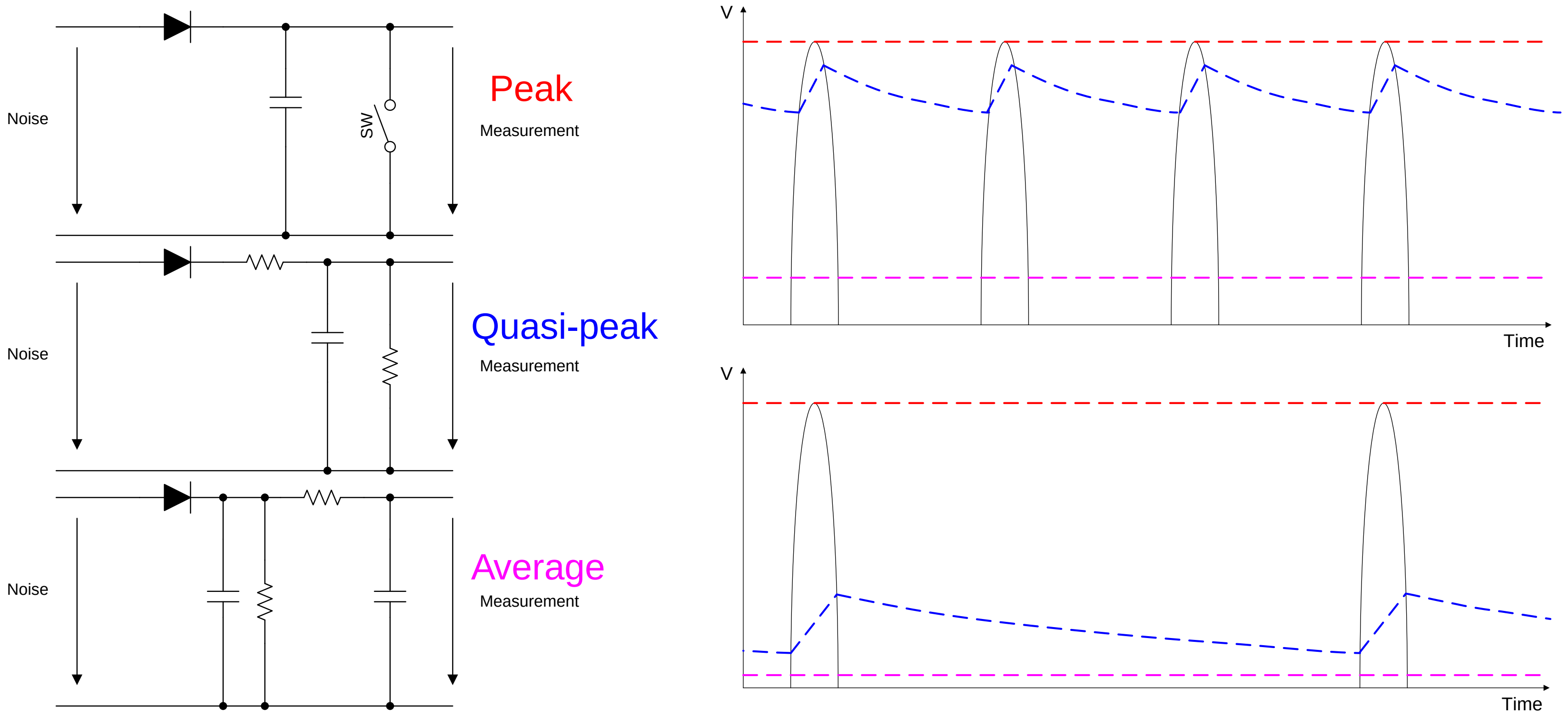
$$V_{noise} = 60dB\mu V = 10^{\frac{60}{20}} \times \mu V = 1mV$$

$$I_{noise} = \frac{1mV}{50\Omega} = 20\mu A$$

$$I_{noise} = 20\mu A = 20\log(20)\, dB\mu A = 26.02dB\mu A$$

EMI noise current has very low amplitude

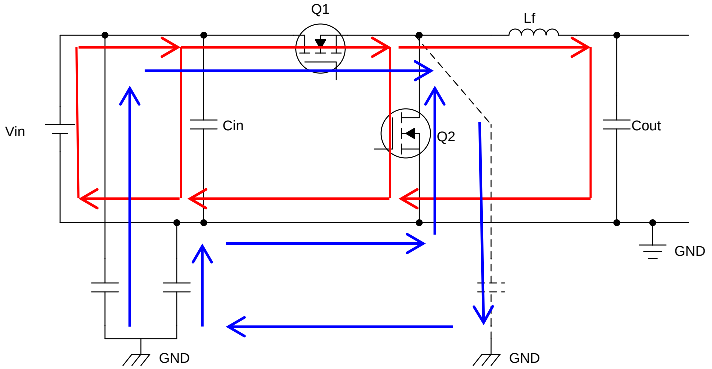
EMI detector, peak, quasi-peak, average



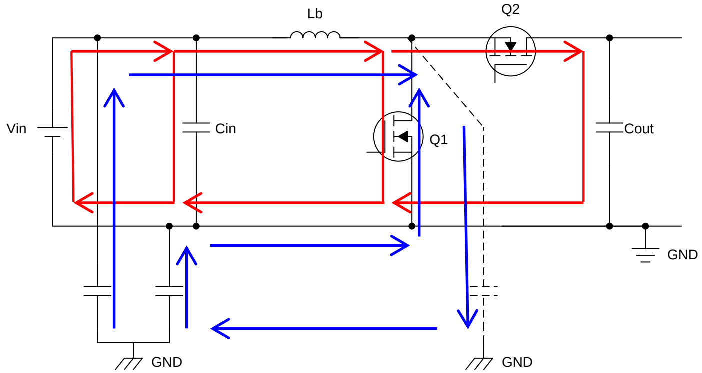
DM and CM conducted noise paths: buck & boost

1. **Differential-mode (DM)** noise current flows in power lines with opposite directions
2. **Common-mode (CM)** noise current flows in power lines with same direction

Buck



Boost



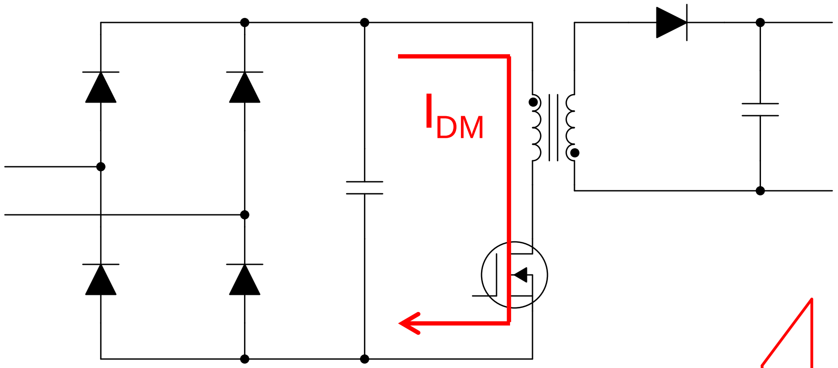
DM noise behavior

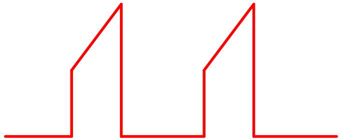
"Current driven", di/dt, magnetic field, low impedance

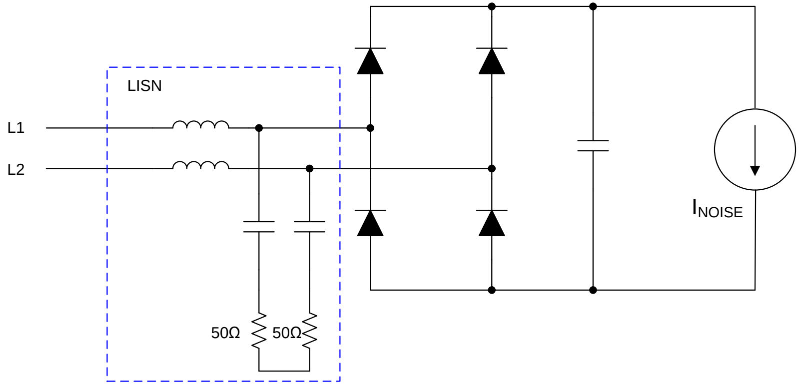
CM noise behavior

"Voltage driven", dv/dt, electric field, high impedance

DM noise equivalent circuit

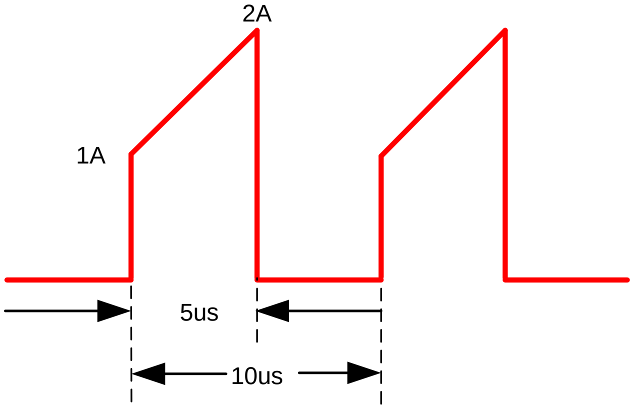


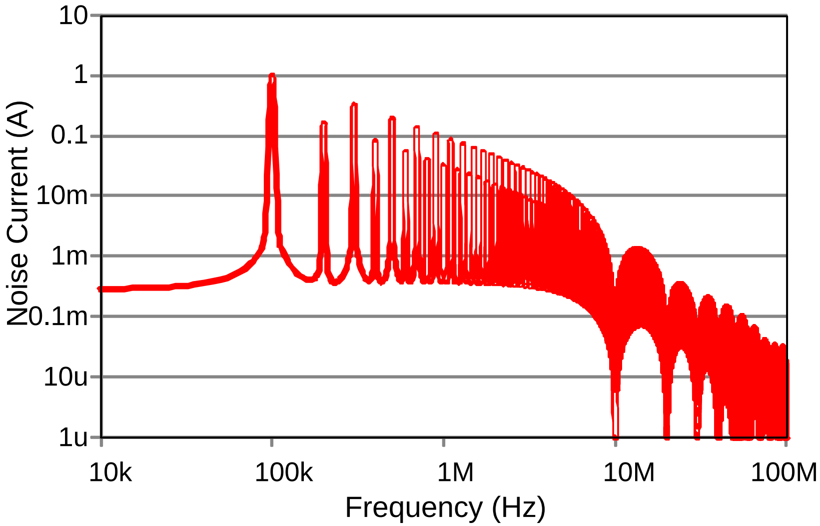




- The differential mode current is essentially the current used to deliver power to the system (input current)
- It’s normally a trapezoidal or triangular shape for switch mode power supplies

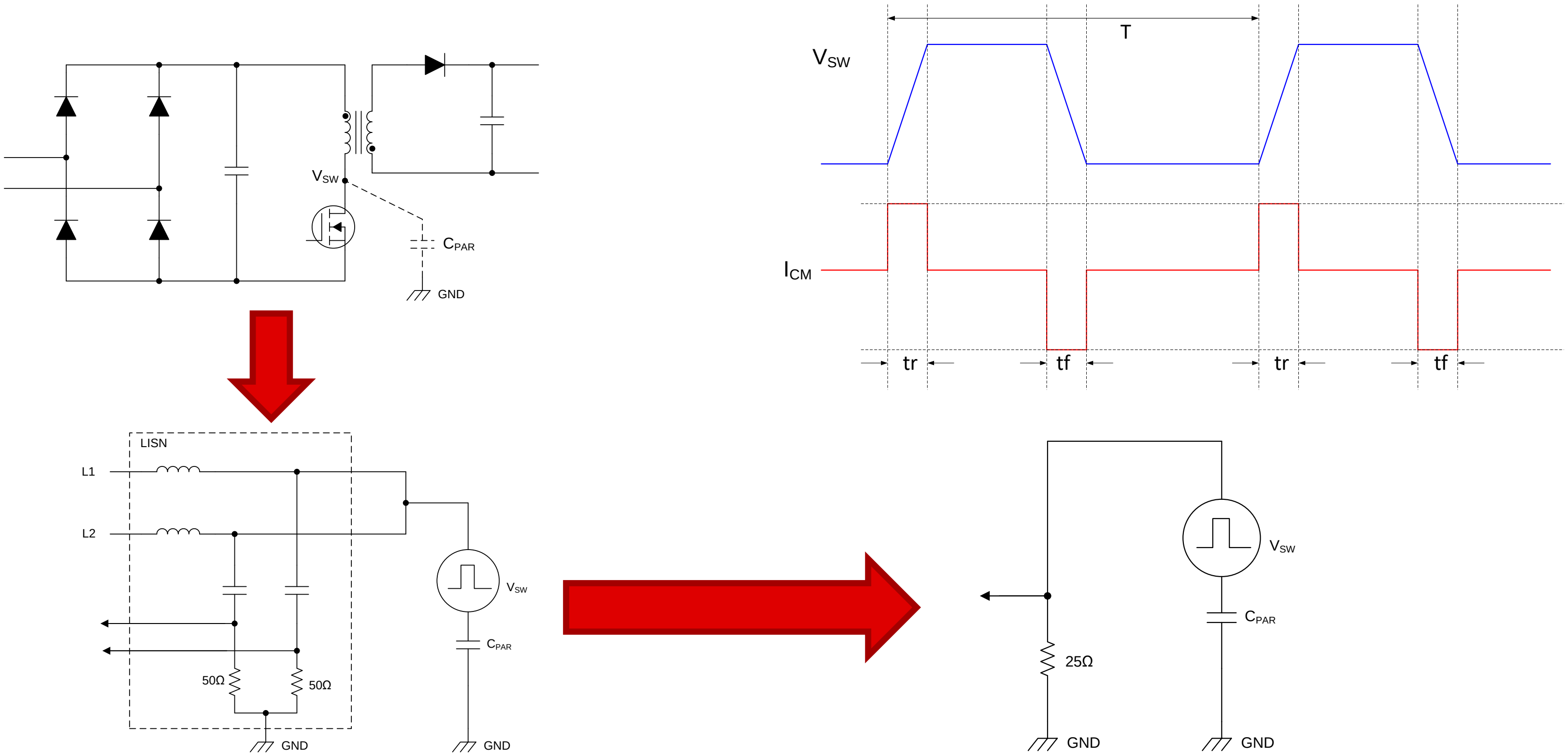
DM noise spectrum



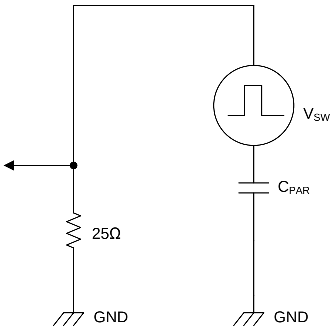


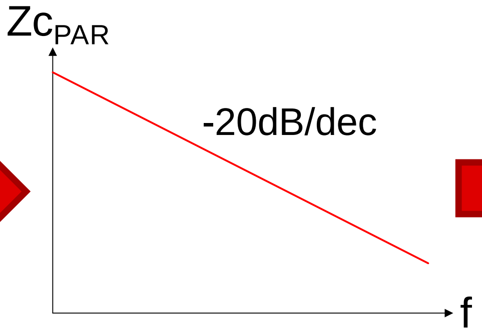
- The trapezoidal current shape gives roughly a -20dB/dec slope
- The DM noise can be easily estimated based on power stage operation waveforms

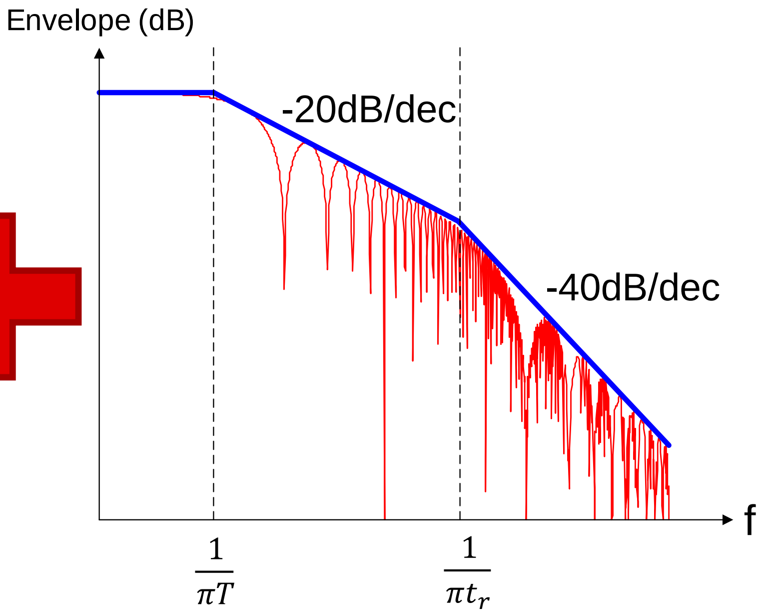
Equivalent circuit for CM noise

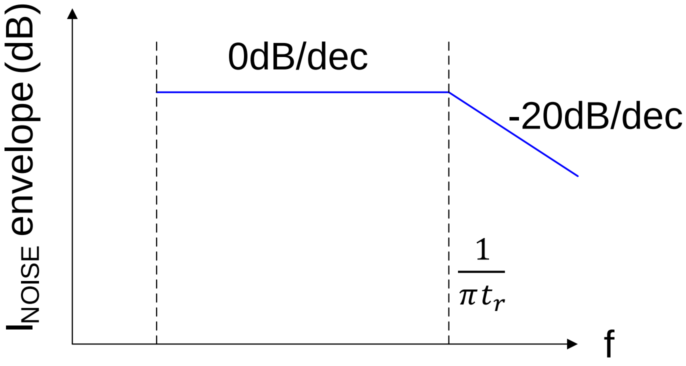


CM noise current spectrum





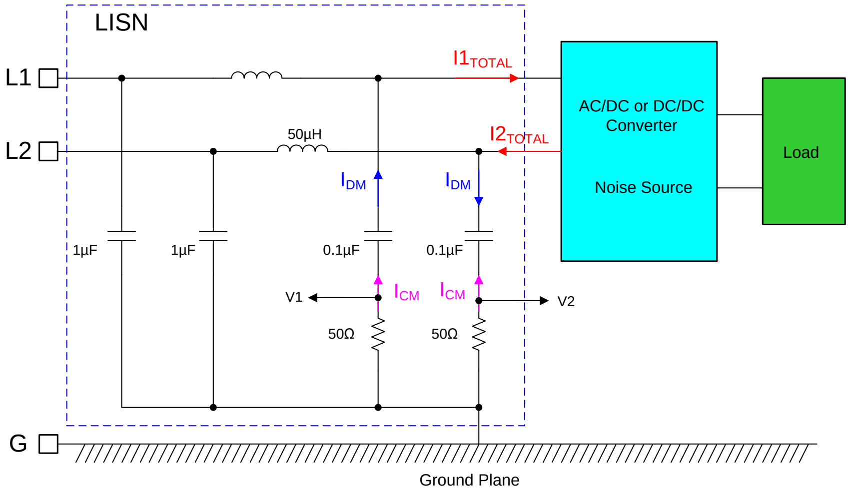




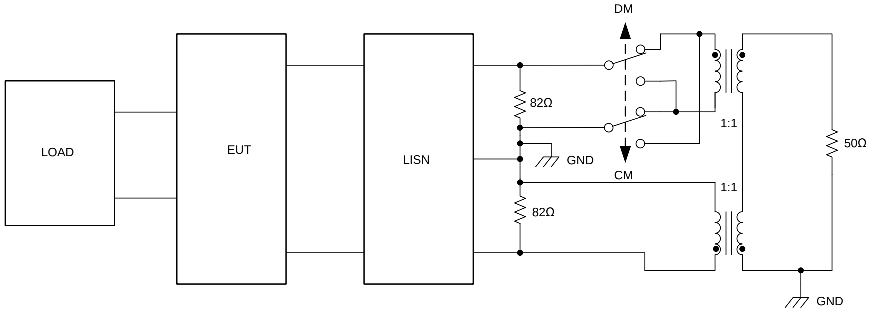
Common mode noise appears as a flat envelope

What can I do to improve CM EMI?

Measure conducted emissions (DM & CM) with LISN



$$\left|\frac{V_1 + V_2}{2}\right| = 50\Omega \times |I_{CM}| \qquad \left|\frac{V_2 - V_1}{2}\right| = 50\Omega \times |I_{DM}|$$

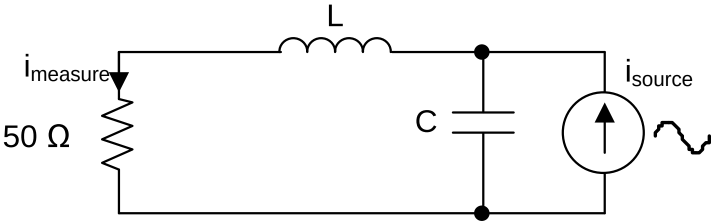


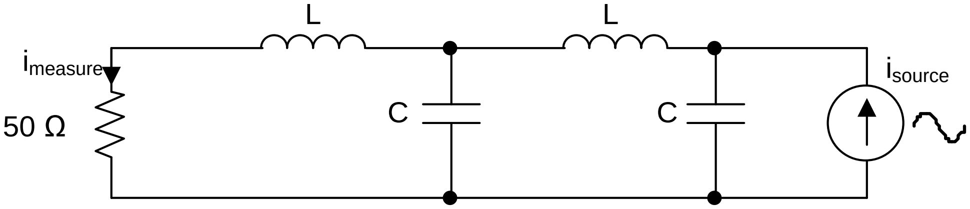
Separation of **DM/CM conducted emissions**:

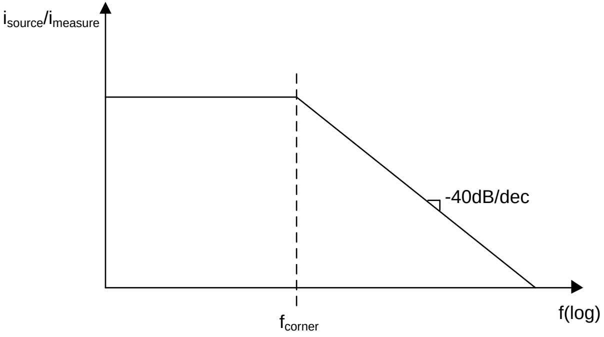
1. Diagnosis of power supply conducted EMI
   - **Troubleshoot** source of emissions
2. EMI filter design
   - Directly measure the required DM & CM **attenuation**
   - Minimize filter component count & size for **optimized design**

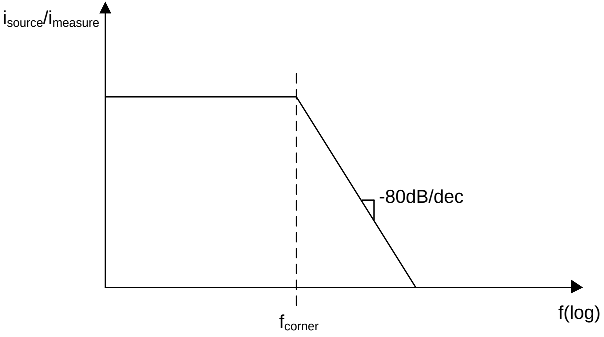
Characterization, evaluation, and design of noise separator for conducted EMI noise diagnosis, Shuo Wang; F.C. Lee ; W.G. Odendaal, IEEE Transactions on Power Electronics , Year: 2005, Volume: 20, Issue: 4, Pages: 974 - 982

Filter attenuation









$$f_{corner} = \frac{1}{2\pi\sqrt{L \times C}}$$

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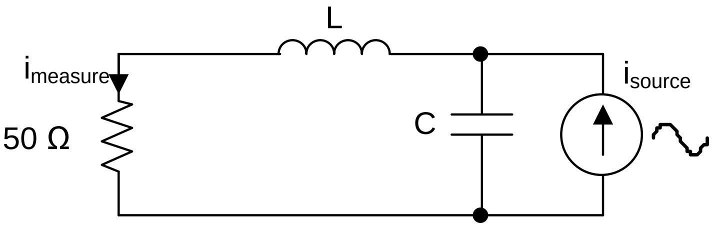
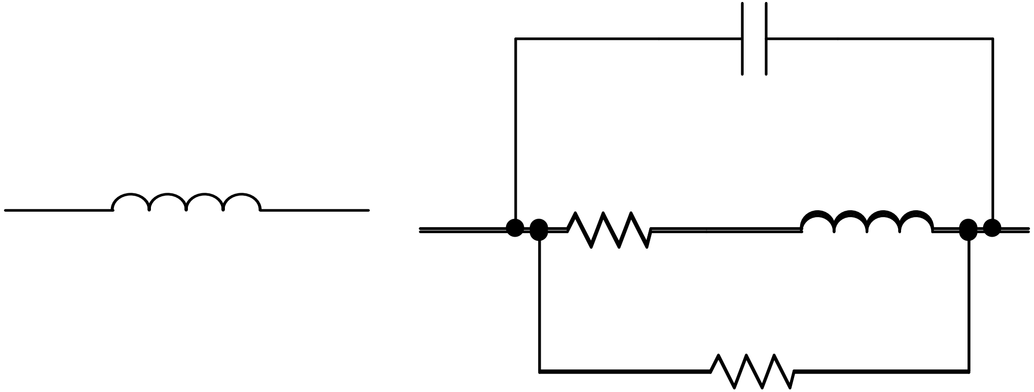
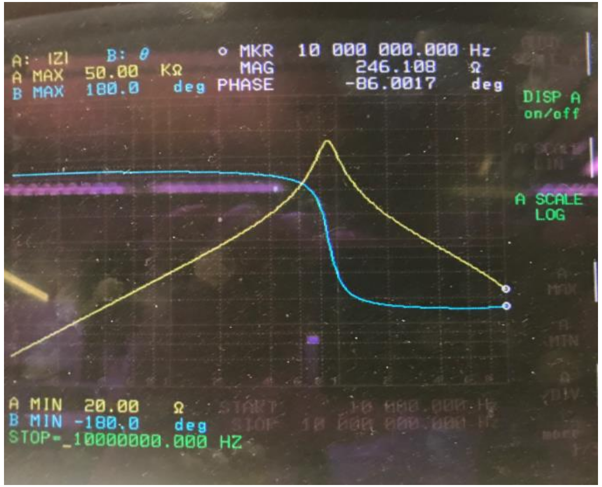
What if the two stages are not the same?

Equivalent circuit for inductor

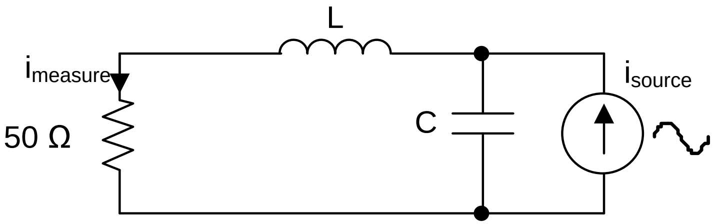


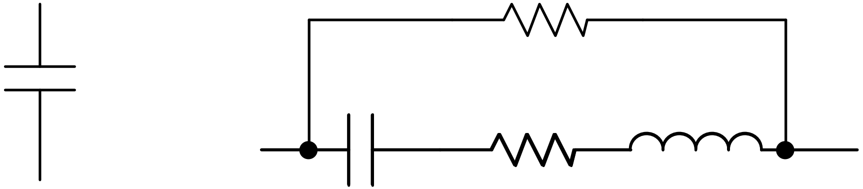


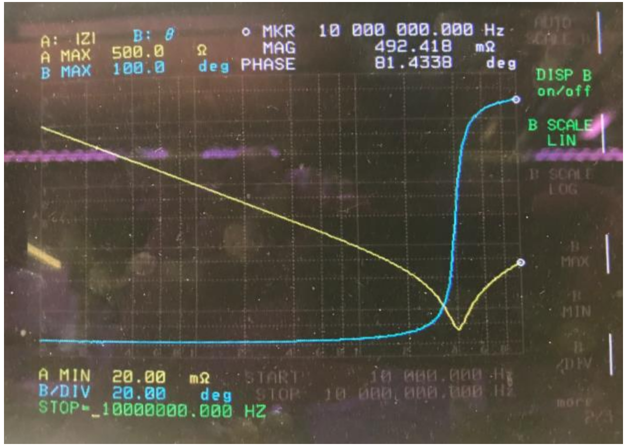


Inductor might not be an inductor at certain frequency

Equivalent circuit for capacitor

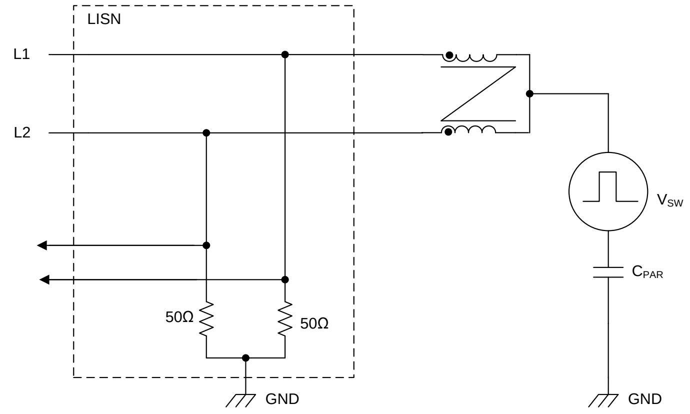


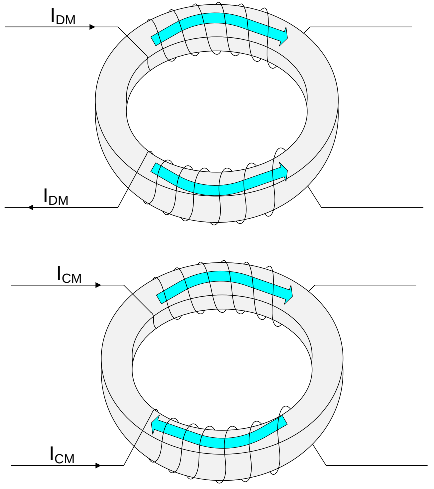




Capacitor might not be a capacitor at certain frequency

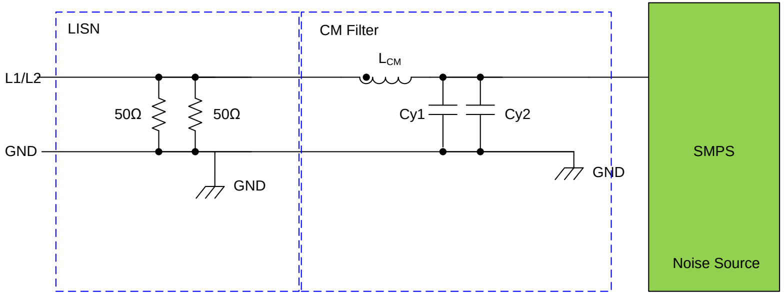
CM filter





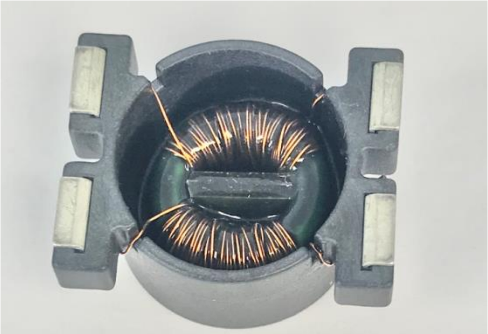
$$L_{eq} = L_{leak}$$

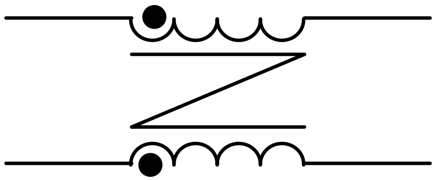
$$L_{eq} = L_M$$

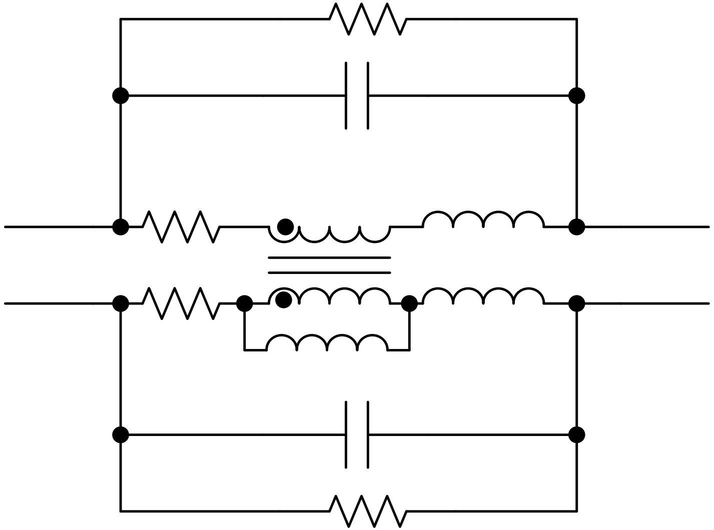


- CM inductor has large inductance for common mode current, while very little inductance for differential mode current
- CM capacitor (Y-cap) often used to provide high frequency path for the common mode current and provides more attenuation

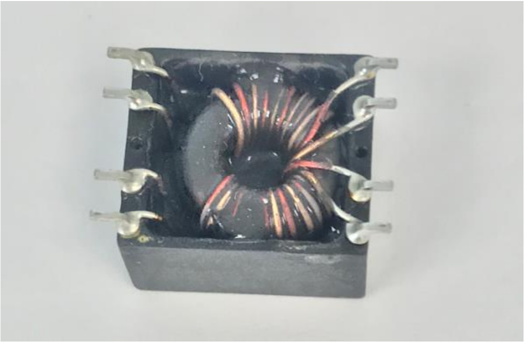
Common mode inductor equivalent circuit

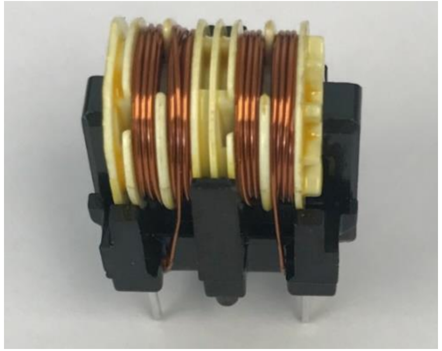


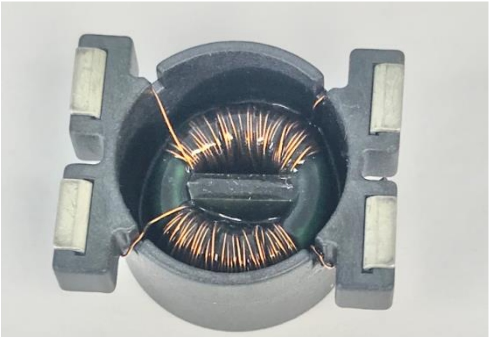




CM inductor constructions







Bifilar

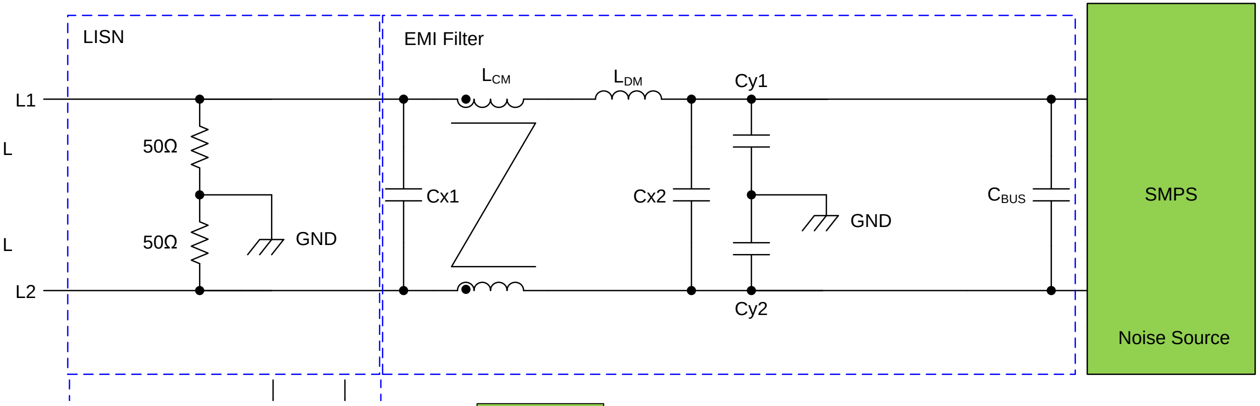
- Properties
  - Less differential impedance
  - High capacitive coupling
  - Less leakage inductance
- Application
  - Data lines
  - Sensor lines
  - USB, HDMI

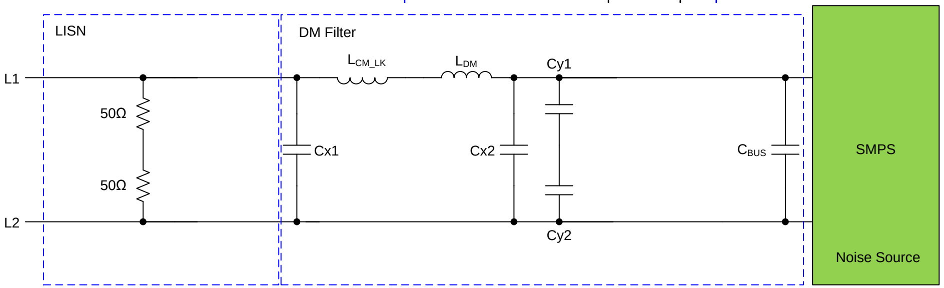
Sectional

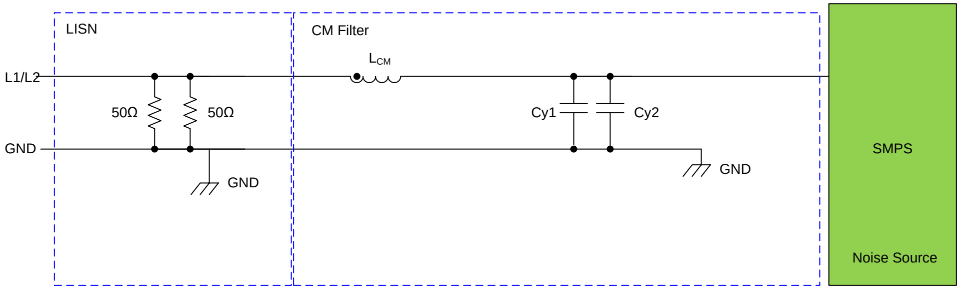
- Properties
  - Low capacitive coupling
  - High leakage inductance
- Applications
  - Power supply input/output filter
  - Switching power supply decoupling

EMI filter, DM & CM equivalent circuits

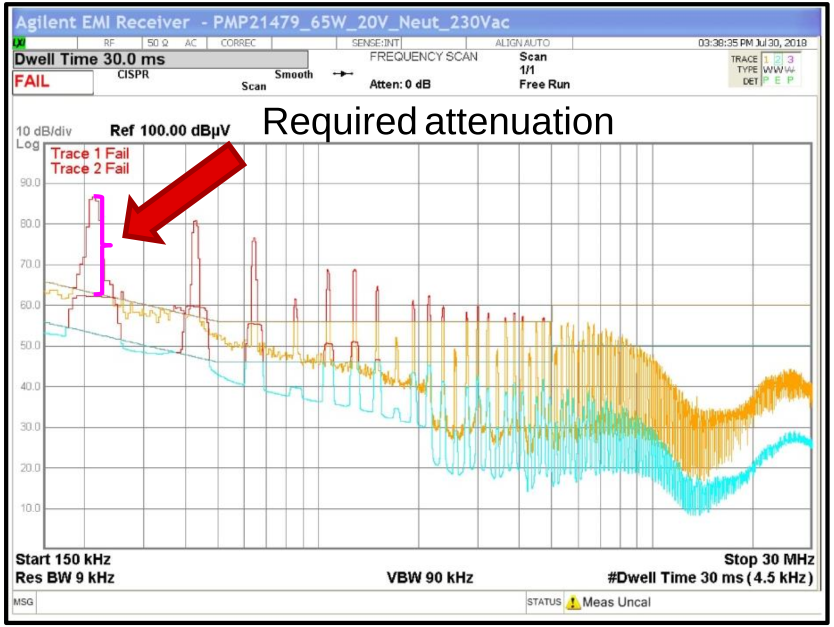
Standard π-filter





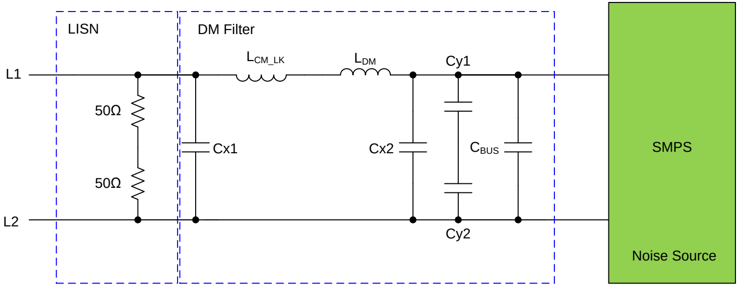


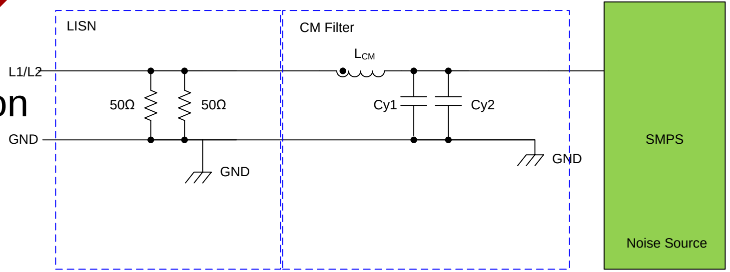
Design EMI filter flow chart



Measure raw noise

Required attenuation at noise peak

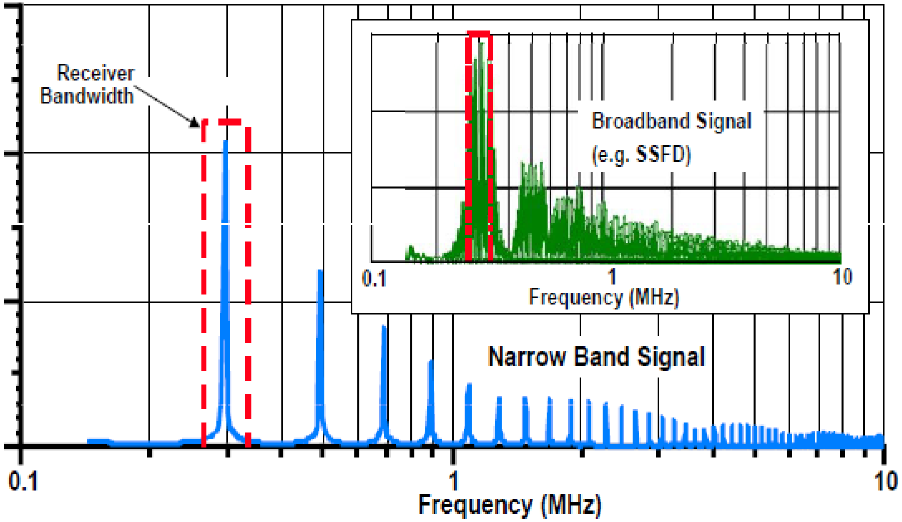




Choose appropriate L & C to provide attenuation at the frequency

Spread spectrum/dithering: what is it?

Spread spectrum is a technique to reduce EMI by dithering the switching frequency



Spread spectrum reduces the overall peak value while widening the spectrum

Summary

- EMI noise is created/associated with the switching mode power supply operation
- The EMI noise is measured through LISN
  - The noise current needs to be very low amplitude
- The EMI noise can be separated into DM and CM noise
  - DM noise is part of the power delivery
  - CM noise is coupled through the parasitic capacitor, caused by high dv/dt
- The EMI noise is often mitigated by EMI filtering
  - Differential mode filter
  - Common mode filter
- By measuring the raw EMI noise, the EMI filter can be designed to provide the required noise attenuation