Introduction to EMI in power supply designs: sources, measurement and mitigation methods
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What will I get out of this session?

• Purpose:
  • Explain EMI and the EMI standard
  • Introduction to EMI noise measurement
  • Understand common mode and differential mode noise
  • How to design EMI filter to attenuate the EMI noise

• Part numbers mentioned:

• Reference designs mentioned:
  • PMP21251- Less than 90mW Ultra-low Standby Power Auxless AC-DC Power Supply

• Relevant applications:
  • Everything!
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 susceptibility
  - 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 30MHz to 1GHz
- Leverage IC and system-level features:
  - Careful PCB layout
  - Spread spectrum / slew-rate control
  - EMI filtering

PMP21251
Less than 90mW Ultra-low Standby Power
Auxless AC-DC Power Supply
EN55022 limit lines – conducted emissions
Class A and Class B limits, quasi-peak & average, 150kHz–30MHz

Class A
(Heavy industrial)
- QP detector
- AVG detector

Class B
(Residential, commercial & light industrial)
(AC, notebook adapter)
- QP detector
- AVG detector

How conducted EMI is measured

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 $L_1$ and $L_2$
5. Terminated into 50Ω, internal to 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:**

\[ V_{\text{noise}} = 60 \text{dBµV} = 10^{\frac{60}{20}} \times \mu V = 1 \text{mV} \]

\[ I_{\text{noise}} = \frac{1 \text{mV}}{50 \Omega} = 20 \mu A \]

\[ I_{\text{noise}} = 20 \mu A = 20 \log(20) \text{ dBµA} = 26.02 \text{ dBµA} \]

EMI noise current has very low amplitude.
EMI detector, peak, quasi-peak, average

- Peak Measurement
- Quasi-peak Measurement
- Average Measurement
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

**DM noise behavior**
- "Current driven", $di/dt$, magnetic field, low impedance

**CM noise behavior**
- "Voltage driven", $dv/dt$, electric field, high impedance
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.
• 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 source spectrum

\[ |C_n| = A \frac{\tau}{T} \left| \frac{\sin(n\omega_0 \frac{\tau}{2})}{n\omega_0 \frac{\tau}{2}} \right| \left| \frac{\sin(n\omega_0 \frac{t_r}{2})}{n\omega_0 \frac{t_r}{2}} \right| \]

\[ t_r = t_f \]
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

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

EMI filter, DM & CM equivalent circuits

**Standard π-filter**

- **LISN**
  - L1
  - L
  - L2
  - 50Ω

- **EMI Filter**
  - Cx1
  - L_CM
  - Cy1
  - Cy2
  - L_CM
  - C_BUS

- **DM Filter**
  - L_CM
  - Cy1
  - Cy2

- **CM Filter**
  - L_CM
  - Cy1
  - Cy2

- **SMPS**
  - Noise Source

**Components:**
- L1, L2: Inductors
- 50Ω: Resistors
- Cx1, Cy1, Cy2: Capacitors
- C_BUS: Bus Capacitor
- L_CM: Common Mode Inductor
- DM Filter: Differential Mode Filter
- CM Filter: Common Mode Filter
CM filter

- 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.

\[ L_{eq} = L_{leak} \]

\[ L_{eq} = L_M \]
Design EMI filter flow chart

Required attenuation

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
References

http://focus.ti.com.cn/cn/download/shared/panasia/sem908009_2_Rice_Segal_slides_V5.pdf (slides)


