Introduction to EMI in power supply designs

High Voltage Seminar 2021

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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 spectrum
• 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

### Class A
(Heavy industrial)

<table>
<thead>
<tr>
<th>Frequency (MHz)</th>
<th>Noise Level (dBµV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
<td>79dBµV</td>
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<tr>
<td>1</td>
<td>73dBµV</td>
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<tr>
<td>10</td>
<td>66dBµV</td>
</tr>
<tr>
<td>100</td>
<td>60dBµV</td>
</tr>
</tbody>
</table>

- **QP detector**
- **AVG detector**

### Class B
(Residential, commercial & light industrial)

(Heavy industrial)

<table>
<thead>
<tr>
<th>Frequency (MHz)</th>
<th>Noise Level (dBµV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
<td>66dBµV</td>
</tr>
<tr>
<td>1</td>
<td>56dBµV</td>
</tr>
<tr>
<td>10</td>
<td>46dBµV</td>
</tr>
<tr>
<td>100</td>
<td>50dBµV</td>
</tr>
</tbody>
</table>

- **QP detector**
- **AVG detector**

**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

**Functional equivalent circuit of a LISN, not a complete schematic**
• 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 $60 \text{dB}_\mu\text{V}$ at 10MHz

What is the current level at the conducted emission limit in: (a) $\mu\text{A}$, (b) $\text{dB}_\mu\text{A}$

**ANSWER:**

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

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

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

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

**DM noise behavior**
“Current driven”, di/dt, magnetic field, low impedance

**Boost**

**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.
• 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

**Diagram Description:**
- The circuit diagram shows a basic CM (Common Mode) noise model.
- The diagram includes components such as ground (GND), power rails (VSW, CIS), and parasitic elements (C, L1, L2).
- The diagram also illustrates waveforms for VSW and ICM, indicating transitions and periods (tr, tf).

**Additional Information:**
- The circuit model is intended for analyzing CM noise in power electronic applications.
- Parasitic capacitance (CPAR) and inductance (L) are depicted to highlight their effects on signal integrity.

**Brand:**
- Texas Instruments

**Page Reference:**
- Page 13
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


\[
\begin{align*}
\left| \frac{V_1 + V_2}{2} \right| &= 50\Omega \times |I_{CM}| \\
\left| \frac{V_2 - V_1}{2} \right| &= 50\Omega \times |I_{DM}|
\end{align*}
\]
Filter attenuation

\[ f_{\text{corner}} = \frac{1}{2\pi \sqrt{L \times C}} \]

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

- 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.

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

\[ L_{eq} = L_M \]
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 \( \pi \)-filter

\[ \text{GND} \quad \text{SMPS} \quad \text{Noise Source} \]

\[ \text{L1} \quad \text{L2} \quad 50\Omega \quad 50\Omega \]

\[ \text{LISN} \quad \text{EMI Filter} \quad \text{CY1} \quad \text{CY2} \quad \text{CY1} \quad \text{CY2} \quad \text{CBUS} \]

\[ \text{LDM} \quad \text{LCM} \]

\[ \text{GND} \quad \text{SMPS} \quad \text{Noise Source} \]

\[ \text{L1/L2} \quad 50\Omega \]

\[ \text{LISN} \quad \text{CM Filter} \quad \text{CY2} \quad \text{CY1} \quad \text{LCM} \quad 50\Omega \quad \text{GND} \]

\[ \text{SMPS} \quad \text{Noise Source} \]

\[ \text{Texas Instruments} \]
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
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