TI Webinar Series

Designing Wide-VIN Low-EMI Power Converters

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Agenda

• Application Uses of Wide Input Voltage (Wide VIN) DC/DC Converters
• Approaches to Mitigate EMI in Switching Power Supply Design
  • Identifying EMI Critical Paths
  • IC Selection
  • PCB Layout
  • Spread Spectrum, Slew Rate Control, and Other Techniques
• Input EMI Filter Design
• WEBENCH EMI Tool
TI Wide Vin DC/DC Converters for Demanding Systems

Focus Applications

- **Automotive**
  - 12V/24V battery

- **Industrial**
  - 24V & higher Bus

- **Communications**
  - 24V/48V systems

Products

- **Buck Controllers & Regulators**
- **Boost and Buck-boost Controllers and Regulators**
- **Fly-Buck™ Multi-output Circuits**
- **Voltage References**

System Benefits

- **Wide Vin Operation**
  - Withstands transients without external protection circuitry

- **High Efficiency**

- **2MHz Switching**
  - Smaller PCB area, AM band avoidance

- **Low Iq**
  - Longer battery life

- **Low EMI**
EMI in Switch Mode Power Supplies

**GOAL:**
- **EMI Noise Generation**
- **EMC Noise Compatibility**
Engineering Approach To Mitigate EMI

**NOISE SOURCE**
Unwanted Emissions

- **Conducted**
  - EMI Filters
  - Electric Fields
- **Magnetic Fields**
- **Radiated**

**COUPLING**

- **Shielding**
- **EMI Filters**

**SUSCEPTIBLE SYSTEM**

**Identify Significant EMI Sources**

**Identify Critical Paths**

**Optimize IC Selection and PCB Design**

**Add EMI Filter / Snubber / Shielding**
Identify the Source of EMI – SW Node

- Minimize critical path area
- Separate noisy ground path from quiet ground
Noise Source and Mitigation Method

Single-turn air-core inductor
Self-inductance

\[ L \propto \text{Loop Area} \]

Voltage Spike

\[ v = L \frac{di}{dt} \]

Mitigation =
Reduce Loop Area
Critical Path Area Comparison

Critical Path Area Reduction

- Long Critical Path = Large Loop Area

**Grounding**

- SW max = 18.1V
- Vout = 140mVpp
Critical Path Area Comparison

• Short Critical Path = Small Loop Area

<table>
<thead>
<tr>
<th>Comparison</th>
<th>SW max (V)</th>
<th>Vout p2p (mV)</th>
<th>EMI peak (dBµV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smaller Area</td>
<td>16.2</td>
<td>64</td>
<td>45</td>
</tr>
<tr>
<td>Larger Area</td>
<td>18.1</td>
<td>140</td>
<td>50</td>
</tr>
</tbody>
</table>

Grounding

VOUT = 16.2V max
Vout = 64mVpp

LM53801_VIN=12V, VOUT=5.0V, No SS, ICload=1A, Cin close
EMI Mitigation by PCB Layout

Critical Path Area Reduction

- **Ground Plane**
  - Return Current Takes The Least IMPEDANCE Path
  - Unbroken Ground Plane Provides Shortest Return Path

Grounding

Current flow in top layer trace

Return current path in unbroken ground plane directly under path - Area minimized, B field minimized

Trace or Cut on the ground plane

Return current path enclose much larger area if the direct path is blocked
Pinout Designed With Performance In Mind
Compact, Low EMI, and Excellent Thermal Performance

LM43603
Parallel Input Cap Placement for Automotive

- SWITCH
- VIN
- GND
- CIN HF1
- CIN HF2
- LM53635

Components and connectors are labeled appropriately, indicating connections and placements for automotive parallel input cap.
PCB Layout Example – **LM5165** COT Buck Converter

*Remove copper between inductor pads to reduce parasitic capacitance*

*Full layer ground plane under converter top side layout provides H-field cancellation*

*Keep Input Cap close to LM5165*

*Position Feedback Resistors close to FB & GND pins*

*Eliminate copper between inductor pads to reduce parasitic capacitance*

*Position feedback resistors close to FB & GND pins*

*Full layer ground plane under converter top side layout provides H-field cancellation*
What makes a low EMI Buck

SW node capacitive coupling to the environment

Return path of coupling is over Input wires
-> Now it’s source of the Common Mode Noise

EMI Filter

Buck

DC Source

Input cable

Low pass

140uV pkpk

Output cable

Load

Input Noise

Output Noise

Examples:
1mV pkpk on PCB trace
140uV pkpk with unshielded Cable similar to CISPR

-12dB/Oct -40dB/Dec

C = 7fF

Near E-field coupling

140uV pkpk with unshielded Cable similar to CISPR
Buck Switch Node Voltage Ringing Due to Circuit Parasitics

Switch node ringing generates EMI in the FM Band > 30 MHz
FET Package and PBC Parasitics

- MOSFET package inductance, and capacitance
- PCB inductance and capacitance
Buck Switch Node with Slew Rate Control

Using slew rate control the switch node ringing is eliminated.

\( R_{HOH} = 10 \, \text{ohms} \)
\( R_{HOL} = 0 \, \text{ohms} \)
\( L_{LOH} = 10 \, \text{ohms} \)
\( R_{LOL} = 10 \, \text{ohms} \)
Benefits of Gate Driver Slew Rate Control

- Gate turn-on and turn-off times can be independently controlled via series resistors
- Optimizing gate drive slew rate reduces EMI with ~1% reduction in efficiency (as measured on LM5140 EVM)

No Slew Rate Control

With Slew Rate Control

Measured on LM5140 Standard EVM:
2.2MHz, 3.3V/5.0Vout
Spread spectrum/Dithering – What is it?

- Spread spectrum is a means of reducing EMI interference by dithering the switching regulator frequency, in the case of LM53600/53601, by +/-4%. This has the effect of spreading the noise spectrum and reducing the fundamental energy, as shown.

Fundamental with narrow spectrum and high amplitude

Spread spectrum reduces the fundamental signal energy and the overall peak value while widening the spectrum.
Differential Mode Conducted EMI

- Differential Mode Conducted EMI
  - In DC-DC converter topology differential mode noise usually dominates common mode
  - Involves the Normal Operation of the Circuit
  - Only Related to CURRENT, not voltage
  - For example, with the same power level Buck converter, lower input voltage means higher input current, thus worse conducted EMI

- Why we care?
  - Excessive Input and/or Output Voltage Ripple can compromise operation of Supply and/or Load
Input Filter Design for Conducted EMI

There are two basic requirements for the conducted EMI filter:

• Meet noise attenuation requirement (i.e. CISPR 25)
• Not interfere with the normal operation of the SMPS converter

Example of a Buck regulator

• No input filter
• Fails CISPR 25 regulation limits

But how do we estimate how much filter attenuation to add?
Necessary Input Filter Attenuation

Methods of estimating the filter attenuation prior to making a certified measurement with a LISN (Line Impedance Stabilization Network) and Spectrum Analyzer

- **Method 1 – estimation using oscilloscope measurement**
  - Measure the input ripple voltage using a wide bandwidth scope and calculate the attenuation.
    \[
    |\text{Att}|_{dB} = 20 \times \log \left( \frac{V_{\text{in, ripple}}}{1 \mu\text{V}} \right) - V_{\text{MAX}}
    \]
  - \(V_{\text{MAX}}\) is the allowed dB\(\mu\text{V}\) noise level for the particular EMI standard.

- **Method 2 – Estimation using the first harmonic of input current**
  - Assume the input current is a square wave (small ripple approximation)
    \[
    |\text{Att}|_{dB} = 20 \log \left( \frac{1}{\pi^2 f_s C_{\text{IN}} \sin(\pi D)} \right) - V_{\text{max}}
    \]
  - \(V_{\text{MAX}}\) is the allowed dB\(\mu\text{V}\) noise level for the particular EMI standard.
  - \(C_{\text{IN}}\) is the existing input capacitor of the Buck converter.
  - \(D\) is the duty cycle, \(I\) is the output current, \(F_s\) is the switching frequency.
Typical Conducted EMI Filter

Follow the design steps below:

- Calculate the required attenuation using Method 1 or Method 2.
- Capacitor $C_{IN}$ represents the existing capacitor at the input of the switching converter.
- Inductor $L_f$ is usually between $1\mu H$ and $10\mu H$, but can be smaller to reduce losses if this is a high current design.
- Calculate capacitor $C_f$. Use the larger of the two values ($C_{fa}$ and $C_{fb}$) below:

$$C_{fa} = \frac{C_{IN}}{C_{IN}L_f(2\pi f_s/10)^2 - 1}$$

$$C_{fb} = \frac{1}{L_f} \left(\frac{10^{\text{Att@dB}/40}}{2\pi f_s}\right)^2$$

- Capacitor $C_d$ and its ESR provides damping so that the $L_f C_f$ filter does not affect the stability of the switching converter.

$$C_d \geq 4 \times C_{IN}$$

$$\text{ESR}_d \approx \sqrt{\frac{L_f}{C_{IN}}}$$
Conducted EMI Before and After Filter

LM53603 – 150kHz to 30MHz

Input 13V, Output 5V@3A, resistor load, CISPR 25 CE setup
Red Line: Class 5 Limits (Peak/Average Detection)
Yellow: Peak detection result
Blue: Average detection result

Using guidelines on the previous slides, the filter was implemented and Conducted EMI retaken
COT Converter with EMI Input Filter

Low-\(I_Q\) Synchronous DC/DC Converter, 5V @ 150mA

Input Filter & Protection

EMI filtering
Inrush limit

TVS clamp for surge protection

Input Supply

LM5165

Input Filter & Protection

Input Supply

TVS clamp for surge protection
Conducted EMI Plots: CISPR 22 Class B (150kHz → 30MHz)

Input 13.5V, Output 5V @ 100mA, COT mode, Resistive load, CISPR 22 CE setup

Average detector
Peak detector

Unfiltered

Red Lines  Class B Limits  (Peak & Average detection)

Yellow  Peak detection result
Blue  Average detection result

Input filter: $L_{IN} = 22\ \mu H, \ C_{X2} = 10\mu F$
Conducted EMI Filter Design Tool - WEBENCH®

- Auto calculated or custom Input filter
- Spectrum Analysis before and after input filter
- EMI Limits
Further Reading

• Input Filter Design for Switching Power Supplies (*SNVA538*)
• Simple Success With Conducted EMI From DC-DC Converters (*SNVA489*)
• Simple Success with Conducted EMI and Radiated EMI for LMR160X0 (*SNVA755*)