Optimizing EMI Behavior of Low-Power DCDC Converters

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Basic Considerations
Step-Down Converter

\[ V_{L-T1} = V_{IN} - V_{OUT} \]
\[ V_{L-T2} = -V_{OUT} \]
\[ \Delta V_L = V_{IN} \]
\[ D = \frac{V_{OUT}}{V_{IN}} \]
\[ \frac{V_{OUT}}{V_{IN}} = D \]

Diagram showing the converter circuit with inductor \( L \), switch \( S \), input capacitor \( C_{IN} \), diode \( D \), output capacitor \( C_{OUT} \), input voltage \( V_{IN} \), and output voltage \( V_{OUT} \).
Step-Down Converter - Parasitics

\[ V_L = L \cdot \frac{di}{dt} \]
Spectrum

Example:

Switching frequency 2.5 MHz (400ns)
Duty cycle 30% (120ns)
Rise/fall time 2.. 4 ns
Example

Switching frequency 2.5 MHz (400ns)
Duty cycle 30% (120ns)
Rise/fall time 2.4 ns
# Structures

## Component Values

<table>
<thead>
<tr>
<th>Capacitors</th>
<th>Inductance for resonance at</th>
<th>5</th>
<th>10</th>
<th>50</th>
<th>100</th>
<th>500</th>
<th>1000 MHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.01 uF</td>
<td></td>
<td>636.6</td>
<td>159.2</td>
<td>6.4</td>
<td>1.6</td>
<td>0.1</td>
<td>0.0 nH</td>
</tr>
<tr>
<td>0.1 uF</td>
<td></td>
<td>63.7</td>
<td>15.9</td>
<td>0.6</td>
<td>0.2</td>
<td>0.0</td>
<td>0.0 nH</td>
</tr>
<tr>
<td>1 uF</td>
<td></td>
<td>6.4</td>
<td>1.6</td>
<td>0.1</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0 nH</td>
</tr>
<tr>
<td>5 uF</td>
<td></td>
<td>1.3</td>
<td>0.3</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0 nH</td>
</tr>
<tr>
<td>10 uF</td>
<td></td>
<td>0.6</td>
<td>0.2</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0 nH</td>
</tr>
<tr>
<td>100 uF</td>
<td></td>
<td>0.1</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0 nH</td>
</tr>
</tbody>
</table>

## Mechanical structures

<table>
<thead>
<tr>
<th>Structure size</th>
<th>related frequency</th>
<th>λ</th>
<th>λ/2</th>
<th>λ/4</th>
<th>λ/8</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 mm</td>
<td>300000</td>
<td>300000</td>
<td>150000</td>
<td>75000</td>
<td>37500 MHz</td>
</tr>
<tr>
<td>5 mm</td>
<td>60000</td>
<td>30000</td>
<td>15000</td>
<td>7500</td>
<td>750 MHz</td>
</tr>
<tr>
<td>10 mm</td>
<td>30000</td>
<td>15000</td>
<td>7500</td>
<td>3750 MHz</td>
<td></td>
</tr>
<tr>
<td>50 mm</td>
<td>6000</td>
<td>3000</td>
<td>1500</td>
<td>750 MHz</td>
<td></td>
</tr>
<tr>
<td>100 mm</td>
<td>300</td>
<td>150</td>
<td>75</td>
<td>37.5 MHz</td>
<td></td>
</tr>
<tr>
<td>1000 mm</td>
<td>30</td>
<td>15</td>
<td>7.5</td>
<td>3.75 MHz</td>
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</table>

## Inductors

<table>
<thead>
<tr>
<th>Inductors</th>
<th>Capacitance for resonance at</th>
<th>5</th>
<th>10</th>
<th>50</th>
<th>100</th>
<th>500</th>
<th>1000 MHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1 nH</td>
<td></td>
<td>63663.85</td>
<td>15915.96</td>
<td>636.64</td>
<td>159.16</td>
<td>6.37</td>
<td>1.59 nF</td>
</tr>
<tr>
<td>1 nH</td>
<td></td>
<td>6366.39</td>
<td>1591.60</td>
<td>63.66</td>
<td>15.92</td>
<td>0.64</td>
<td>0.16 nF</td>
</tr>
<tr>
<td>10 nH</td>
<td></td>
<td>636.64</td>
<td>159.16</td>
<td>6.37</td>
<td>1.59</td>
<td>0.06</td>
<td>0.02 nF</td>
</tr>
<tr>
<td>100 nH</td>
<td></td>
<td>63.66</td>
<td>15.92</td>
<td>0.64</td>
<td>0.16</td>
<td>0.01</td>
<td>0.00 nF</td>
</tr>
</tbody>
</table>

## Frequency

<table>
<thead>
<tr>
<th>Frequency</th>
<th>related wavelength</th>
<th>λ</th>
<th>λ/2</th>
<th>λ/4</th>
<th>λ/8</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 MHz</td>
<td>30000</td>
<td>30000</td>
<td>15000</td>
<td>7500</td>
<td>37500 mm</td>
</tr>
<tr>
<td>50 MHz</td>
<td>6000</td>
<td>3000</td>
<td>1500</td>
<td>750 mm</td>
<td></td>
</tr>
<tr>
<td>100 MHz</td>
<td>3000</td>
<td>1500</td>
<td>750</td>
<td>375 mm</td>
<td></td>
</tr>
<tr>
<td>500 MHz</td>
<td>600</td>
<td>300</td>
<td>150</td>
<td>75 mm</td>
<td></td>
</tr>
<tr>
<td>1000 MHz</td>
<td>300</td>
<td>150</td>
<td>75</td>
<td>3.75 mm</td>
<td></td>
</tr>
</tbody>
</table>
Components
Capacitor impedance vs. frequency
(same case size)

$L = 550\text{pH (0402)}$

Smaller Caps are only better around the resonance frequency if you keep the same case size
Input Capacitor selection

**Figure 8. Impedance of an Actual Capacitor (Non-Ideal)**

- Impedance falls due to C
- Impedance rises due to ESL
- Resonance creates a minimum

**Figure 9. Impedance of an Actual Capacitor (Non-Ideal) in Different Surface-Mount Packages**

- Impedance falls due to C
- Impedance rises due to ESL
- Resonance creates a minimum impedance

**Figure 10. Impedance of Three Capacitors, the Same Surface-Mount Packages**

- 1μF, 0.1μF, 0.01μF, 0805, 0603, 0402
- Red, green, and blue lines are 3 separate capacitors. Yellow is their parallel combination.

**Figure 11. Impedance of Three Capacitors, Scaled Surface-Mount Packages**

- 1μF, 0.1μF, 0.01μF, 0805, 0603, 0402
- Red, green, and blue lines are 3 separate capacitors. Yellow is their parallel combination.
Filter Capacitors

- 4700 pF, 0402 size
- 470 pF, 0402 size
Inductor

Shielded

Unshielded

Marking

Texas Instruments
PCB Layout Structures
PCB Simulations – Routing on Top Layer only

<table>
<thead>
<tr>
<th>Copper Layer</th>
<th>Inductance</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 Copper Layer</td>
<td>73.7 nH</td>
</tr>
<tr>
<td>1 Copper Layer (100µm distance)</td>
<td>3.37 nH</td>
</tr>
<tr>
<td>1 Copper Layer (50µm distance)</td>
<td>2.03 nH</td>
</tr>
<tr>
<td>2 Copper Layer</td>
<td>3.37 nH</td>
</tr>
</tbody>
</table>
PCB Simulations – Routing on Top Layer only

- **100MHz**
  - No Copper Layer
  - 1 Copper Layer

- **500MHz**
  - No Copper Layer
  - 1 Copper Layer

- **1000MHz**
  - No Copper Layer
  - 1 Copper Layer
PCB Simulations – Routing on 2 Signal Layers

<table>
<thead>
<tr>
<th>Layer Description</th>
<th>Inductance</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 Copper Layer</td>
<td>2,215 nH</td>
</tr>
<tr>
<td>1 Copper Layer (640 µm distance)</td>
<td>2,19 nH</td>
</tr>
<tr>
<td>1 Copper Layer (320 µm distance)</td>
<td>2,16 nH</td>
</tr>
<tr>
<td>2 Copper Layer</td>
<td>2,18 nH</td>
</tr>
</tbody>
</table>
PCB Simulations – Top Layer only - Routing

100MHz

No Copper Layer

Copper Layer

500MHz

1000MHz
EMI Measurements
Setup – CISPR22 (Industrial)
Measurement Examples

different input connection
different supply voltages
Detailed Analysis
Layout and component selection
Layout and Component Selection
Layout and Component Selection
Component Selection and Placement

C1, C2  22 uF, 0603 size
C9, C10  not assembled

C1, C2  470 pF, 0402 size
C9, C10  22 uF, 0603 size
Component Selection and Placement

- C1, C2: 22 uF, 0603 size
- C9, C10: not assembled

- C1, C2: 470 pF, 0402 size
- C9, C10: 22 uF, 0603 size

400 MHz range
Mitigation Strategies
Shielding Layers
Shielding Layer
Shielding Layer
Shielding Layer

Spectral Comparison
Comparison between 6.4 Hz to 16.44 dBm
Comparison Frequency: 2.962 to 49.000 MHz

Spectral Comparison
Comparison between 6.25 to 7.66 dBm
Comparison Frequency: 2.962 to 49.000 MHz
Shielding Layer
Snubber at the Switch Node
Snubber

RC Snubber Effect

Level in dBu

Frequency in Hz

Initial  With Snubber
Input Capacitor Design
Switching Noise and Overshoots

Default Assembly

470 pF 0402 Capacitor at the Input
Switching Noise

Oscilloscope probe connected

Oscilloscope probe not connected
Resonance Effects in the Input Capacitors
Resonance Effects in the Input Capacitors
Comparison

RC Snubber - Input capacitor Effect Comparison

- Initial
- With Snubber
- With Input Capacitor
Spread Spectrum?
Waveforms and Spectrum
Fixed Frequency Operation

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Thank you