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Using Active Clamp Technology to Maximize Efficiency in a Telecom Bus Converter

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Agenda

1. Basic Operation of Flyback and Forward Converters
2. Active Clamp Operation and Benefits
3. Active Clamp Forward Design
4. Design Review PMP5711
Basic Power Stages

Flyback
- Transformer stores energy
- R1 dissipates leakage and some magnetizing energy
  - Typically 2 to 5% of output power

Forward
- Transformer transfers energy
  - Storage is in L1
- R1 dissipates magnetizing plus leakage energy
  - Typically 3 to 10% of output power

How can we avoid loss in R1?
Secondary Winding Currents

- Assuming 50% duty cycle and CCM
  - Synchronous rectifiers force CCM

- RMS flyback current = 2 X RMS forward current

- For low voltage/high current output, forward is best choice
Output Capacitor Currents

- Flyback output capacitors see much higher current
  - Higher RMS current increases heating
  - Higher peak current requires much lower ESR

- Result is more, higher quality capacitors in flyback
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Active Clamp Operation

$L_{mag}$ and $L_{leakage}$ are energized

Current commutes to Q2 body diode

Current resonates, changes direction

Current commutes to Q1 body diode or $C_{oss}$

\[ D \times T_{sw} \rightarrow t_{delay} \rightarrow (1-D) \times T_{sw} \rightarrow t_{delay} \]
Active Clamp Configurations

- Easy to drive clamp FET
- Higher capacitor voltage
- P-channel FET

- Floating gate drive
- Lower capacitor voltage
- N-channel FET
Active Clamp Benefits

**RCD Clamp**
- Most of leakage energy is dissipated as heat
- “Hard” switching results in power losses
- More difficult implementation of self-driven synchronous rectifiers with Forward
- Voltage spike on Q1 drain at turn off can be EMI issue

**Active Clamp**
- Most of leakage energy is reclaimed
- Zero voltage switching reduces losses
- Simple Implementation of self-driven synchronous rectifiers with forward
- No voltage spike on Q1 drain at turn off
- Nearly lossless recovery of magnetizing energy in forward
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Active Clamp Forward Design

- Reflected primary voltage during reset time allows self driven sync rectifiers
- No leakage spike at Q1 turn off
- Primary current resets to third quadrant resulting in better core utilization
- Unlike flyback, clamp resonant frequency is determined by magnetizing inductance and $C_{\text{clamp}}$
Forward Clamp Circuit

\[ f_{\text{clamp}} = \frac{1}{2 \times \pi \times \sqrt{L_{\text{magnetizing}} \times C_{\text{clamp}}}} \]

\[ V_{\text{hump}} = \frac{V_{\text{in}} \times D \times (1 - D)}{8 \times L_{\text{magnetizing}} \times f_{\text{SW}}^2 \times C_{\text{clamp}}} \]

\[ I_{Q2\_\text{RMS}} = \frac{V_{\text{in}} \times D \times \sqrt{1 - D}}{2 \times \sqrt{3} \times L_{\text{magnetizing}} \times f_{\text{SW}}} \]

(Peak current is \( I_{\text{mag}} \); RMS clamp current is much less than flyback)
Forward Soft Switching – Q1 Turn-Off

- Magnetizing and reflected load current flowing in Q1
- Transfers to Q2 body diode
  - Delay from Q1 turn-off to Q2 turn-on
- Zero voltage switching of Q2
- Not load or line dependent
Forward Soft Switching – Q1 Turn-On

Light Loads

- No current in Q4 or Q5 during delay time
- Allows Q1 to achieve ZVS
Forward Soft Switching – Q1 Turn-On

- Current flows in body diodes of Q4 and Q5 during delay time
- Q1 drain voltage = $V_{IN}$ when Q1 turns On
- Partial zero voltage switching

Heavy Loads

![Circuit Diagram]

- $V_{IN}$
- $L_{mag}$
- $V_{OUT}$
- $V_{DS_{Q1}}$ (50 V/div)
- $I_{Q1}$ (1 A/div)
- $V_{DS_{Q2}}$ (50 V/div)
- $I_{Q2}$ (1 A/div)
Forward Synchronous Rectifiers

<table>
<thead>
<tr>
<th>Output Voltage</th>
<th>PRI:SEC Turn Ratio</th>
<th>MAX Sync FET $V_{DS}$ Stress</th>
<th>Sync FET $V_{DS}$ Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.3 V</td>
<td>6:1</td>
<td>12.5 V</td>
<td>20 V</td>
</tr>
<tr>
<td>5 V</td>
<td>4.5:1</td>
<td>17 V</td>
<td>30 V</td>
</tr>
<tr>
<td>12 V</td>
<td>1.88:1</td>
<td>40 V</td>
<td>60 V</td>
</tr>
</tbody>
</table>

- Turn ratios and voltages for telecom 35- to 75-VDC input
- FET gate rating of 20 V or less
- 3.3-V output can be driven directly from transformer winding
- Outputs >3.3 V require gate protection
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Physical Size – 5.0V/35A Forward Converter

$L \times W \times H = 93mm \times 31mm \times 19mm$
Waveforms – 5.0V/35A Forward Converter

Vds primary NFETs

Vds sync. rectifiers

Vds freewheeling FET

Vds clamping PFET

Vgs sync. rectifiers

Vgs freewheeling FET
Efficiency – 5.0V/35A Forward Converter

Effcy > 94% in a range of 13A to 35A, 95% around 20A
Dynamic Behavior – 5.0V/35A Forward Conv.

small signal analysis of outer loop w/ network analyzer at 30Amps load, results in:
bandwidth > 2kHz, phasemargin >70degs, gain margin <=-12dB
Dynamic Behavior – 5.0V/35A Forward Conv.

large signal analysis with load step 50%, 15Amps / 30Amps
Ripple & Noise – 5.0V/35A Forward Conv.

Ripple: 40mVpp, Noise: 110mVp at max. load 35Amps
Thermal Behavior – 5.0V/35A Forward Conv.

**Top side at max. load 35A at forced cooling 400lfm**

<table>
<thead>
<tr>
<th>Name</th>
<th>Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q5</td>
<td>38.8°C</td>
</tr>
<tr>
<td>Q4</td>
<td>38.6°C</td>
</tr>
<tr>
<td>Q3</td>
<td>35.2°C</td>
</tr>
</tbody>
</table>

**Bottom side at max. load 35A at forced cooling 400lfm**

<table>
<thead>
<tr>
<th>Name</th>
<th>Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>R101</td>
<td>65.8°C</td>
</tr>
<tr>
<td>D10</td>
<td>59.1°C</td>
</tr>
<tr>
<td>D9</td>
<td>52.3°C</td>
</tr>
<tr>
<td>Q1</td>
<td>55.4°C</td>
</tr>
<tr>
<td>D3</td>
<td>55.0°C</td>
</tr>
<tr>
<td>Q9</td>
<td>47.8°C</td>
</tr>
<tr>
<td>Q10</td>
<td>52.1°C</td>
</tr>
<tr>
<td>Q11</td>
<td>51.1°C</td>
</tr>
</tbody>
</table>
Active Clamp Forward 5.0V/35A, 175-W Bus Converter Using UCC2897A
Summary

• Adding active clamp and sync rectifiers improves efficiency of forward (and flyback) up to 5% (Efficiencies >90%, here up to 95%)

• Forward provides best efficiency due to lower conduction losses than flyback

• Forward can be scaled to higher output power with similar results

• Flyback for multiple outputs or when cost is most important
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