Saber Tutorial
Quasi-resonant Flyback Converter Simulation

Alan Courtay
March 7, 2016
Agenda

• Quasi-Resonant Flyback Converter (AN1326)
  – Principles of Operation
  – Simulation vs. Measurement
• Accurate Datasheet-Driven Modeling
  – Controller Chip
  – MOSFET
  – Transformer
• Automated Verification
  – EMI
  – Loss / Efficiency
L6565-Based 50W QR ZVS Flyback

Vin: 50/60Hz, 88 to 264 Vac

Vout1: 105 V ± 5%
Iout1: 0.1 to 0.35 A
Vripple1: 1%

Vout2: 14 V ± 10%
Iout2: 0.1 to 1 A
Vripple2: 1%
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Power Stage

Llk+Lp

Cd

Llk&Cd

Lp&Cd

Vds

Vin

Currents

Ipeak

Demagnetization

Discontinuous Conduction Mode
Peak Current Mode Control

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RCD Clamp Power Stage

Output Voltage Regulation Feedback
L6565-Based 50W QR ZVS Flyback

![Diagram of L6565-based 50W QR ZVS Flyback circuit](image-url)
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Current Sense and Primary Voltage
Full Load, Vin = 100 V

Ch2: Q1 drain voltage
Ch3: current sense pin
Current Sense and Primary Voltage
Full Load, Vin = 380 V

Ch2: Q1 drain voltage
Ch3: current sense pin
Current Sense and Primary Voltage
Half Load, \( \text{Vin} = 100 \, \text{V} \)

Ch2: Q1 drain voltage
Ch3: current sense pin

Current Sense

Drain Voltage
Current Sense and Primary Voltage
Half Load, Vin = 380 V

Ch2: Q1 drain voltage
Ch3: current sense pin
Cycle Skipping / Frequency Foldback
Light Load, Vin = 300 V

Ch1: Q1 drain voltage
Ch2: 105 V output
Current Sense and Primary Voltage
Standby, Vin = 380 V

Burst Mode

Ch1: Q1 drain voltage
Ch2: current sense pin
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Modeling Controller IC
Modeling Controller IC

L6565

Valley detection model with StateAMS tool

Blanking time model with TLU tool

Frequency foldback

Blanking time model with TLU tool

Frequency foldback
Modeling Controller IC

L6565

**Line voltage feedforward function implemented in MAST**

Limits power capability at high line voltage

Turn-off

```
template line_feedforward vff comp vout
  electrical vff, comp, vout
  { result ivs
    equations
      ivs : v(vout) = 0.16*(v(comp)-2.5)*(3-v(vff))
      i(vout) += ivs
  }
```
Modeling Power MOSFET

N - CHANNEL 800V - 1.2Ω - 6.5A - TO-220/TO-220FP

PowerMESH™ MOSFET

<table>
<thead>
<tr>
<th>TYPE</th>
<th>V_{DS}</th>
<th>R_{D(on)}</th>
<th>I_{D}</th>
</tr>
</thead>
<tbody>
<tr>
<td>STP7NB80</td>
<td>800 V</td>
<td>&lt; 1.5 Ω</td>
<td>6.5 A</td>
</tr>
<tr>
<td>STP7NB80FP</td>
<td>800 V</td>
<td>&lt; 1.5 Ω</td>
<td>6.5 A</td>
</tr>
</tbody>
</table>

- TYPICAL R_{D(on)} = 1.2 Ω
- EXTREMELY HIGH dv/dt CAPABILITY
- 100% AVALANCHE TESTED
- VERY LOW INTRINSIC CAPACITANCES
- GATE CHARGE MINIMIZED

DESCRIPTION

- L6565
- pc817
- TL431
Modeling Power MOSFET

• DC Characteristics

Characterized Temperatures

<table>
<thead>
<tr>
<th>Temp1</th>
<th>Temp2</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>75</td>
</tr>
</tbody>
</table>

Vgs0 = 6
Vds0 = 20.06
Ids0 = 7.32
Rds0 = 1.5
Rd = 0.865
Rs = 0.1
Rg = 2.4

\[ V_{ds} \text{ from 0 to 30 by 0.1} \] Temp = 25
\[ V_{gs} = 5.67 \]
Modeling Power MOSFET

- DC Characteristics
- Interelectrode Capacitances

![Graph showing DC Characteristics and Interelectrode Capacitances](image)
Modeling Power MOSFET

• DC Characteristics
• Interelectrode Capacitances
• Gate Charge Characteristic
Modeling Transformer

- Ferrite Core 3C85
  - Hysteresis (major and minor BH loops)
  - Frequency dependent losses (hysteresis and eddy currents)
Modeling Transformer

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Modeling Transformer

• Ferrite Core 3C85
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• Core geometry
  – Air gap
  – Lamination
Modeling Transformer

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  - Frequency dependent losses (hysteresis and eddy currents)
- Core geometry
  - Air gap
  - Lamination
- Windings (Cauer - 1D Model)
  - Flux leakage
  - Frequency dependent loss (skin and proximity effects)
  - Winding capacitances
Modeling Transformer

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L6565-based 50W QR Flyback (ST AN1326)
L6565-based 50W QR Flyback (ST AN1326)
Parallel Computing
<table>
<thead>
<tr>
<th>Task Label</th>
<th>Task Definition</th>
<th>Description</th>
<th>Task Result</th>
<th>Task Status</th>
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<tbody>
<tr>
<td>vary</td>
<td>vary-param flyback2_v_sin_v_sin1.amplitude</td>
<td>0 Failed</td>
<td>Complete</td>
<td>Complete</td>
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<td>flyback2_v_sin_v_sin1.amplitude-05</td>
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<td>flyback2_v_sin_v_sin1.amplitude-10</td>
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<td>flyback2_v_sin_v_sin1.amplitude-15</td>
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<td>flyback2_v_sin_v_sin1.amplitude-55</td>
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<td>flyback2_v_sin_v_sin1.amplitude-60</td>
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<td>flyback2_v_sin_v_sin1.amplitude-65</td>
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<td>flyback2_v_sin_v_sin1.amplitude-70</td>
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<td>flyback2_v_sin_v_sin1.amplitude-90</td>
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<tr>
<td>efficiency</td>
<td>efficiency = power_out / power_in</td>
<td>0.870595622795</td>
<td>Complete</td>
<td>Complete</td>
</tr>
<tr>
<td>power_in</td>
<td>power_in = (mess1-mess2)/freq</td>
<td>58.1488388357</td>
<td>Complete</td>
<td>Complete</td>
</tr>
<tr>
<td>power_out</td>
<td>power_out = (mess2-mess1)/freq</td>
<td>50.7413091465</td>
<td>Complete</td>
<td>Complete</td>
</tr>
<tr>
<td>power_d1</td>
<td>power_d1 = (mess2-mess1)/freq</td>
<td>2.04641618252693</td>
<td>Complete</td>
<td>Complete</td>
</tr>
<tr>
<td>power_d2</td>
<td>power_d2 = (mess2-mess1)/freq</td>
<td>1.08604087819610</td>
<td>Complete</td>
<td>Complete</td>
</tr>
<tr>
<td>power_d3</td>
<td>power_d3 = (mess2-mess1)/freq</td>
<td>1.0253116922650696</td>
<td>Complete</td>
<td>Complete</td>
</tr>
<tr>
<td>power_d4</td>
<td>power_d4 = (mess2-mess1)/freq</td>
<td>0.27213834076785</td>
<td>Complete</td>
<td>Complete</td>
</tr>
<tr>
<td>power_d5</td>
<td>power_d5 = (mess2-mess1)/freq</td>
<td>0.700739531622</td>
<td>Complete</td>
<td>Complete</td>
</tr>
<tr>
<td>power_d6</td>
<td>power_d6 = (mess2-mess1)/freq</td>
<td>0.86976791676666</td>
<td>Complete</td>
<td>Complete</td>
</tr>
<tr>
<td>power_core</td>
<td>power_core = (mess2-mess1)/freq</td>
<td>2.065930486528</td>
<td>Complete</td>
<td>Complete</td>
</tr>
<tr>
<td>power_winding</td>
<td>power_winding = (mess2-mess1)/freq</td>
<td>0.99531697941901</td>
<td>Complete</td>
<td>Complete</td>
</tr>
<tr>
<td>power_NTC</td>
<td>power_NTC = (mess2-mess1)/freq</td>
<td>1.183948375253</td>
<td>Complete</td>
<td>Complete</td>
</tr>
<tr>
<td>power_TL01</td>
<td>power_TL01 = (mess2-mess1)/freq</td>
<td>0.01402756955991</td>
<td>Complete</td>
<td>Complete</td>
</tr>
<tr>
<td>power_R12</td>
<td>power_R12 = (mess2-mess1)/freq</td>
<td>0.127992161017</td>
<td>Complete</td>
<td>Complete</td>
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<tr>
<td>power_R2</td>
<td>power_R2 = (mess2-mess1)/freq</td>
<td>0.018663293692</td>
<td>Complete</td>
<td>Complete</td>
</tr>
<tr>
<td>power_R3</td>
<td>power_R3 = (mess2-mess1)/freq</td>
<td>0.854413798655</td>
<td>Complete</td>
<td>Complete</td>
</tr>
</tbody>
</table>

NOTE: Restored :flyback2_v_sin_v_sin1.amplitude to its original initial value expression/association.

Task CloseFiles
<table>
<thead>
<tr>
<th>Task Status</th>
<th>Description</th>
<th>Task Label</th>
<th>Task Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Complete</td>
<td>power_in</td>
<td>vary</td>
<td>vary-param flyback2v_sin_v_sin1.amplitude-d5</td>
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<tr>
<td>Complete</td>
<td>power_out</td>
<td>vary</td>
<td>vary-param flyback2v_sin_v_sin1.amplitude-d5</td>
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<tr>
<td>Complete</td>
<td>efficiency</td>
<td>vary</td>
<td>vary-param flyback2v_sin_v_sin1.amplitude-d5</td>
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<tr>
<td>Complete</td>
<td>power_D1</td>
<td>vary</td>
<td>vary-param flyback2v_sin_v_sin1.amplitude-d5</td>
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<tr>
<td>Complete</td>
<td>power_D2</td>
<td>vary</td>
<td>vary-param flyback2v_sin_v_sin1.amplitude-d5</td>
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<tr>
<td>Complete</td>
<td>power_D3</td>
<td>vary</td>
<td>vary-param flyback2v_sin_v_sin1.amplitude-d5</td>
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<tr>
<td>Complete</td>
<td>power_D4</td>
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<td>vary-param flyback2v_sin_v_sin1.amplitude-d5</td>
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<td>vary-param flyback2v_sin_v_sin1.amplitude-d5</td>
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<td>power_D6</td>
<td>vary</td>
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<tr>
<td>Complete</td>
<td>power_core</td>
<td>vary</td>
<td>vary-param flyback2v_sin_v_sin1.amplitude-d5</td>
</tr>
<tr>
<td>Complete</td>
<td>power_model</td>
<td>vary</td>
<td>vary-param flyback2v_sin_v_sin1.amplitude-d5</td>
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<tr>
<td>Complete</td>
<td>power_NTC</td>
<td>vary</td>
<td>vary-param flyback2v_sin_v_sin1.amplitude-d5</td>
</tr>
<tr>
<td>Complete</td>
<td>power_R1</td>
<td>vary</td>
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<td>vary</td>
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<tr>
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<td>power_R3</td>
<td>vary</td>
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<tr>
<td>Complete</td>
<td>power_R4</td>
<td>vary</td>
<td>vary-param flyback2v_sin_v_sin1.amplitude-d5</td>
</tr>
</tbody>
</table>

**Most dissipative components**

NOTE: Restored flyback2v_sin_v_sin1.amplitude to its original initial value expression/association.
Conduction Losses

Switching Losses

NTC thermistor adjusted to 2.8Ω

Rac = 35kΩ added across primary to account for air gap fringing field losses
NTC thermistor adjusted to 2.8Ω

Rac = 35kΩ added across primary to account for air gap fringing field losses
Conclusion

• High fidelity models characterized from datasheets
• Automated design verification / regression testing over broad operating conditions
  – Experiment Analyzer
  – Fault Injection
  – Worst Case Analysis / Extreme Value Analysis
  – Statistical variations (Monte Carlo)
• Scalable solution
  – Capacity for large designs (network of power converters)
  – User or site (company wide) model library management
  – Distributed/grid iterative analysis (parametric Vary, Monte-Carlo, Worst-Case Analysis, Fault)
Thank You

- Flyback design available on Synopsys Forum
- Improved IGBT Tool in 2016.03

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