A simple, robust and low-EMI solution for inverter gate-driver bias supplies
Agenda

• Inverter and isolated gate driver bias supply architectures
• Different ways of creating isolated bias supply
  – Control method
  – Topology
  – Transformer
• LLC based open-loop isolated bias supply
  – Operation principles
  – Circuit variations
  – Voltage regulation
  – Multiple outputs
• Performance demonstration
Inverters in different applications

- Traction inverter
- Motor drive
- UPS
- Onboard charger
Example: inverter isolation boundaries

How to bias the isolated drivers?
Different gate driver architectures

- Centralized system has lowest cost, but heavy and difficult to manage fault
- Distributed system distribute the weight and fault, but more expensive
- Semi-distributed is somewhere in the middle
Output voltage control

- Close loop
  - Secondary side feedback
    - Well regulated output
    - No need pre-regulator
    - More components
    - Less reliable due to the opto coupler

- Close loop
  - Primary side feedback
    - Semi regulated output
      - Determined by cross regulation
    - No need pre-regulator
    - Noise sensitive due to the output voltage sampling method

- Open loop
  - No feedback
    - No control loop, robust operation
    - Less noise
      - Coupling only through the transformer
    - Unregulated output, need pre-regulator

Open-loop control provides a robust solution
Topologies used for isolated bias supply

Flyback

Push-pull

LLC
Flyback converter topology

• Flyback can easily create multiple outputs
  • Voltage proportional to the turns ratio
  • Suitable for centralized architecture
• Can be controlled with opto feedback or primary side feedback
• Need well coupled transformer

Basic Flyback Circuit
Push-pull topology

• With 50% duty cycle operation, in each half switching cycle, output is connected with input through the transformer
• Filter inductor is needed if the duty cycle is less than 50%
• Transformer needs to have low leakage inductance to avoid ringing and device over stress
• Good for distributed and semi-distributed architecture
Transformer parameter impacts to system EMI

- High dv/dt couples through transformer parasitic capacitor to the primary side
- Higher EMI noise
- Extra loss
- More noise to the controller, CMTI issue
- It gets worse with SiC or GaN devices with higher dv/dt
Transformer structure: less parasitic capacitance

The capacitance can be reduced by increasing the insulator thickness. Less effective due to the large surface area.

Split bobbin reduces the capacitance by reducing the surface area and increasing the distance. Much smaller capacitance can be achieved.

Increasing the distance reduces the capacitance while increasing the leakage inductance.
How topologies respond to leakage inductance

Flyback

- Leakage energy can’t be transferred to secondary side
- Leakage causes
  - More EMI noise due to ringing
  - More loss
  - More device stress
- Leakage needs to be minimized

Push-pull

LLC

- Leakage is part of resonant circuit
- Leakage energy is fully recovered
- No extra ringing caused by the leakage
- No limitations on the leakage inductance
• At resonant frequency, the impedance of resonant tank is equal to zero, input and output is shorted through the transformer. Fixed frequency open-loop control is possible

• The leakage inductance of the transformer can be used as the resonant inductor
## Transformers for isolated bias supply

<table>
<thead>
<tr>
<th></th>
<th>LLC Transformer</th>
<th>Push-Pull Transformer</th>
<th>Three-winding Flyback</th>
<th>Two-winding PSR Flyback</th>
<th>Half-Bridge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Core</td>
<td>Core</td>
<td>Core</td>
<td>Core</td>
<td>Core</td>
<td>Core</td>
</tr>
<tr>
<td>Bobbin</td>
<td>Bobbin</td>
<td>Bobbin</td>
<td>Bobbin</td>
<td>Bobbin</td>
<td>Bobbin</td>
</tr>
<tr>
<td>Split bobbin</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Primary</td>
<td>Primary</td>
<td>Primary</td>
<td>Primary</td>
<td>Primary</td>
<td>Primary</td>
</tr>
<tr>
<td>Split Primary</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Capacitance
- **C_{Pri-Sec}**: ~20 pF
- **Secondary side windings need thicker insulation**

### CMTI
- **>150 V/ns**
- **Worse than LLC**

### Cost
- **1X**
- **>1.15**

### EMI
- **Best**
- **Good**

### Regulation
- **Good**
- **Better**

### Summary

LLC converter provides an order of amplitude capacitance reduction.
LLC converter variations

Transformer variations

Rectification Variations

Two-winding
Center-tap
Multi-output

Full-wave
Center-tap
Voltage-doubler
Voltage-doubler
Primary vs. Secondary side resonant

Secondary side resonant is less sensitive to switching frequency error
The voltage regulation is determined by transformer turns ratio and resistive loss, as well as the diode drop.

It is critical to keep the resistive loss low to get best load regulation.
Illustration of voltage regulation

- For a fix switching frequency inverter, the gate driver load is fixed
  - The output voltage regulation can be very tight
- For a variable frequency inverter, the gate driver load varies
  - The output voltage varies more
- The standby mode load voltage tends to go up
  - It could be too high that need extra help from a Zener diode
  - It is mainly determined by the diode junction capacitor

<table>
<thead>
<tr>
<th>Normal operation</th>
<th>Standby mode load</th>
<th>Vout</th>
</tr>
</thead>
<tbody>
<tr>
<td>Min load</td>
<td>Max load</td>
<td></td>
</tr>
<tr>
<td>Fixed Fre.</td>
<td>Iload_3</td>
<td>Iload_3</td>
</tr>
<tr>
<td>Var. Fre.</td>
<td>Iload_1</td>
<td>Iload_2</td>
</tr>
</tbody>
</table>
Split single output voltage into dual outputs

**Zener split**
- Lowes cost
- Unregulated outputs

**Shunt Regulator**
- Higher cost
- Regulated negative output
- Unregulated positive output

**Shunt Regulator & Linear regulator**
- Highest cost
- Regulated output
UCC25800-Q1
Low-cost LLC transformer driver with high performance

**Features**

- Operation from 9 V to 34 V (40 V Abs Max)
- 6 W from 24-V input, Up to 10 W from 34-V input
- Integrated half-bridge MOSFETs
- Programmable fixed switching frequency up to 1.2 MHz
  - 1.2 MHz default, resistor settable 100 kHz – 1 MHz
  - Frequency accuracy +/-6% maximum over temperature
  - External SYNC function
- Drive multiple transformers with one UCC25800-Q1
- Automatic dead time adjustment with programmable maximum
- Integrated soft-start
- Disable pin with fault code output
- Two-level over current protection
  - Programmable via external resistor
  - UCC25800L is latched after over current
  - UCC25800R is retry after over current
- Over Temperature Protection
  - 160°C Junction
  - 10°C Hysteresis
- AEC Q100 Qualified

**Benefits**

- Low common mode noise due to minimal interwinding capacitance in transformer
- Simple design, highly integrated, no bootstrap capacitor
- High switching frequency for smaller size and more robustness

[Disclaimer: Specs, features & pinouts subject to change without prior notice.]
UCC25800-Q1 measurement data

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>SPECIFICATIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input voltage range</td>
<td>6V – 26V</td>
</tr>
<tr>
<td>Output voltage and current</td>
<td>+18V / -5V</td>
</tr>
<tr>
<td>Switching frequency</td>
<td>2.2MHz and 500 kHz</td>
</tr>
<tr>
<td>Isolation</td>
<td>Yes, 2500 VAC (1 sec)</td>
</tr>
<tr>
<td>Topology</td>
<td>SEPIC + Open loop LLC transformer driver</td>
</tr>
</tbody>
</table>

Predictable Startup of +/- rails

1% Load Regulation

Surpasses CISPR 25 Class 5 EMI Standard

Pass - LLC Board Only with Filter
Multiple outputs

Driving one transformer with multiple secondary side windings

Driving multiple two winding transformers
Example: driving multiple transformers

Single primary side power stage drives three transformers and secondary side circuits.
Three matched output voltages are created.
EMI noise performance comparison

5-V push-pull

24-V LLC

24-V Flyback

LLC has much lower high frequency EMI noise

*No EMI filter added
EMI noise when connected with inverter

When connected with inverter and bias the isolated gate drivers, LLC solution provides a much lower EMI noise due to the less parasitic capacitance.
CMTI performance

Operation is not affected by >150 V/ns CMTI
Transformer design considerations

- Transformer design is simple
  - Two windings
  - Turns ratio is roughly the voltage ratio between the input and output voltage (plus the diode drop)
  - Square voltage on primary side, setting up the volt-second rating
  - Lowest Rac possible
  - No airgap

- Once the transformer is made, measure the leakage inductance from secondary side
  - Short the primary side while measuring

- Match the leakage inductance with resonant capacitor

<table>
<thead>
<tr>
<th>Part number (Wurth)</th>
<th>Turn ratio</th>
<th>Leakage inductance</th>
<th>Input / Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>750319331</td>
<td>1:1</td>
<td>1.4 uH</td>
<td>24 V/24 V</td>
</tr>
<tr>
<td>750319177</td>
<td>1.67:1</td>
<td>1.48 uH</td>
<td>15 V/24 V</td>
</tr>
<tr>
<td>750319177</td>
<td>1:1.67</td>
<td>0.53 uH</td>
<td>24 V/15 V</td>
</tr>
</tbody>
</table>
Summary

• Isolated bias supply is needed for biasing the isolated gate drivers in the inverters
  – Open loop control provides a robust solution, less noise sensitive

• LLC topology is able to utilize the transformer leakage inductance and minimize the transformer primary side to secondary side parasitic capacitance
  – Less EMI noise

• The open loop LLC converter provides a simple, robust solution
  – Less EMI
  – High CMTI
  – Good voltage regulation
  – Multiple output capability
IMPORTANT NOTICE AND DISCLAIMER

TI PROVIDES TECHNICAL AND RELIABILITY DATA (INCLUDING DATASHEETS), DESIGN RESOURCES (INCLUDING REFERENCE DESIGNS), APPLICATION OR OTHER DESIGN ADVICE, WEB TOOLS, SAFETY INFORMATION, AND OTHER RESOURCES “AS IS” AND WITH ALL FAULTS, AND DISCLAIMS ALL WARRANTIES, EXPRESS AND IMPLIED, INCLUDING WITHOUT LIMITATION ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE OR NON-INFRINGEMENT OF THIRD PARTY INTELLECTUAL PROPERTY RIGHTS.

These resources are intended for skilled developers designing with TI products. You are solely responsible for (1) selecting the appropriate TI products for your application, (2) designing, validating and testing your application, and (3) ensuring your application meets applicable standards, and any other safety, security, or other requirements. These resources are subject to change without notice. TI grants you permission to use these resources only for development of an application that uses the TI products described in the resource. Other reproduction and display of these resources is prohibited. No license is granted to any other TI intellectual property right or to any third party intellectual property right. TI disclaims responsibility for, and you will fully indemnify TI and its representatives against, any claims, damages, costs, losses, and liabilities arising out of your use of these resources.

TI's products are provided subject to TI's Terms of Sale (https:www.ti.com/legal/termsofsale.html) or other applicable terms available either on ti.com or provided in conjunction with such TI products. TI’s provision of these resources does not expand or otherwise alter TI’s applicable warranties or warranty disclaimers for TI products.

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265
Copyright © 2021, Texas Instruments Incorporated