Driving SiC MOSFETs in auxiliary power supplies
Content

• Block diagram of end equipment with high-voltage bias power
• Flyback topology candidate comparison
• Design considerations of SiC flyback control circuitry
• Summary
SiC material properties + power system benefits

### Intrinsic material properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Definition</th>
<th>Si</th>
<th>GaN</th>
<th>SiC – 4H</th>
</tr>
</thead>
<tbody>
<tr>
<td>$E_g$ (eV)</td>
<td>Bandgap energy</td>
<td>1.12</td>
<td>3.4</td>
<td>3.2</td>
</tr>
<tr>
<td>$E_{BR}$ (MV/cm)</td>
<td>Critical field breakdown voltage</td>
<td>0.3</td>
<td>3.3</td>
<td>3.5</td>
</tr>
<tr>
<td>$v_s$ ($\times 10^7$ cm/s)</td>
<td>Saturation velocity</td>
<td>1.0</td>
<td>2.5</td>
<td>2.2</td>
</tr>
<tr>
<td>$\mu$ (cm$^2$/V.s)</td>
<td>Electron mobility</td>
<td>1400</td>
<td>900-2000</td>
<td>900</td>
</tr>
<tr>
<td>$\lambda$ (W/cm.K)</td>
<td>Thermal conductivity</td>
<td>1.3</td>
<td>1.5</td>
<td>4.5</td>
</tr>
</tbody>
</table>

### Properties leading to system benefits

- **Impact on operation**: Lower switching losses, System...
  1. Size, 2. Cost, 3. Weight Reduction
- **Impact on power stage**: High-voltage operation, Higher switching frequency + Smaller filters & passives
- **Impact on end equipment**: Fewer cooling needs
Aux power supplies in central PV inverter

- **Where:**
  - Typical power levels of 20 W to 150 W
  - Operating input voltage range: 1000 V to 1500 V DC

- **Why SiC?**
  - Higher VDS rating (1700 V SiC)
  - High efficiency
Aux power supply of electricity meter

• Where:
  – Typical power levels of 15 W – 20 W
  – Operating input voltage range: 300 V to 950 V DC

• Why SiC?
  – Higher VDS rating
Aux power supply in AC motor drive

- **Where:**
  - Typical power levels of 20 W – 60 W
  - Operating input voltage range:

<table>
<thead>
<tr>
<th>Grid voltage</th>
<th>Input voltage range</th>
</tr>
</thead>
<tbody>
<tr>
<td>200 vac, 3phase</td>
<td>100 V – 400 V</td>
</tr>
<tr>
<td>380 – 480 vac, 3phase</td>
<td>200 V – 820 V</td>
</tr>
<tr>
<td>525-690 vac, 3phase</td>
<td>300 V – 1130 V</td>
</tr>
</tbody>
</table>

- **Why SiC?**
  - Higher VDS rating
  - Removal of heatsink

SiC Flyback Converter
Aux power supply in traction inverter of EV

- **Where:**
  - Redundant/back-up power supplies using Flyback topology
  - Typical power levels of 10 W to 20 W
  - Operating input voltage range: 50 V to 1 kV DC

- **Why SiC?**
  - Higher VDS rating (1700 V SiC)
  - High Efficiency
Traction inverter bias power supply configurations

Case 1: 12 V Vbatt to 24 V

Case 2: DC/DC (1~6) to SiC Flyback

Case 3: DC/DC (1~6) to SiC Flyback

Case 4: DC/DC (1~6) to SiC Flyback

SiC Flyback

800 V Vbatt (30 - 960 V)

12 V Vbatt

24 V

V_backup

DC/DC (1~6)

800 V Vbatt (30 - 960 V)

24 V

SiC Flyback

V_backup

800 V Vbatt (30 - 960 V)

DC/DC (1~3)

24 V

SiC Flyback

DC/DC (1~3)
Content

• Block diagram of end equipment with high-voltage bias power
• **Flyback topology candidate comparison**
• Design considerations of SiC flyback control circuitry
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**Flyback Topology Candidate: Loss Comparison**

Specifications: 800-V Vin to 15 Vout. Pout = 60 W, fsw=140 kHz, CCM, T_J=125°C, T_A=105°C

<table>
<thead>
<tr>
<th>Loss Type</th>
<th>Cascoded Si Flyback (900 V, 1.2 Ω, IPD90R1K2C3ATMA1 x 2)</th>
<th>SiC Flyback (1700 V, 1.2 Ω, SCT2H12NY)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conduction Loss</td>
<td>0.304 W for Rds(on) at 125°C = 2.1 Ω x 2</td>
<td>0.124 W Rds(on) at 125°C = 1.71 Ω</td>
</tr>
<tr>
<td>Turn-on Loss</td>
<td>0.84 W for 0-500V Eoss (0.42W x 2)</td>
<td>1.14 W for 0-1000V Eoss</td>
</tr>
<tr>
<td>Gate Driving Loss</td>
<td>0.176 W for 0-15V gate drive (88mW x 2)</td>
<td>0.035 W for 0-18V gate drive</td>
</tr>
<tr>
<td>Sum</td>
<td>1.62 W (not including gate clamp loss of cascade switch)</td>
<td>1.3 W</td>
</tr>
</tbody>
</table>
TIDA-00173 (Cascoded Flyback)

400-V to 690-V AC Input, 50-W Flyback Isolated Power Supply Reference Design for Motor Drives
**Flyback Topology Comparison: BOM Difference**

<table>
<thead>
<tr>
<th></th>
<th><strong>Cascoded Si Flyback</strong></th>
<th><strong>SiC Flyback</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(900 V, 1.2 Ω, IPD90R1K2C3ATMA1 x 2)</td>
<td>(1700 V, 1.2 Ω, SCT2H12NY)</td>
</tr>
<tr>
<td>MOSFET</td>
<td>$0.2 \times 2 = 0.4$</td>
<td>$1.0 \times 1 = 1.0$</td>
</tr>
<tr>
<td>Gate Clamp</td>
<td>$0.15 \times 2 = 0.3$</td>
<td>$0$</td>
</tr>
<tr>
<td>TVS diode</td>
<td>$0.01 \times 5 = 0.05$</td>
<td></td>
</tr>
<tr>
<td>HV resistor stack</td>
<td>470kΩ, 0.1W: $0.05 \times 2 = 0.1$</td>
<td></td>
</tr>
<tr>
<td>Clamp Capacitors</td>
<td>100pF, 500V, X7R:</td>
<td></td>
</tr>
<tr>
<td>Heatsink</td>
<td>513201B02500G: $0.5 \times 2 = 1.0$</td>
<td>513201B02500G: $0.5 \times 1 = 0.5$</td>
</tr>
<tr>
<td>Sum</td>
<td>$1.85$</td>
<td>$1.5$</td>
</tr>
</tbody>
</table>
TIDA-01505 (SiC Flyback) Automotive 40V-1000Vin, 15Vout, 60W Flyback Reference Design for 800-V Battery System

**Design Features**

- Wide-Vin isolated Flyback DC/DC converter over the Ultra wide input voltage range of 40 V to 1000 V DC, up to 1200 V transient.
- Regulated output voltage 15 V (<5% regulation) and output current up to 4 A.
- SiC MOSFET solution with high voltage rating, low gate charge and fast switching transients.
- SiC gate driver adaption from an integrated MOSFET gate driver utilizing center-tapped transformer.
- Constant switching frequency with duty cycle range from 15% to 80%.
- Current mode control with cycle-to-cycle over current limitation.
- Automotive Grade 1 qualified Transformer with Reinforced isolation (tested at 5.7 kV High-Pot).

**Tools & Resources**

- TIDA-01505 Tools Folder
- Test Data/Design Guide
- Design Files: Schematics, BOM and BOM Analysis, Design Files

**Design Benefits**

- Designed for isolated unidirectional power supplies in HEV/EV Traction Inverter systems.
- Support regenerative breaking with the minimum start-up voltage of 40V.
- Extendable to higher voltage and higher power range.
- Automotive Grade 1 qualified Transformer with Reinforced isolation.

![Flyback Controller Diagram](image-url)
Experimental Results of TIDA-01505 (SiC Flyback)

- Start-up
- Shutdown
- Load transient response
- Measured efficiency
Content

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## General purpose PWM controllers

<table>
<thead>
<tr>
<th>Parameter</th>
<th>UCC28C4x</th>
<th>UCC280x UCC2813-x</th>
<th>UC284x A TL284xB</th>
<th>UC284x TL284x</th>
</tr>
</thead>
<tbody>
<tr>
<td>Process technology</td>
<td>BiCMOS</td>
<td>BiCMOS</td>
<td>Bipolar</td>
<td>Bipolar</td>
</tr>
<tr>
<td>Absolute maximum VDD</td>
<td>20 V</td>
<td>12 V</td>
<td>30 V</td>
<td>30 V</td>
</tr>
<tr>
<td>Supply current at 50 kHz</td>
<td>2.3 mA</td>
<td>0.5 mA</td>
<td>11 mA</td>
<td>11 mA</td>
</tr>
<tr>
<td>Startup current</td>
<td>50 μA</td>
<td>0.1 mA</td>
<td>0.5 mA</td>
<td>1 mA</td>
</tr>
<tr>
<td>Over-current propagation delay</td>
<td>50 ns</td>
<td>100 ns</td>
<td>150 ns</td>
<td>150 ns</td>
</tr>
<tr>
<td>Reference voltage accuracy</td>
<td>±1%</td>
<td>±2%</td>
<td>±2%</td>
<td>±2%</td>
</tr>
<tr>
<td>E/A reference accuracy</td>
<td>±25 mV</td>
<td>±60 mV</td>
<td>±80 mV</td>
<td>±80 mV</td>
</tr>
<tr>
<td>Maximum operating frequency</td>
<td>1 MHz</td>
<td>1 MHz</td>
<td>500 kHz</td>
<td>500 kHz</td>
</tr>
<tr>
<td>Output rise/fall times</td>
<td>35 ns</td>
<td>44 ns</td>
<td>50 ns</td>
<td>50 ns</td>
</tr>
<tr>
<td>UVLO turn-on accuracy</td>
<td>±1.0 V</td>
<td>±1.2 V</td>
<td>±1.5 V</td>
<td>±1.5 V</td>
</tr>
</tbody>
</table>

**UC284x, TL284x, UCC280x, UCC2813-x, UCC28C4x are all P2P parts.**

**Improvements provide:**
- Greatly reduced power requirement
- Eliminates bootstrap supply
- Fewer external components
- Lower junction temperature
- Reduced stress during faults
- No current sense R/C filter networks
- Faster response to faults
- Higher frequency operations
Aux power supply using UCCx8C4y

Secondary Side Regulated Auxiliary Power Supply

Soft start

Slope compensation

Si MOSFET

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PWM Controller requirements for driving SiC MOSFET

<table>
<thead>
<tr>
<th>Ultra high-voltage (1700 V)</th>
<th>High-voltage (1200 V)</th>
<th>Mid-voltage (650 V to 900 V)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Vgs Max Recommended:</strong> 20V</td>
<td><strong>Vgs Max Recommended:</strong> 20V</td>
<td><strong>Vgs Max Recommended:</strong> 18V</td>
</tr>
<tr>
<td>Cree C2M1000170D</td>
<td>STmicro SCT10N120</td>
<td>Rohm SCT3120AL</td>
</tr>
<tr>
<td>Rohm SCT2H12NY</td>
<td>Microsemi MSC080SMA120J</td>
<td>STmicro SCTH35N65G2V</td>
</tr>
<tr>
<td>Littlefuse LSIC1MO170E</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Vgs Max Recommended:</strong> 15V</td>
<td><strong>Vgs Max Recommended:</strong> 18V</td>
<td><strong>Vgs Max Recommended:</strong> 15V</td>
</tr>
<tr>
<td>Infineon IMBF170R1K0M1</td>
<td>Infineon IMW120R350M1H</td>
<td>Onsemi NTBG020N090SC1</td>
</tr>
<tr>
<td><strong>Vgs Max Recommended:</strong> 15V</td>
<td></td>
<td>Cree E3M0280090D</td>
</tr>
<tr>
<td>Infineon IMW120R350M1H</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- High sensitivity of SiC FET on-resistance calls for
  - Less variation in controller output voltage
- High zero temp-co voltage of SiC FET calls for
  - Higher UVLO-off threshold from controller
- Commercial off-the-shelf SiC FET Vgs Max rating varies from manufacturer to manufacturer
  - Controller VDD has to be > 20V
- Requires clamped voltage at the output of the controller
  - Multiple clamp options for different Vgs ratings

Rohm 1700 V, 1.0Ω SiC MOSFET
SiC-based aux power supply using UCCx8C4y

**Pros:**
- Voltage accuracy
- Efficient SiC drive

**Cons:**
- High system cost
- High BOM count

UVLO Comparator:
- Implements UVLO turn-off threshold externally
- Choose external turn-off threshold less than the internal turn-on threshold
- Choose open-drain comparator e.g. TLV2352

LDO:
- Regulates the voltage across VDD
- Choose LDO output voltage less than Max allowable Vgs of SiC MOSFET
- Choose low-iq LDO e.g. TPS76901

Gate Driver:
- Choose Gate Driver with VDD greater than Max allowable Vgs of SiC MOSFET e.g. UC2705

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SiC-based aux power supply using UCCx8C4y

UVLO Comparator:
- Implements UVLO turn-off threshold externally
- Choose external turn-off threshold less than the internal turn-on threshold
- Choose open-drain comparator e.g. TLV2352

LDO:
- Regulates the voltage across VDD
- Choose LDO output voltage less than Max allowable Vgs of SiC MOSFET
- Choose low-iq LDO e.g. TPS76901

Pros:
➢ Voltage accuracy
➢ High system cost
➢ High BOM count
➢ Sub-optimal SiC drive

Cons:
➢ High system cost
➢ High BOM count
➢ Sub-optimal SiC drive
SiC-based aux power supply using UCCx8C4y

Pros:
➢ No optocoupler
➢ Low system cost

Cons:
➢ Poor voltage accuracy
➢ Sub-optimal SiC drive

UVLO Comparator:
• Implements UVLO turn-off threshold externally
• Choose external turn-off threshold less than the internal turn-on threshold
• Choose open-drain comparator e.g. TLV2352

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Summary

• Silicon MOSFETs are not desirable in high-voltage auxiliary power supplies due to their poor figure of merit and high cost

• Single-switch flyback with SiC MOSFET is the preferred topology for high-voltage auxiliary power supplies

• SiC MOSFETs allow greater system-level benefits, such as low cost, small size and high efficiency

• Gate drive of SiC MOSFET needs careful consideration:
  – SiC MOSFET on-resistance is highly sensitive to the gate voltage
  – Driving SiC MOSFET with insufficient voltage leads to thermal runaway

• GP PWM controllers along with necessary external components, such as comparator/LDO/gate driver, can drive SiC MOSFETs reliably and efficiently in high-voltage auxiliary power supplies
Thank you
Backup
SIMetrix model with external UVLO comparator
SIMetrix simulation with external UVLO comparator
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