Texas Instruments

HIGH VOLTAGE SEMINAR

SUTEJ REDDY CHALLA

HIGH VOLTAGE CONTROLLERS

DRIVING SiC MOSFETS IN AUXILIARY POWER SUPPLIES

Content

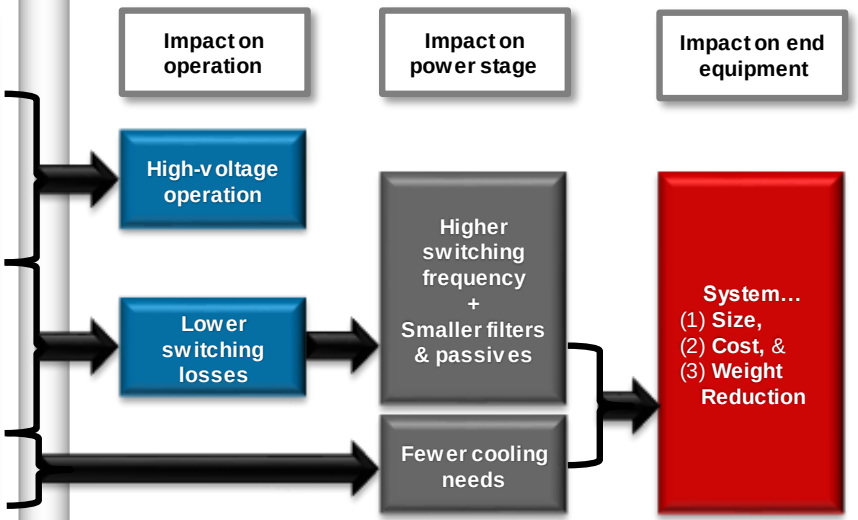
- **Block diagram of end equipment with high-voltage bias power**
- Flyback topology candidate comparison
- Design considerations of SiC flyback control circuitry
- Summary

SiC material properties + power system benefits

Intrinsic material properties

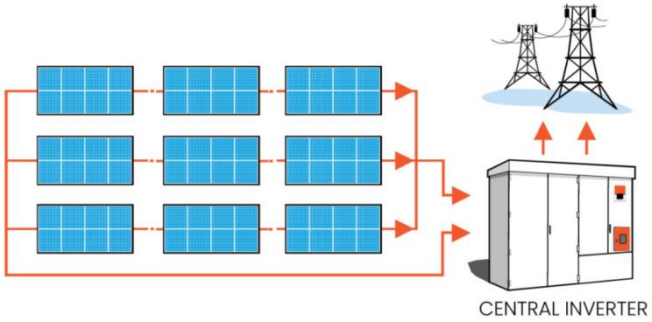
Property	Definition	Si	GaN	SiC – 4H
E_G (eV)	Bandgap energy	1.12	3.4	**3.2**
E_{BR} (MV/cm)	Critical field breakdown voltage	0.3	3.3	**3.5**
v_s (x10^7 cm/s)	Saturation velocity	1.0	2.5	**2.2**
μ (cm^2/V.s)	Electron mobility	1400	990-2000	**900**
λ (W/cm.K)	Thermal conductivity	1.3	1.5	**4.5**

Properties leading to system benefits

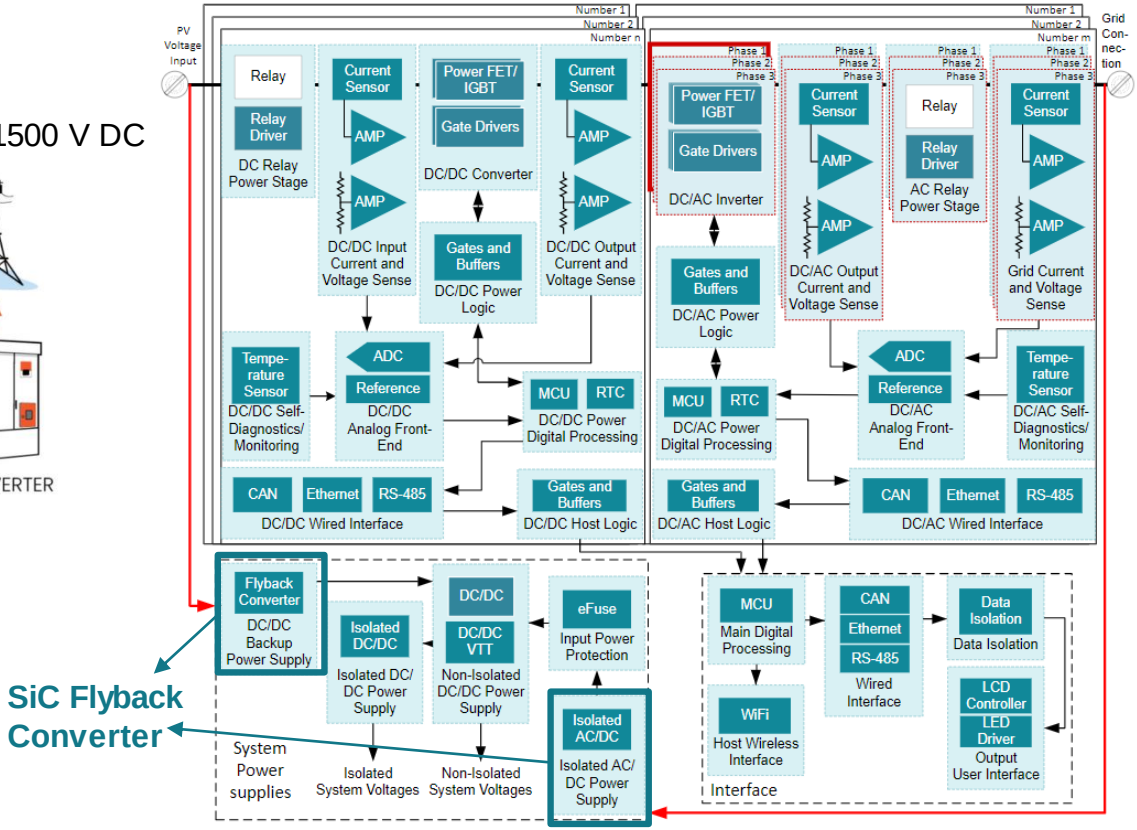


Aux power supplies in central PV inverter

- **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

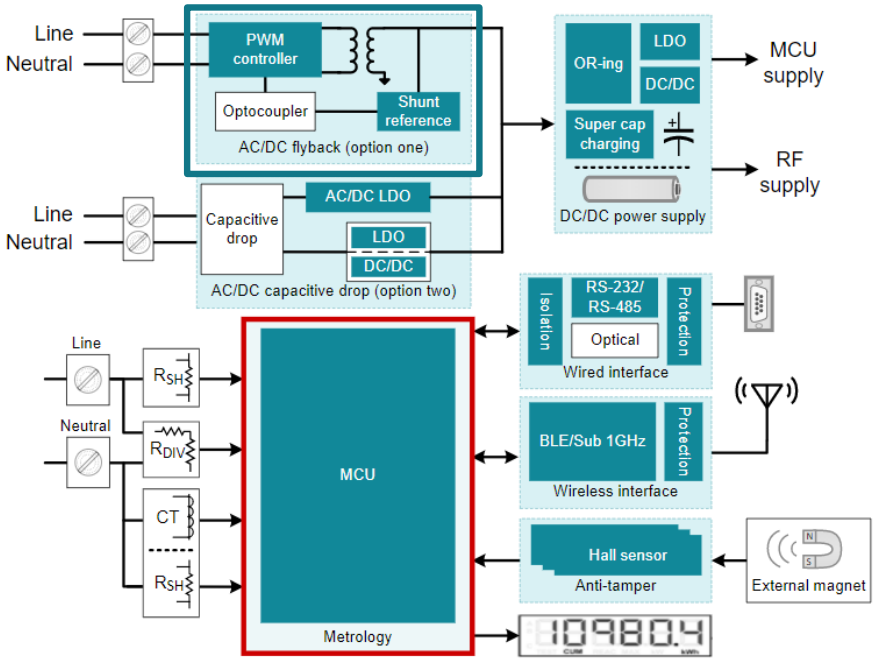


Aux power supply of electricity meter

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

- **Why SiC?**
  - Higher VDS rating

SiC Flyback Converter

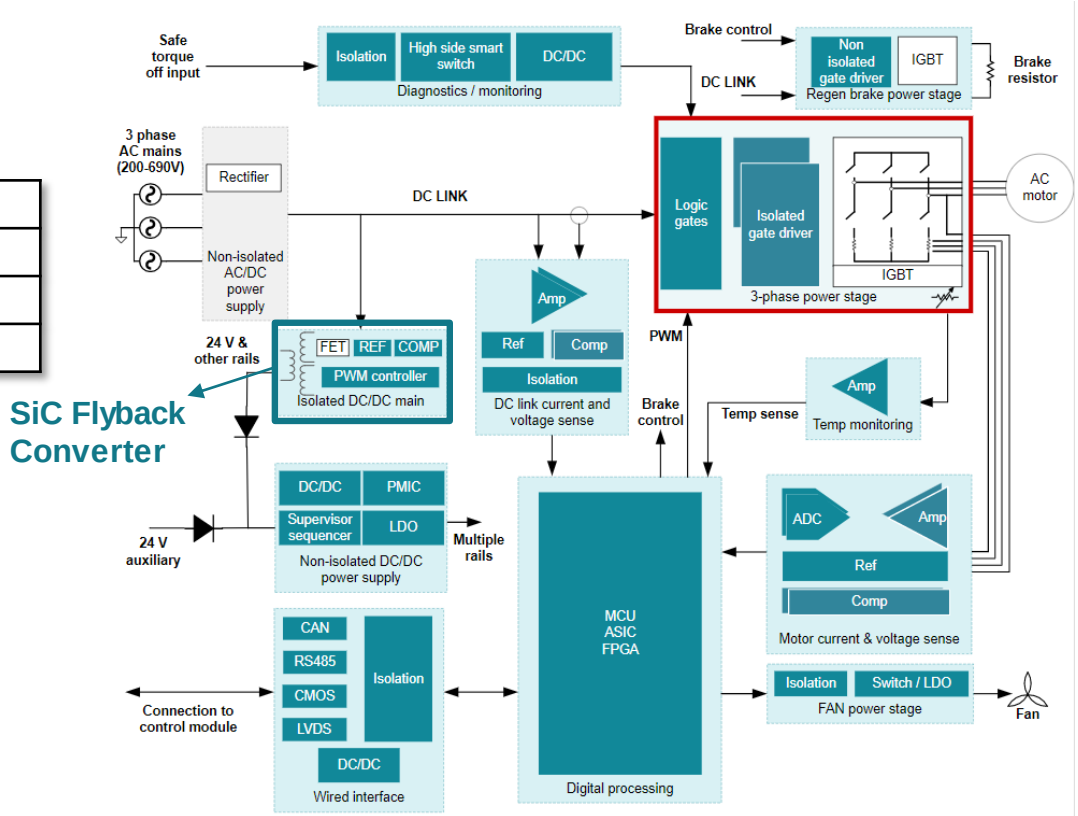


Aux power supply in AC motor drive

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

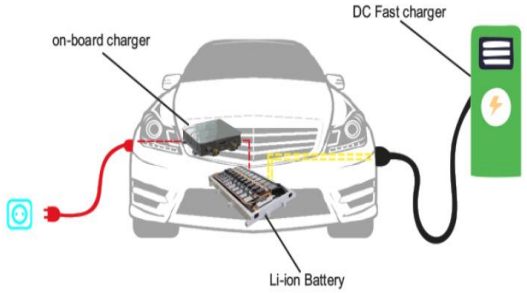
Grid voltage	Input voltage range
200 vac, 3phase	100 V – 400 V
380 – 480 vac, 3phase	200 V – 820 V
525-690 vac, 3phase	300 V – 1130 V

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



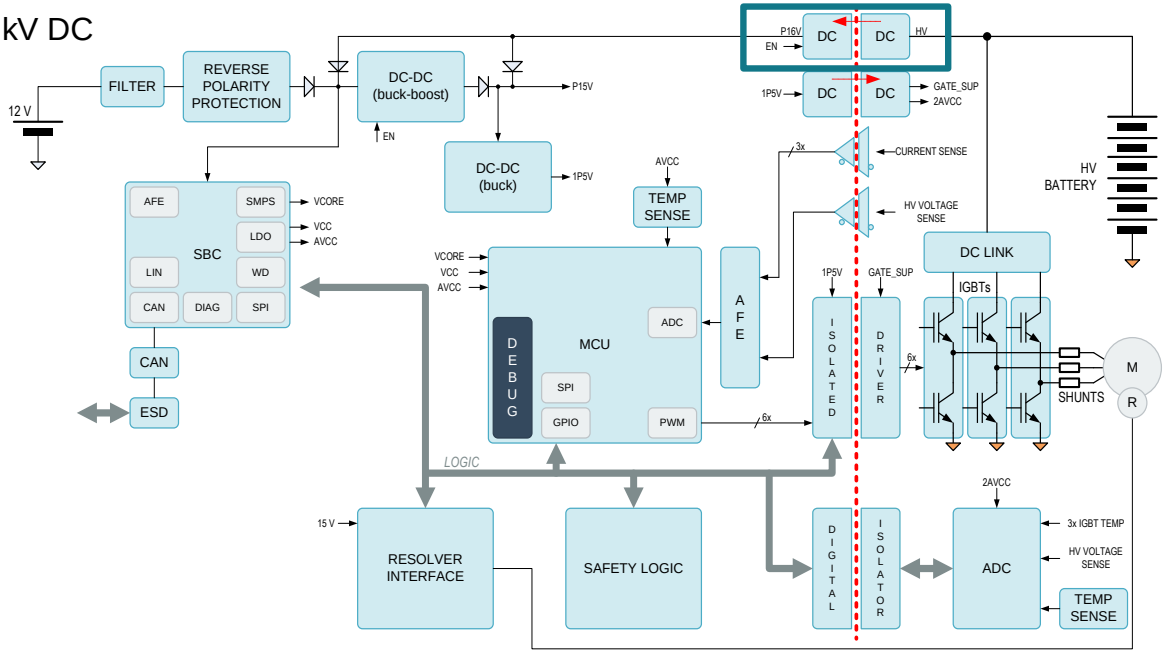
Aux power supply in traction inverter of EV

- **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

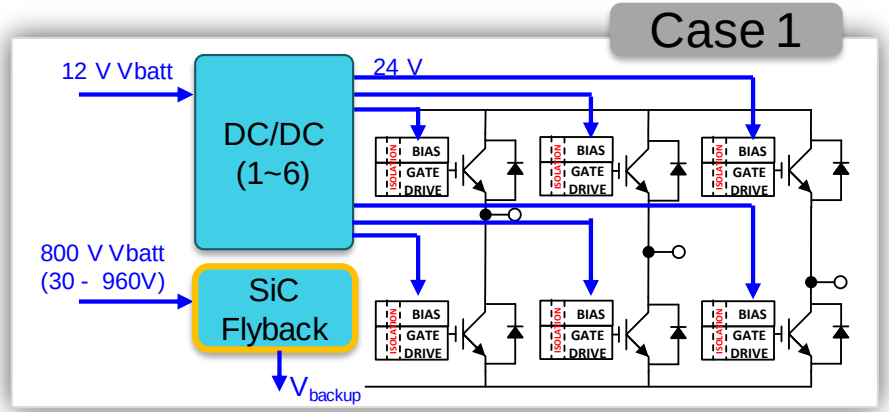


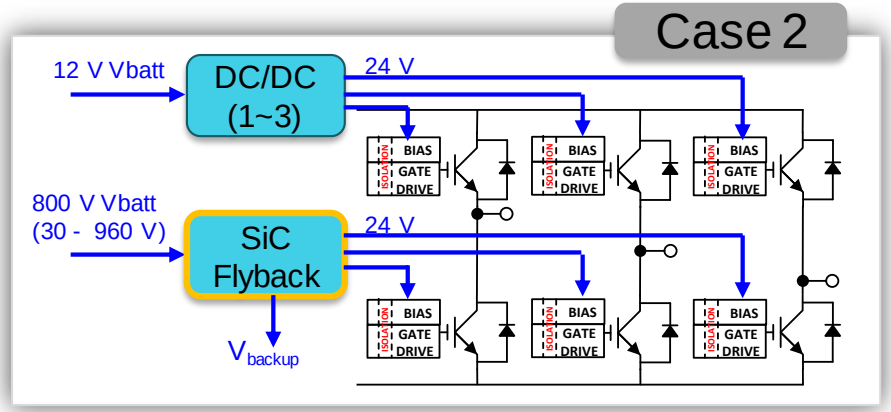
- **Why SiC?**
  - Higher VDS rating (1700 V SiC)
  - High Efficiency

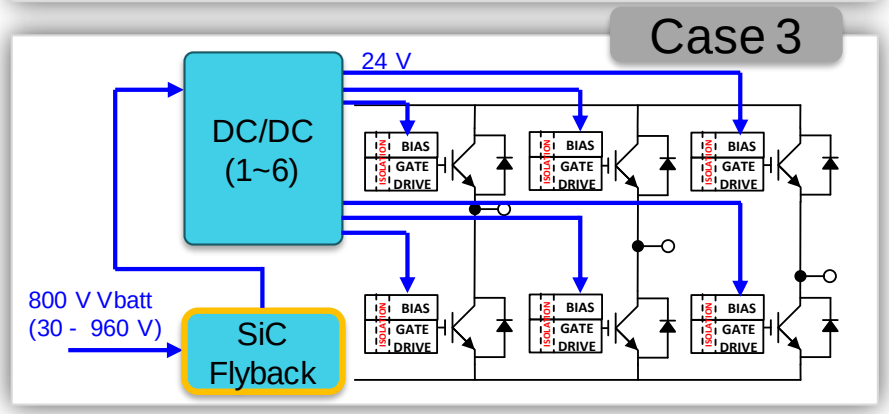
SiC Flyback Converter

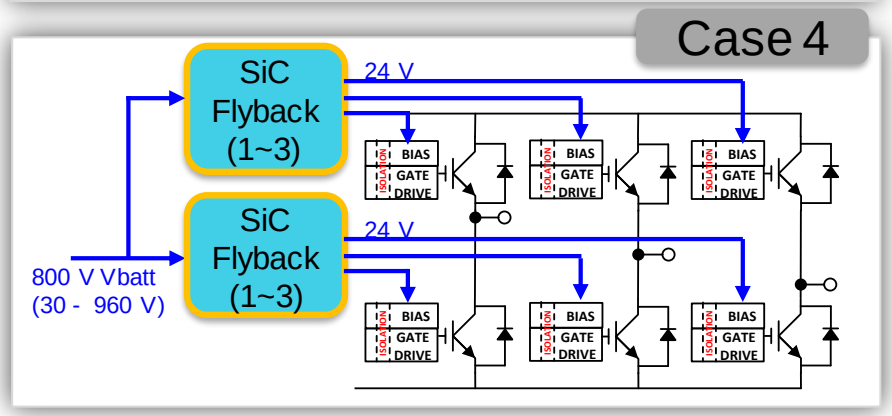


Traction inverter bias power supply configurations









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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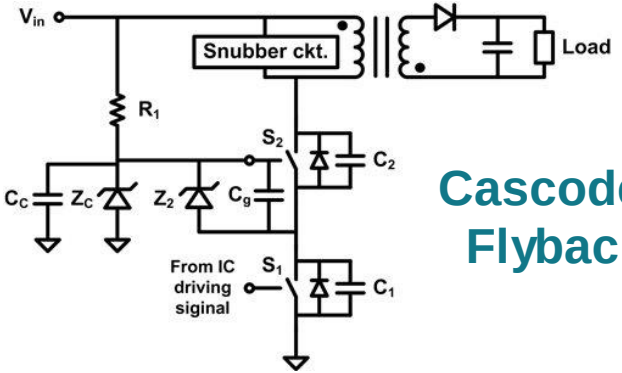
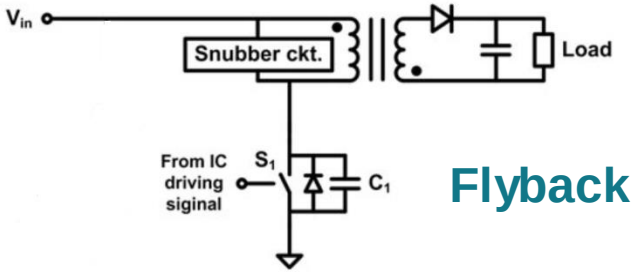
Flyback Topology Candidate: Loss Comparison



Cascoded Flyback



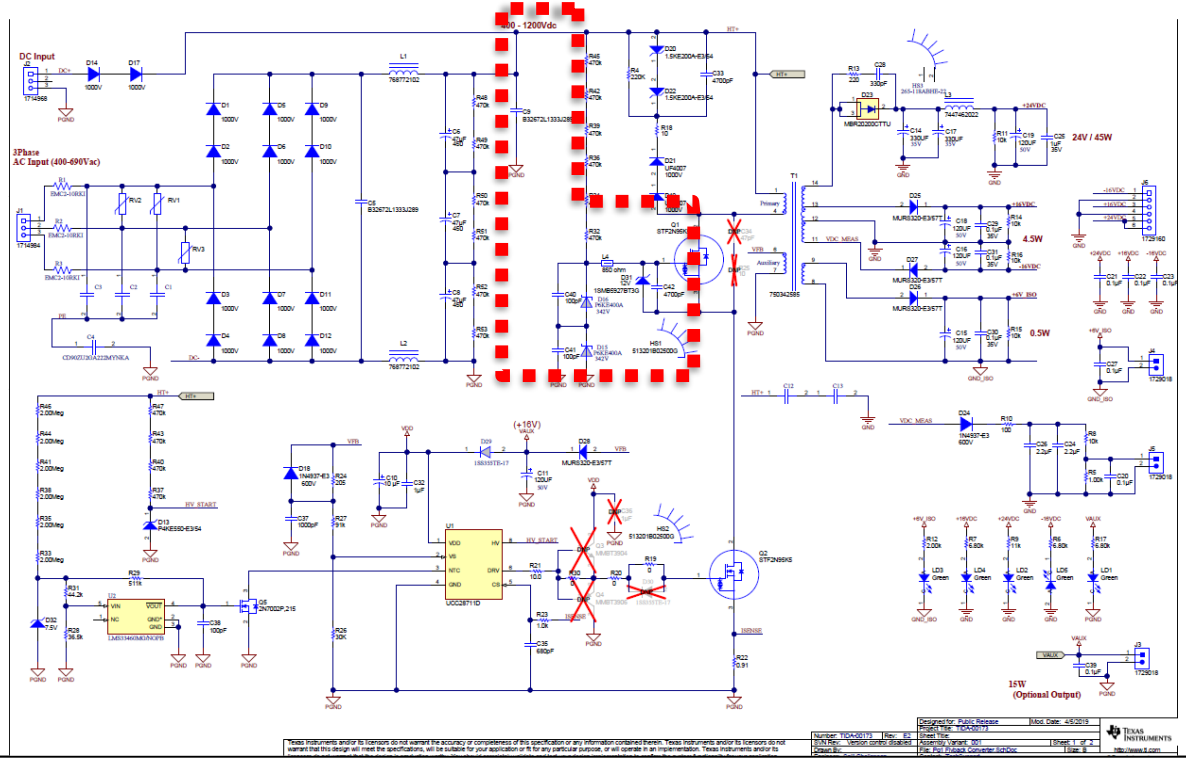
Flyback

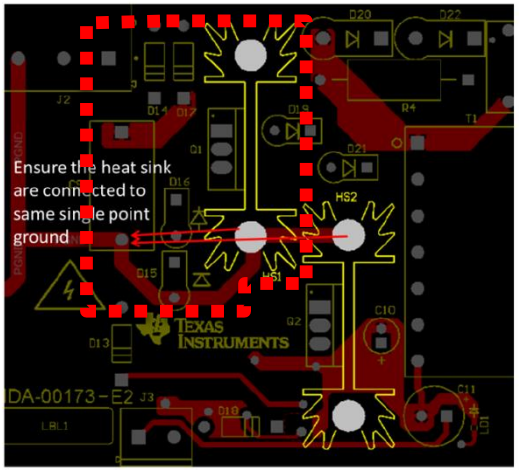
Specifications: 800-V Vin to 15 Vout. Pout = 60 W, fsw=140 kHz, CCM, T_J=125°C, T_A=105°C

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

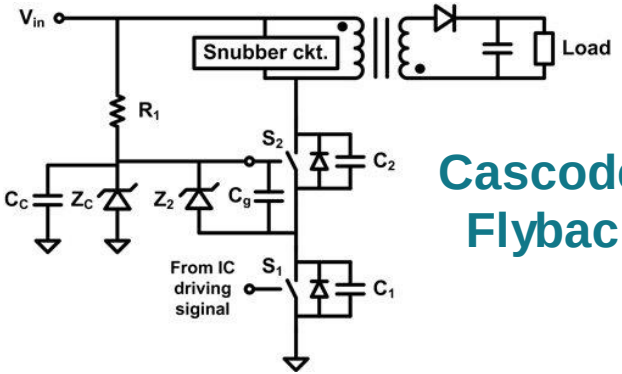
TIDA-00173 (Cascoded Flyback)

400-V to 690-V AC Input, 50-W Flyback Isolated Power Supply Reference Design for Motor Drives

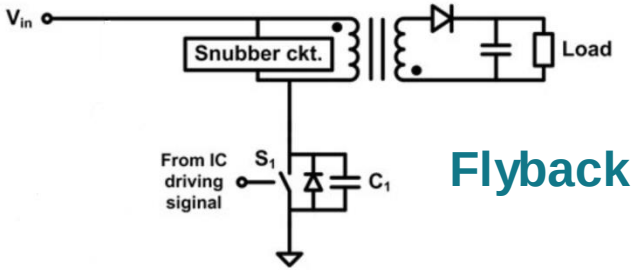




Flyback Topology Comparison: BOM Difference



Cascoded Flyback



Flyback

	Cascoded Si Flyback (900 V, 1.2 Ω, IPD90R1K2C3ATMA1 x 2)	SiC Flyback (1700 V, 1.2 Ω, SCT2H12NY)
MOSFET	$0.2 x 2 = $0.4	$1.0 x 1 = $1.0
Gate Clamp	342V, 1.1 A, TVS diode: $0.15 x 2 = $0.3 HV resistor stack 470kΩ, 0.1W: $~0.01 x 5 = $0.05 Clamp Capacitors 100pF, 500V, X7R: $0.05 x 2 =$0.1	0
Heatsink	513201B02500G: $0.5 x 2= $1.0	513201B02500G: $0.5 x 1= $0.5
Sum	$1.85	$1.5

TIDA-01505 (SiC Flyback) Automotive 40V-1000Vin, 15Vout, 60W Flyback Reference Design for 800-V Battery System

Design Features

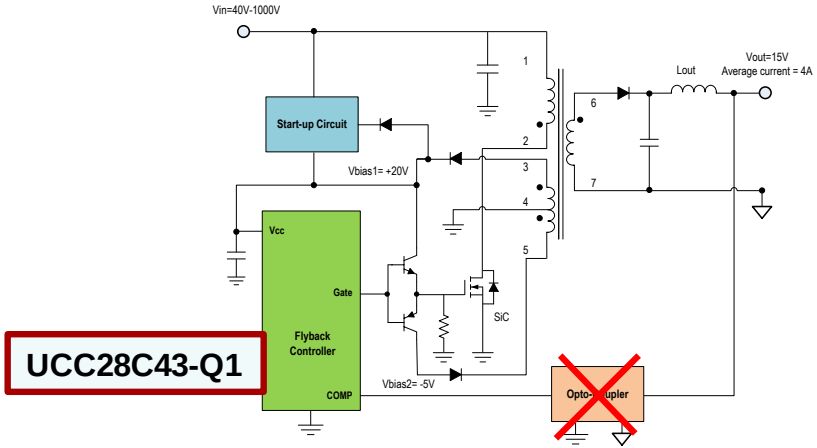
- Wide-Vin isolated Flyback DC/DC converter over the Ultra wide input voltage range of 40 V to 1000 V DC, up to 1200 V transient.
- Regulated output voltage 15 V (<5% regulation) and output current up to 4 A.
- SiC MOSFET solution with high voltage rating, low gate charge and fast switching transients.
- 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

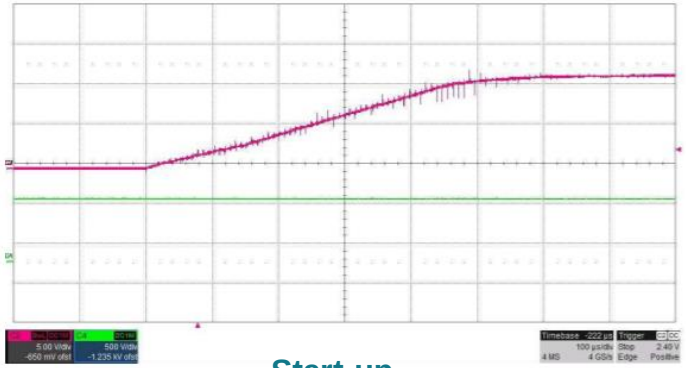
- **TIDA-01505 Tools Folder**
- **Test Data/Design Guide**
- **Design Files:** Schematics, BOM and BOM Analysis, Design Files

Design Benefits

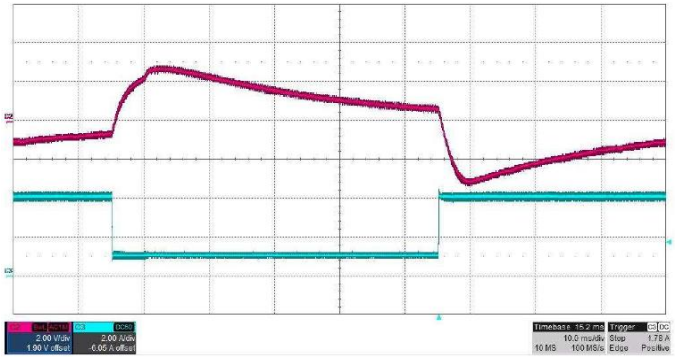
- Designed for isolated unidirectional power supplies in HEV/EV Traction Inverter systems.
- Support regenerative breaking with the minimum start-up voltage of 40V.
- Extendable to higher voltage and higher power range.
- Automotive Grade 1 qualified Transformer with Reinforced isolation.



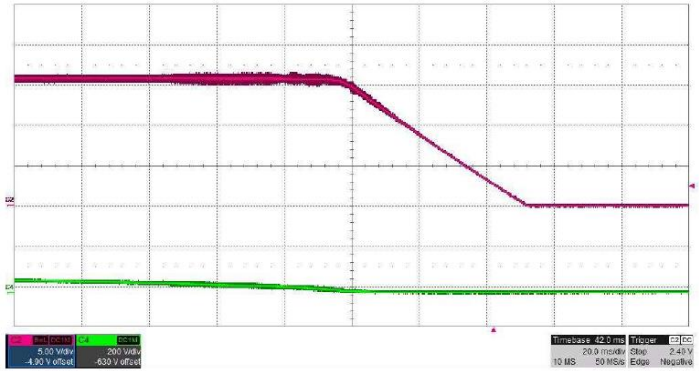
Experimental Results of TIDA-01505 (SiC Flyback)



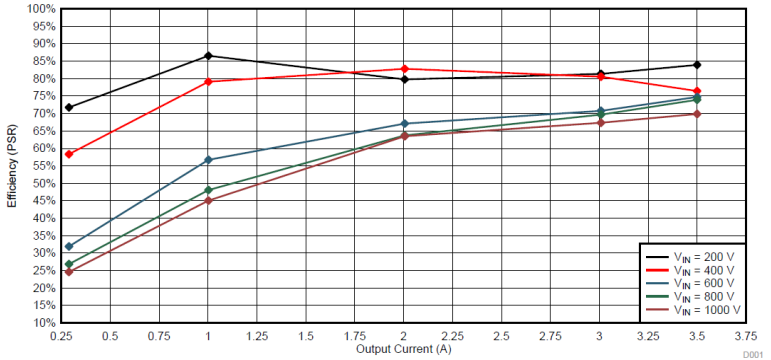
Start-up



Load transient response



Shutdown



Measured efficiency

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General purpose PWM controllers

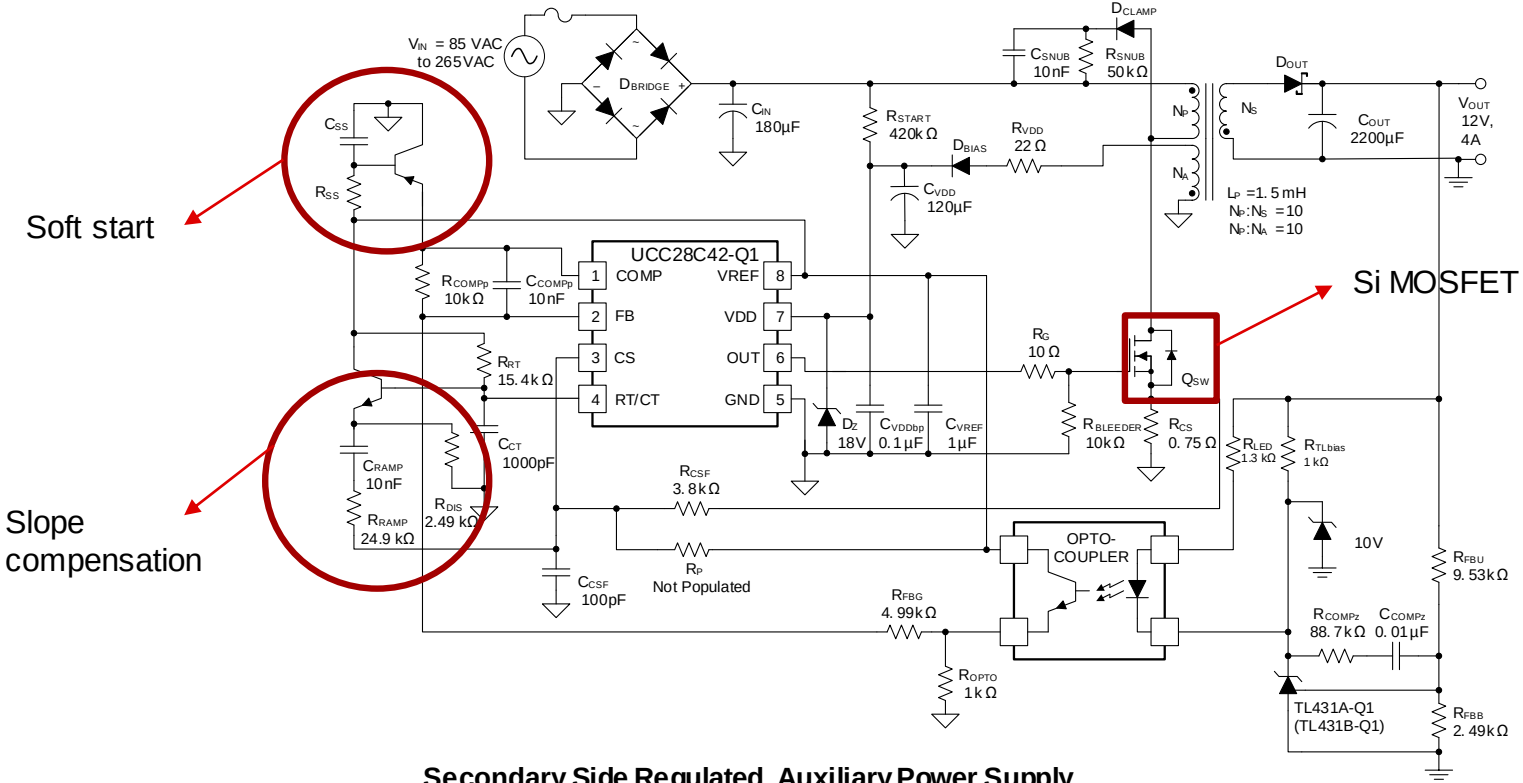
Parameter	UCC28C4x	UCC280x UCC2813-x	UC284xA TL284xB	UC284x TL284x
Process technology	**BiCMOS**	BiCMOS	Bipolar	Bipolar
Absolute maximum VDD	**20 V**	12 V	30 V	30 V
Supply current at 50 khz	**2.3 mA**	0.5 mA	11 mA	11 mA
Startup current	**50 µA**	0.1 mA	0.5 mA	1 mA
Over-current propagation delay	**50 ns**	100 ns	150 ns	150 ns
Reference voltage accuracy	**±1%**	±2%	±2%	±2%
E/A reference accuracy	**±25 mV**	±60 mV	±80 mV	±80 mV
Maximum operating frequency	**1 MHz**	1 MHz	500 kHz	500 kHz
Output rise/fall times	**35 ns**	44 ns	50 ns	50 ns
UVLO turn-on accuracy	**±1.0 V**	±1.2 V	±1.5 V	±1.5 V

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

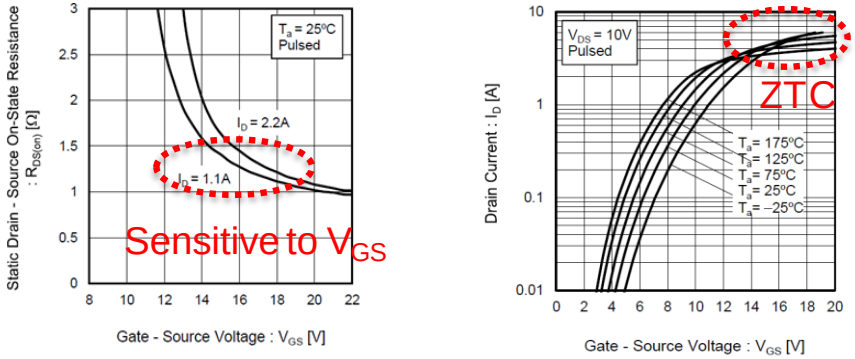
Aux power supply using UCCx8C4y



Secondary Side Regulated Auxiliary Power Supply

PWM Controller requirements for driving SiC MOSFET

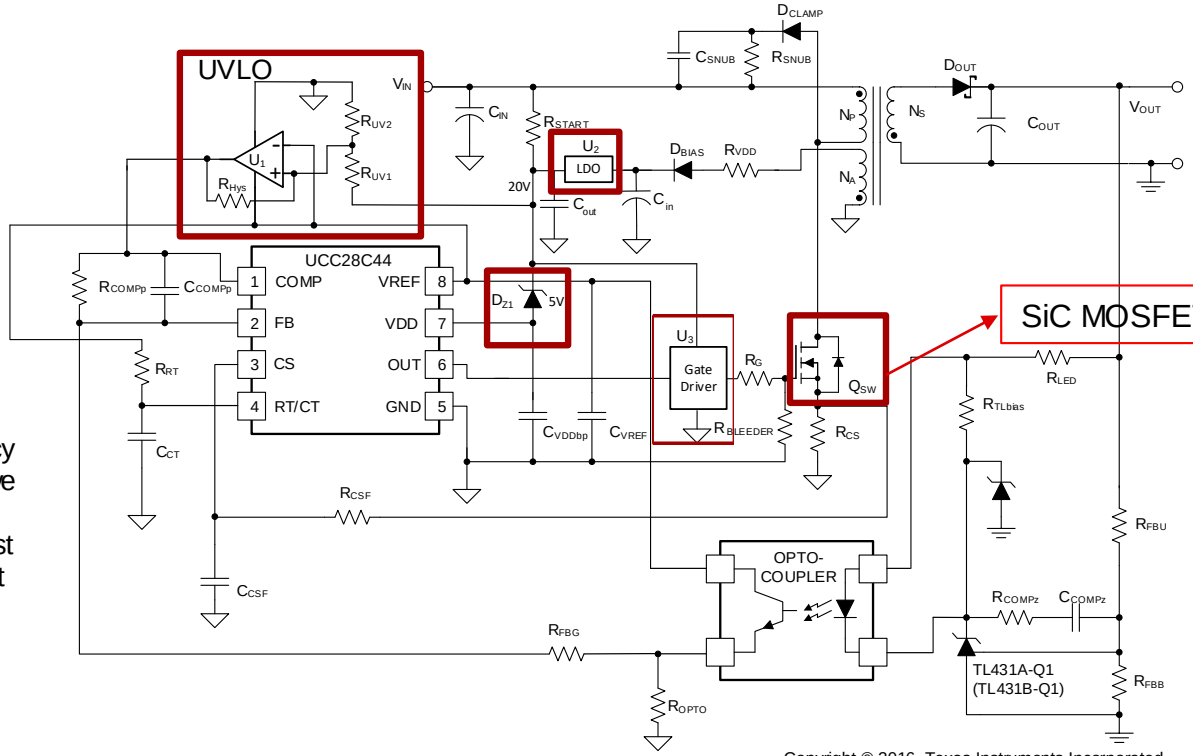
Ultra high-voltage (1700 V)	High-voltage (1200 V)	Mid-voltage (650 V to 900 V)
Vgs Max Recommended: 20V Cree C2M1000170D Rohm SCT2H12NY Littlefuse LSIC1MO170E	**Vgs Max Recommended: 20V** STmicro SCT10N120 Microsemi MSC080SMA120J	**Vgs Max Recommended: 18V** Rohm SCT3120AL STmicro SCTH35N65G2V
Vgs Max Recommended: 15V Infineon IMBF170R1K0M1	**Vgs Max Recommended: 18V** Infineon IMW120R350M1H **Vgs Max Recommended: 15V** Cree C3M0350120J	**Vgs Max Recommended: 15V** Onsemi NTBG020N090SC1 Cree E3M0280090D



Rohm 1700 V, 1.0Ω SiC MOSFET

- 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

SiC-based aux power supply using UCCx8C4y



SSR regulation with external driver

Pros:
- Voltage accuracy
- Efficient SiC drive

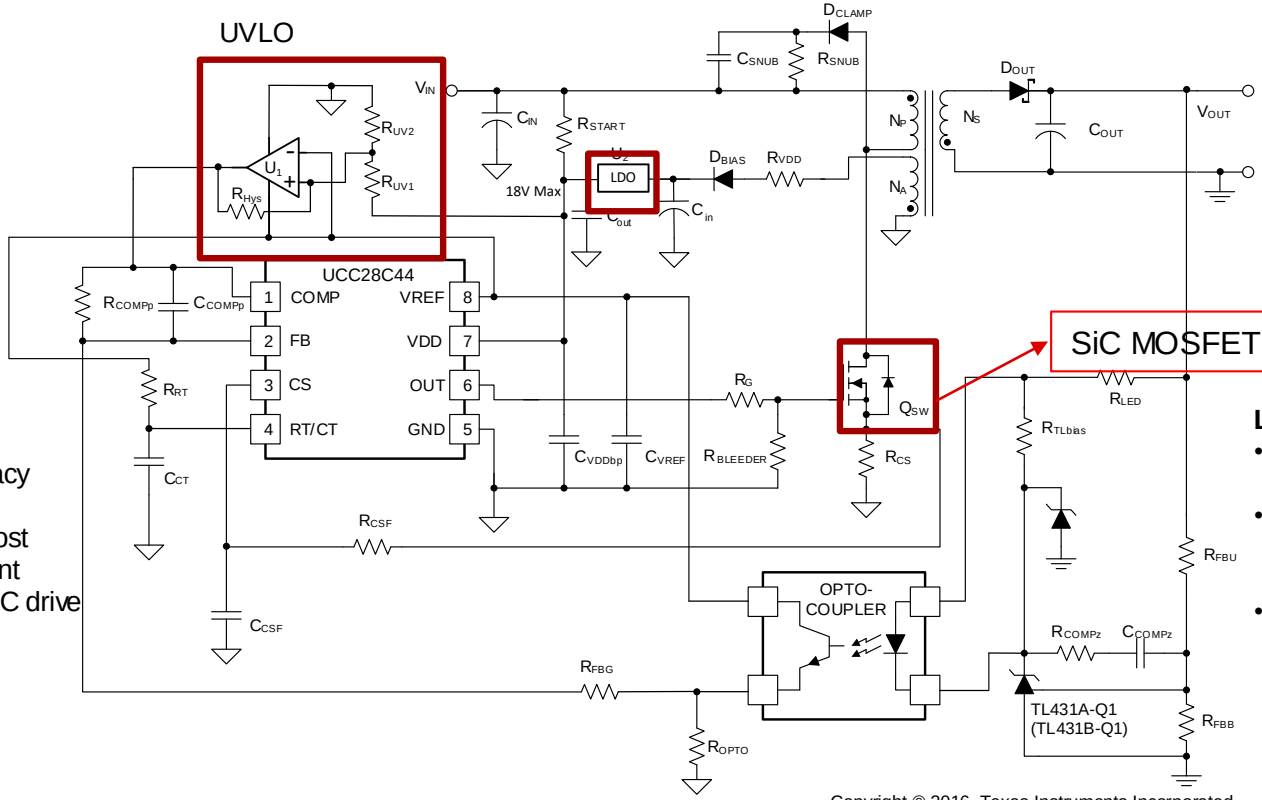
Cons:
- High system cost
- High BOM count

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

SiC-based aux power supply using UCCx8C4y



Pros:
- Voltage accuracy

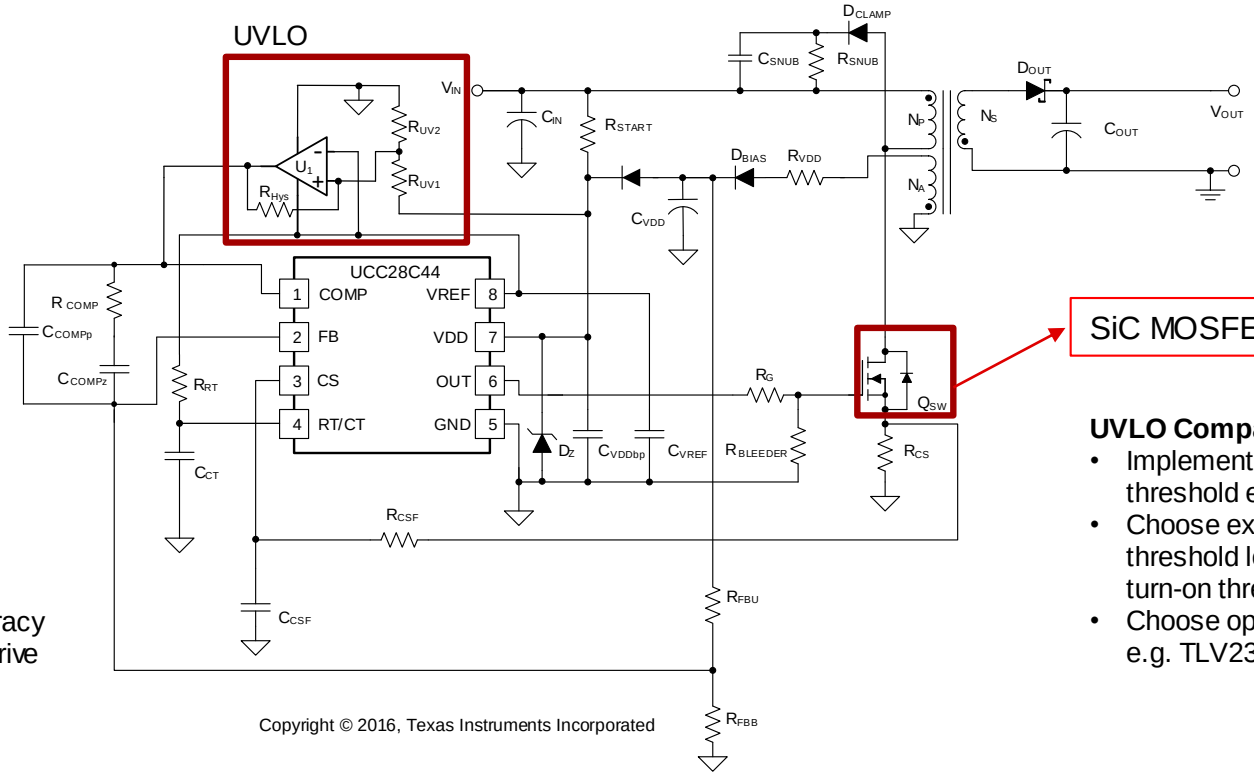
Cons:
- High system cost
- High BOM count
- Sub-optimal SiC drive

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

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

SSR regulation

SiC-based aux power supply using UCCx8C4y



Bias Winding Regulation

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

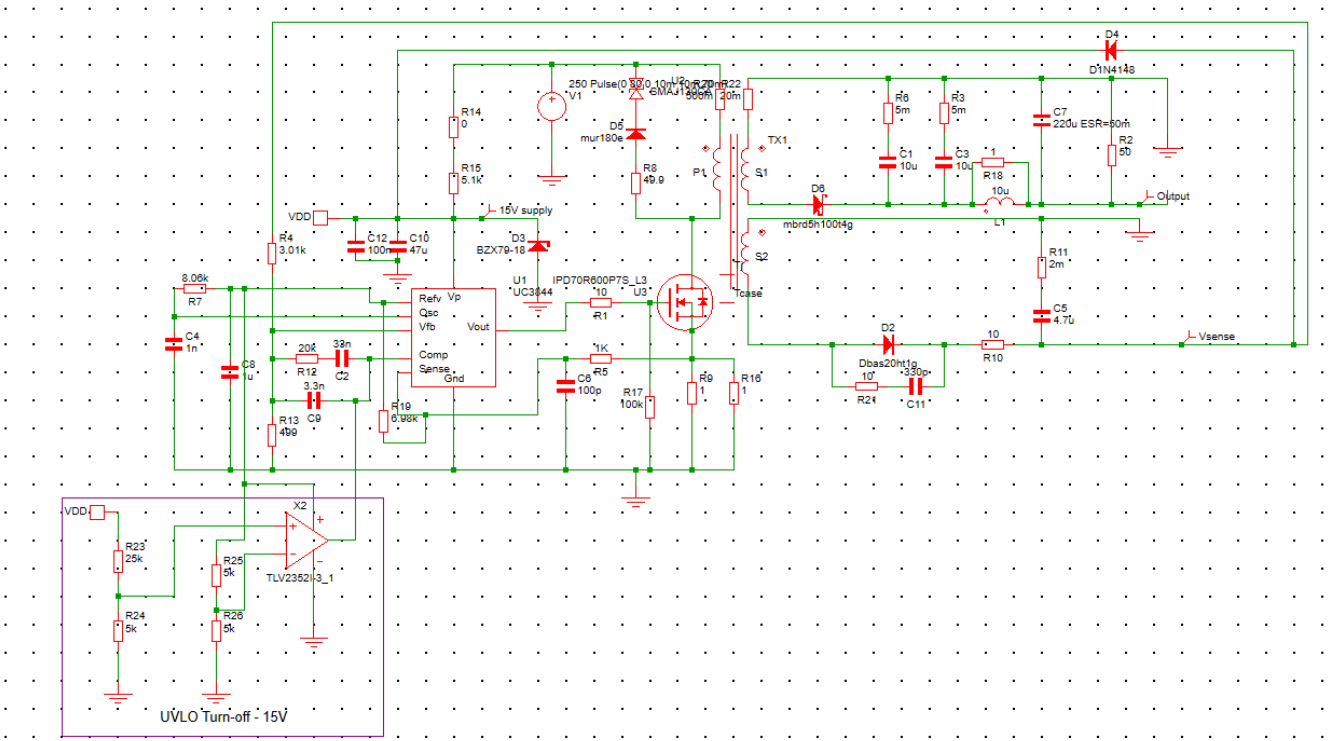
Summary

- 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

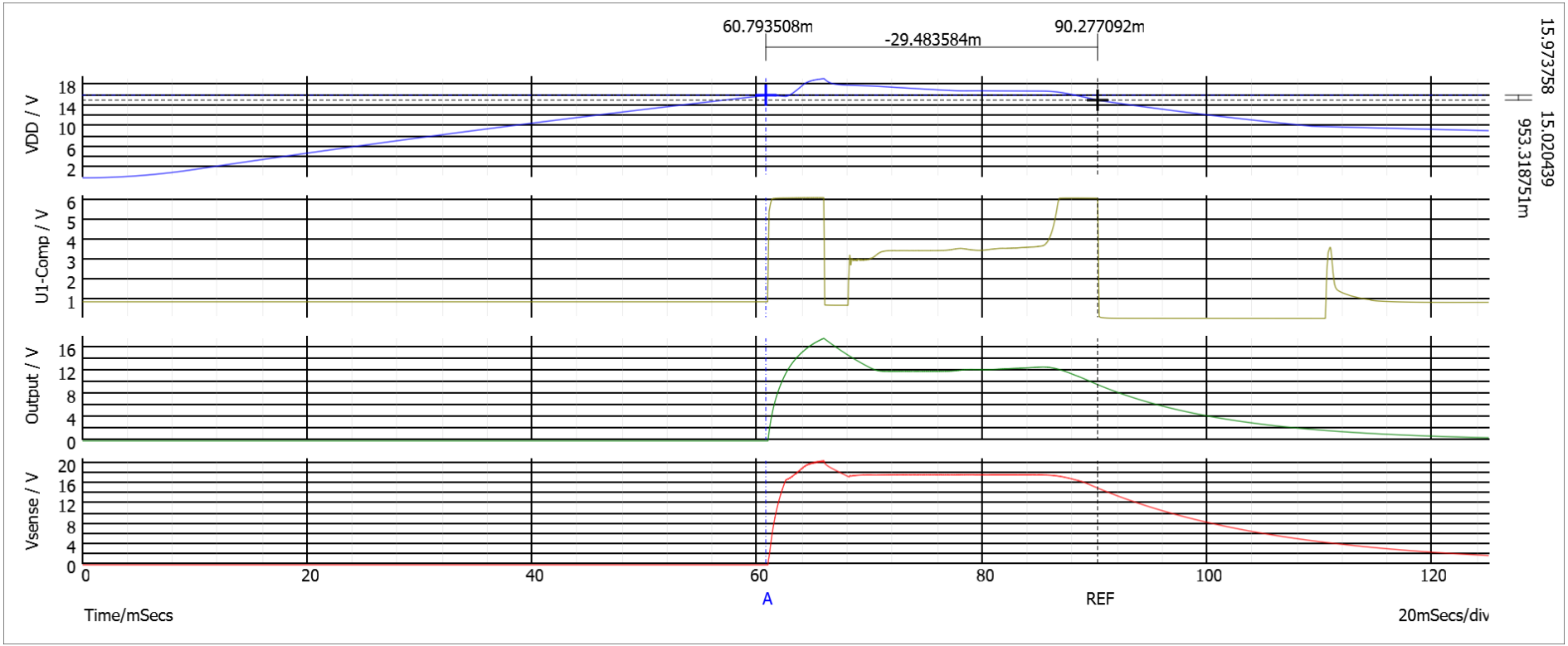
Thank you

Backup

SIMetrix model with external UVLO comparator



SIMetrix simulation with external UVLO comparator



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