Improving Totem-Pole PFC and On Board Charger performance with next generation components

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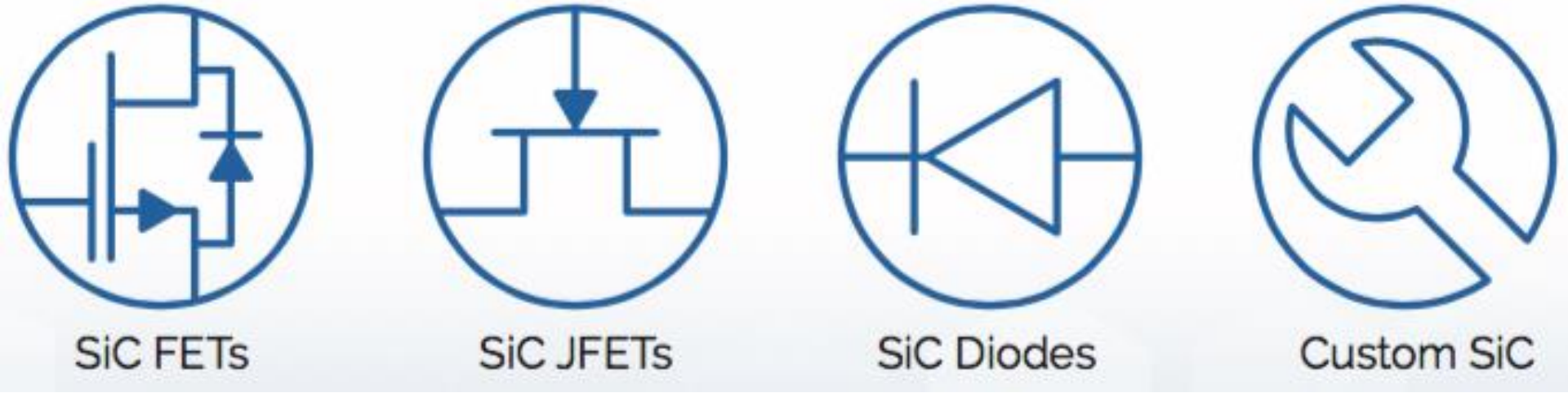


UnitedSiC history

Company Founded — 1999

Acquired and recapitalized by current board and management team — 2009

Built Pilot Production Fab — 2010

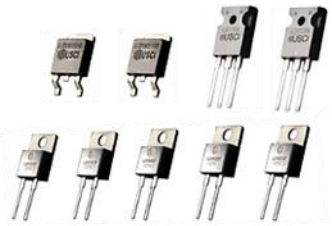
Established 4” foundry relationship — 2011

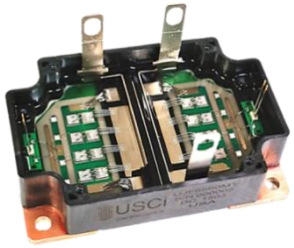
First foundry-based diodes and JFETs manufactured — 2012

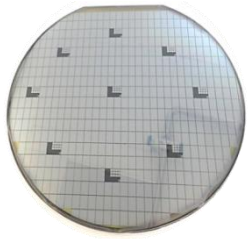
Released the xR 1200V & 650V JBS diode series and the 1200V Normally-on JFETs — 2013

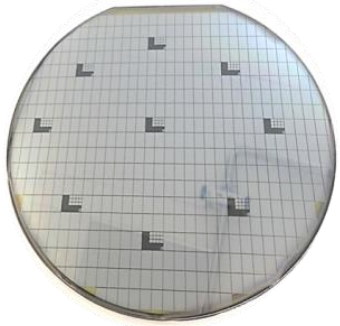
Initiated 6” Fab Transfer — 2014

6” wafer line qualification & production; Diode, Cascode 650V/1200V release
1200V MOSFET release — 2015 / 2017







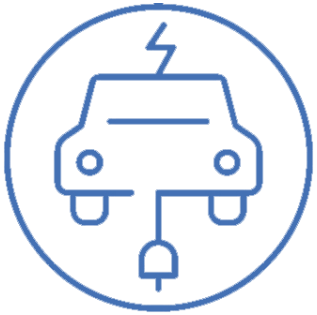


UJC series ease-of-use

Technology	USCi Cascode Replacement
Si MOSFET or Si Superjunction	UJC 650V Series
IGBT with FRD	UJC 1200V Series
SiC MOSFET with SiC SBD	UJC 1200V Series

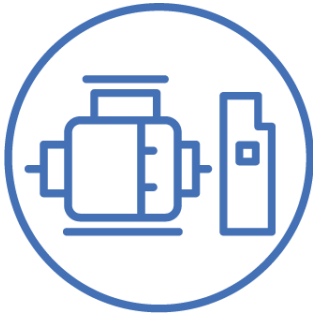
Replace IGBTs, SiC MOSFETs or Si Superjunction devices with no change to gate drive voltages

- UJC: Gen 1
- UJ3C: Gen 3 standard
- UF3C: Gen 3 fast

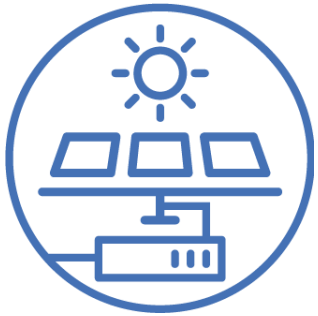


Electric Vehicles

Power Supplies

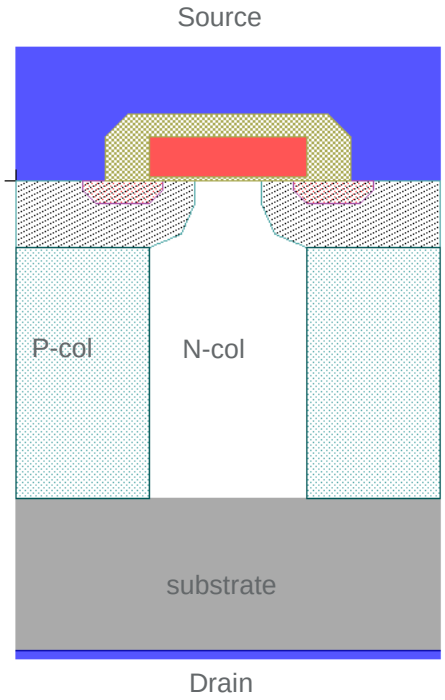


Industrial Drives

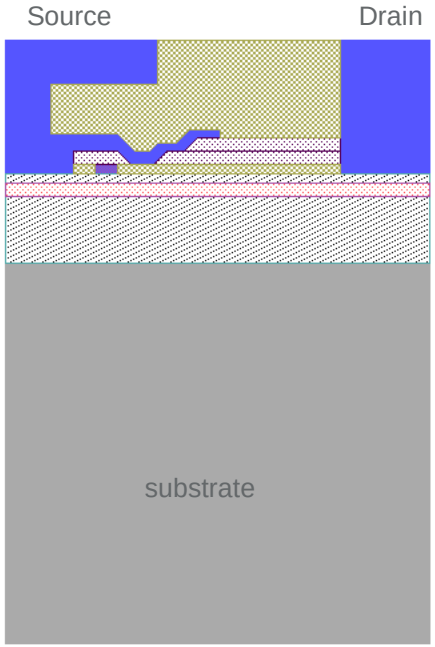


Renewable Energy

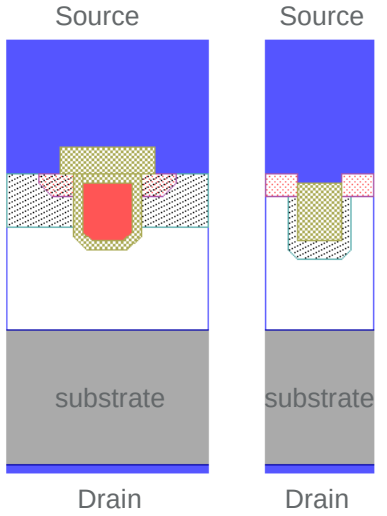
650V technologies compared



Silicon Superjunction
vertical current flow



GaN HEMT
lateral current flow



Trench MOS

Trench JFET

SiC
vertical current flow

RDSA (active area) comparison: 650V class

Technology	SiC Cascode 650V-45mΩ (UJC6505K)	Commercial SiC MOSFET	Commercial GaN HEMT	Commercial Si Superjunction
R_{DSA}	0.75 mΩ-cm²	2-3 mΩ-cm²	3-7 mΩ-cm²	10 mΩ-cm²
Normalized Die Area	1	2.6X	4X	13X
E_{OSS}	7.5 µJ	32 µJ	12 µJ	14 µJ
Avalanche Capability	YES	YES	NO	YES
Short Circuit	YES	YES	NO	YES

Comparison with Superjunction

TABLE I. KEY DATASHEET PARAMETERS OF USCI'S 650V CASCODE SWITCH COMPARED TO SUPERJUNCTION MOSFET

Device	R_{DS}	Q_G	Q_{GS}	Q_{GD}	Q_{rr}	E_{OSS}	V_{TH}	TCR	Gate Drive	Die Area
	mΩ	*nC*	*nC*	*nC*	*μC*	*μJ*	*V*	*@ 150C*		
SiC Cacode UJC06505T	34	58	15	15	0.15	8	5	1.8	0 to 12V	1
Si Superjunction IPP65R045C7	40	93	23	30	13	11.7	3.5	2.4	0 to 12V	7.3×

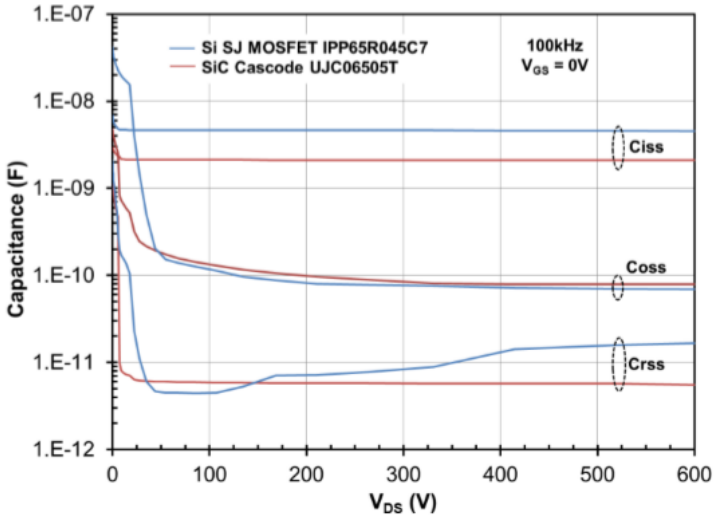


Fig. 3. Capacitance curves comparison between SiC Cascode UJC06505T and superjunction MOSFET IPP65R045C7

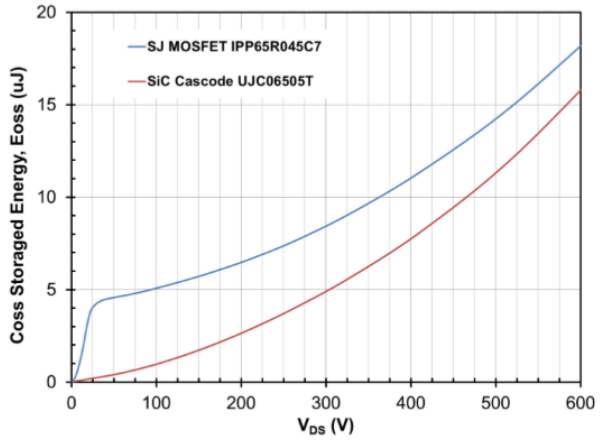


Fig. 4. Eoss comparison between SiC Cascode UJC06505T and superjunction MOSFET IPP65R045C7.

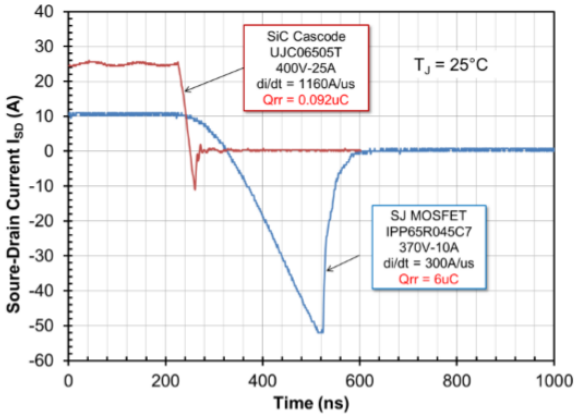
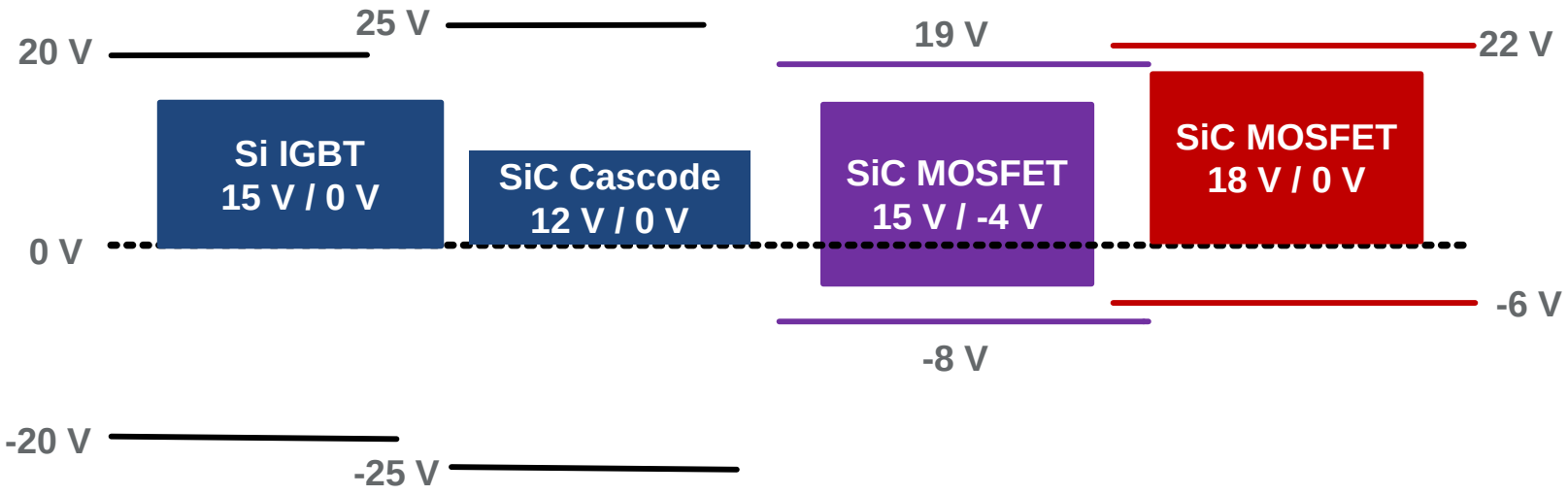


Fig. 5. Diode reverse recovery comparison between SiC Cascode and Super Junction MOSFET

SiC Cascode gate drive benefit



Maximum VGS rating vs. recommended VGS
SiC MOSFET can be operated at Vgs=0V in some circuits

- **Easy Drop-in**
  12V turn-on makes SiC cascode an easy choice for drop-in replacement
- **Extra Margin in VGS**
  SiC cascode has higher margin in VGS design and requires no negative VGS for turn-off

Totem pole PFC – UJC06505K

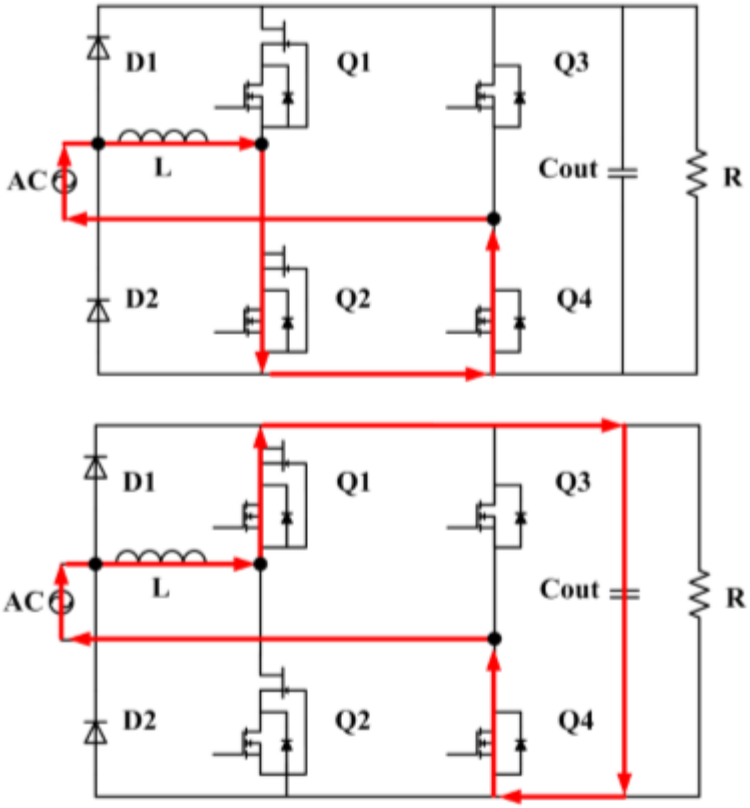


Fig. 1. CCM totem-pole PFC operation in positive half cycle with an active switch in conduction (top) and a freewheeling device in conduction (bottom).

TABLE I. DESIGN PARAMETERS.

Input Voltage	115 V to 230 V (60 Hz AC)
Output Voltage	400 V (DC)
Input Current	8.7 A (RMS)
Rated Power	1 kW at 115 Vac; 1.5 kW at 230 Vac
Switching Frequency	100 kHz
SiC Cascodes (Q1, Q2)	UJC06505K
Si MOSFETs (Q3, Q4)	IPW65R019C7
Input Inductor	300 µH at no load
Output Capacitor	560 µF, 500 V

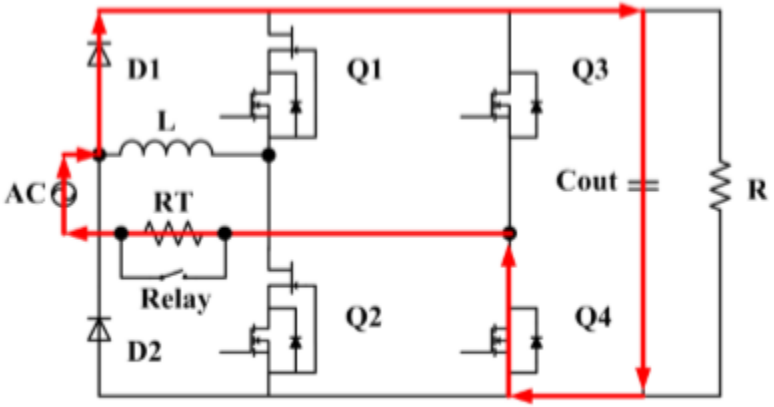


Fig. 2. Soft start-up of totem-pole PFC with positive AC input voltage.

Totem pole PFC – UJC06505K

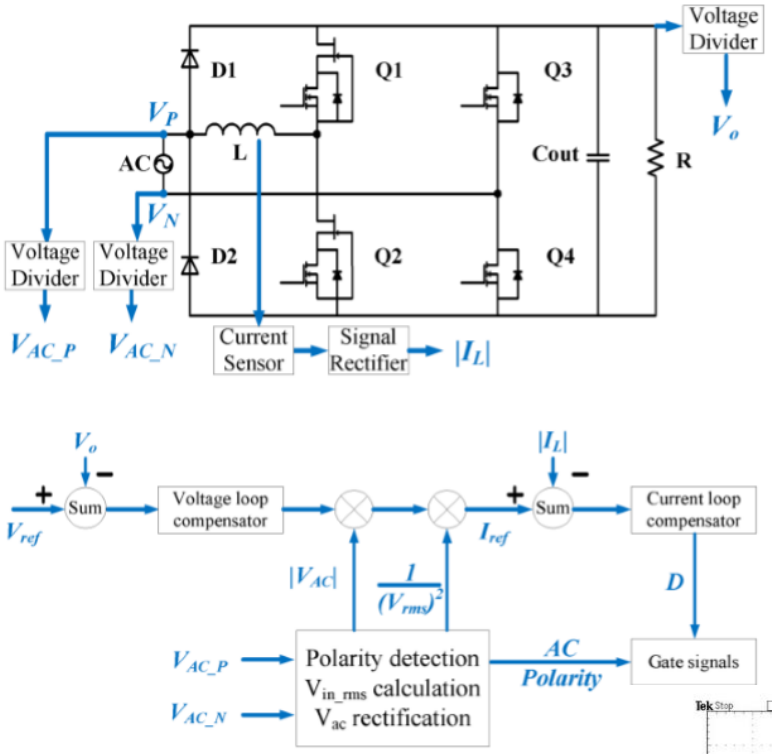
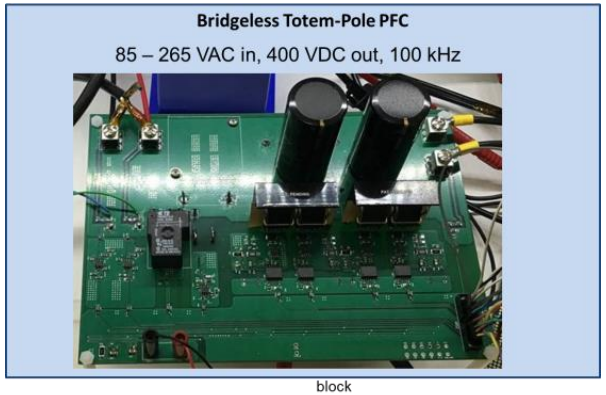


Fig. 4. Average current control scheme for totem-pole PFC



block

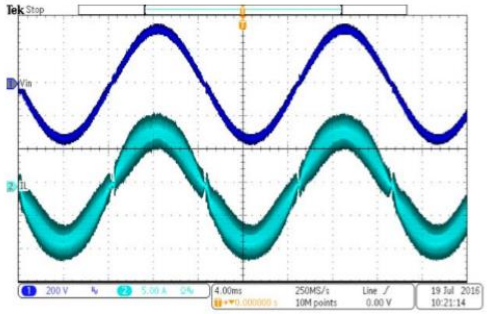


Fig. 10. 230 V AC input voltage (top) and inductor current (bottom) at 1.3 kW load.

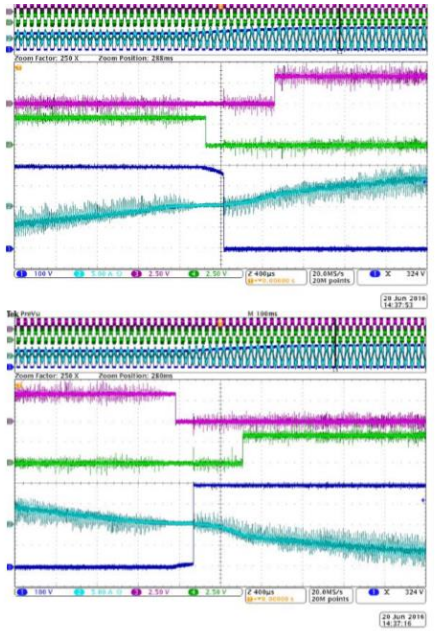
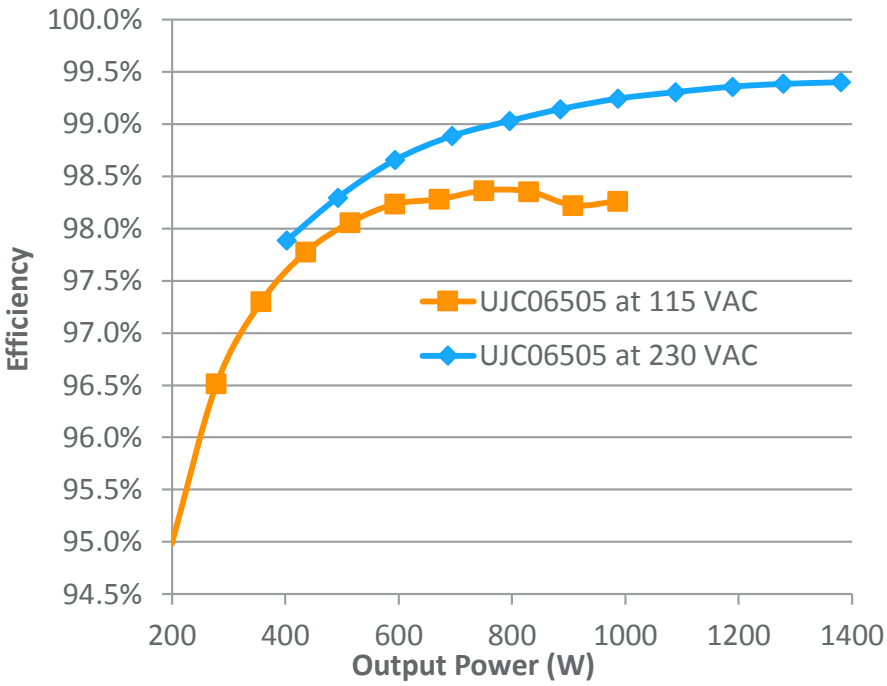


Fig. 11. Inductor current (light blue CH2) at zero crossing, from negative to positive (top), from positive to negative (bottom). (CH1: V_N potential to DC output ground; CH3: DSP gate signal of Q4; CH4: DSP gate signal of Q3)

Totem pole PFC – UJC06505K



Does not include auxiliary supply losses

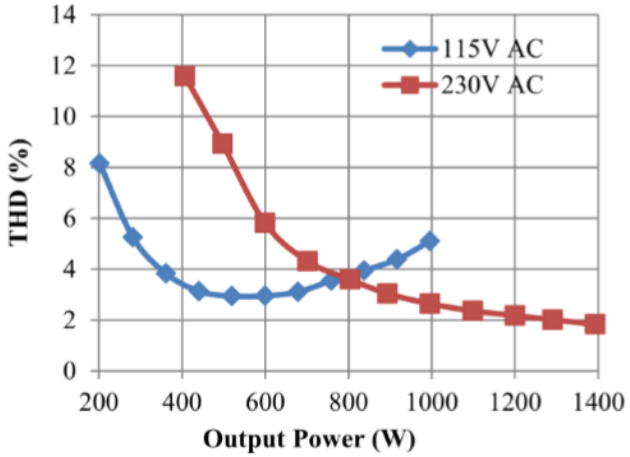
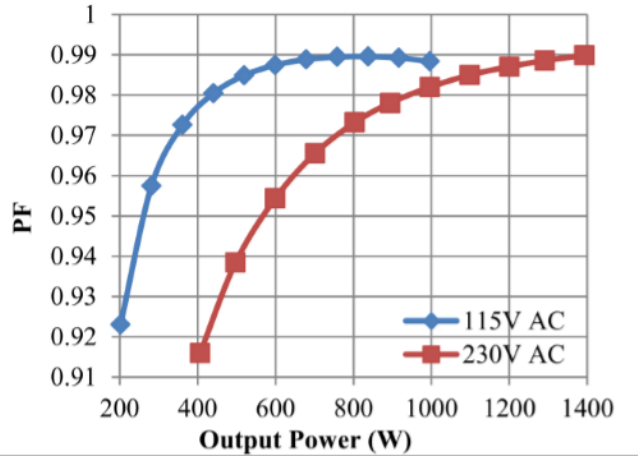
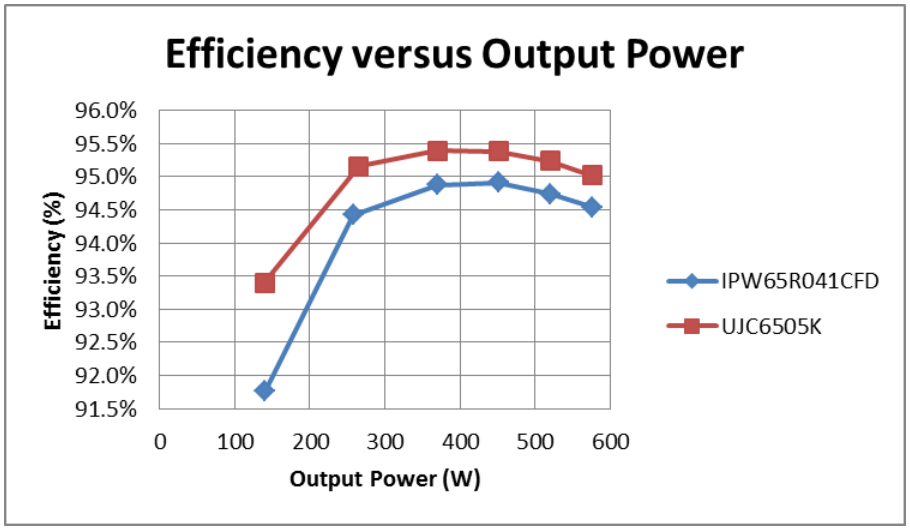


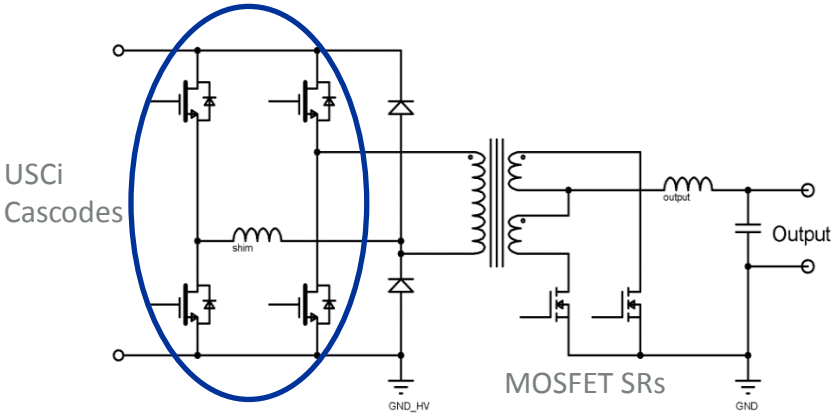
Fig. 8. THD at high line and low line input with 100 kHz switching frequency.



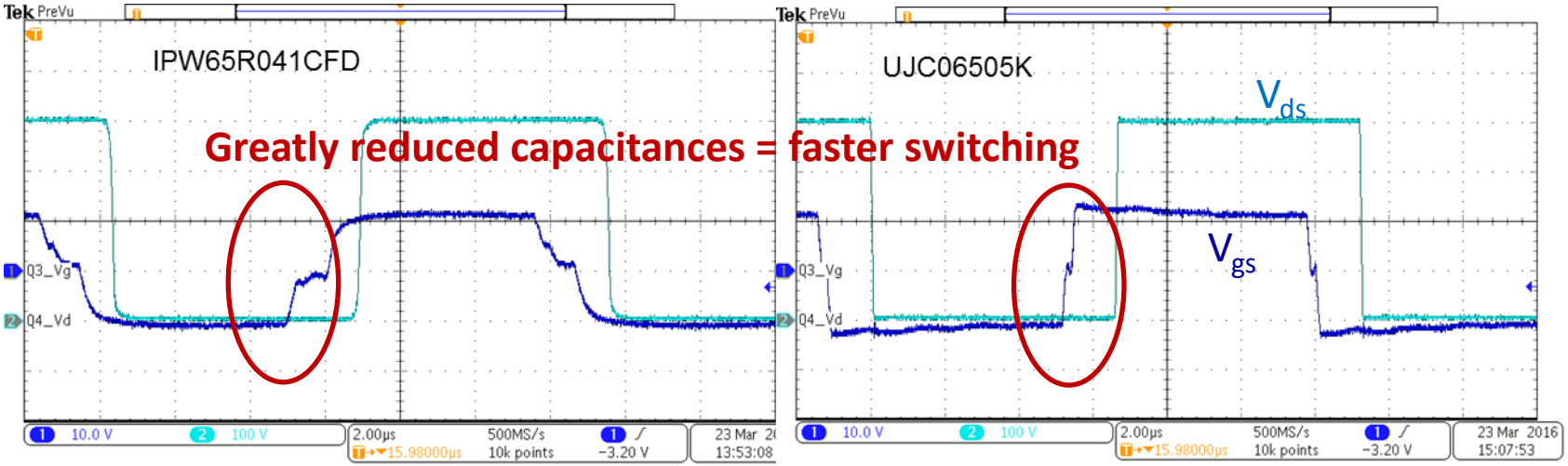
650V Cascode vs. Superjunction

Test results of cascode drop-in replacement of super-junction MOSFET in phase shift full bridge





Phase shift full bridge (PSFB) circuit with synchronous rectifier (SR) output



Cascode for soft switching

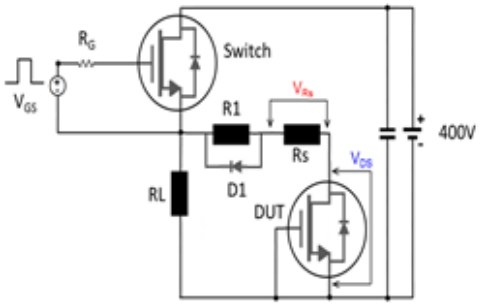


Fig. 1: Experimental setup for measuring the intrinsic loss of a power switch.

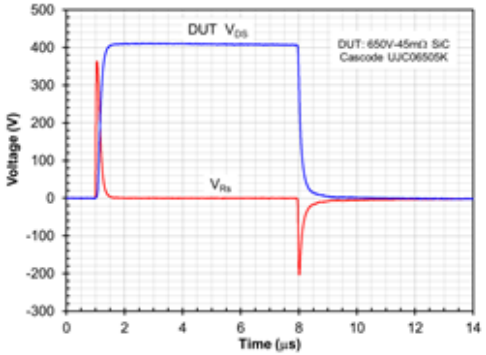


Fig. 2: Measured waveforms of the DUT drain voltage and the voltage across Rs.

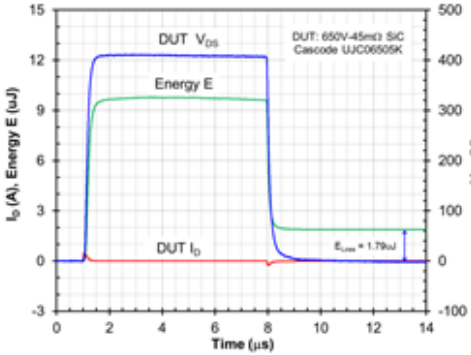


Fig. 3: Energy and DUT current waveforms obtained from the voltage waveforms in FIG. 2.

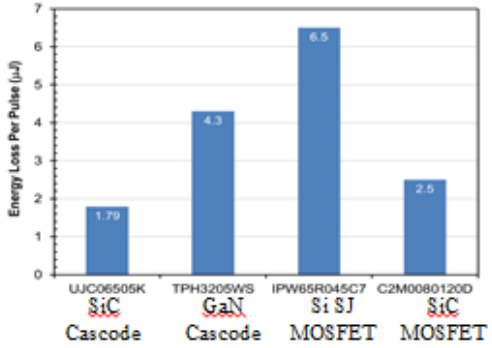
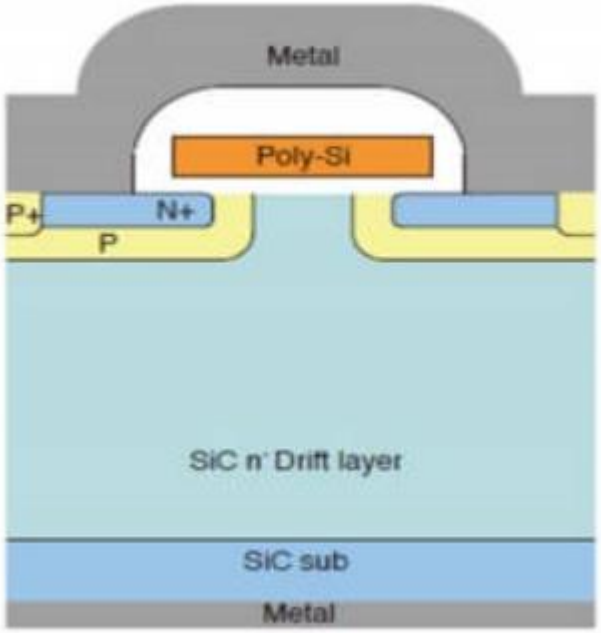
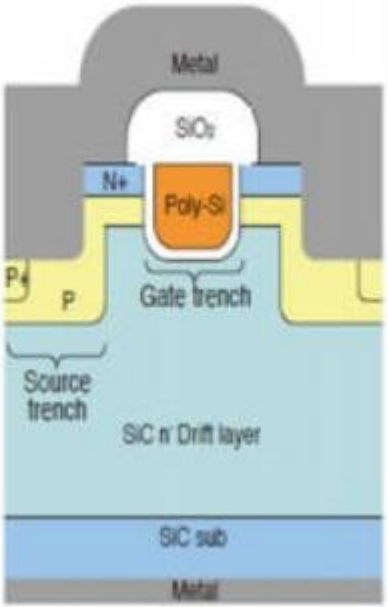


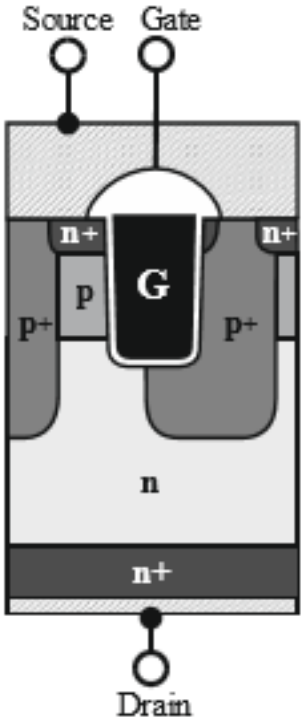
Fig. 4: Comparison of the measured intrinsic energy losses of the 650V-45mΩ SiC cascode, the 600V-52mΩ GaN cascode, the 650V-45mΩ Si superjunction MOSFET and the 1200V-80mΩ SiC MOSFET.

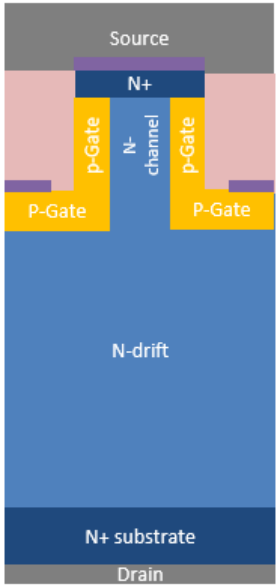
- Intrinsic loss mechanisms being studied for soft switched operation of cascodes for ultra-high frequency
- This manifests itself as the loss from ramping the voltage up and down with zero current.
- SiC Cascodes found to be superior in a comparative assessment
  - Near 0 Cds of JFET eliminates the capacitive divider problem
- Further refinements in technology needed to push >1MHz
- Will use logic level MOSFETs with ultra-low Qg Vth=2V, 5V gate drive and low inductance surface mount packaging. This type of operation is not possible with SiC MOSFET which needs a wider gate voltage swing with larger Qg.

SiC MOSFET landscape









Standard Planar MOSFET

- Gate oxide shielding – narrow JFET region
- Worse mobility Si face
- Adds to RdsA

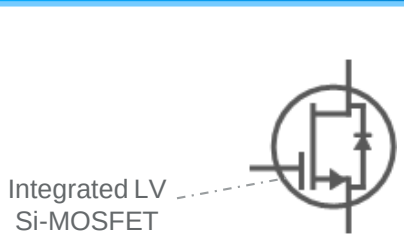
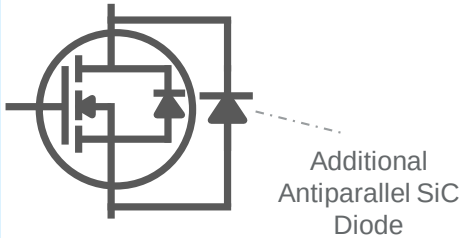
Rohm Trench MOSFET

Infineon Trench MOSFET

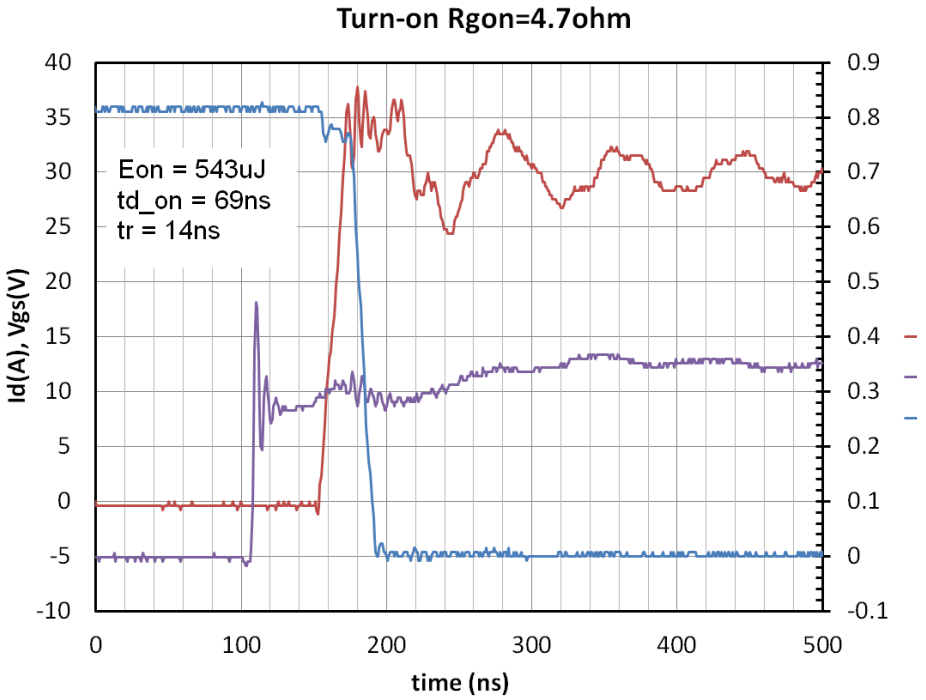
- Trench bottom Gate oxide shielding – deep p regions. Adds to RdsA
- Better a-face/m-face mobility

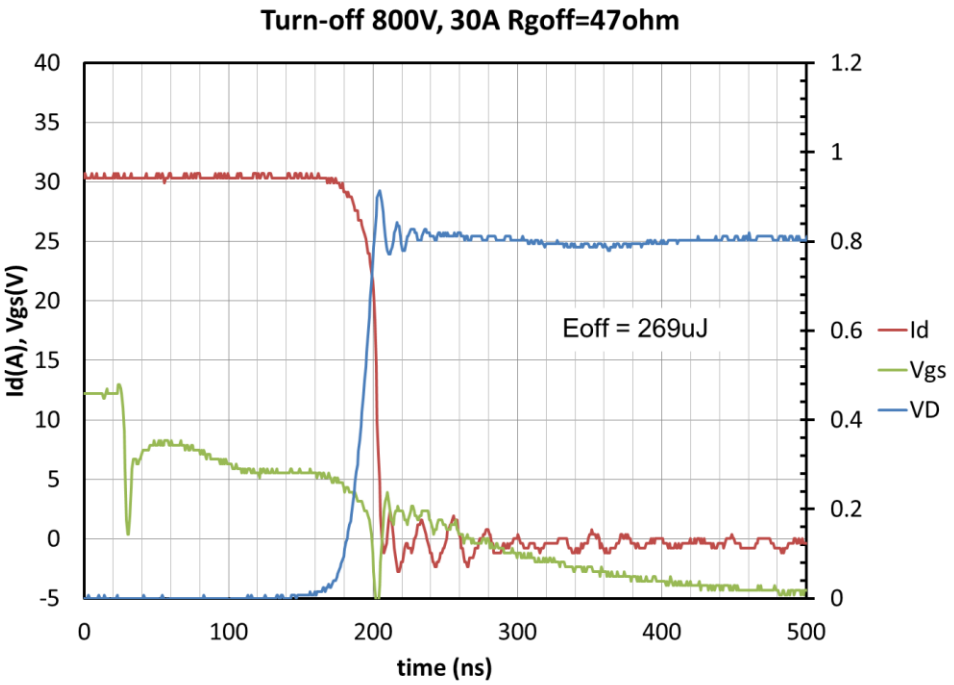
USCi Trench JFET

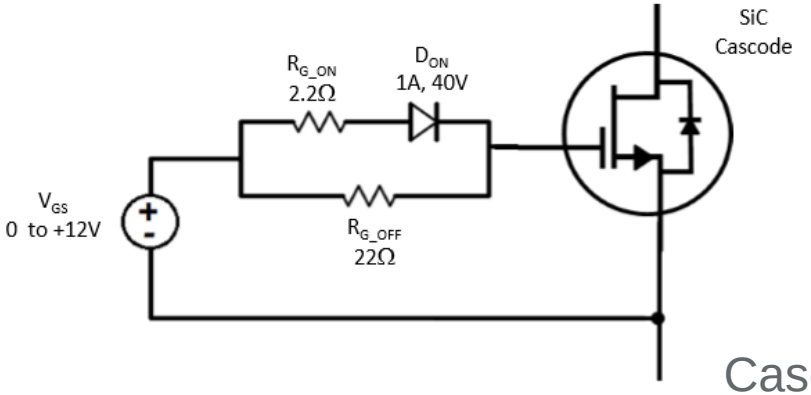
UnitedSiC 1200V vs. competition

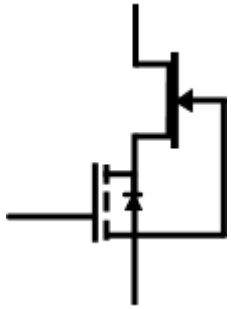
	Normally Off USCi Cascode	Normally Off Typical SiC MOSFET
		
Die Size	(Smaller) R_{DSA}~ 1.75mW-cm^2	(Larger) R_{DSA}~ 3.1- 4.5 mW-cm^2
Gate Drive	(Standard) V_{GS} = 0V to 12V OR (SIC) V_{GS} = -10V to 20V	V_{GS} = -5V to 15/18/20V
Threshold	$V_{GS(TH)}$ = 5V Typical	$V_{GS(TH)}$ = 2-3V Typical
Intrinsic Diode	Low Qrr, +10% Over Temperature	High Qrr, High VF 3X Over Temperature
Avalanche	Yes	Yes
Short Circuit	Yes	Low

Inductive switching, 800V, 30A





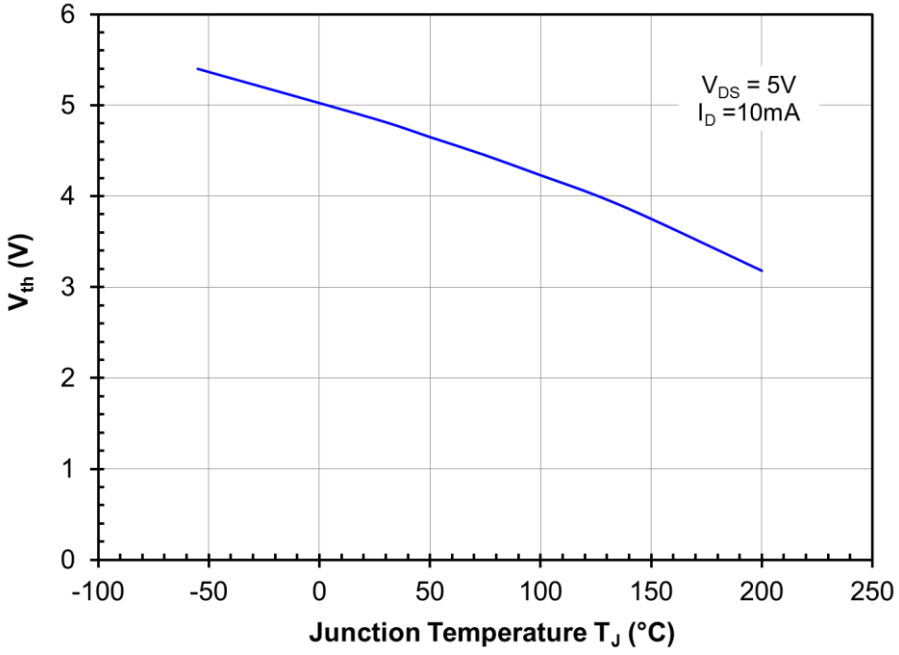




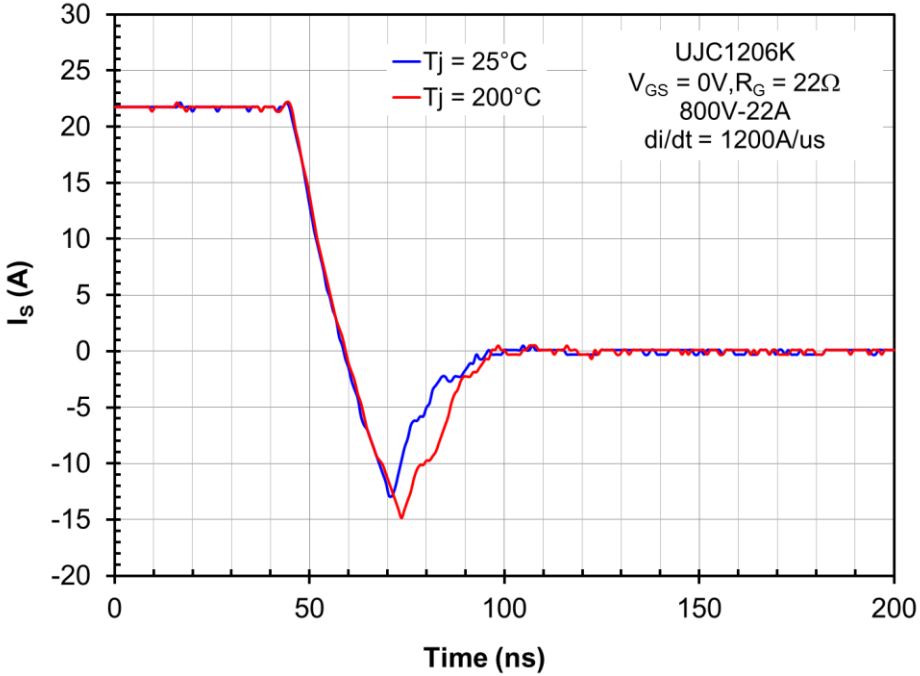
Use Higher R_{GOFF} to control turn-off speed

Cascode Internal Schematic

UJC1206K temperature characteristics

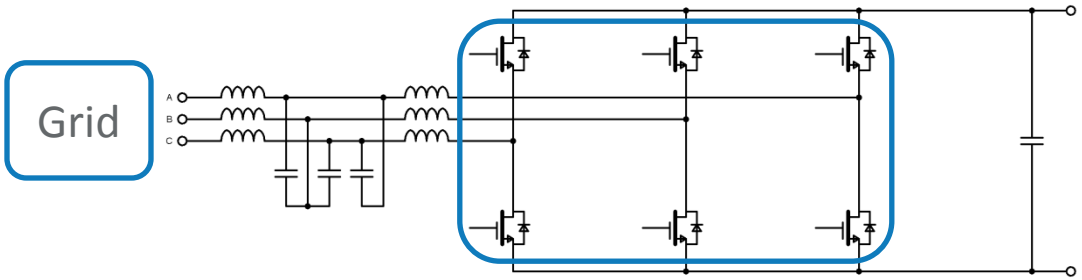


Vth is >3V at 175C

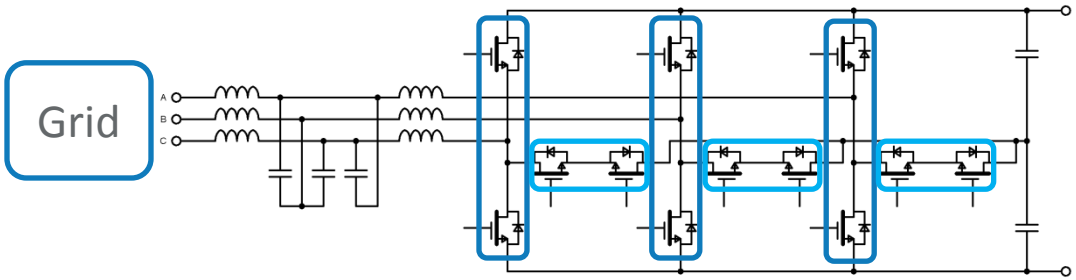


It is important to follow guidelines for Rgoff for both the HS and LS FET in the half-bridge

Fresh 3φ rectifier designs



Two-level active front end (rectifier)



Three-level active front end (rectifier)

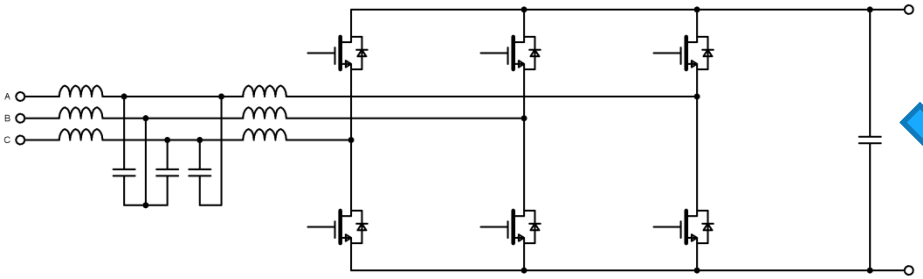
USCi 1200V Cascode:
- UJC1206K
- UJC1210K
- UJ3C120040K3S
- UJ3C120080K3S
- UJ3C120150K3S

USCi 650V Cascode:
- UJ3C065030K3S
- UJ3C065080K3S
- UJC06505K

- Compact, efficient AFE made possible by low $R_{DS(on)}$ with 1200 V rating combined with excellent reverse conduction and recovery characteristic
- Low noise, low charge reverse recovery eliminates the need for bypass and blocking diodes as in Vienna rectifier with super-junction MOSFETs
- Extremely high efficiency is possible, especially with three-level topology, due to very low switching loss
- Can use switching algorithm with three-level topology to reduce or eliminate common-mode voltages

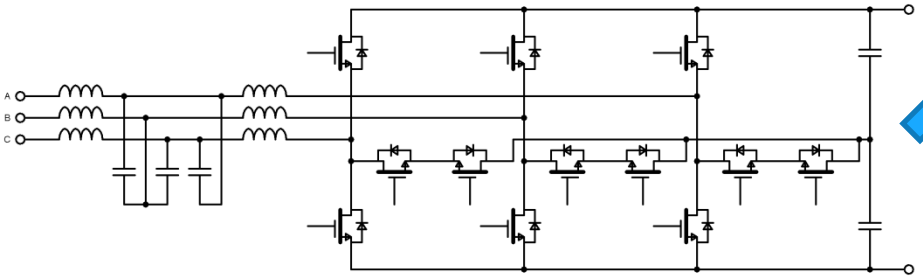
Charge up with high power

Grid

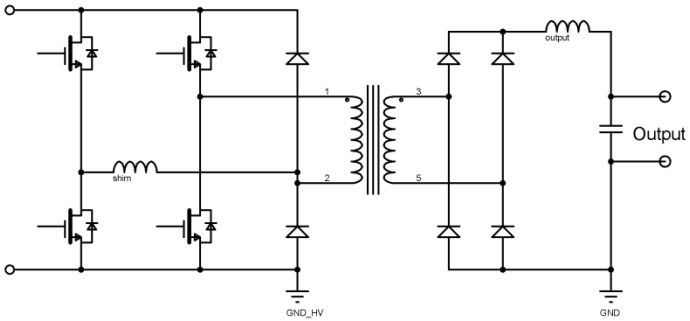


300V - 480V AC two-level active front end (rectifier)

Grid



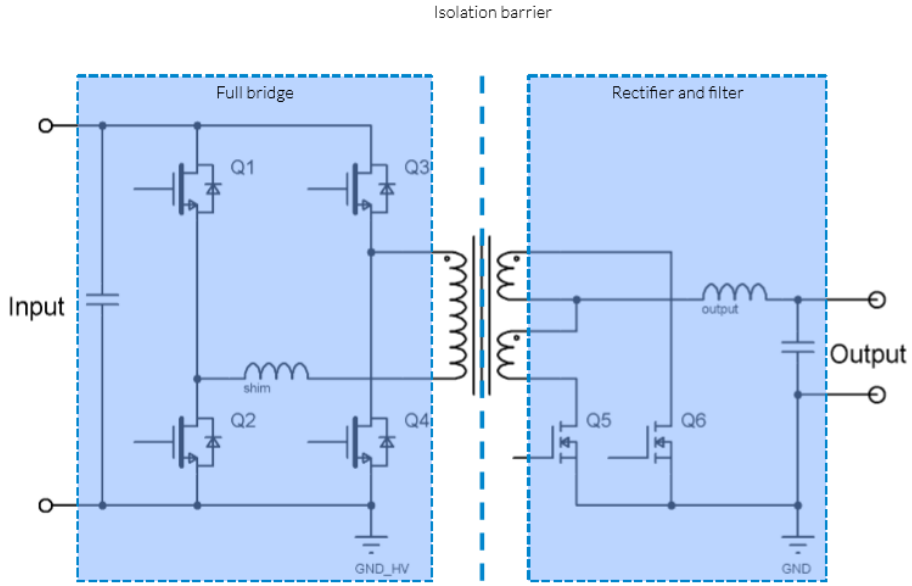
400V - 600V AC three-level active front end (rectifier)

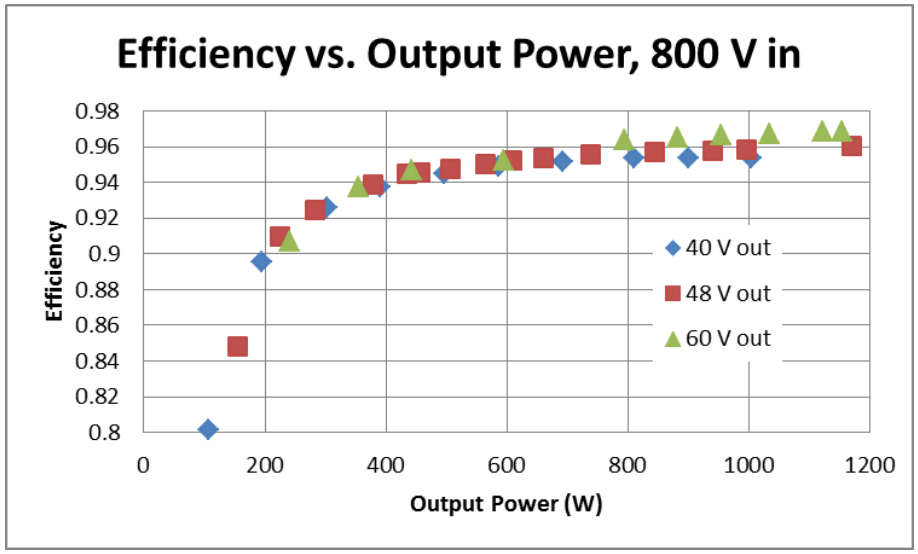


High voltage phase shift full bridge

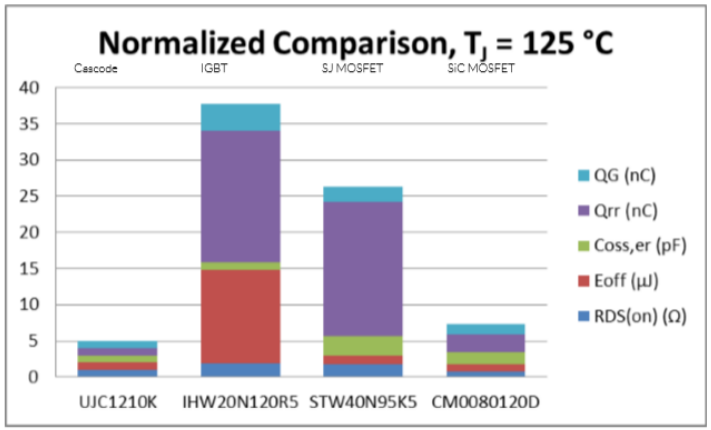
- High power battery charger fed by three-phase grid connection
- Three-phase active front end (AFE) as rectifier yields efficient, compact design
- Phase shift full bridge (PSFB) with 700 to 800 V input, hundreds of Volts output
- Typical application: on or off-board electric vehicle charger

High voltage PSFB





Comparison with Previous Device Technologies



- Previous technologies include IGBT, super-junction MOSFET, and SiC MOSFET
- IGBTs have very high turn-off switching power loss, slow-switching reverse diode
- Super-junction MOSFETs have larger chip size, slow-switching reverse diode
- SiC MOSFET has larger chip size, asymmetric gate drive (-5 to 18 V typically)
- USCi cascode is the best performing PSFB switch

USCi 1200 V Cascode:
- UJ3C120080K3S
- UJ3C120040K3S
- UJC1206K
- UJC1210K

Summary

- United SiC 650V and 1200V SiC based transistors use standard gate drives
- With excellent diode recovery, high Vth at temperature and fast switching, they greatly improve hard and soft switching performance
- Examples in Totem-Pole PFC and On-board chargers (Rectifier and DC-DC) discussed in this presentation.
- For more information, contact sales@unitedsic.com.