UnitedSiC Presentation, March 2018

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UnitedSiC Company History

Simply More Efficient

Released of Gen 3, AECQ-101 650V & 1200V Cascodes

Company Founded

Built Pilot Production Fab

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

1999 2009 2010 2011 2012 2013 2014 2017 2018

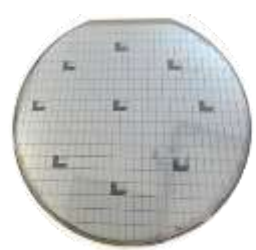
Acquired and recapitalized by current board and management team

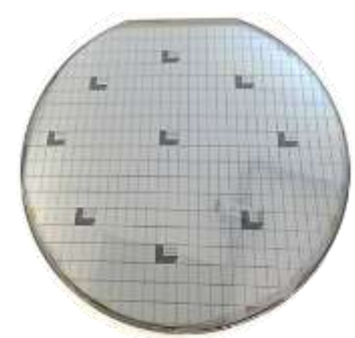
Established 4” foundry relationship

First foundry-based diodes and JFETs manufactured

Initiated 6” Fab Transfer

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

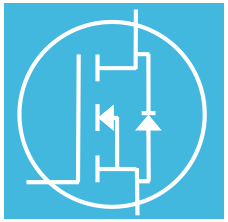




Technology Focus

UnitedSiC — Simply More Efficient

R&D: SiC MOSFETS, Custom Products / ICs

Schottky Diodes	SiC JFETS	Cascodes	SiC MOSFETS	Custom Products / ICs
				
World class performance in higher voltage devices	Normally-On Devices ideally suited for current limiting and protection	Normally-Off Devices for Superior Performance in Switching Applications	Well Suited to 3.3-6.5KV applications	Standard Platforms can be customized for unique applications
Wide Band Gap Schottky Diodes & SiC Module Die	**Circuit Protection**	**IGBT Discretes & Silicon Superjunction**	**HV Si MOSFETs IGBTs**	**Integrated Circuits & High Temperature Die**

Market Areas Addressed—Taking Today's Silicon Approaches to the Next Level

650V – >10kV	650 – 6.5kV	650 – 1700V	3300V – 10kV	50V

Spanning Across the Voltage Spectrum

Power supplies, EV battery, solar inverters	Circuit breakers, TVS, current limiters	Power supplies, EV battery, solar inverters	Medical, Traction, solar inverters	High temperature or extreme environment applications

With a Multitude of Product Applications

Generation 3 Diode part list

Family	Base PN	Description	Samples	RTM	Die	TO-220-2L	TO-247-3L	D2PAK-Flat (F5)	SOT227
650V	UJ3D06504	4A 650V JBS Diode	Q3 17	MP	MP	MP		D	
650V	UJ3D06506	6A 650V JBS Diode	Q3 17	MP	MP	MP		D	
650V	UJ3D06508	8A 650V JBS Diode	Q3 17	MP	MP	MP		D	
650V	UJ3D06510	10A 650V JBS Diode	Available	MP	MP	MP		D	
650V	UJ3D06512	12A 650V JBS Diode	Q4 17	MP	n/a	MP			
650V	UJ3D06516	16A 650V JBS Diode	Now	MP	n/a	MP			
650V	UJ3D06520	20A 650V JBS Diode	Now	MP	n/a	MP	MP	D	
650V	UJ3D06530	30A 650V JBS diode	Available	MP	MP	MP			
650V	UJ3D06560	2X 30A 650V JBS diode	Available	MP	n/a	MP	MP		
650V	UJ3D065200	200A 650V JBS diode	Available	Q1 18	D				D

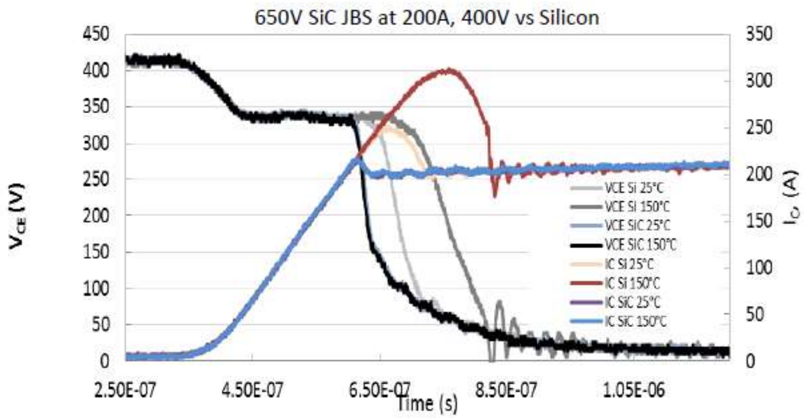
MP: Mass Production ES: Engineering samples available D: under development

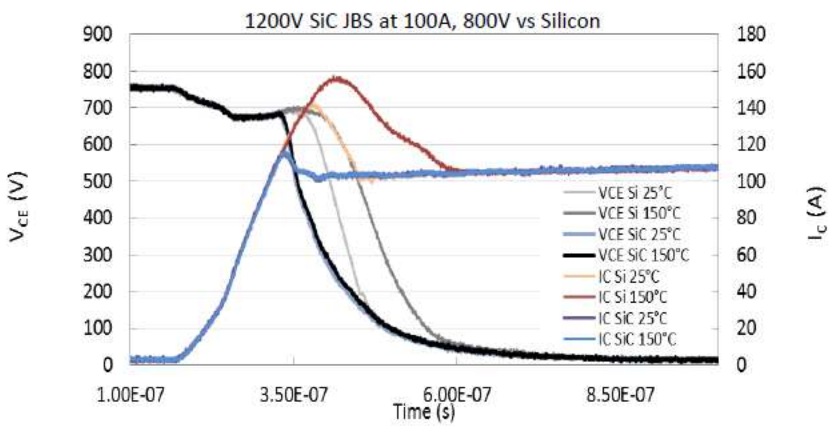
Generation 3 Diode part list

Family	Base PN	Description	Samples	RTM	Die	TO-220-2L	TO247-3L	D2PAK-Flat (F5)	SOT227
1200V	UJ3D1202	2A 1200V JBS diode	Now	MP	MP	MP		D	
1200V	UJ3D1205	5A 1200V JBS diode	Now	MP	MP	MP		D	
1200V	UJ3D1210	2x5A 1200V JBS diode	Now	MP	n/a		D	D	
1200V	UJ3D1210	10A 1200V JBS diode	Now	MP	MP	MP	MP	D	
1200V	UJ3D1220	2X10A 1200V JBS diode	Now	MP	n/a		MP		
1200V	UJ3D1250	50A 1200V JBS diode	Now	MP	MP		MP		
1200V	UJ3D12100	100A 1200V JBS diode	ES	Q2 ’18	ES				D

MP: Mass Production ES: Engineering samples available D: under development

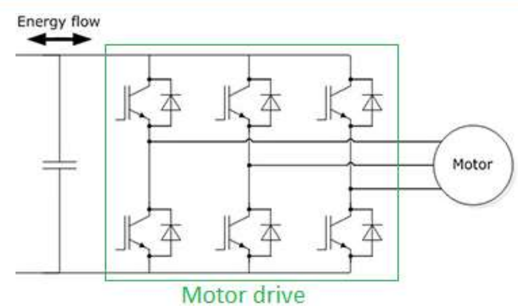
High Current Diode in Hybrid Application





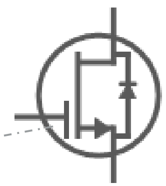
Diode Device	IGBT Device	V_{bus} (V)	I_C (A)	T_{Case} (°C)	di/dt (A/μs)	Q_{RR} (μC)	E_{on} (mJ)
650V-200A SiC UJ3D065200Z	600V 200A IXGN200N60B3	400	200	25	900	0.36	13.2
600V-230A Si VS-UFL230FA60						4.0	16.2
650V-200A SiC UJ3D065200Z				150		0.35	13.2
600V-230A Si VS-UFL230FA60						16.9	23.2
1200V-100A SiC UJ3D1210OZ	1200V 100A IXYN100N120C3	800	100	25	830	0.38	12.0
1200V 140A Si VS-HFA140FA120						3.2	16.0
1200V-100A SiC UJ3D12100Z				150		0.38	12.0
1200V 140A Si VS-HFA140FA120						7.4	21.0

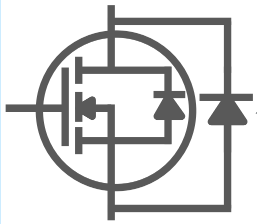
At 6 kHz and Tj=150 °C, turn-on loss roughly halves with SiC
139 W (Si) to 79 W (SiC) at 400 V, 200A
126 W (Si) to 72 W (SiC) at 800 V, 100A



Benefits available by swapping die, no system change needed

USCI Gen 2 SiC FET vs SiC MOSFET



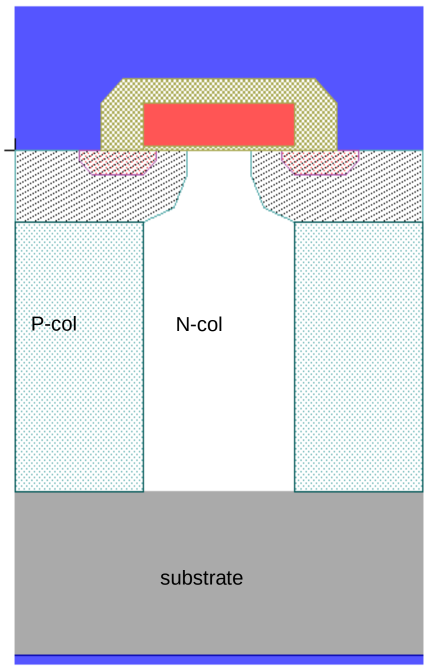


	Normally Off USCi SiC FET	Normally Off Typical SiC MOSFET
Die Size	(Smaller) R_{DSA}~ 1.75mW-cm^2	(Larger) R_{DSA}~ 3.1- 4.5 mW-cm^2
Gate Drive	(Standard) V_{GS} = 0V to 12V OR (SIC) V_{GS} = -20V to 20V	V_{GS} = -5V to 20V
Threshold	$V_{GS(TH)}$ = 5V Typical	$V_{GS(TH)}$ = 2.2V Typical
Intrinsic Diode	VSD=1.5V, Low Qrr, +10% Over Temperature	High VF (4.6V), High Qrr, 3X Over Temperature
Avalanche	Yes	Yes
Short Circuit	4 us guaranteed, 8us typical	Low

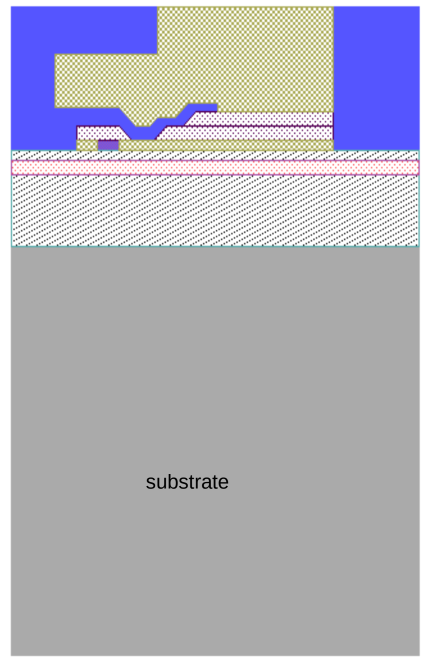
$R_{DS,A}$ (active Area) comparison for 650V Class

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

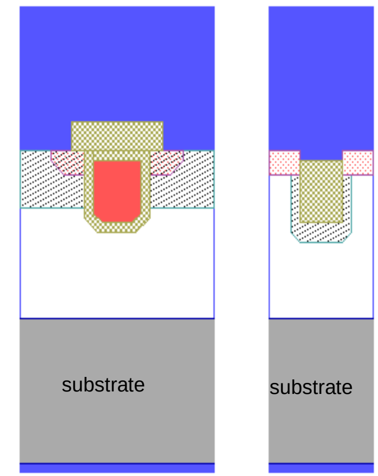
$R_{DS,A}$ (active Area) comparison for 650V Class



Silicon Superjunction FET
Vertical current flow



GaN HEMT
Lateral current flow

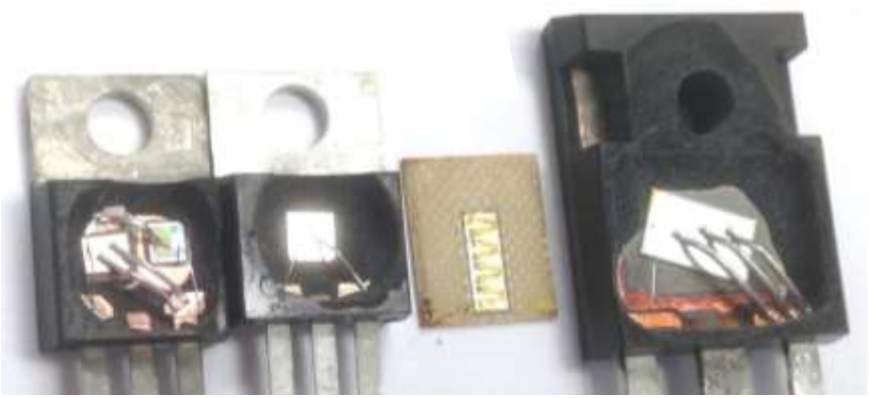


Trench MOS **Trench JFET**

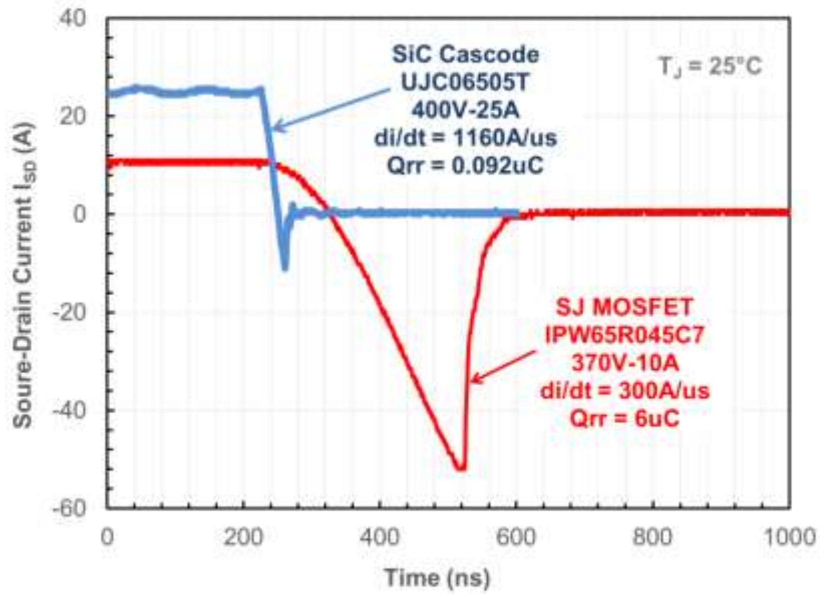
SiC FET
Vertical current flow

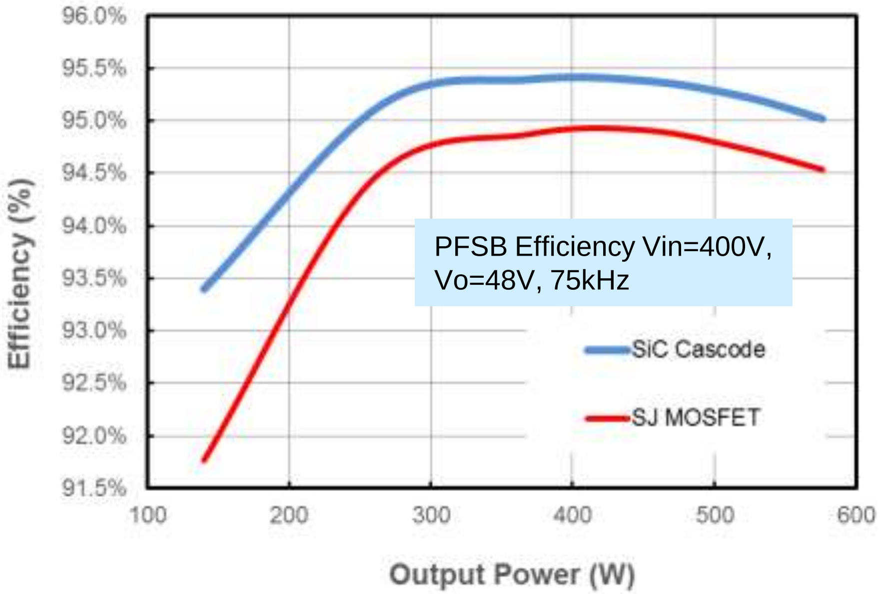
650V Comparison: SiC Cascode vs SJFET

Device	SiC Cascode UJC06505T	SiC Mosfet SCT2120AF	E-mode GaN GS66508B	Si Superjunction IPP65R045C7
R_{DSA} (mΩ–cm²)	0.75	8.4	6.6	11.6
RDS*Eoss (mΩ–μJ)	255	960	350	480
Vth (V)	5	2.8	1.3	3.5
Avalanche Capability	Yes	Yes	No	Yes



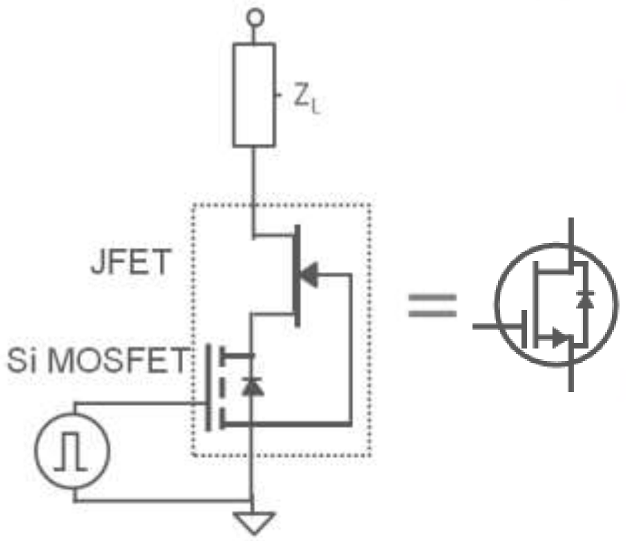
UJC6505T Cascode | SCT2120AF SiC MOSFET | GS66508B GaN HEMT | IPW65R045C7 Si Superjunction





How the cascodes works

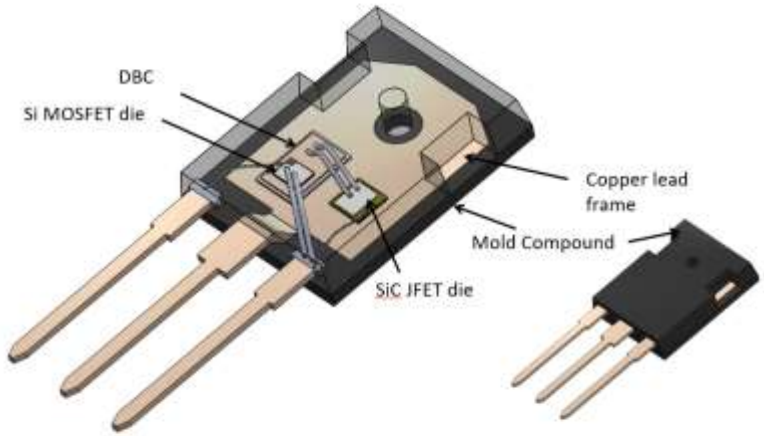
JFET V_{GS} = - MOSFET V_{DS}



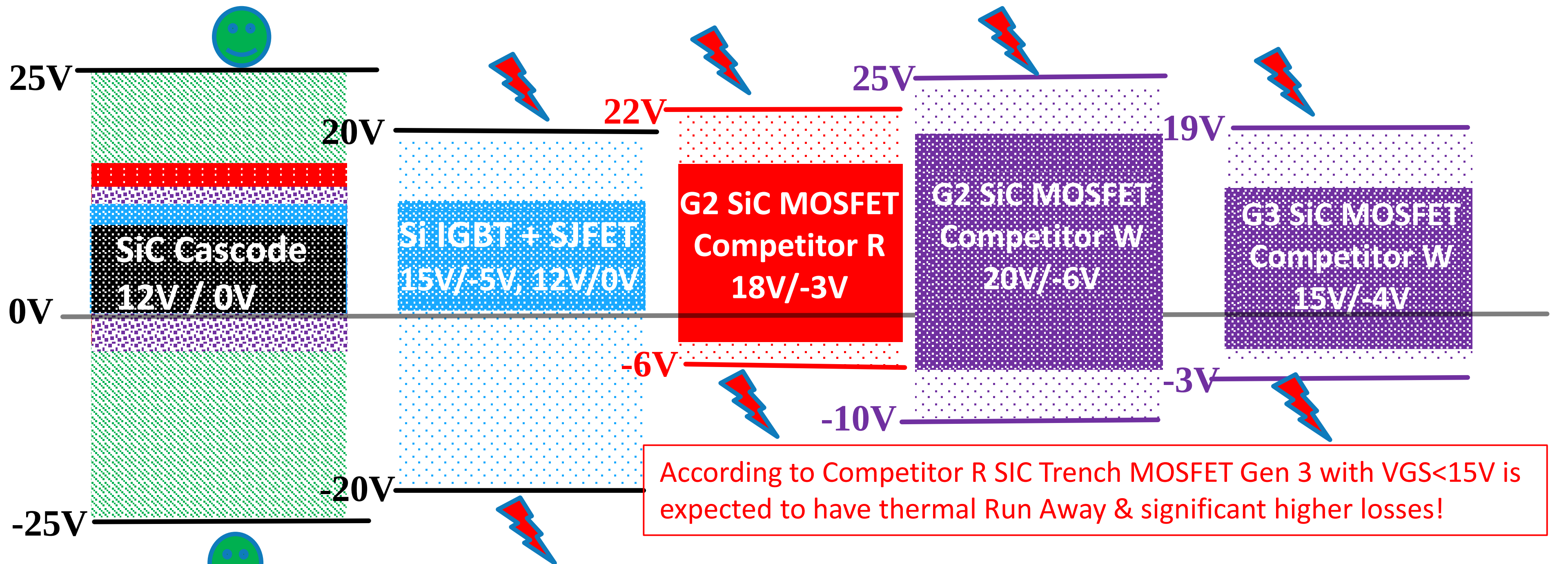
Cascode Internal Operation

Turn On
- MOSFET turns “On”
  - MOSFET V_{GS} > MOSFET V_{TH}
  - MOSFET V_{DS} ~ 0 V
- JFET turns “On”
  - MOSFET V_{DS} ~ 0, JFET V_{GS} ~ 0 V
    - JFET V_{TH} is -6 V typical

Turn Off
- MOSFET turns “Off”
  - MOSFET V_{GS} < MOSFET V_{TH}
  - MOSFET “Off”, V_{DS} rises > 6 V
- JFET turns “Off”
  - High Voltage Across JFET V_{DS}



Gate Drive comparison for various Technologies



Maximum VGS rating vs. recommended VGS

- **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.
- **Integrated safety features**
  Integrated clamping diode protects gates from |25V| and adds ESD protection
- **True Second source to any Si [IGBT, SJFET] and SIC MOSFET**

Body Diode V_F: SiC-Cascode vs -MOSFET

Knee Voltage = 0.7V

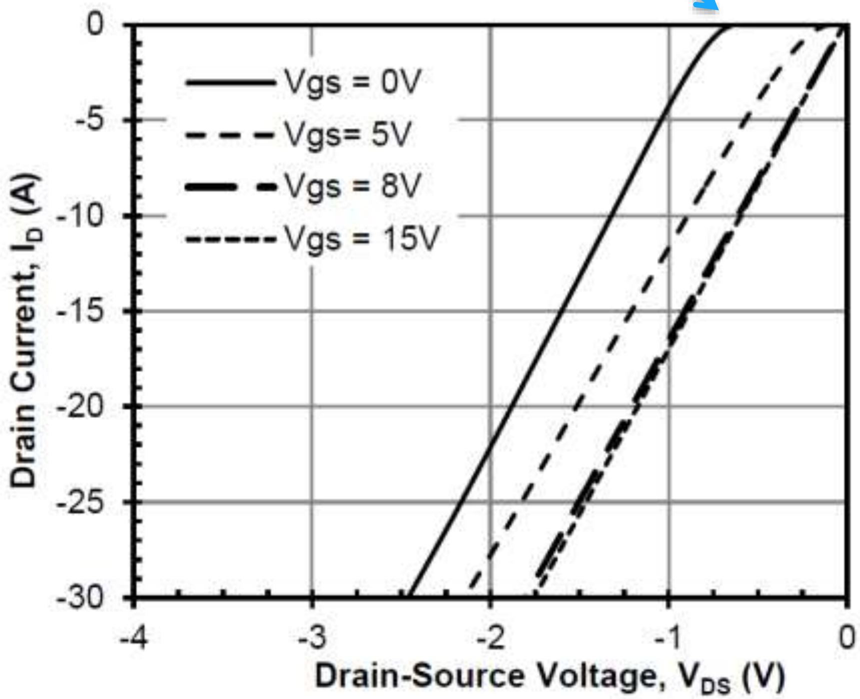


Figure 10 3rd quadrant characteristics at T_J = 25°C

Knee Voltage = 2.1V

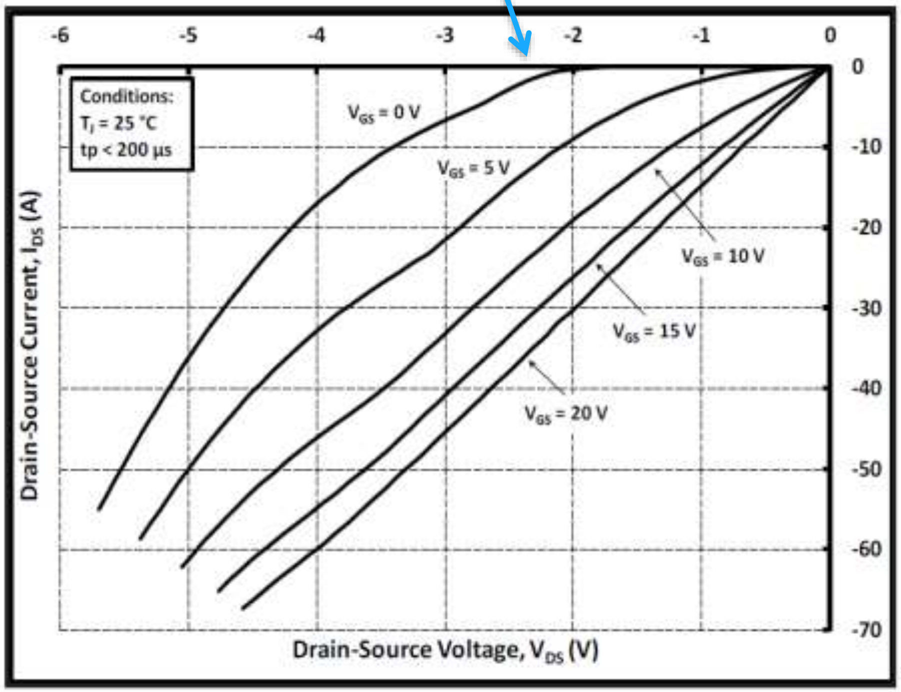


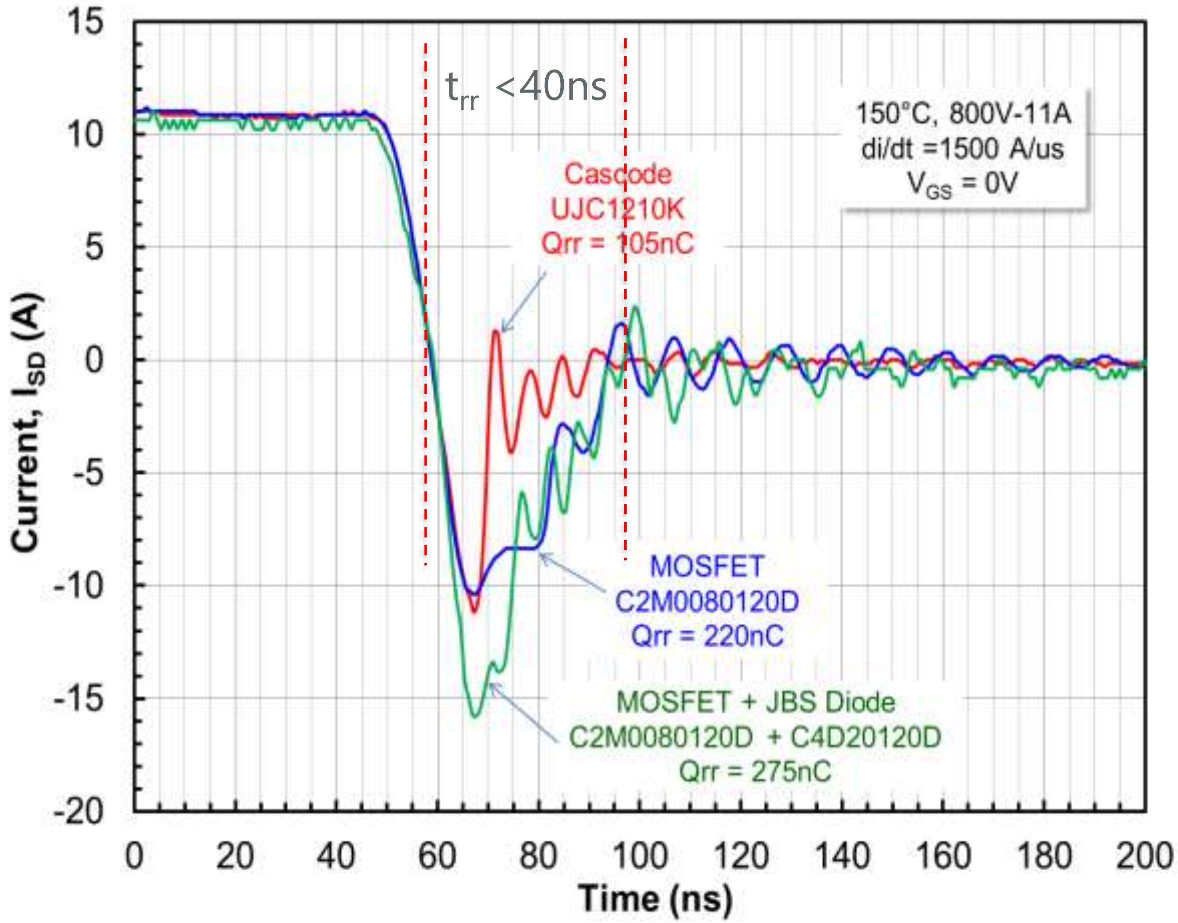
Figure 14. 3rd Quadrant Characteristic at 25 °C

USCi's SiC Cascode UJC1210K

SiC MOSFET C2M0080120D

Low V_F eliminates need for separate anti-parallel diode

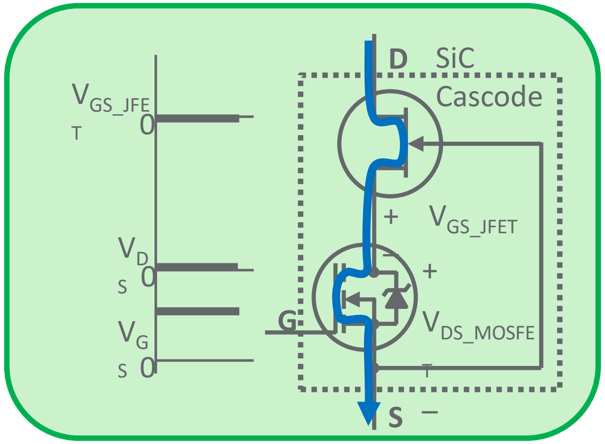
Body diode Qrr: SiC-Cascode vs -MOSFET



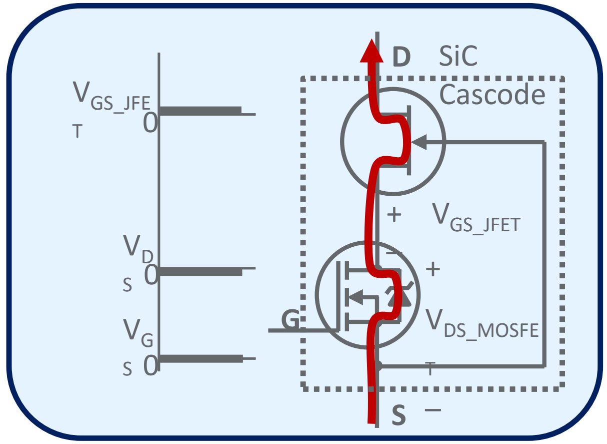
Gen2, 150 ° C, 800 V, 11A, 1500 A/μs

- Performed on in-house double-pulse tester
- Gate-source shorted, V_{GS} = 0 V
- 800 V inductive load

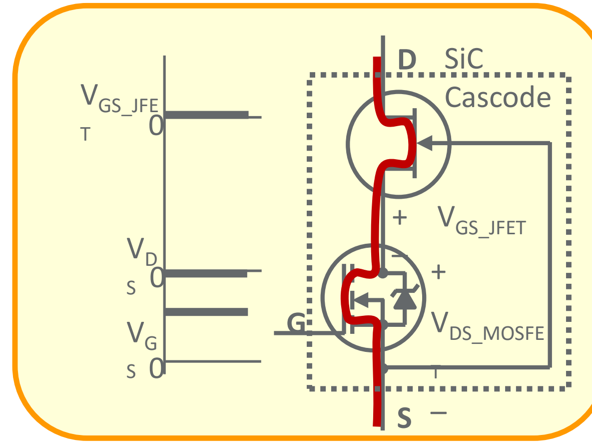
3rd quadrant operation



Forward current



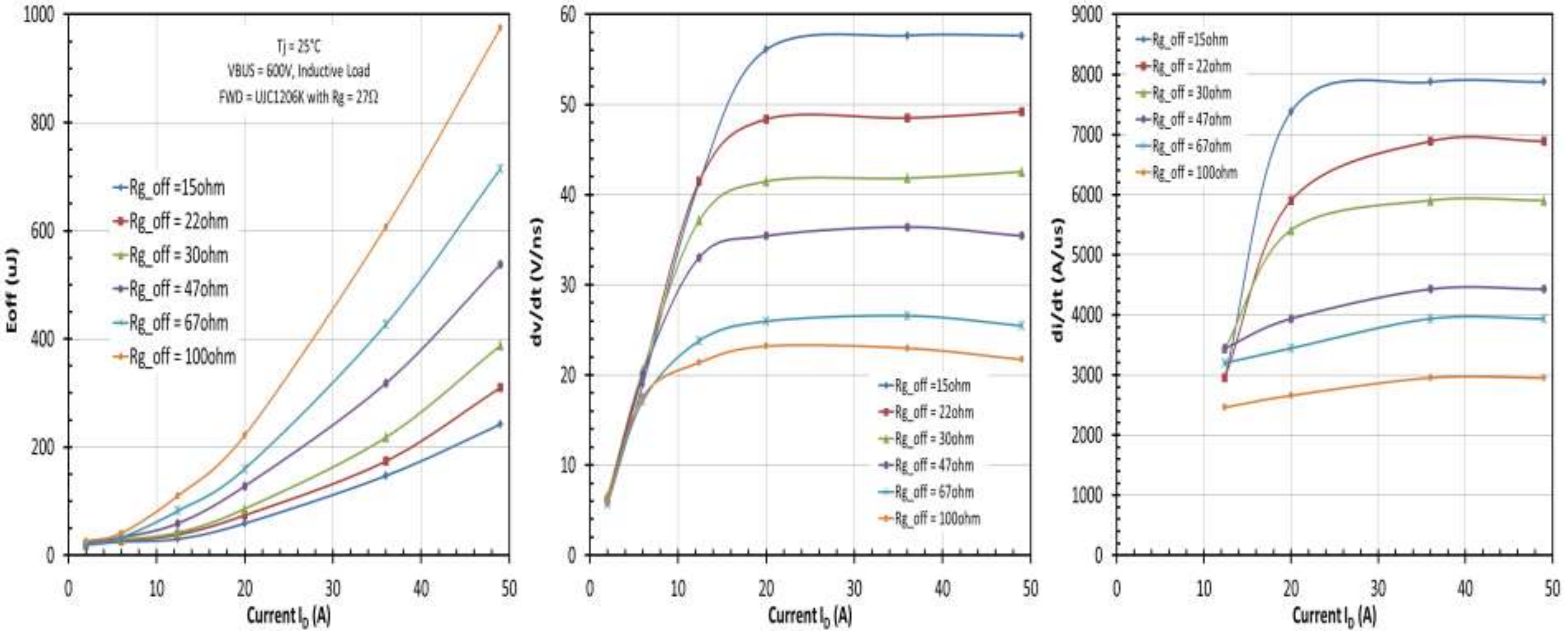
Reverse current, non-synchronous



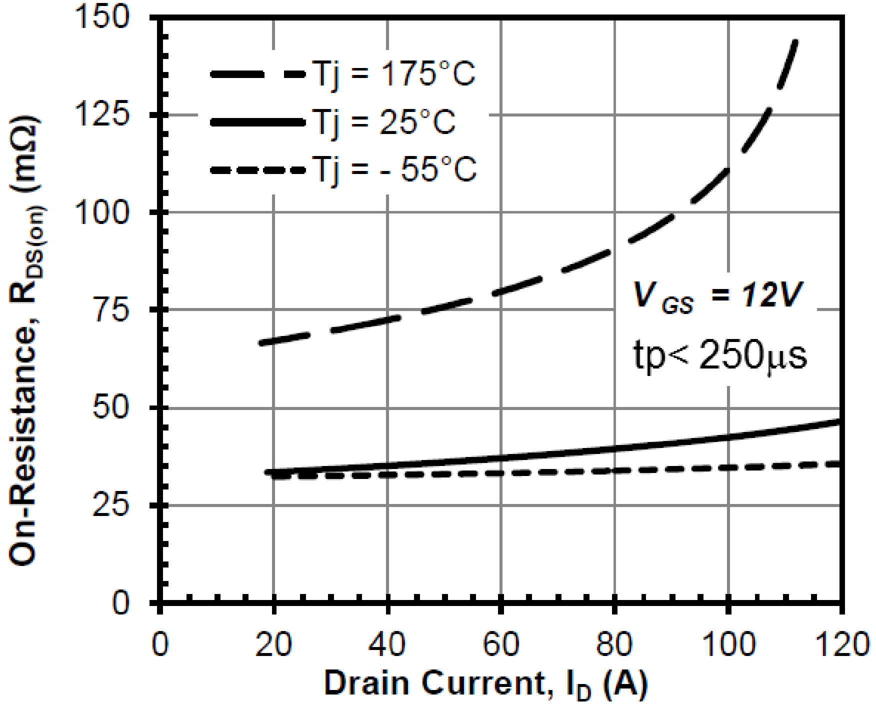
Reverse current, synchronous

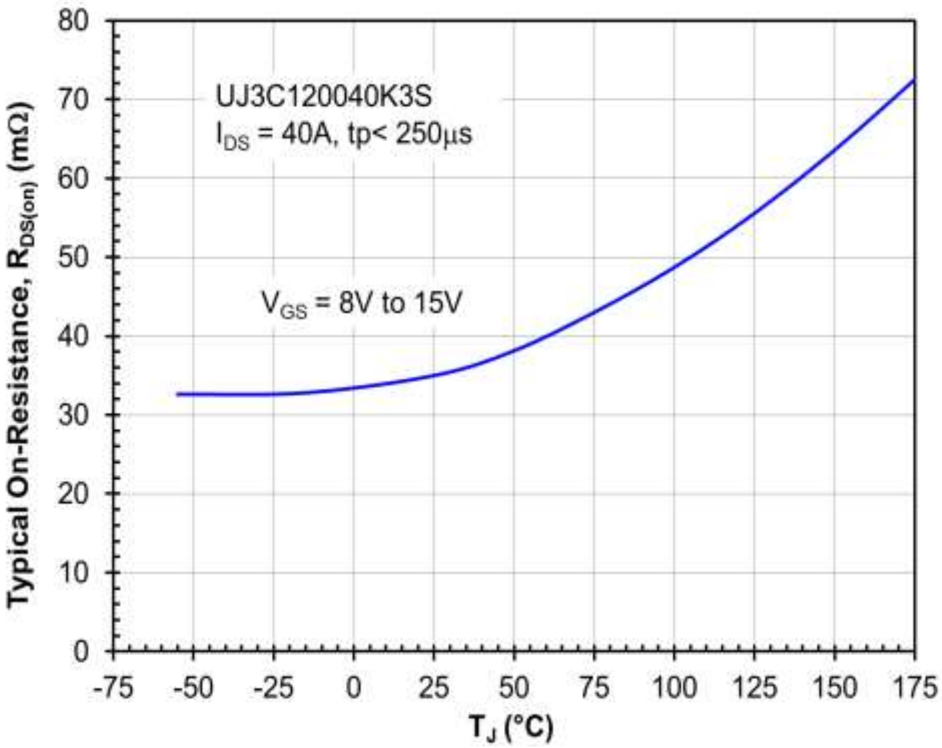
- SiC cascode is fully on with gate-source voltage between 10 to 20 V, **just like a MOSFET**
- Current flows in either direction through JFET
- Reverse current flows through MOSFET body diode or through MOSFET channel
- In all cases, JFET gate-source voltage is essentially zero; JFET is fully on

Control of dv/dt through RG



$R_{DS,on}$ dependency on Temperature and V_{GS}





Generation 2 Cascodes part list

Family	Base PN	Description	Samples	Production	Die	T0-220	TO247-3L	TO247-4L	D2pak-3L
1200V JFET	UJN1208K	1200V 80mΩ SiC JFET	Available	MP	MP		MP		
1200V JFET	UJN1205K	1200V 45mΩ SiC JFET	Available	MP	MP		MP		

Family	Base PN	Description	Samples	Production	Die	T0-220	TO247-3L	TO247-4L	D2pak-3L
1200V Cascode	UJC1206K	1200V 60mΩ SiC Cascode	Available	MP	MP		MP		
1200V Cascode	UJC1210K	1200V 100mΩ SiC Cascode	Available	MP	MP		MP		
1200V Cascode	UJC1220KS	1200V 220mΩ SiC Cascode	Available	n/a	n/a		SP		
650V Cascode	UJC06505K	650V 45mΩ SiC Cascode	Available	MP	MP	SO	MP		

MP: Mass Production ES: Engineering samples available SO: Sample only

Generation 3 Cascodes part list

Family	PN	Description	Samples	Production	Package
	General Purpose				
1200V Cascode	UJ3C120150K3S	1200V 150mΩ SiC Cascode	Q2 18	Q2 18	TO247-3L
1200V Cascode	UJ3C120080K3S	1200V 80mΩ SiC Cascode	Now	MP	TO247-3L
1200V Cascode	UJ3C120040K3S	1200V 40mΩ SiC Cascode	Now	MP	TO247-3L
650V Cascode	UJ3C065080K3S	650V 80mΩ SiC Cascode	Now	MP	TO247-3L
650V Cascode	UJ3C065030K3S	650V 30mΩ SiC Cascode	Now	MP	TO247-3L
650V Cascode	UJ3C065080T3S	650V 80mΩ SiC Cascode	Now	MP	TO220-3L
650V Cascode	UJ3C065030T3S	650V 30mΩ SiC Cascode	Now	MP	TO220-3L
650V Cascode	UJ3C065080B3S	650V 80mΩ SiC Cascode	Now	Q2 18	D2PAK-3L
650V Cascode	UJ3C065030B3S	650V 30mΩ SiC Cascode	Now	Q2 18	D2PAK-3L
	Hard Switched Apps				
650V Cascode	UF3C065040K3S	650V 40mΩ SiC Cascode Fast	Q2 18	Q3 18	TO247-3L
650V Cascode	UF3C065040T3S	650V 40mΩ SiC Cascode Fast	Q2 18	Q3 18	TO220-3L
650V Cascode	UF3C065040K4S	650V 40mΩ SiC Cascode Fast	Q2 18	Q3 18	TO247-4L
650V Cascode	UF3C065030K4S	650V 30mΩ SiC Cascode Fast	Q2 18	Q3 18	TO247-4L
650V Cascode	UF3C065080K4S	650V 80mΩ SiC Cascode Fast	Q2 18	Q3 18	TO247-4L
1200V Cascode	UF3C120150K4S	1200V 150mΩ SiC Cascode Fast	Q2 18	Q3 18	TO247-4L
1200V Cascode	UF3C120080K4S	1200V 80mΩ SiC Cascode Fast	ES	Q3 18	TO247-4L
1200V Cascode	UF3C120040K4S	1200V 40mΩ SiC Cascode Fast	ES	Q3 18	TO247-4L

MP: Mass Production

ES: Engineering samples available

Qual report on the website

UJ3C065030T3S / UJ3C065080T3S

Product Qualification Report

Description:	Cascode – 6 Inch, 650V
Package Type:	TO-220
Process Technology:	SiC, Si MOSFET
Date issued:	03/13/2018

Test Name	Test Standard	# Samples x # Lots	Results
High Temperature Reverse Bias (HTRB)	MIL-STD-750-1 M1038 Method A (1000 Hours) T_J=175°C, V=80% V_{max}	77x4 lots	Pass
High Temperature Gate Bias (HTGB)	JESD22 A-108 (1000 Hours) T_J=175°C, V=100% V_{max} (+25V), bias in on direction	77x4 lots	Pass
Highly Accelerated Stress Test (HAST)	JESD22 A-110 (96 Hours) T_A=130°C/85%RH	77x4 lots	Pass
Intermittent Operating Life (IOL)	MIL-STD-750 Method 1037 $DT_J \geq 125$°C, 3000 cycles (5 minutes on/ 5 minutes off)	77x3 lots	Pass
Temperature Cycle (TC)	JESD22 A-104 (1000 Cycles)	77x3 lots	Pass
Autoclave (PCT)	JESD22 A-102 121°C/ RH = 100%, 96 hours, 15psig	77x3 lots	Pass

Conclusion

This report summarizes the reliability tests applied to United Silicon Carbide products listed above. As a result of the testing, these products are considered qualified and available for unrestricted use within the limitations prescribed by the appropriate datasheets.

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Generation 3 JFETs part list

Family	PN	Description	Samples	Production	Package
	Soft Switched Apps				
1200V JFET	UJ3N120140K3S	1200V 150mΩ SiC JFET	Q2 18	Q2 18	TO247-3L
1200V JFET	UJ3N120070K3S	1200V 70mΩ SiC JFET	Now	MP	TO247-3L
1200V JFET	UJ3N120025K3S	1200V 25mΩ SiC JFET	Now	MP	TO247-3L
650V JFET	UJ3N065070K3S	650V 70mΩ SiC JFET	Now	MP	TO247-3L
650V JFET	UJ3N065020K3S	650V 20mΩ SiC JFET	Now	MP	TO247-3L

MP: Mass Production ES: Engineering samples available

Main Changes in Gen 3 Cascodes

- T_{JMAX} rating raised to 175 ^{o}C
- V_{GSMAX} rating raised to +/- 25V
- Built-in ESD protection diodes between MOSFET gate-source
- Compatible with all forms of standard Si and SiC gate drive voltages, with plenty of positive and negative voltage margin
- Current rating increased by reducing R_{THJC} (same die size, improved die attach technology)
- Rdson at 150 ^{o}C improved compared to G2
- No change to UIS rating, but able to handle higher peak currents in avalanche
- Due to higher peak current, Short Circuit rating is removed
- Switching losses decrease with T_j, due to the reduction of JFET R_g with T

Part Number	**Rdstyp**	**Rdsmax**	**RthJC**	**RthJCmax**	**Id(100)**	**Coss(er)**	**Eoss**
	mohn	**mohm**	**C/W**	**C/W**	**A**	**pF**	**uJ**
UJ3C065080K3S	75	100	0.61	0.79	20.4	77	6.2
UJ3C065030K3S	27	35	0.26	0.34	53	230	18.5
UJ3C120080K3S	75	100	0.45	0.59	23.9	59	19
UJ3C120040K3S	35	50	0.27	0.35	44	112	35.6
UJC06505K	34	45	0.84	1.1	23.5	100	8
UJC1210K	70	100	0.85	1.1	14	57	18.5
UJC1206K	42	60	0.5	0.65	24.5	98	31

UnitedSiC
Simply More Efficient

Comparison Gen 2 vs Gen 3 vs MOSFET

Same $R_{DS,on}$, half die size

USCi — 80mOhm

SiC MOSFET — 80mOhm

Same Die size, half $R_{DS,on}$

USCi — 40mOhm

SiC MOSFET — 80mOhm

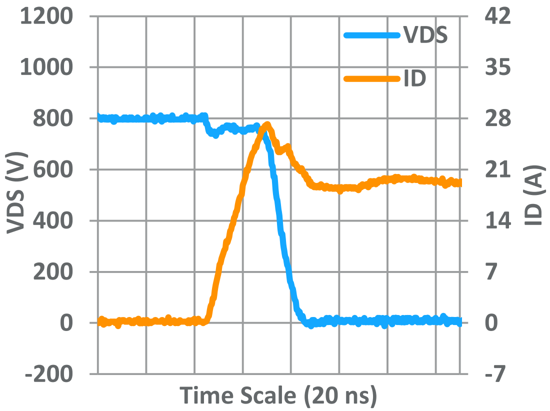
			UJC1210K	UJ3C120080KS	C2M080120K
			Trench Cas	G3 Cascode	Planar
TJMAX		C	150	175	150
RthJCmax		C/W	1.1	0.59	0.65
Vgsmax		V	+/-20	+/-25	-5/20
Vdsmax		V	1200	1200	1200
ESD		KV	1.7	3.5	
Id (Tc=100C)		A	14	23.9	24
Rds 25		mohm	70	75	80
Rds 150		mohm	161	148	128
Rds 175		mohm		168	
Vth		V	5	5	2.6
Qg		nC	47.5 (0-12)	51 (-5 to 15)	62 (-5 to 20)
Rg		ohm	1	4.5	4.6
Ciss		nF	2214	1500	950
Coss (1000V)		nF	45	40	80
Crss		nF	3	2.1	7.6
VF	**10A**	V	1.4	1.5	3.3
Qrr 25	**20A/800V**	nC	112		192
Qrr 150/175C	**20A/800V**	nC	127	180	
Eon HB 125C	**20A/800V**	uJ	407	392	446
Eoff HB 125C	**20A/800V**	uJ	100	107	140
RthjC		C/W	1.1	0.59	0.65
SCWT	**600V**	us	4	NA	NA
Eas		mJ	64	64	

USCi UJ3C series is fabricated on 6-inch SiC in an TS16949 certified FAB according to AECQ-101

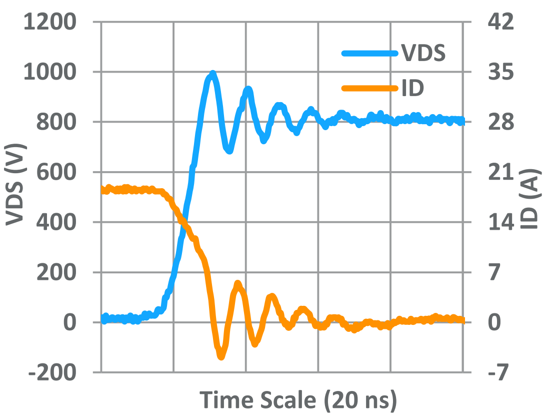
Comparison Gen 2 vs Gen 3 vs MOSFET

UnitedSiC GEN 2

UJC1210K, 12V/-5V
Rgon = 2.3 Ω, Rgoff = 10 Ω, Eon = 406 uJ
didt = 1.28 A/ns, dvdt = 69 V/ns

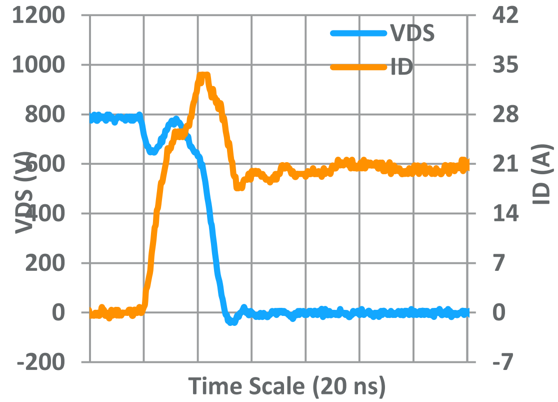


UJC1210K
Rgon = 2.3 Ω, Rgoff = 10 Ω, Eoff = 101 uJ
didt = 4.2 A/ns, dvdt = 86 V/ns

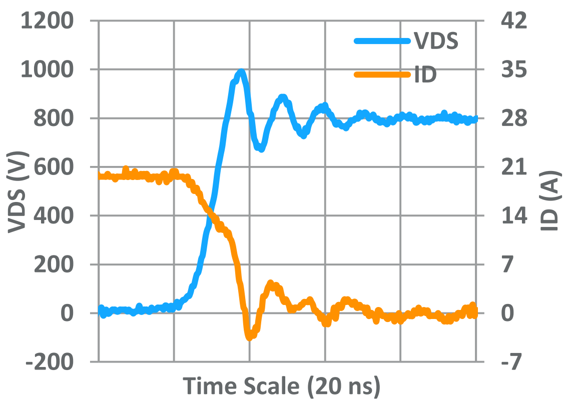


UnitedSiC Gen 3

UJ3C120080K3S, 15V/-5V
Rgon = 1 Ω, Rgoff = 20 Ω, Eon = 392 uJ
didt = 2.78 A/ns, dvdt = 78 V/ns

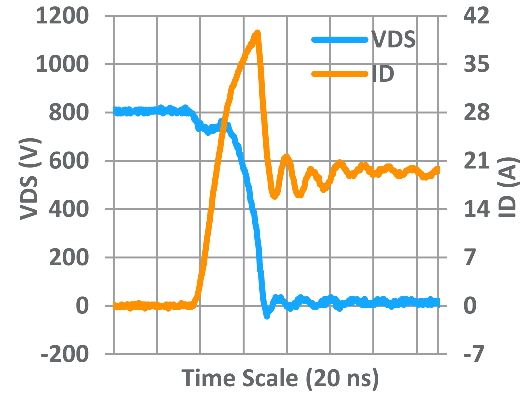


UJ3C120080K3S
Rgon = 1 Ω, Rgoff = 20 Ω, Eon = 107 uJ
didt = 3.7 A/ns, dvdt = 85 V/ns

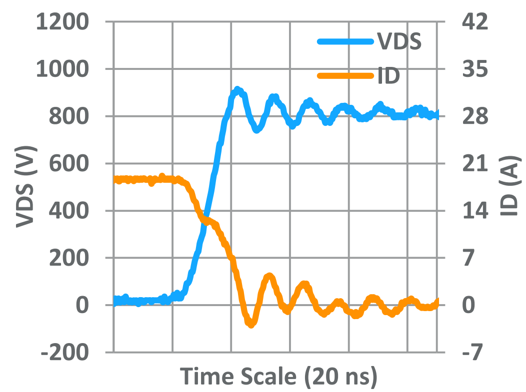


SiC MOSFET Gen2

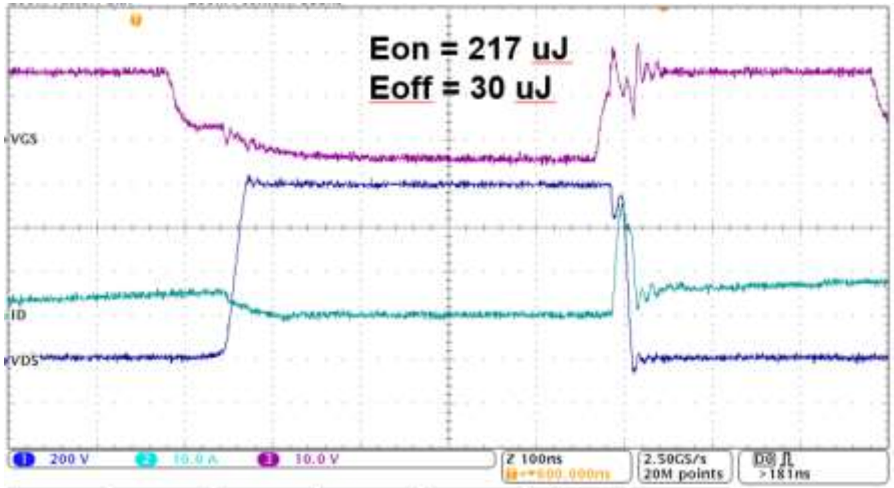
C2M080120D, 18V/-5V
Rgon = 5 Ω, Rgoff = 5 Ω, Eon = 446 uJ
didt = 2.1 A/ns, dvdt = 71 V/ns



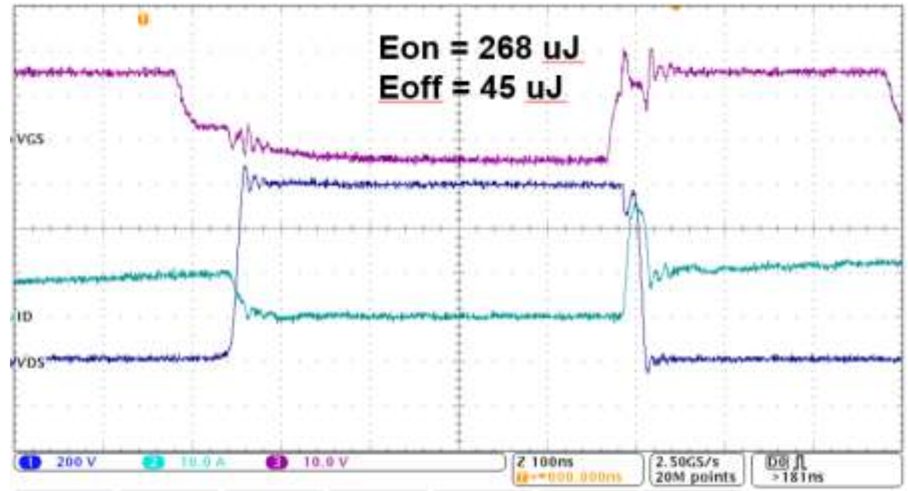
C2M080120D
Rgon = 5 Ω, Rgoff = 5 Ω, Eoff = 115 uJ
didt = 2.3 A/ns, dvdt = 60 V/ns



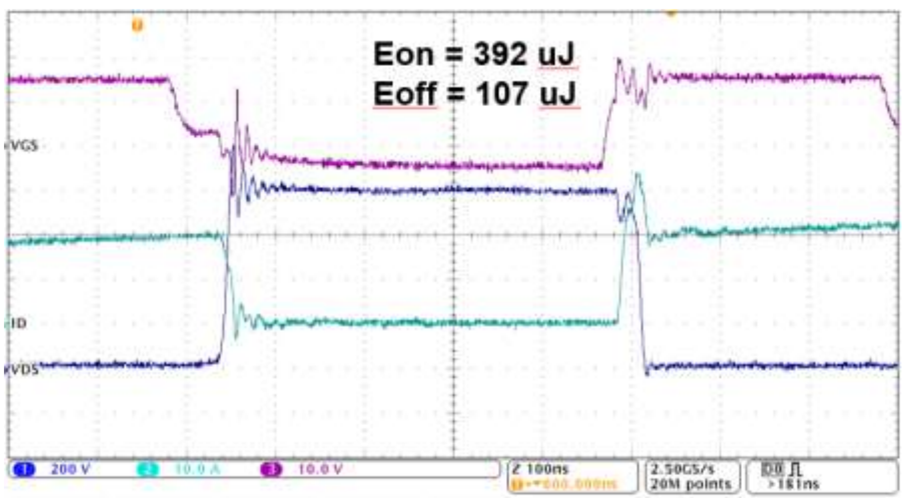
Half-Bridge, V_{GS}=15V/-5V, 125C
$R_{G,on}$=1Ohm, $R_{G,off}$=20Ohm



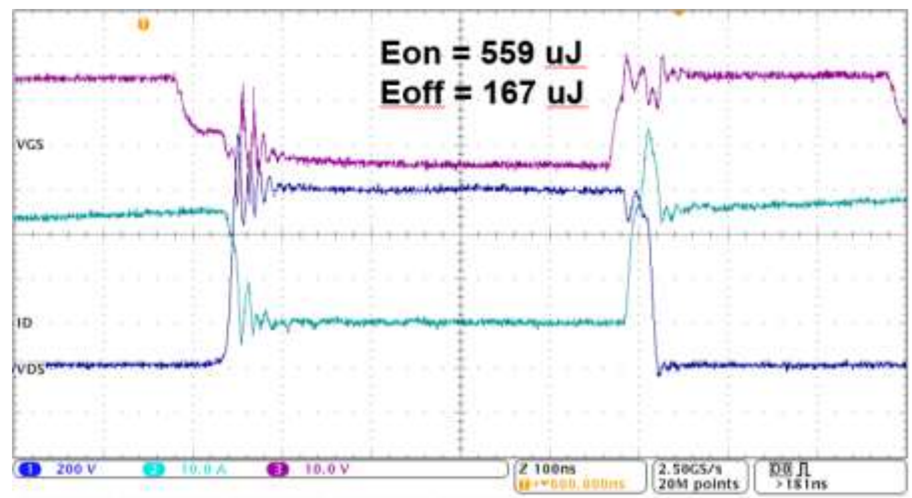
5A, 800V



10A, 800V

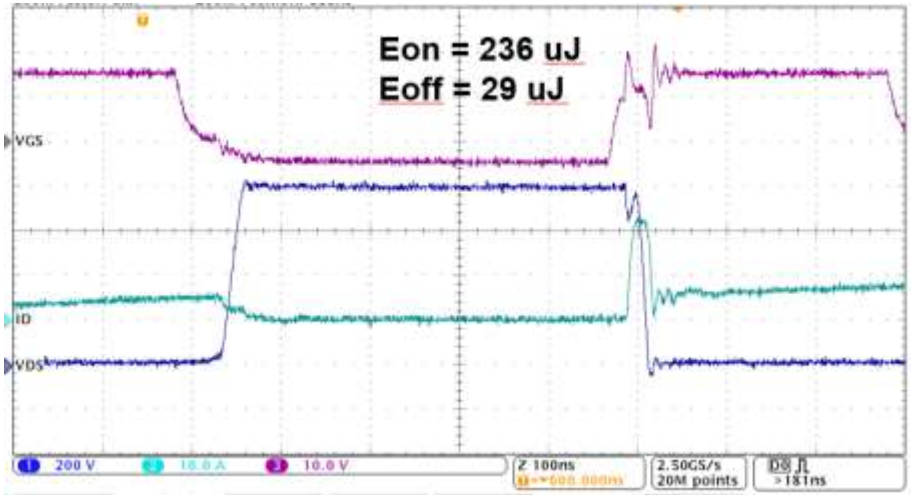


20A, 800V

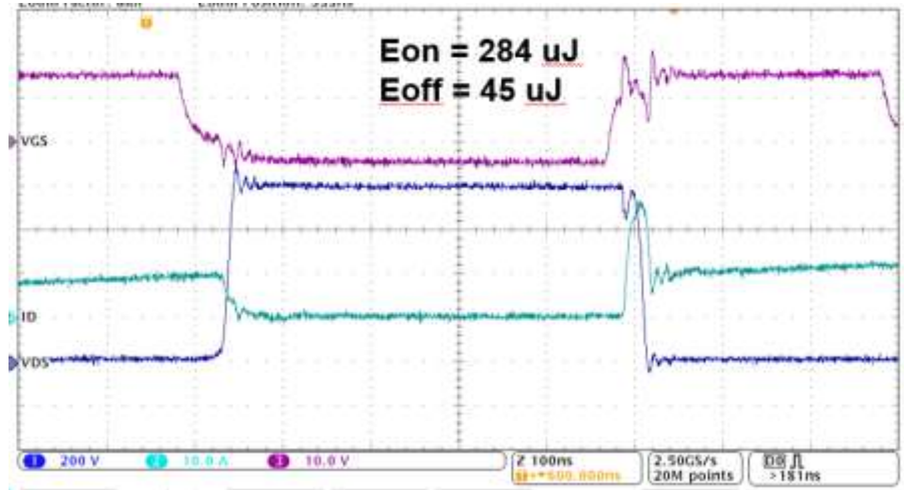


25A, 800V

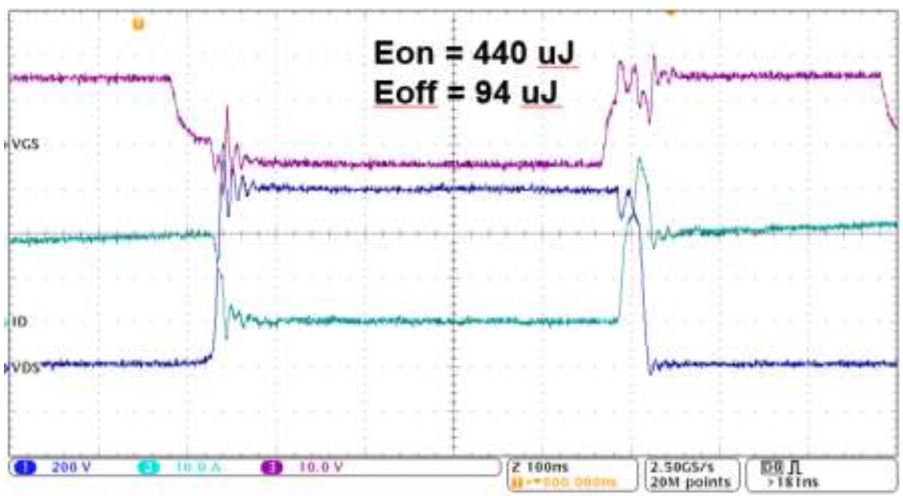
Half-Bridge, V_{GS}=15V/-5V, 125C
$R_{G,on}$=2.3Ohm, $R_{G,off}$=8Ohm



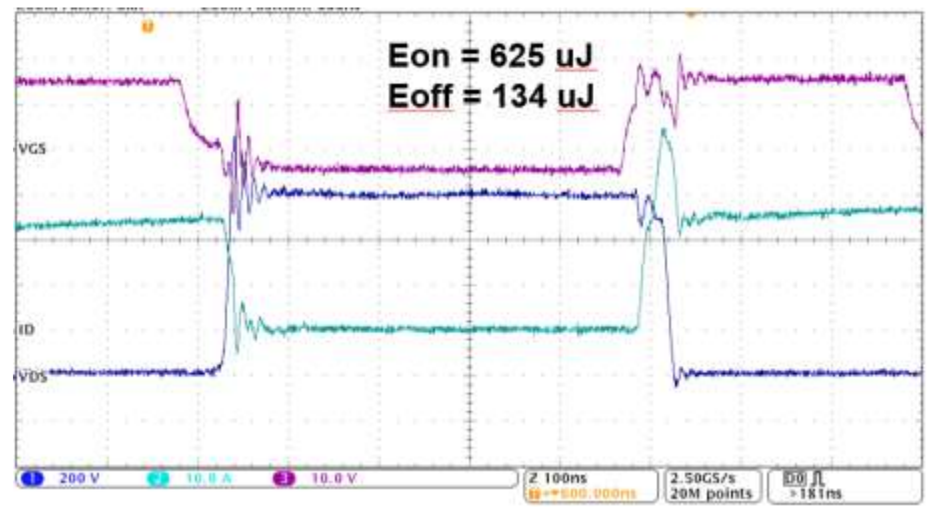
5A, 800V



10A, 800V



20A, 800V



25A, 800V

Gate Drive recommendation

Chopper mode with SiC Schottky

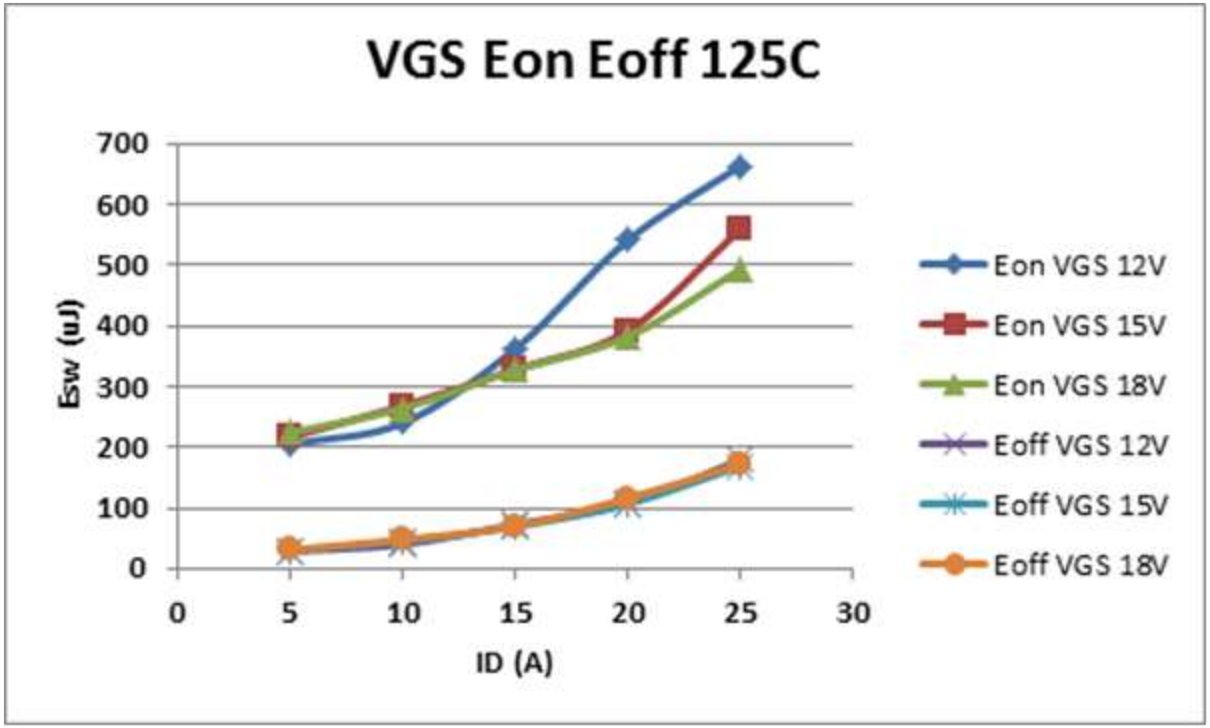
- Gate drive voltages of 0-12V sufficient at lower currents. Recommend +15V/-5V for switching >20A.
- Use Rgon=1ohm, Rgoff=10ohm if ferrite bead is not used. Similar to UJC1210K.
- Use Rg from 1-3.3ohm with ferrite bead (BLM41PG600SN1L). In this case, there is no need for a separate Rgon/Rgoff.
- The standard TO247-3L has high source inductance. The ferrite bead helps suppress unwanted gate oscillations both at turn-on and turn-off, resulting in improved switching across a wider range of Rg.

Half-bridge mode, using the same device as HS/LS

- Gate drive voltages of 0-12V sufficient at lower currents. Recommend +15V/-5V for switching >20A.
- Use Vgs=+15/-5V and Rgon=1ohm, Rgoff=20ohm for half-bridge hard switched applications.
- Equally good performance achieved using Vgs=+15/-5V and Rg from 2-3.9ohm with ferrite bead (BLM41PG600SN1L). In this case, there is no need for a separate Rgon/Rgoff.
- The standard TO247-3L has high source inductance During the high di/dt seen in diode recovery, voltage across the source inductance can turn-on the LV MOS. Using an Rgoff of 10-20ohm can prevent this, but with Rgoff <10ohm, unwanted higher Qrr can occur. Using a ferrite bead at the gate is also effective in preventing this behavior and keeps Eon losses to a minimum. The ferrite bead also allows use of a wider range of Rg.

USCi UJ3C series is fabricated on 6-inch SiC in an automotive qualified FAB

Gate Drive recommendation



HALF BRIDGE
UJ3C120080KS HS+LS

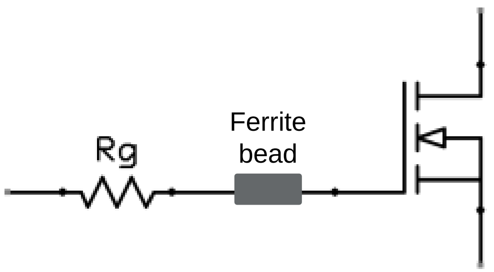
Rgon=1ohm Rgoff=20ohm
Both HS and LS

Tj=125C

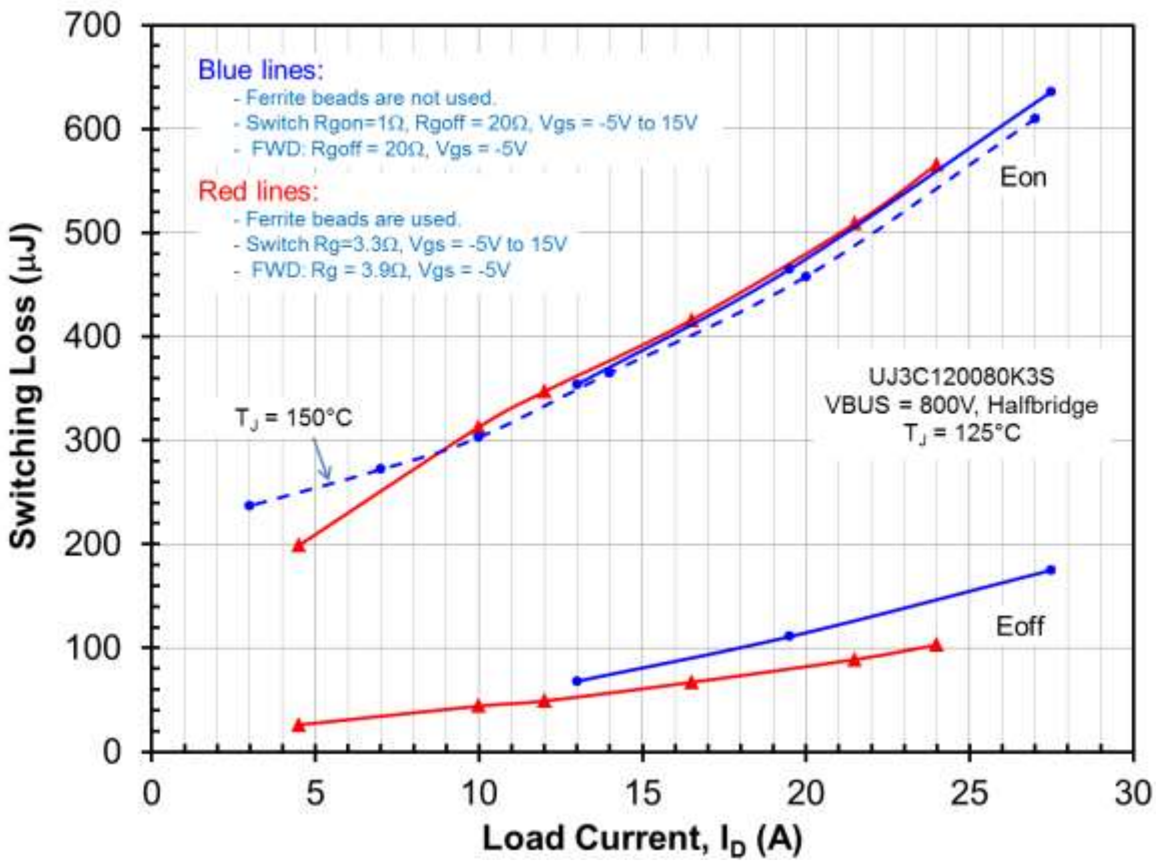
At higher currents, a Vgs>12V allows faster turn-on for lower Eon.

Not much difference below 15A

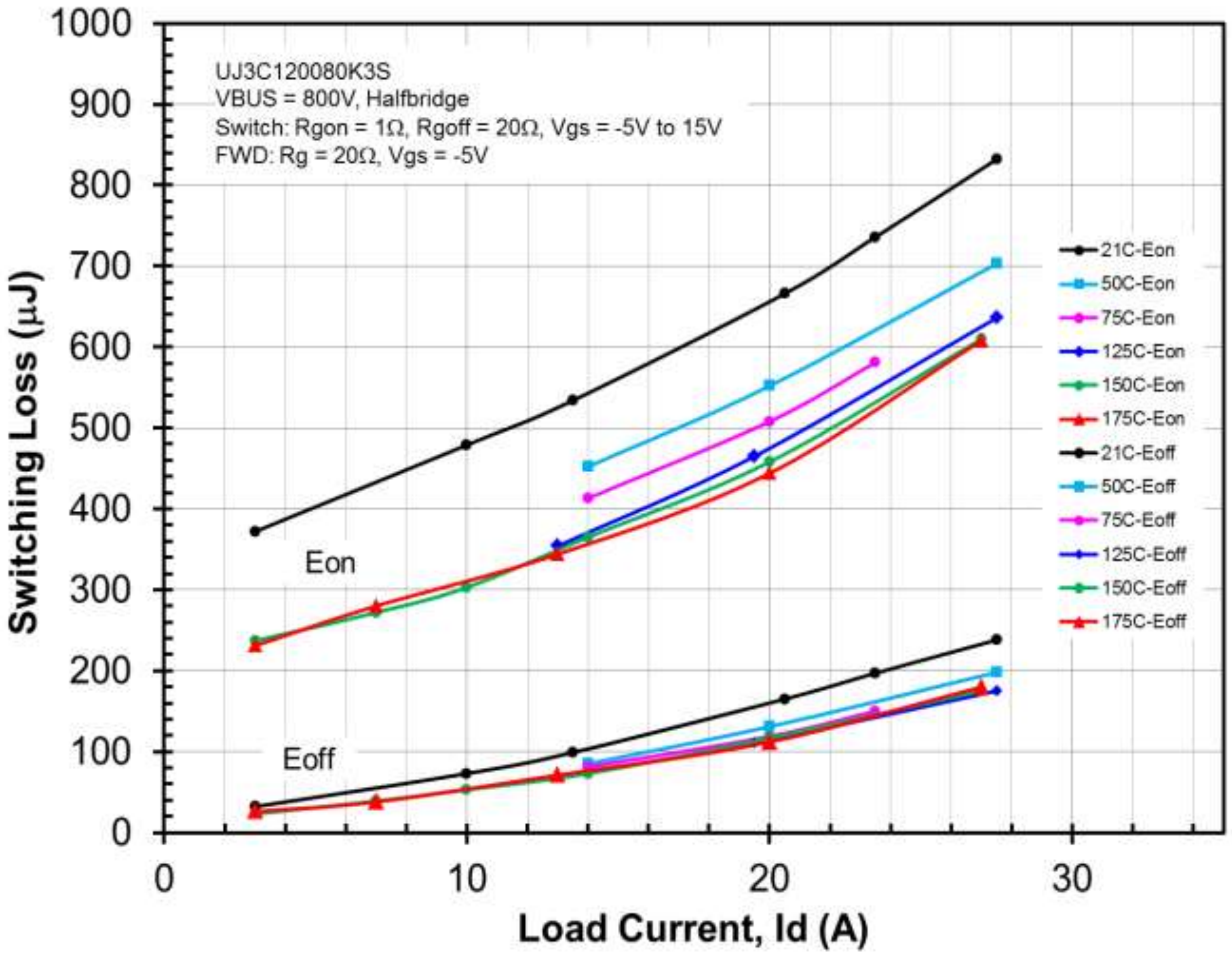
Ferrite Bead



Part #: BLM41PG600SN1L
Description: FERRITE BEAD 60 OHM 1806 1LN

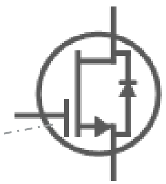
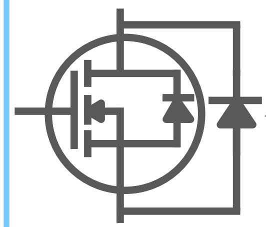


Switching Losses at different T

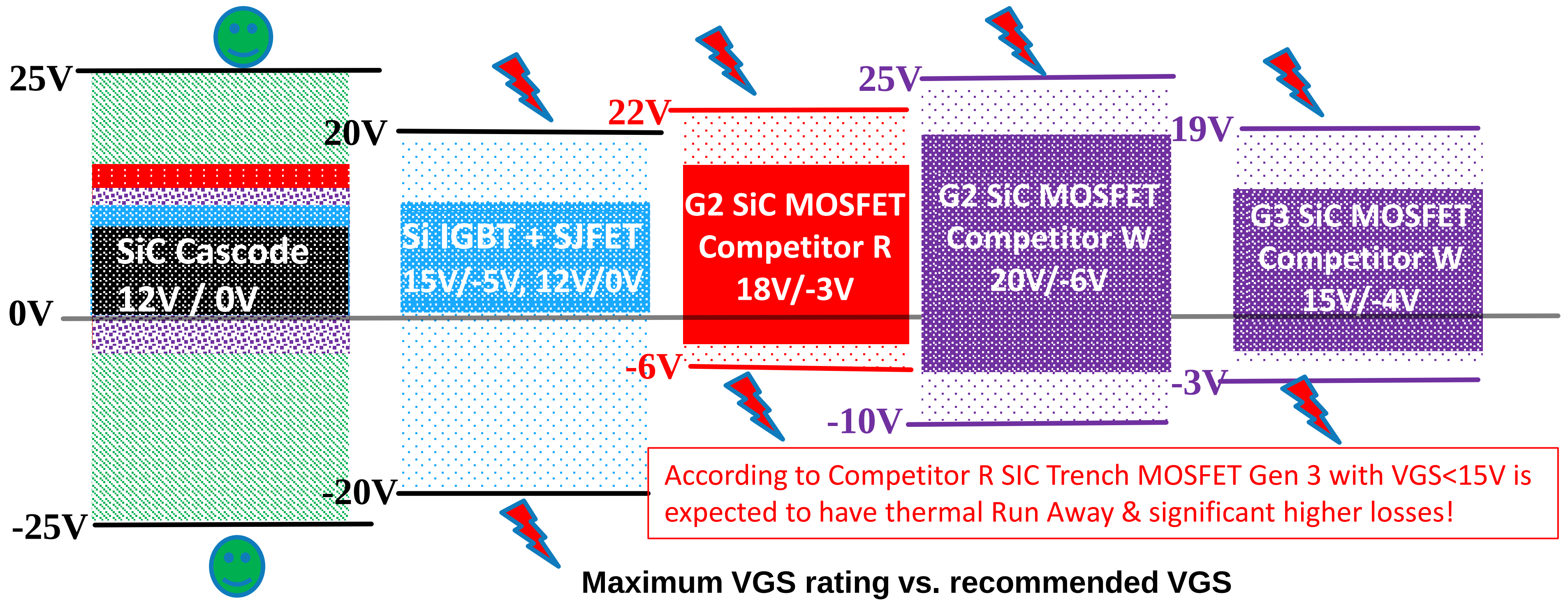


- VBUS = 800V
- Inductive load
- Half-Bridge configuration
- Switch:
  - Rgon = 1Ω
  - Rg_off = 20Ω
  - Vgs = -5V to +15V
- FWD:
  - Rg_off = 20Ω
  - Vgs = -5V

USCI Gen 3 SiC FET vs SiC MOSFET

	Normally Off USCi SiC FET	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} = -25V to 25V	V_{GS} = -5V to 20V
Threshold	$V_{GS(TH)}$ = 5V Typical	$V_{GS(TH)}$ = 2.2V Typical
Intrinsic Diode	VSD=1.5V, Low Qrr, +10% Over Temperature	High VF (4.6V), High Qrr, 3X Over Temperature
ESD Protection	integrated	N/A
Gate Protection	integrated	N/A
Rth,jc	Lowest in industry	higher
Tj,max	175C	Most 150C

USCI Gen 3 SiC FET vs SiC MOSFET



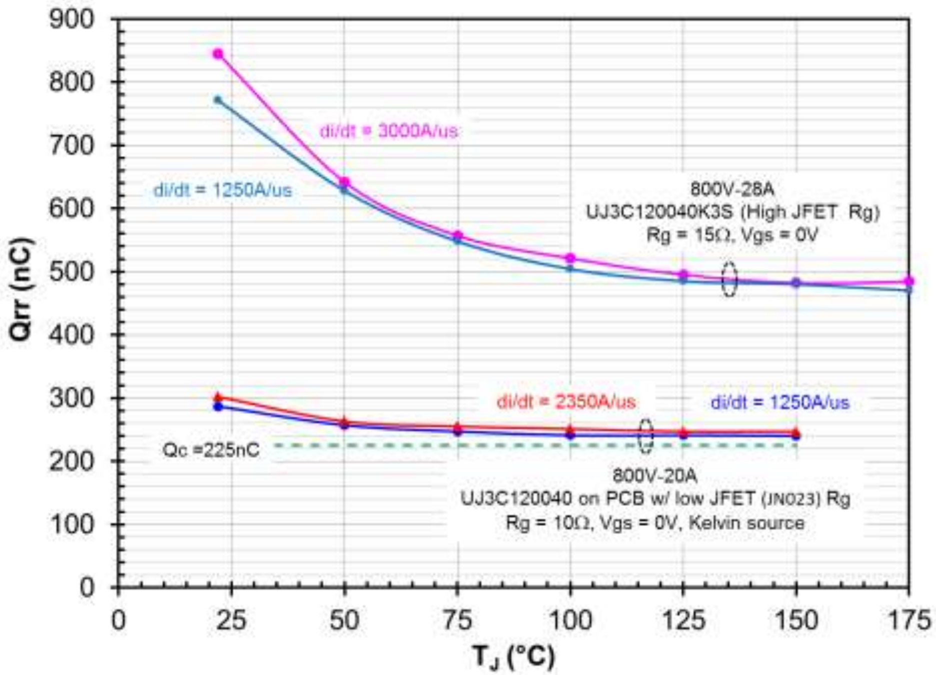
Maximum VGS rating vs. recommended VGS

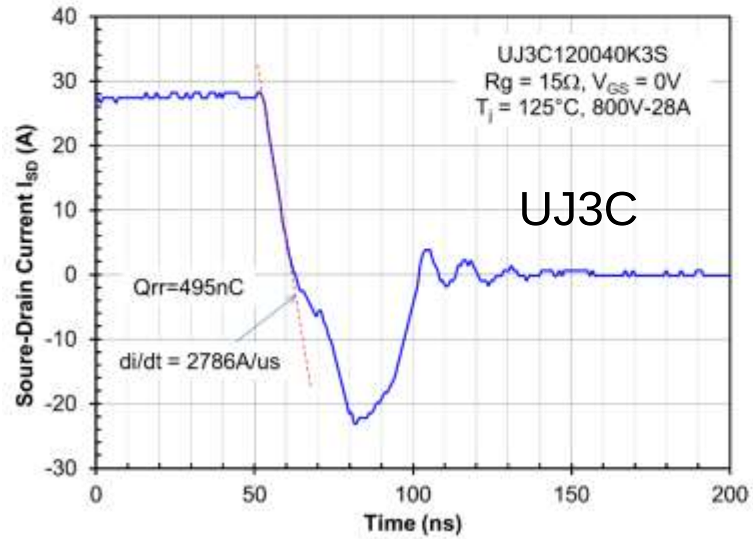
- **Easy Drop-in**
  12V turn-on makes SiC cascode an easy choice for drop-in replacement.
- **Extra Margin in VGS**
  SiC cascode has higher margin in VGS design and requires no negative VGS for turn-off.
- **Integrated safety features**
  Integrated clamping diode protects gates from |25V| and adds ESD protection
- **True Second source to any Si [IGBT, SJFET] and SIC MOSFET**

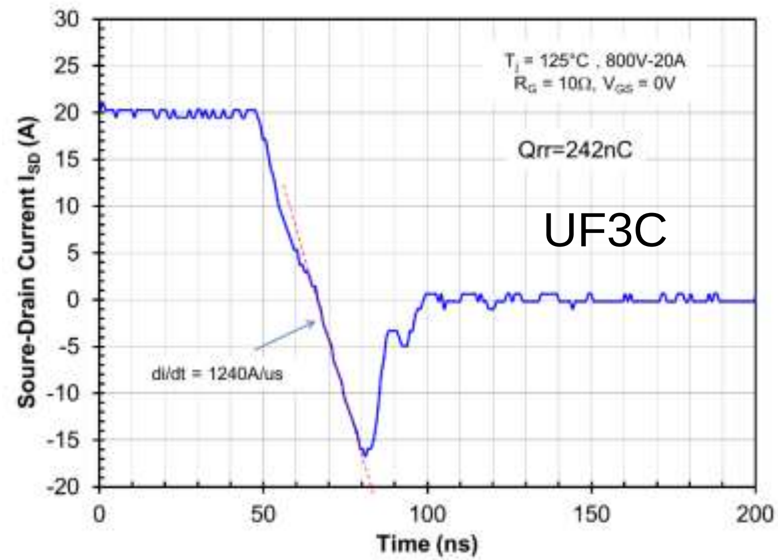
USCI Gen 3 Fast:UF3C

- UF3C series of 650V and 1200V devices uses internal JFET design enhancements to reduce switching loss and Qrr.
- A wide range of these devices will be available in TO247-4L, which allows faster switching without excessive ringing in the gate waveform
- All the benefits of the Gen 3, UJ3C series are retained
  - Low RthJC, improved current ratings
  - ESD protected
  - Fast switching
  - Improved temperature coefficient of R_{DS}

Measure Qrr of UJ3C120040K3S & UF3C120040K4S

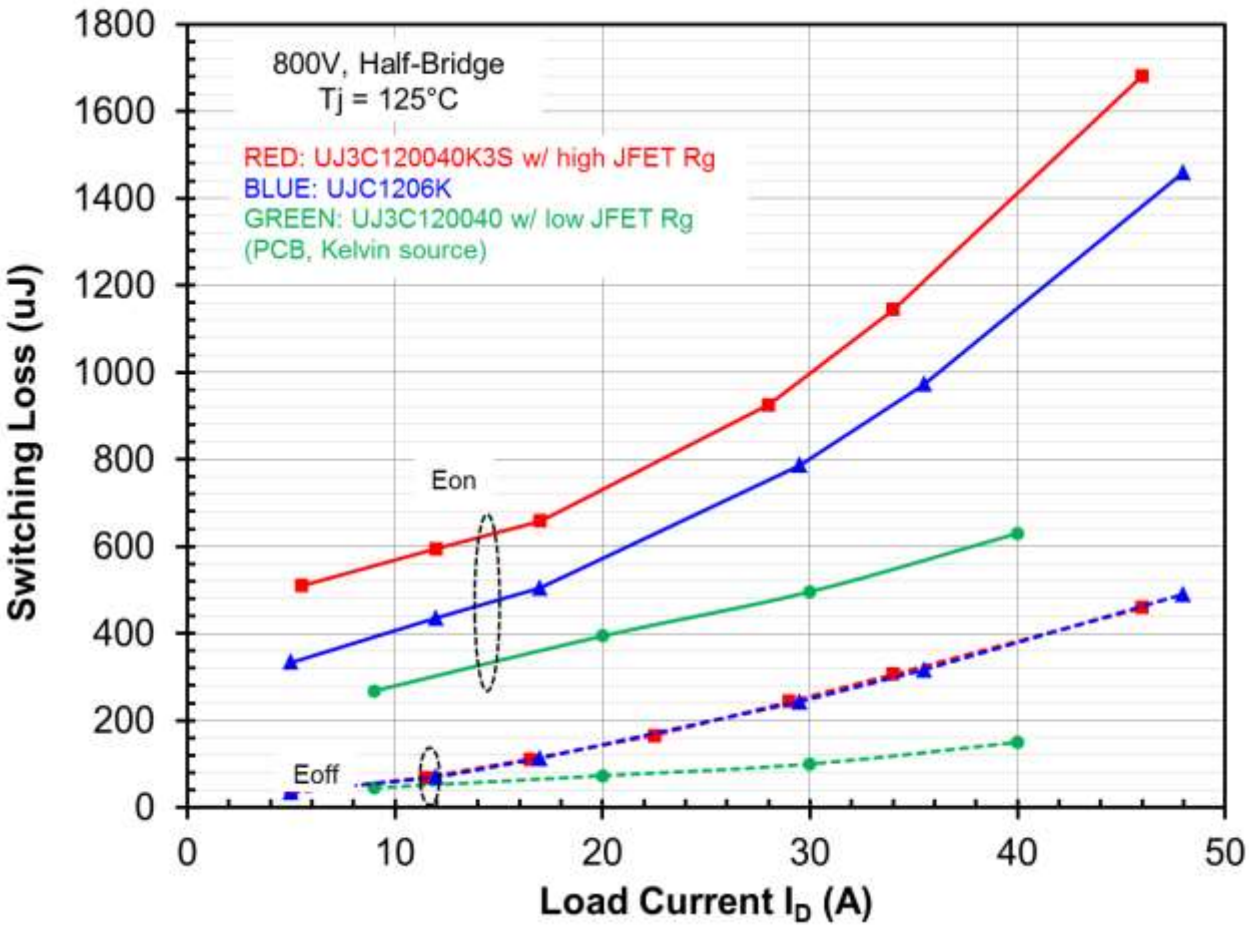






Minimum Qrr in a cascode is Qc, the integrated Coss charge

Switch Loss Comparison of UJC, UJ3C and UF3C



UJC1206K:

V_{GS} = -5V to +15V

- Rg_on = 1.8Ω
- Rg_off = 20Ω

UJ3C120040K3S

V_{GS} = -5V to +15V

- Rg_on = 1.8Ω
- Rg_off = 20Ω

UF3C120040K4S:

- V_{GS} = -5V to +15V
- Rg_on = 20Ω
- Rg_off = 20Ω

Customer Reference: Micropower

Micropower Group to sign long term agreement with United Silicon Carbide Inc.

MICROPOWER GROUP™ POWERFUL SOLUTIONS PARTNER + USCi the power to do more with less =

- Technological partnership
- Phase shifted Full bridge
  (need for an excellent body diode)
- 10kW battery charger
- 30% higher output power with SiC Cascode in same dimensions
- Si-FET replacement and ease of use through Standard Gate drive
- 1.5% higher efficiency

Customer Reference: PRE

PRE + USCi the power to do **more** with **less** =

- Bidirectional converter which is used today in around 50% of the DC Fast Charger in Europe today
- No external SiC Schottky diode in hard switched application needed due to significant reduced body diode (<2V) compared to SiC MOS
- System Cost reduction due to Cascode usage
- Modular reliable systems with proven technology up to 150kW
- Uni and bidirectional from 6kW up to 25kW with V2G / V2H operation
- CHAdeMO and CCS compatible
- 97% efficient, 500V DC and 1000V DC
- Noiseless Power

Applications

- EV Fast Chargers
- Industrial Battery Charger
- Industrial Current Source

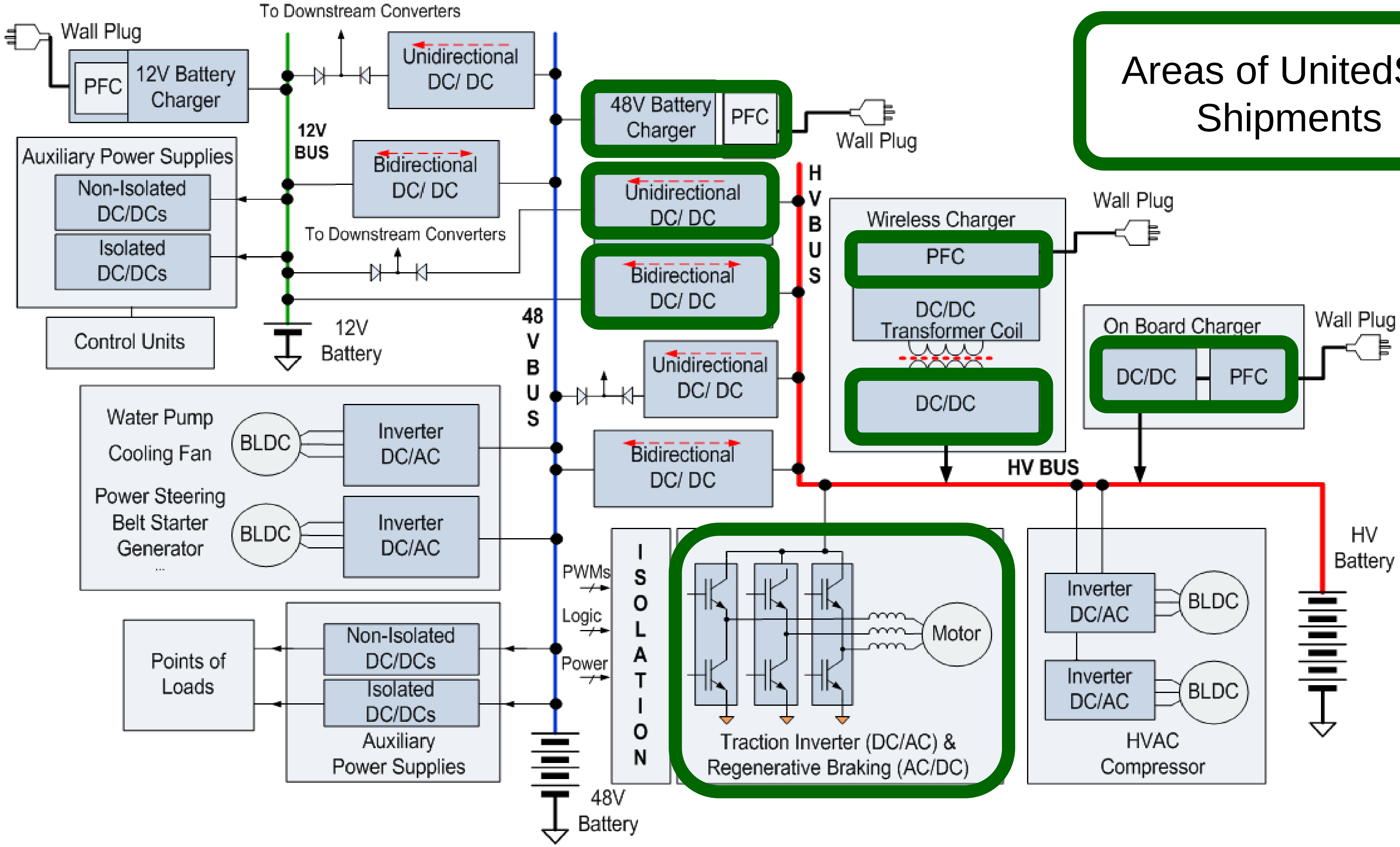
CHAdeMO

Input (Mains)	AC Voltage & Current Range (5)	400Vac +/-10% , 0-16Aac, 47-63Hz (11kVA max.) 3L + N + PE
	Power Factor (Control)	>0,99 @ 400Vac & Rated Power (-0.8 .. +0.8 Reactive Power Control)
	Total Harmonic Current	<3% @ 400Vac & Rated Power
	Efficiency	>95% @ 400Vac & Rated Power
	Stand-by consumption	<1W @ Mains Relay Off /15W @ Mains Relay On (Stand-by)
	Inrush Current (typ.)	50A Cold Start @ 400Vac
	Leakage Current	<3.5mA @ 400Vac

Customer Reference: Behlke

- Technological Partnership
- Easy paralleling due to positive temperature coefficient
- Up to **1000** devices in parallel and series
- Ease of use due to standard gate drive
- Replacement of external FRD due to excellent Body diode performance

Application reference Automotive



Block Diagram Adapted from Texas Instruments

Applications


Server & Datacenter


Lighting & Electronic Ballast


Electronic Vehicles

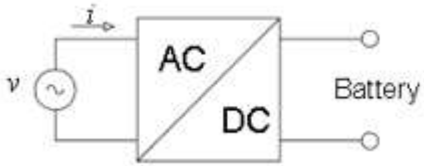

Lab & Din Rail PSU


Battery Charging


Renewable Energy & Storage

Battery Charger topology

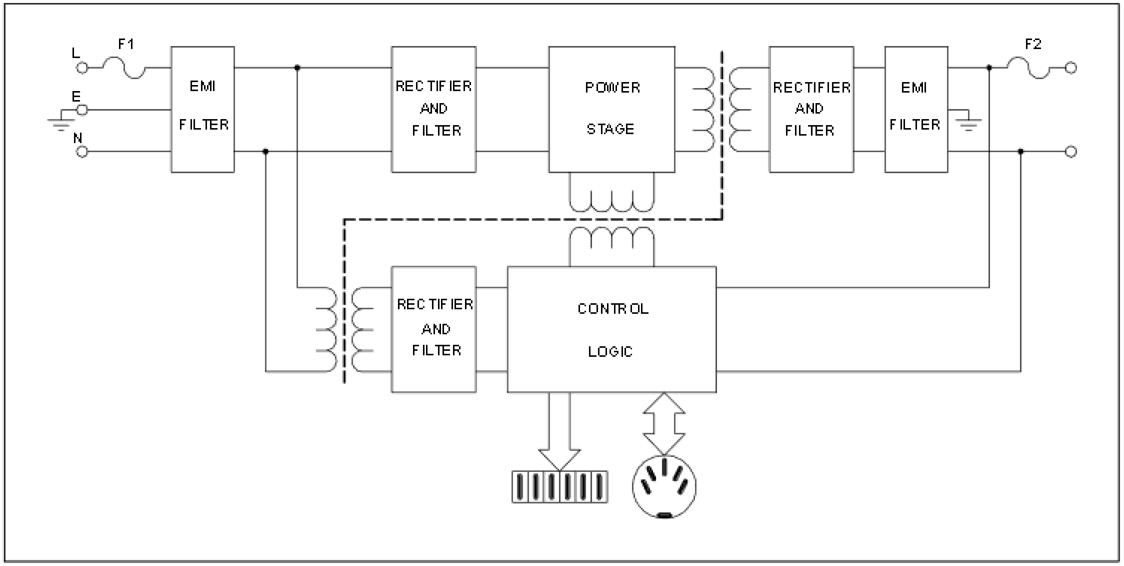
A non controlled traditional battery charger (rectifier) provides a simple direct **AC/DC conversion**



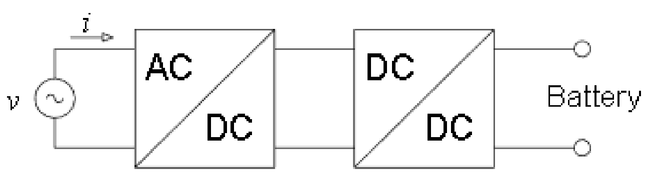
Disadvantages of this solution are:

- Low efficiency
- Large physical size
- Long charge times
- Charge depends on changes in the mains supply (with overcharge danger in the final charge phase)

Block Scheme



In modern battery chargers these disadvantages are solved with an **indirect AC/DC** conversion, by passing through an intermediate DC/DC conversion.



This is the usual method of operation for the SMPS (Switching Mode Power Supply) at high power. This solution gives a good performance for minimum costs and physical dimensions using switches more faster and powerful (modern technology).

The main advantages of this solution are:

- High efficiency
- Reduced dimensions
- Short charge times
- Charge independent from the changes of the mains supply
- Electronic control that provides the desired charge curve

Source: http://www.energicplus.com/content/manuals/Manual-NG1-single-phase-high-frequency-charger.pdf

Battery Charger Requirements

Main power ratings: 3.3kW / 5-6kW / 9-10kW/ 12kW / 21kW modules

Topology: PFC + PSFB + Sec. Side rectifier

Switching Frequency: 75kHz -150kHz

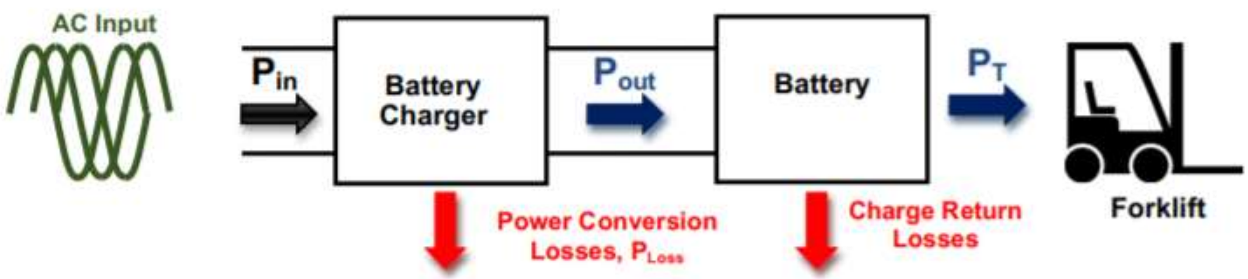
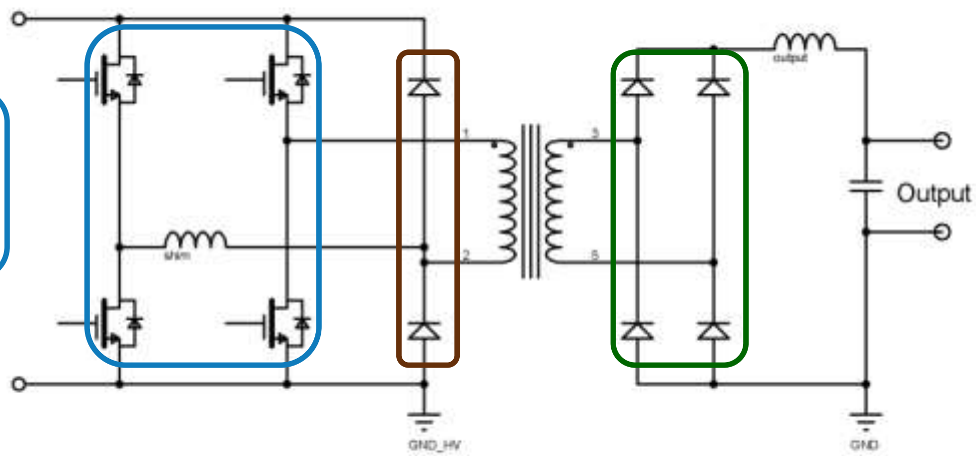


Fig. 1: Battery charger block diagram

700 to 800 V input

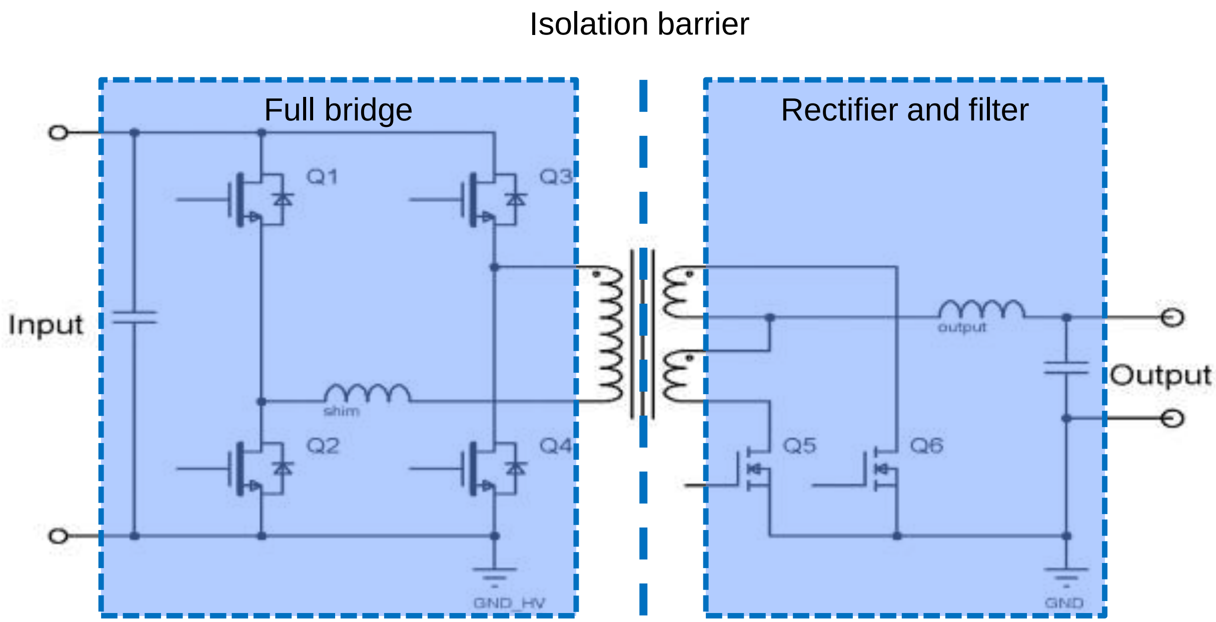


USCi 1200V Cascode:
- UJ3C120150K3S
- UJ3C120080K3S
- UJ3C120040K3S

USCi 1200V Schottky Diode:
- UJ3D1202TS
- UJ3D1205TS

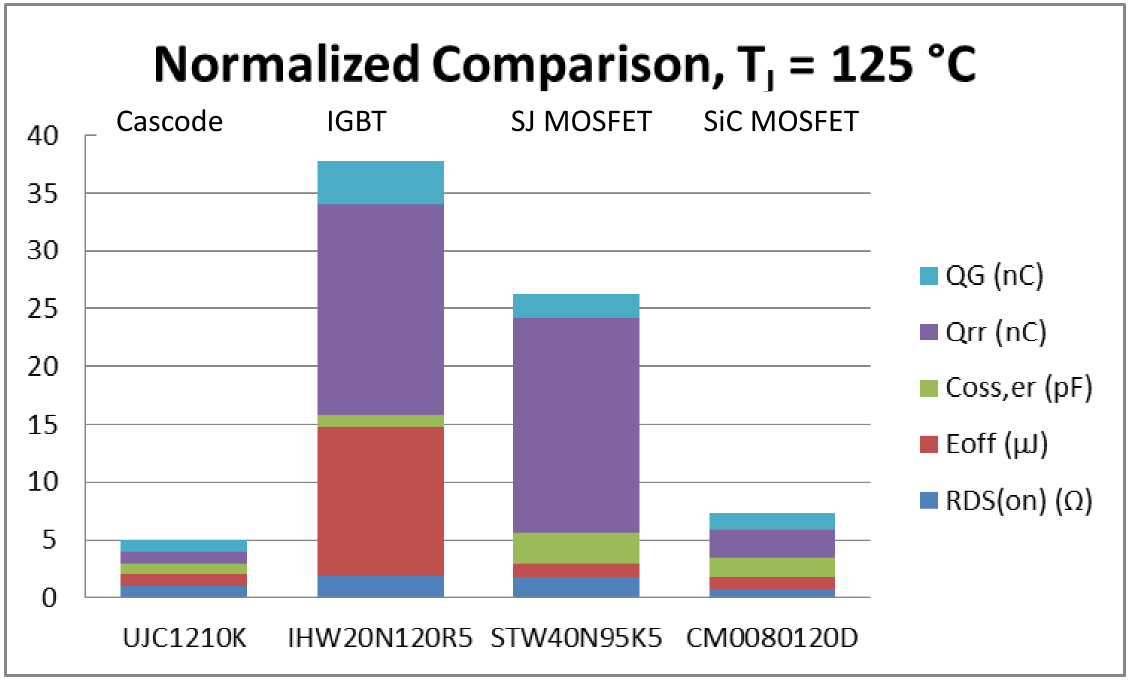
USCi 1200 V Schottky Diode:
- UJ3D1220KSD
- UJ3D1250K

Phase Shifted Full Bridge



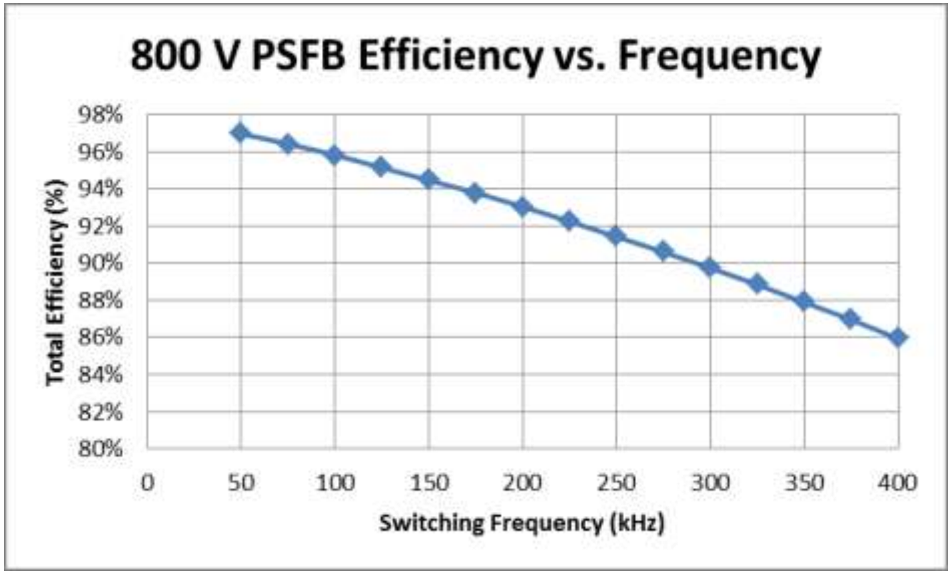
- A Phase Shift Full Bridge (PSFB) is an isolated DC-DC converter
- Highly efficient due to resonant switching
- Suitable for high power levels; hundreds to thousands of Watts
- Typically converts hundreds of Volts at the input to tens of Volts at the output
- Very popular thanks to its high efficiency, density, and reliability

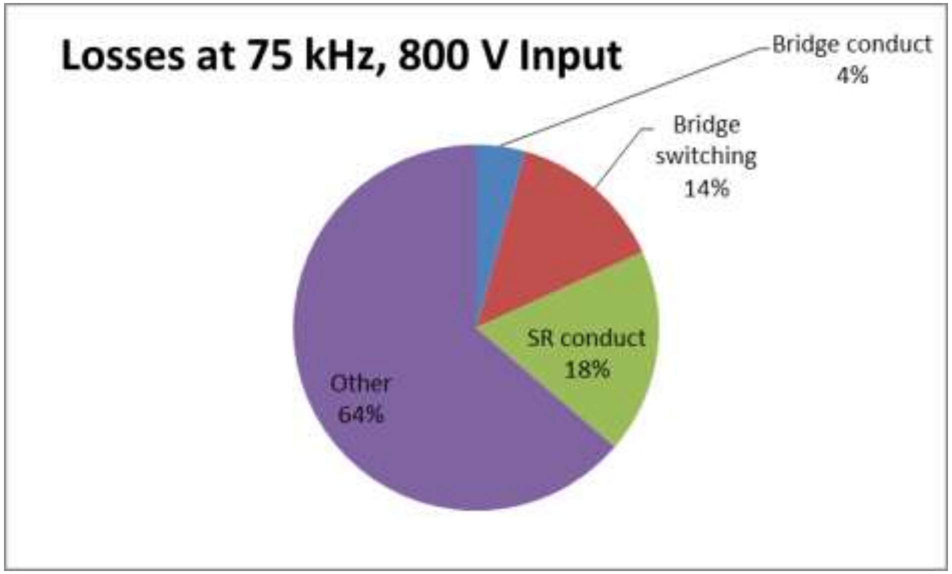
Cascode advantage in PSFB



- 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)
- UnitedSiC cascode is the best performing PSFB switch

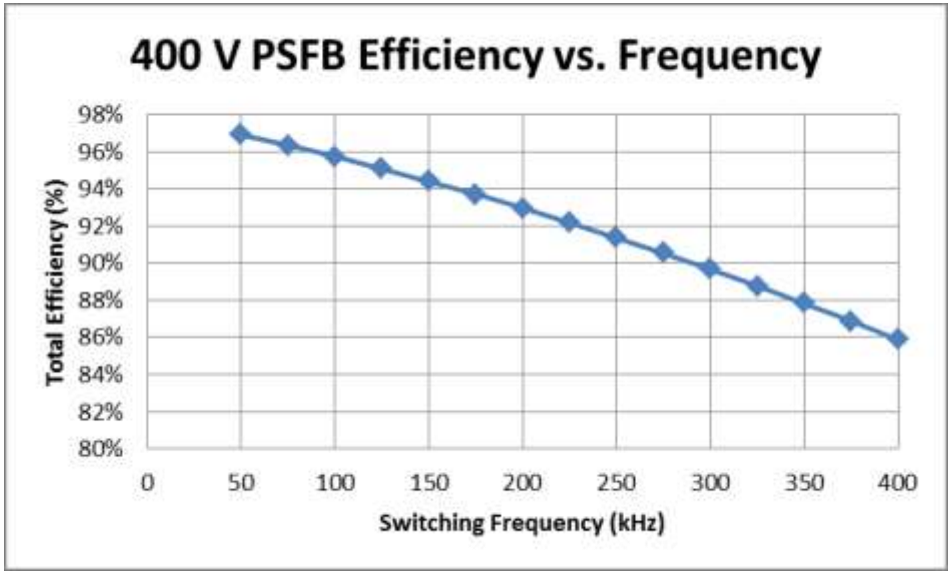
Cascode advantage in PSFB

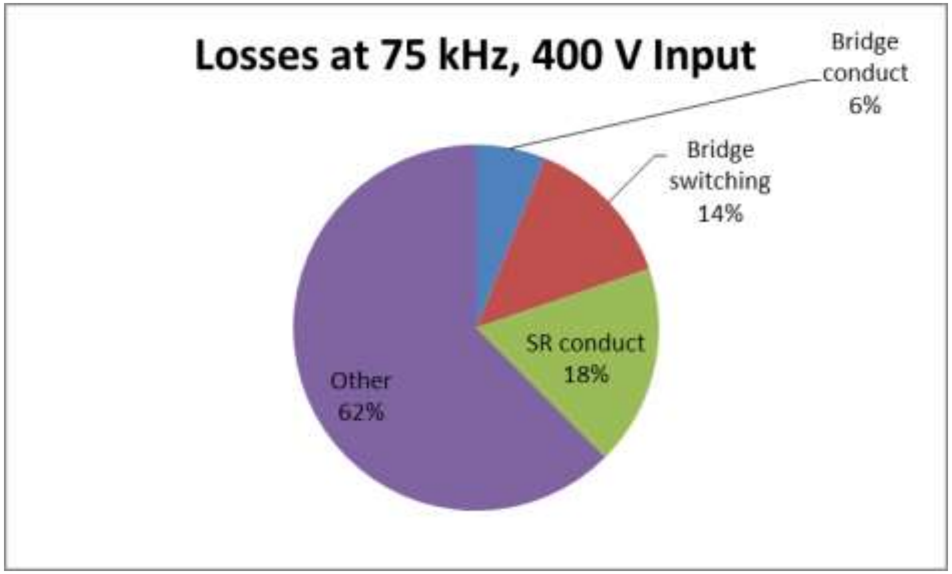




- Much of the loss is SR conduction loss
- Other power loss is from snubbers, magnetics, PCB resistance, gate drive, control power
- As switching frequency increases, skin effects increase losses
- High input voltage requires high resonant inductance, which limits switching frequency due to duty cycle loss to probably 150 kHz depending on voltage ranges

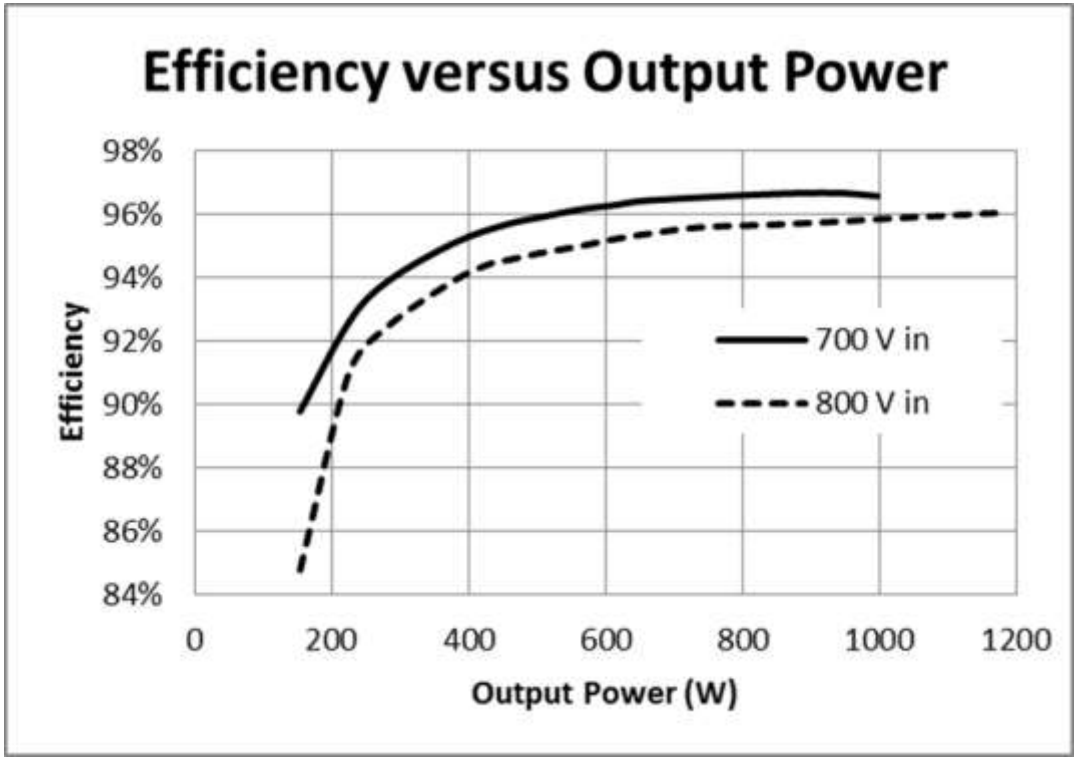
Cascode advantage in PSFB





- Almost identical to 800 V input case
- Lower resonant inductance allows higher switching frequency than for 800 V input PSFB, in practice achievable switching frequency depends on circuit design and operating conditions

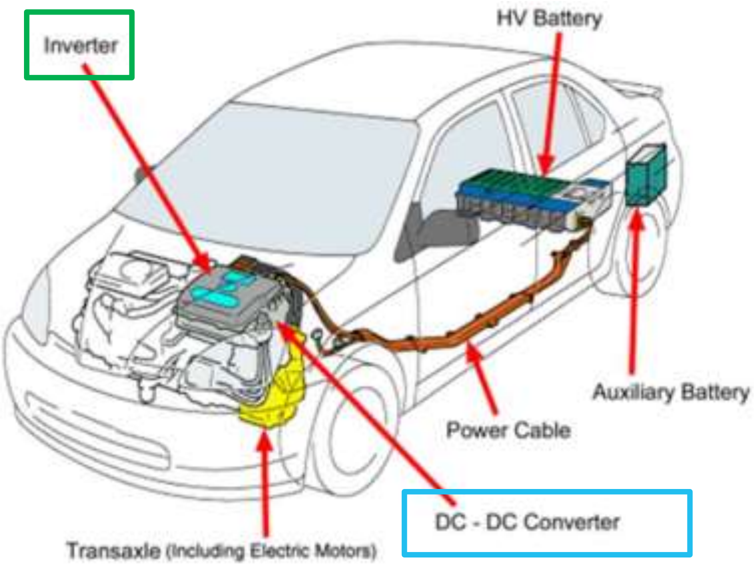
Cascode advantage in PSFB

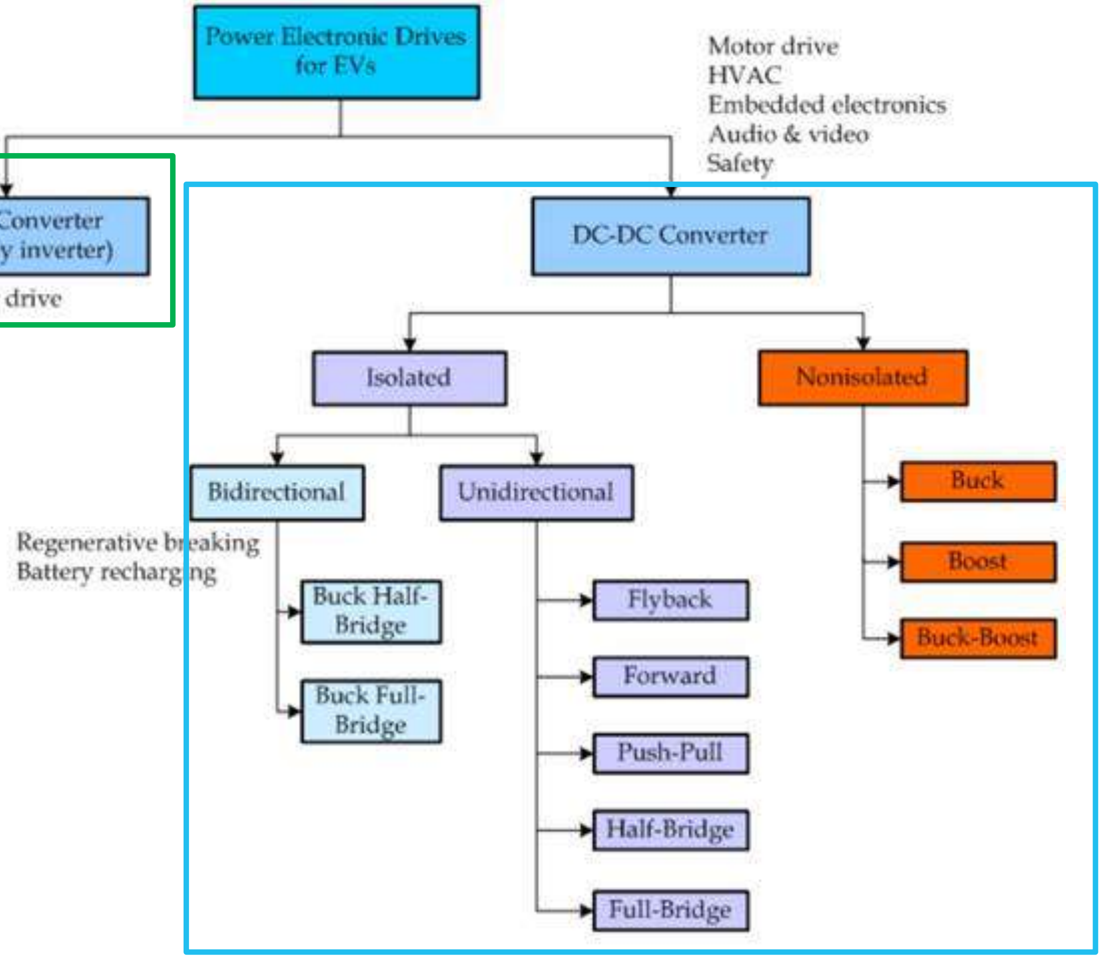


- 700 to 820 V input, 40 to 60 V output, 75 kHz switching frequency
- Resonant below half rated power under all input/output voltage combinations
- >96 % peak efficiency with nominal 800 V input, 48 V output
- These results are well beyond the capability of super-junction MOSFETs and IGBTs

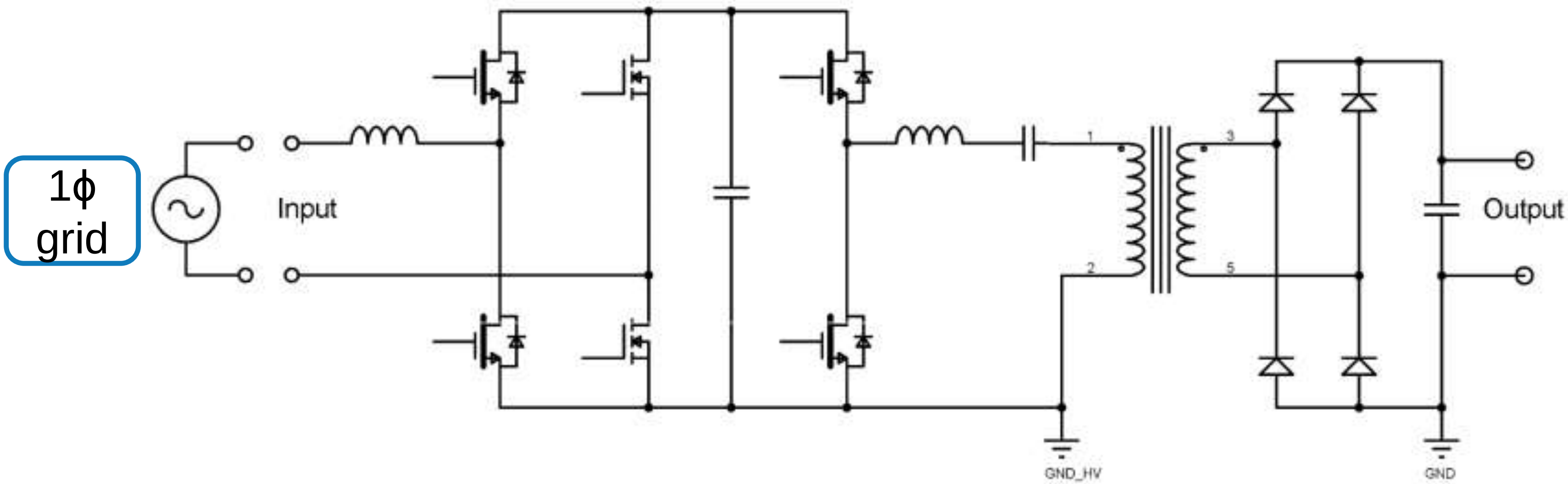
Future in Automotive

Electronic Vehicles





Single Phase OBC: Totem Pole

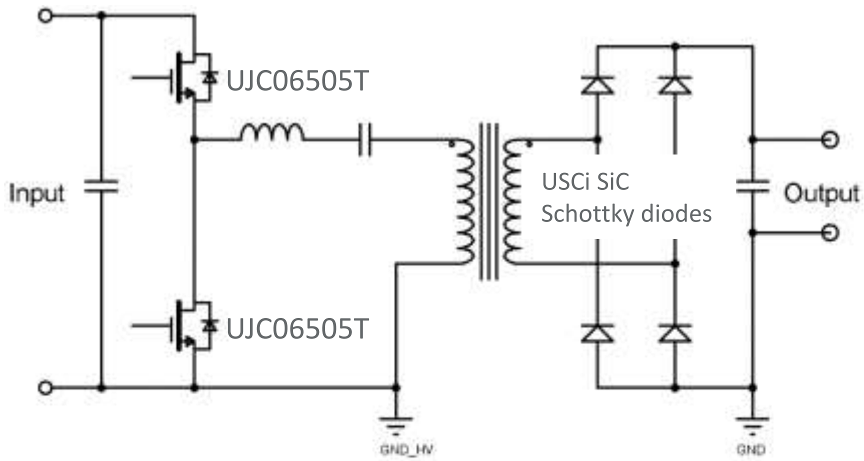


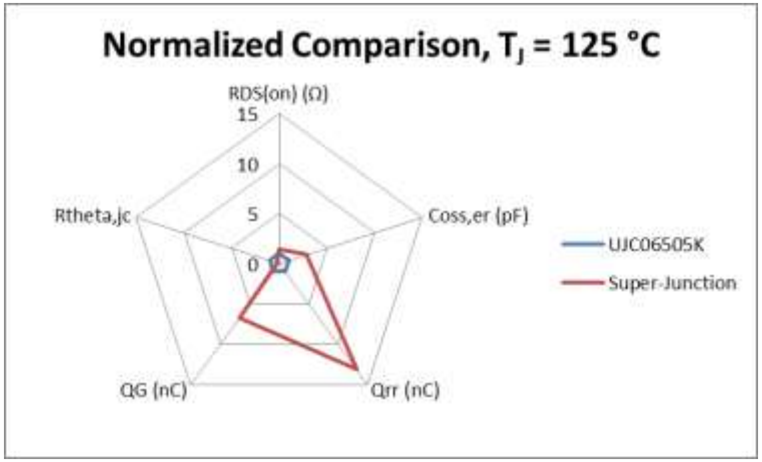
90V – 260V AC totem pole power factor corrector (TPPFC)	LLC DC-DC converter

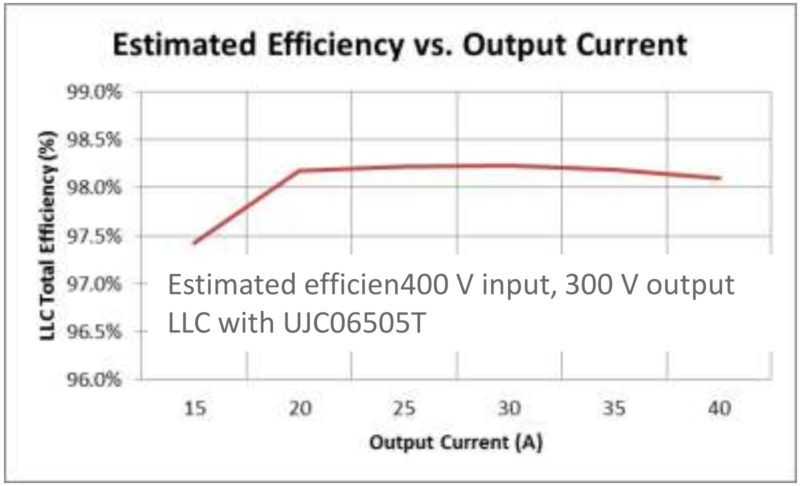
- Hard-switched TPPFC and soft-switched LLC ➔ cascode is optimized for both
  - Excellent reverse conduction and recovery characteristics
  - Best capacitance · $R_{DS(on)}$ figure of merit

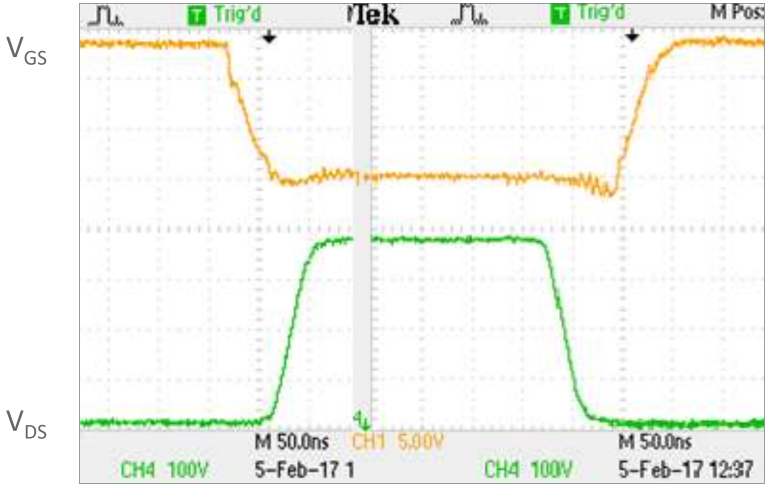
Single Phase OBC: LLC

- Lowest capacitance · $R_{DS(on)}$ figure of merit

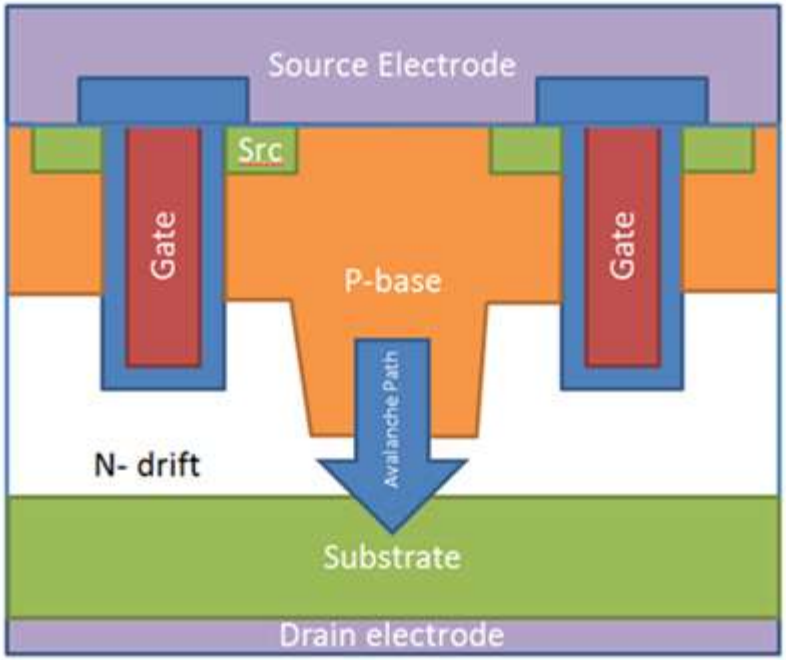








Reliable design of Si MOSFET for use in cascode configuration



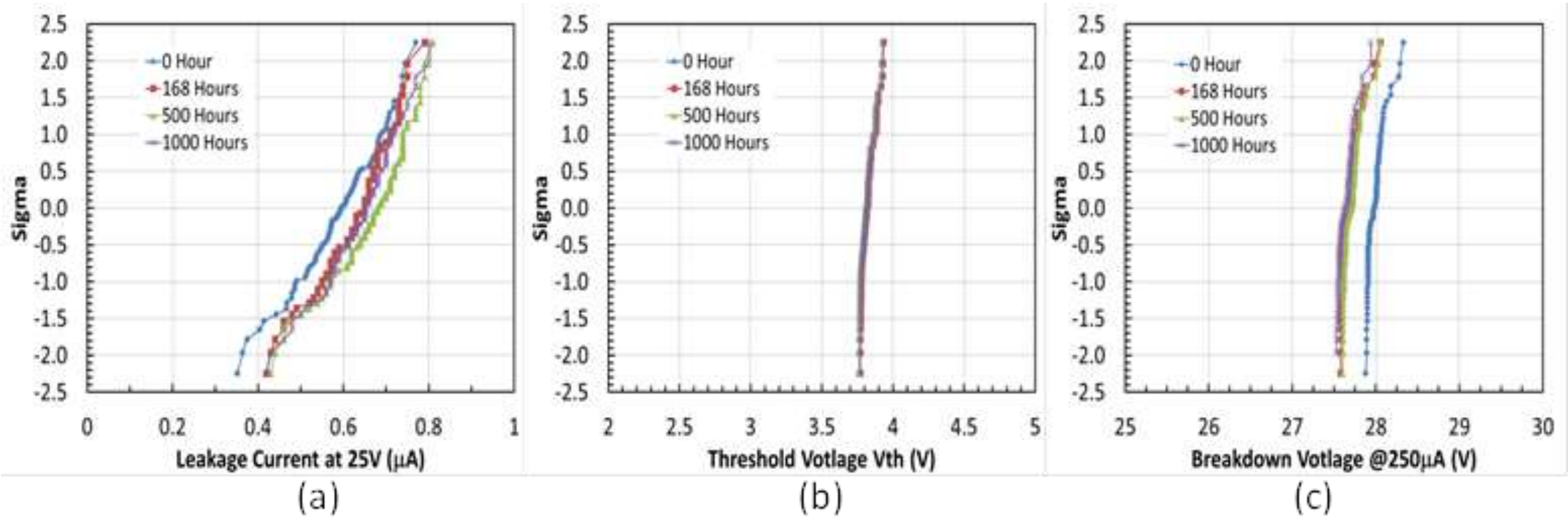
Low-voltage silicon MOSFET designed with an avalanche clamp for continuous or pulsed avalanche mode operation

Verification 1: 1 Million cycles UIS high current low L. Parametric check before and after - Pass

Verification 2: 1000hr BI at 150C in avalanche mode. Parametric check before and after - Pass

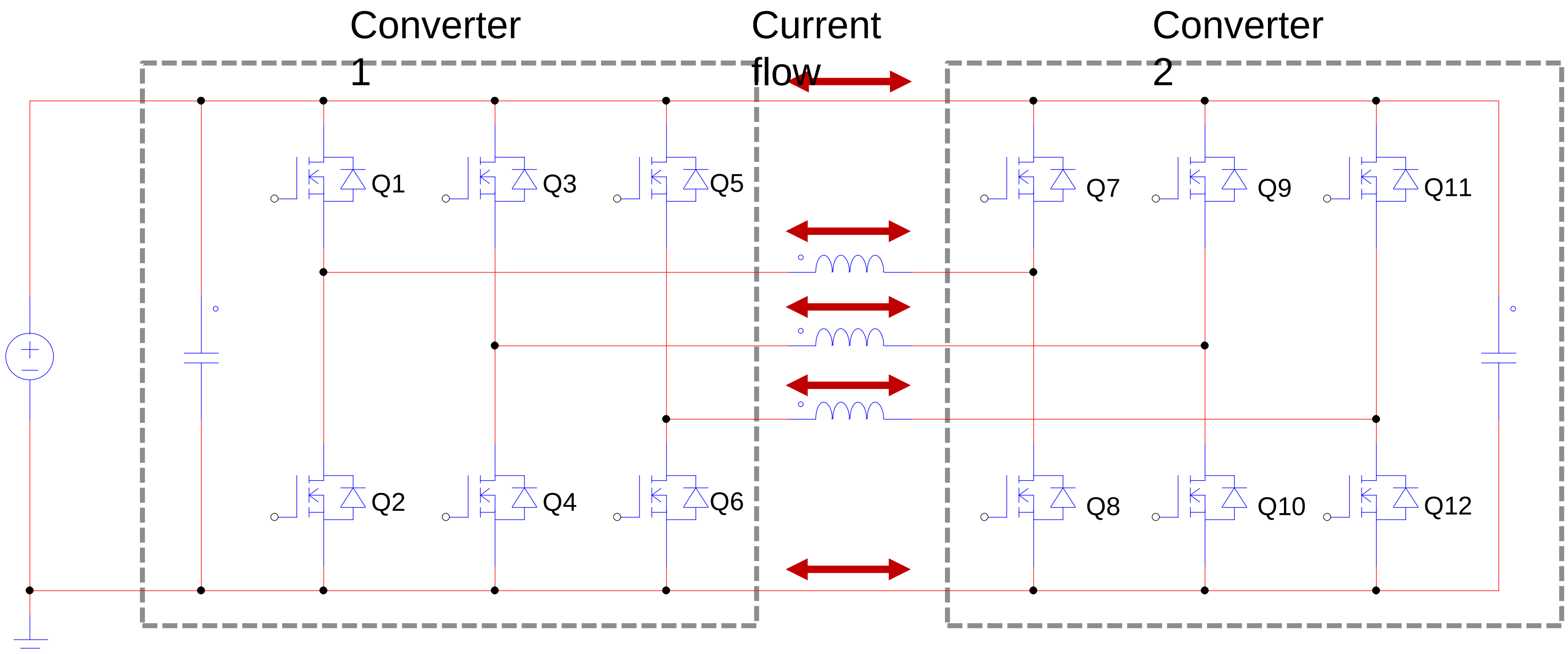
Verification3: 1Million cycle UIS check of final co-packaged cascode. Parametric check before and after – Pass

LV MOS avalanche stability check



Measured shifts in the leakage current at 25V (a), threshold voltage (b), and breakdown voltage at 250µA (c) of the low-voltage silicon MOSFETs before and after 1000 hours of avalanche-mode burn-in at 150°C.

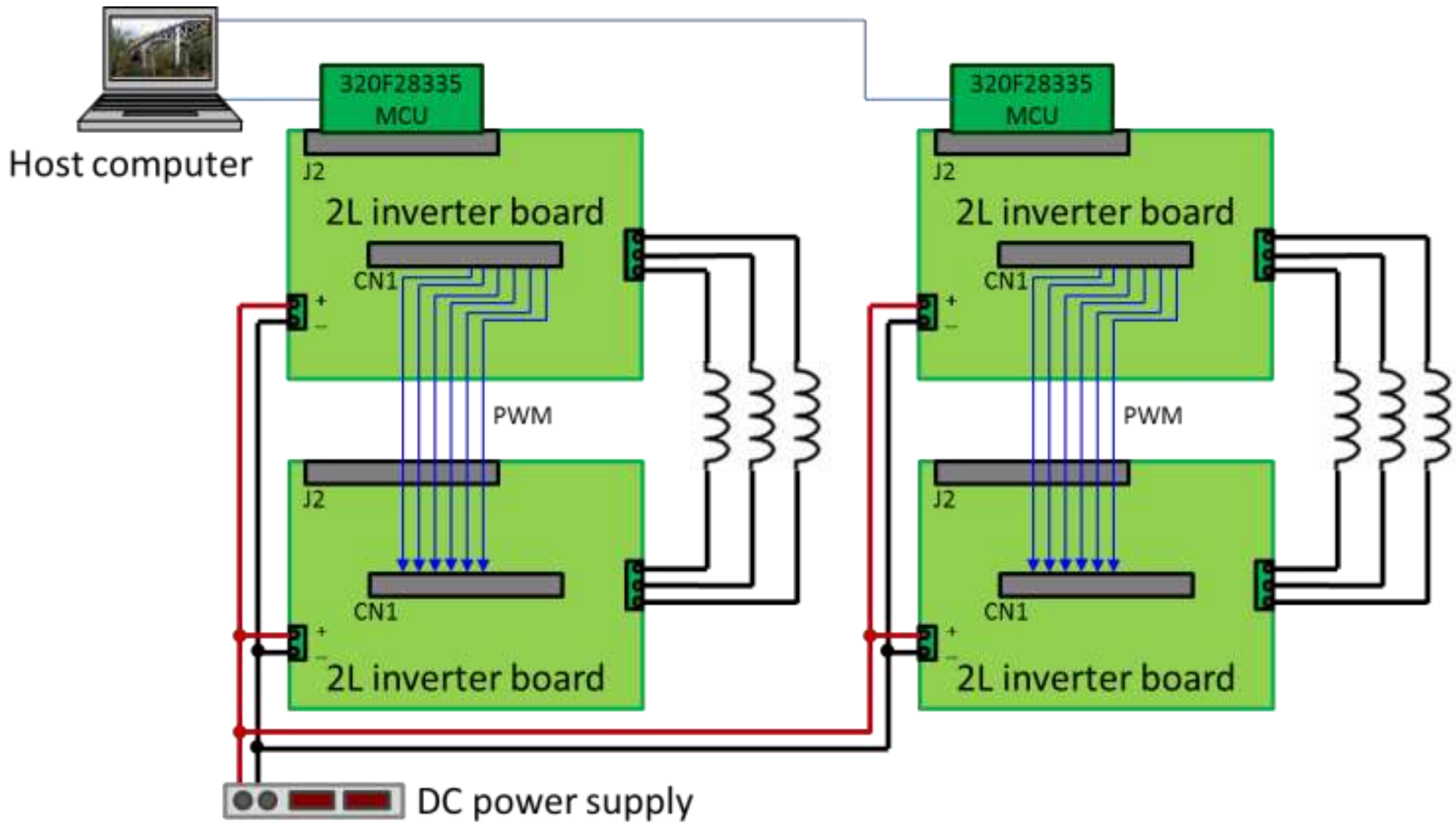
Long Time Recirculating Test



- Current circulates between two converters
  - One converter "sources" current, the other "sinks" it
- Converters connected by inductors between load terminals, DC links tied together
- Only power lost as heat must be supplied by a DC power supply

Test setup

Two pairs of converters share DC power supply and host computer to conserve space and resources



Tests Results

24 pieces of UJC6505K (6 each in 4 converter boards) ran for 1000 hours under the following conditions:

- DC link voltage = 400 VDC
- Switching frequency = 80 kHz
- Fundamental AC frequency = 60 Hz
- AC rms load current = 11 A
- AC power flow between board pairs = 6.6 kW
- Ambient temperature = 22 °C
- Average heat sink temperature = 70 °C with two low-power box fans inside test cabinet

Test result: All device parameters were within normal measurement variation the starting values, and all within specified limits – no parameter drift

Summary Gen 3 Cascodes

- Gen 3 being released
- Part increase with various packages
- Samples available ex stock
- Gen 3 will have USP over SIC MOSFET
  - Superior Thermal Performance
  - ESD and Gate protection
  - Standard Gate drive (second source to any SI or SIC device)
  - No need to rework the gate drive!
  - Superior Performance in PSFB
  - AECQ-101
  - Superior body diode performance
- Gen 3 Fast samples ready. Superior performance due to reduced Qrr losses and advanced packages (TO-247 4L)

Summary Presentation

SiC Diodes

- Best-in-class performance
- Highest currents available
- USCi matched with industry leading die sizes (cost)

SiC JFET

- Best in class devices for special applications

SiC Cascodes

- Ease of use (12V/0V or 20V / -5V Gate Drive)
- Performance (Low Vf , Qrr Body-diode, switching energies)
- Reliability (No SiC Gate oxide, No SiC body diode, 5V Threshold voltage)
- Superior thermal performance (Rth)
- Cost (no SiC FWD necessary, lowest specific Rds,on in industry)

Now Available on:

MOUSER ELECTRONICS

http://unitedsic.com/sales-channel/

Additional

- App Notes, Datasheets and SPICE models available at www.unitedsic.com
- Various Eval Boards already available or available soon (PSFB, PFC, Flyback, LLC, H-Bridge,..)
- Contact: Christopher Rocneanu, Director Sales, +4915121063411, cro@unitedsic.com