Design and Implementation of Future EV, Green Energy and Power System by Using Wolfspeed SiC

Wolfspeed OCT. 2021.

AGENDA

- Wolfspeed Introduction
- Introduction of SiC
- Advantages of Silicon Carbide (SiC)
- Wolfspeed SiC Application Design
  - EV Fast Charging
  - Solar Power
  - Offline Switch Mode Power Supply
- Tips of Gate Driving with SiC MOSFETs

NEW NAME, NEW TICKER—SAME DEDICATED PARTNER

WHAT'S CHANGED

- On October 4, 2021, we officially began operating as Wolfspeed, Inc. and trading under the ticker symbol "WOLF" on the NYSE.
- This marks the culmination of our transformational journey as we now lead the industry transition from silicon to Silicon Carbide as a pure-play, global semiconductor powerhouse.

WHAT IT MEANS

- This is a natural progression that builds on our unsurpassed reputation of developing silicon carbide solutions and capitalizes on the competitive positioning the Wolfspeed brand has in the market.
- By sharpening our focus on our portfolio of silicon carbide products, we're now in the best position to lead a once-in-a-generation technology shift and create the products and materials that our customers use to power a cleaner, better future.

WOLFSPEED AT A GLANCE

Headquarters: Durham, North Carolina

Founded: 1987

Global Footprint: 17 Countries

Website: www.wolfspeed.com

Stock Symbol: WOLF

Stock Exchange: NYSE

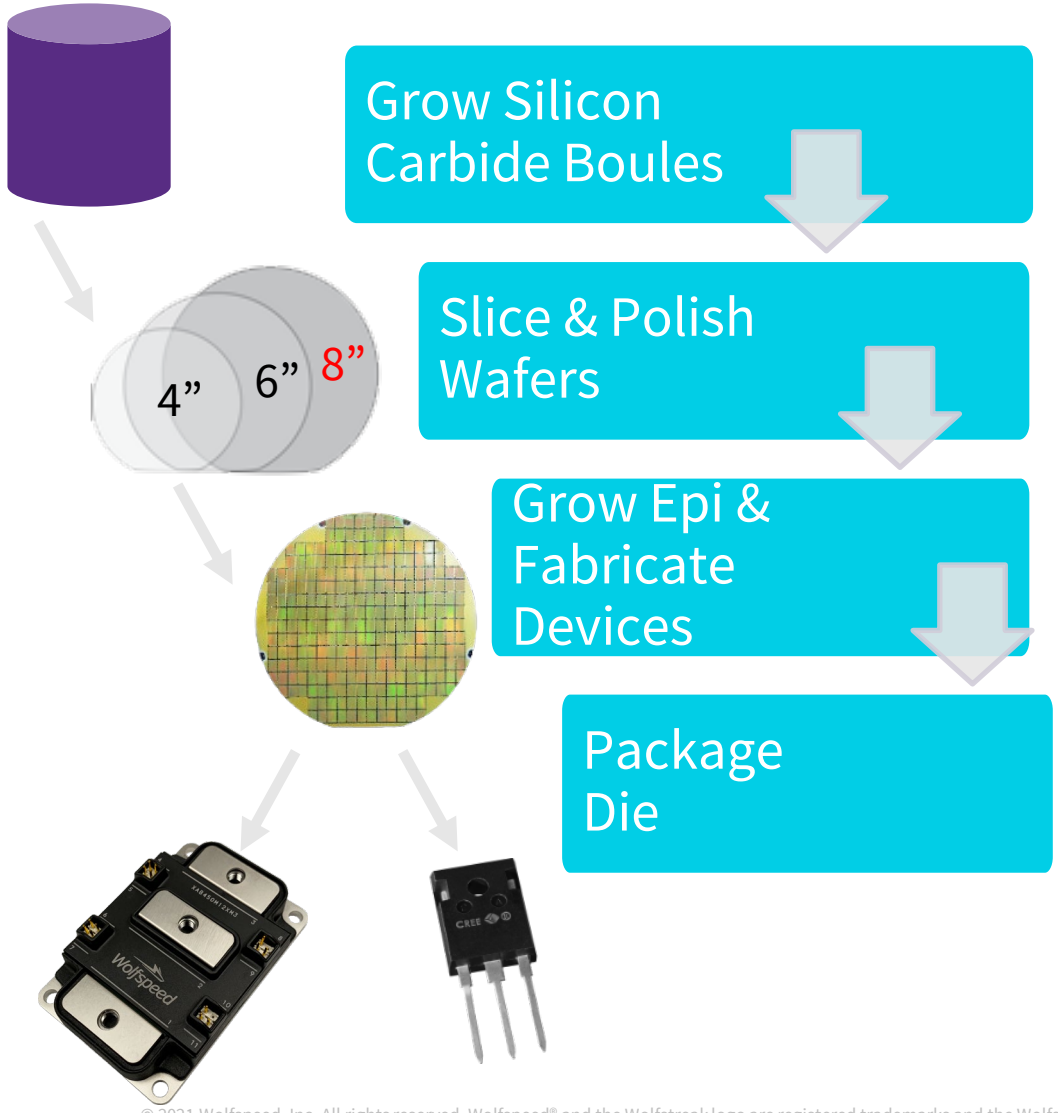
People: ~3,500 Employees

History: 30+ years of technology leadership

Revenue: $525.6M in FY2021

Innovation: ~2,140 Issued Patents

DEEP DOMAIN EXPERTISE SETS US APART



WE ARE THE ONLY VERTICALLY-INTEGRATED POWER & RF SUPPLIER

- Global market-leading position in Silicon Carbide materials and wafers
- 30+ years of intellectual property and expertise
- Over six trillion field hours for Silicon Carbide power devices
- Thousands of customers with millions of MOSFETS and diodes in use
- Unmatched cycles of learning

WE ARE EXPERTS IN THE SCIENCE OF SILICON CARBIDE FABRICATION

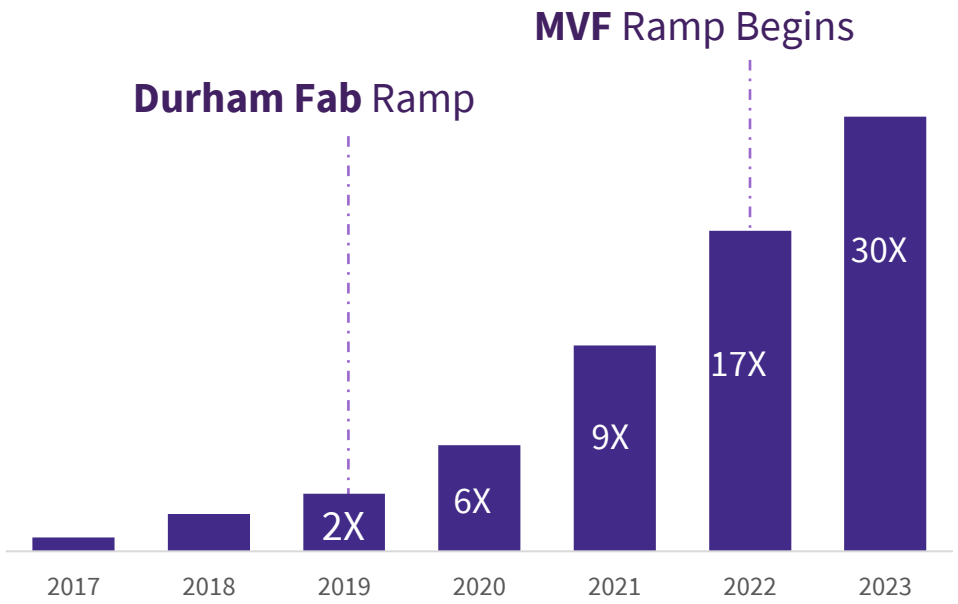
- Our team has in-depth knowledge and experience in the complex process of crystal production
- Silicon Carbide crystals require an extremely hot temperature to grow (2,500 degrees Celsius) and we've mastered control over this environment

UNSURPASSED INTELLECTUAL PROPERTY PORTFOLIO

- Our IP portfolio for GaN and Silicon Carbide devices covers a breadth and depth of high-performing, reliable products that no other company matches

BUILDING A POWERHOUSE SEMICONDUCTOR COMPANY

- Accelerating Capital **Investment** Plan
- Ramping Mohawk Valley at **200mm**
- Renaming the Company **Wolfspeed**



Capacity expansion

484,000

SQ FT STATE-OF-THE-ART FABRICATION FACILITY

>30x

INCREASE IN SILICON CARBIDE WAFER FABRICATION PRODUCTION

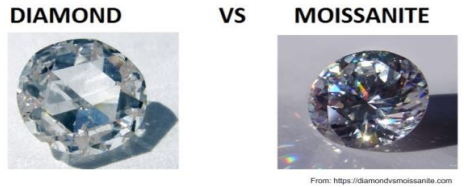
200mm

AUTOMOTIVE-QUALIFIED PRODUCTION FACILITY

BRIEF HISTORY OF SIC AND WOLFSPEED

https://www.tf.uni-kiel.de/matwis/amat/semi_en/kap_a/advanced/ta_1_3.html

- In contrast to diamonds, **SiC** is never found on this world (and thus never became a valued gemstone in the past). Only in fragments of other worlds (i.e. **meteorites**), on occasion contain **SiC** as has been found by **Moissan** in **1905**. Mineralogists thus call "natural" **SiC** " **Moissanite**".
- In **1955**, **Lely** made the next big step in inventing the "**Lely growth method**" to grow **SiC** crystal
- **1987 Cree** Research Inc., the first commercial supplier of **SiC** substrates, was founded



1987 Founded out of North Carolina State University

1989 Commercialized the World's **first silicon carbide Blue LED**

1991 Released world's **first commercial silicon carbide wafers**

1993 Listed on Nasdaq

1998 Created industry's first GaN HEMT on SiC

2000 Demonstrated first-ever GaN MMIC with record power density

2002 Released **first 600V commercial silicon carbide JBS Schottky diode**

2006 Started the LED Revolution with the first lighting class LED

2006 Released industry's **first 1200V silicon carbide Schottky diode**

2011 Released industry's **first silicon carbide MOSFET**

2013 Brought the LED bulb mainstream – forced the industry to respond

2014 Became Department of Defense Trusted GaN Foundry

2015 Exceeded 2 trillion field hours with Power products

2016 Shipped GaN RF devices surpassing 1.3 Gigawatts output power

2016 Leading 150mm silicon carbide wafer market; **introduced 200mm**

2017 Gregg Lowe named new CEO

2018 Acquired Infineon RF Power Business

2019 Selected as silicon carbide partner for the Volkswagen Group FAST Program

2022 New York Mohawk Valley Fab up and **running with 200mm wafer**

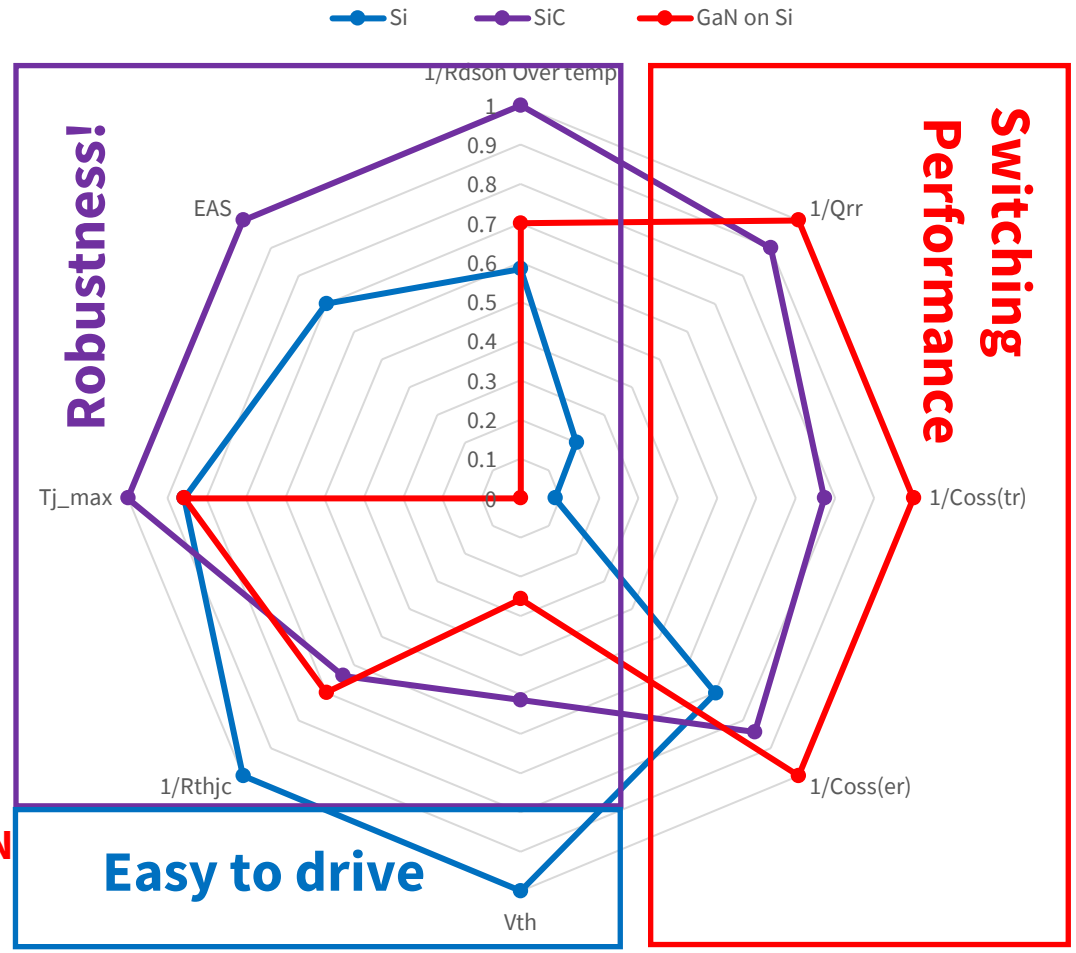
ADVANTAGES OF SILICON CARBIDE (SIC)
KEY PARAMETERS COMPARISON SI VS. SIC VS. GAN

Tj_max→ Higher is better.
Robustness
Winner: **SiC**

EAS→ Higher is better.
Robustness
Winner: **SiC. No EAS capability for GaN**

Rthjc→ Lower is better.
Thermal performance
Winner: **Si**

Vth→ Higher is better.
Immunity to noise. Easy to drive
Winner: **Si. Very low Vth for GaN**



Rdson over temp → Lower is better.
Lower loss @high T→ High efficiency, deliver higher power,
Winner: **SiC**

Qrr→ Lower is better.
Switching loss for CCM sync rectifier
Winner: **GaN, SiC is close to GaN**

Coss(tr) → Lower is better.
dead time / Lm design → high frequency and efficiency
Winner: **GaN, SiC is close to GaN**

Coss(er) → Lower is better.
Minimum switching losses in hard-switching topologies
Winner: **GaN, SiC , Si is not too bad**

APPLICATION:

EV Fast Charging

WHAT: Fast charging DC stations: 30 min charge duration. Bypasses OBC for rapid direct battery charging.

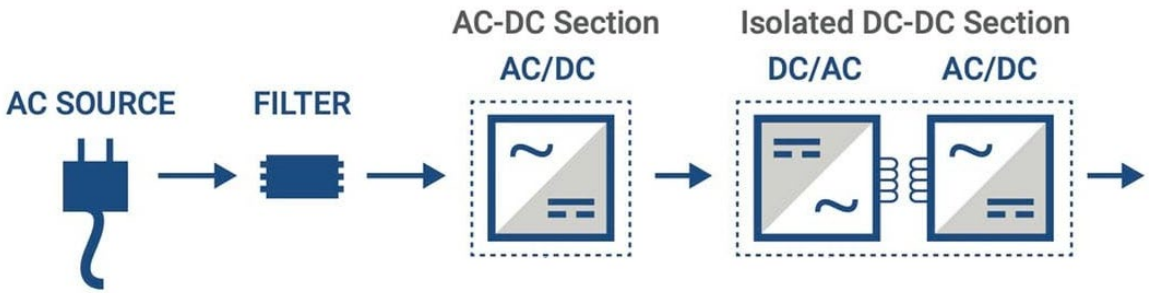
WHERE: PHEV, BEV battery charging 90kW – 350kW (average 160kW).

- DC charge from station to car.
- Typically today constructed from multiple 20-30kW blocks.

WHY: System cost, System efficiency, Power density (smaller stations), charger maintenance/up time. Future trends bidirectional energy flow

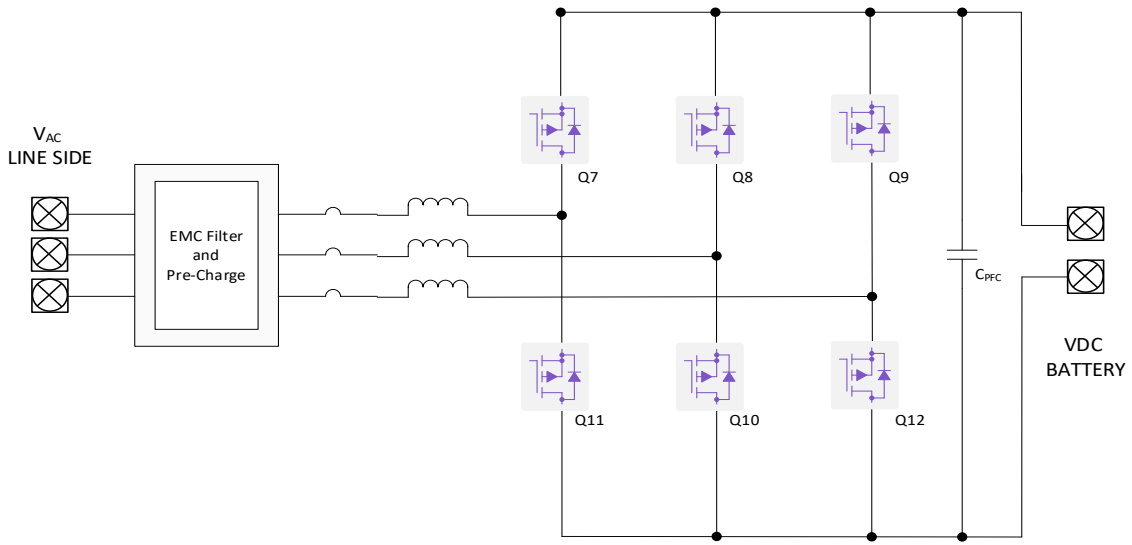
SIC ADVANTAGE:

- ~1-2% higher efficiency, 35-50% increase in power density at comparable system costs
- Less overall system cooling, smaller and cheaper mechanical housing
- Enables better Bidirectional charging for V2G / V2H



3-PHEASE 2-LEVEL ACTIVE FRONT END (AFE) | BI-DIRECTIONAL

AFE at 45Khz, 800V DC Link



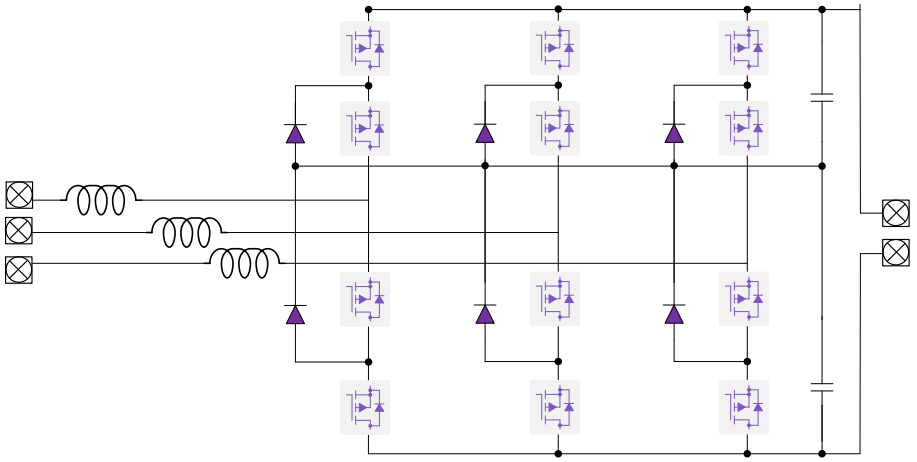
BENEFITS	CHALLENGES
• 1200V SiC enables **Simple** 2-Level bidirectional AFE • SiC enables **Smaller choke** with 2.5x Fsw • Low component count and **Low Cost** • **Mature** Control Scheme	• Cant reduce frequency further to balance core loss • High DC+/DC- swing/voltage MOSFET stress , **High switching loss** • Hard switched 2-Level topology – **EMI concerns**

6 x 1200V 32mOhm Discrete SiC MOSFET (22kW) or
1 x CCB021M12FM3 Wolfspeed WolfPACK(25kW) or
2 x CCB021M12FM3 Wolfspeed WolfPACK(50kW)

Cost	IGBT	SiC
Switch	32%	62%
Choke	40%	19%
Driver	9%	9%
Thermal	19%	10%

METRIC	IGBT	SiC
Fsw	20kHz	45kHz
Power Density	3.5kW/L	4.5kW/L
Efficiency	97.2%	98.2%

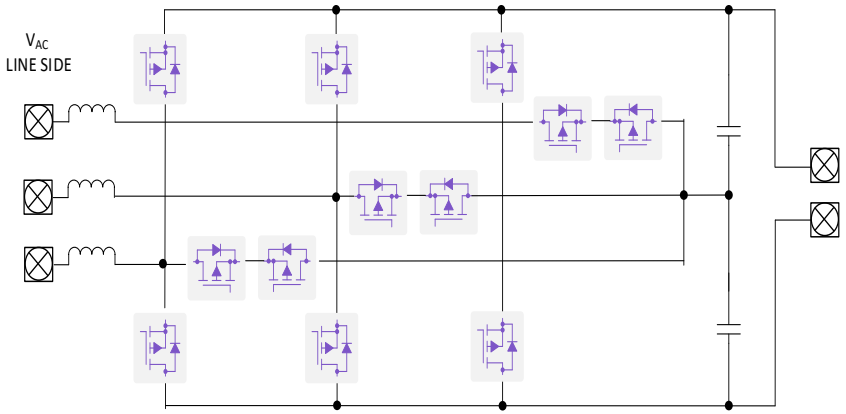
20-30KW A/NPC, TNPC AC-DC CONVERTER | BI-DIRECTIONAL



12x 650V SiC 25mOhm MOSFET +
6x 650V 16A SiC Schottky Diode

SiC BENEFITS vs Si

- Simple Si to SiC transition
- SiC Diode eliminates reverse recovery current for higher efficiency
- Lower power loss

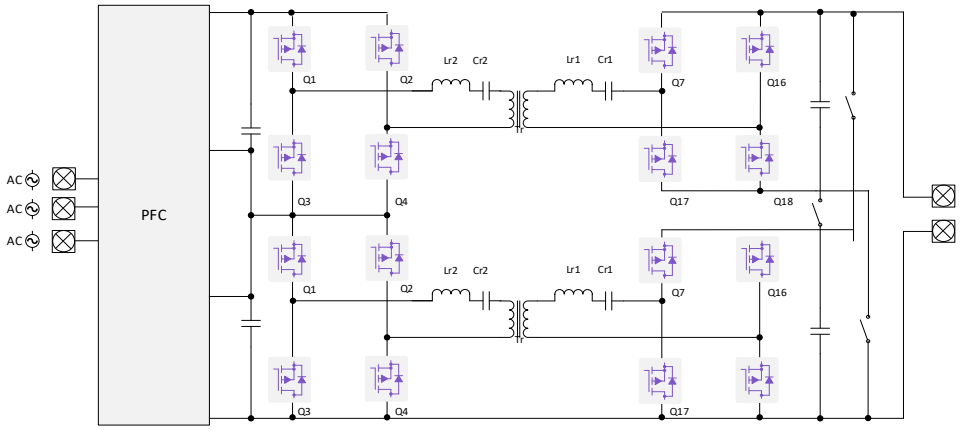


6x 1200V 32mOhm SiC (Outer) +
6x 650V SiC 45mOhm MOSFET (Mid)

SiC BENEFITS vs Si

- 1200V SiC enables high frequency operation (>45kHz)
- Reduce magnetics size
- Lower power loss

20-30KW CASCADE LLC/ 2LEVEL LLC DC-DC CONVERTER | BI-DIRECTIONAL

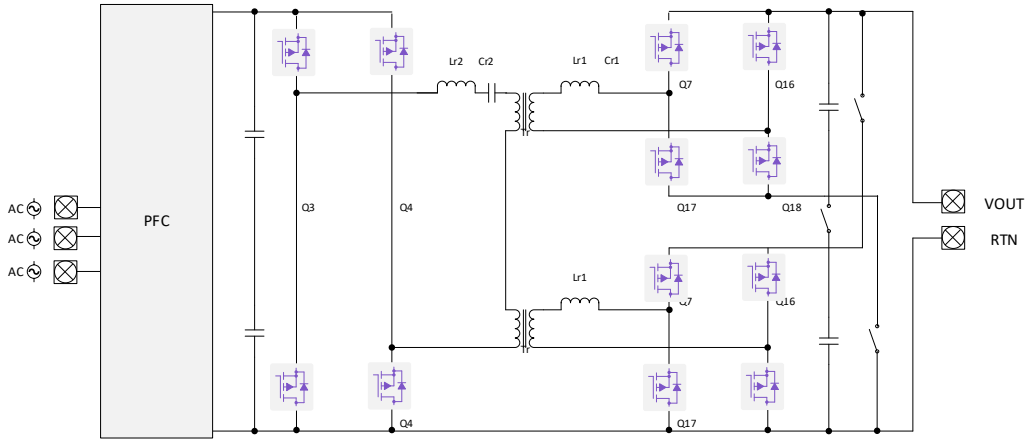


8x 650V 45mOhm SiC MOSFET's

8x 650V 45mOhm SiC MOSFET's

SiC BENEFITS vs Si

- Simple Si to SiC transition
- SiC enables high frequency operation (up to 200kHz)
- Lower power Loss



4x 1200V 32mOhm SiC MOSFET or
2x CAB016M12FM3 Power Module

8x 650V 25mOhm SiC MOSFETs

SiC BENEFITS vs Si

- 1200V SiC enables 2 Level design
- Series LLC Transformer
- SiC enables high frequency operation (up to 200kHz)
- Lower power Loss

Wolfspeed SiC In DC Fast Charger Applications

STACKABLE POWER BLOCKS - BIDIRECTIONAL

STACKABLE POWER BLOCKS – UNIDIRECTIONAL

SUPER STATION - UNIDIRECTIONAL

20kW **30kW** **50kW** **100kW** **300kW** **600kW**

Discrete Blocks (20kW) **x 1**

Discrete Blocks (20kW) **x 3**

Discrete Blocks (30kW) **x 6**

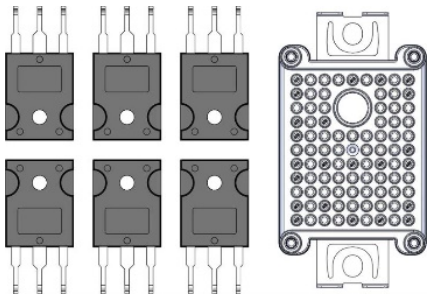
Discrete Blocks (60kW) **x 6**

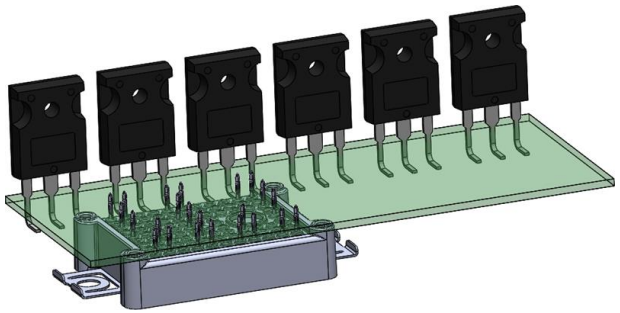
Discrete Blocks (60kW) **x 10**

Module Block (25kW) **x 2**

Module Block (50kW) **x 4**

Module Block (50kW) **x 8**





High Power Integrated Design

APPLICATION:

Offline Switch Mode Power Supply

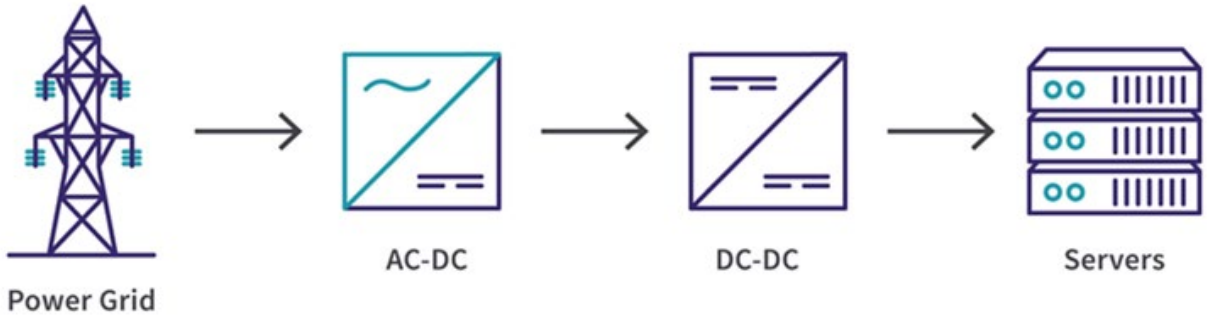
WHAT: Silicon Carbide MOSFETs and Diodes

WHERE: Offline switch mode power supplies

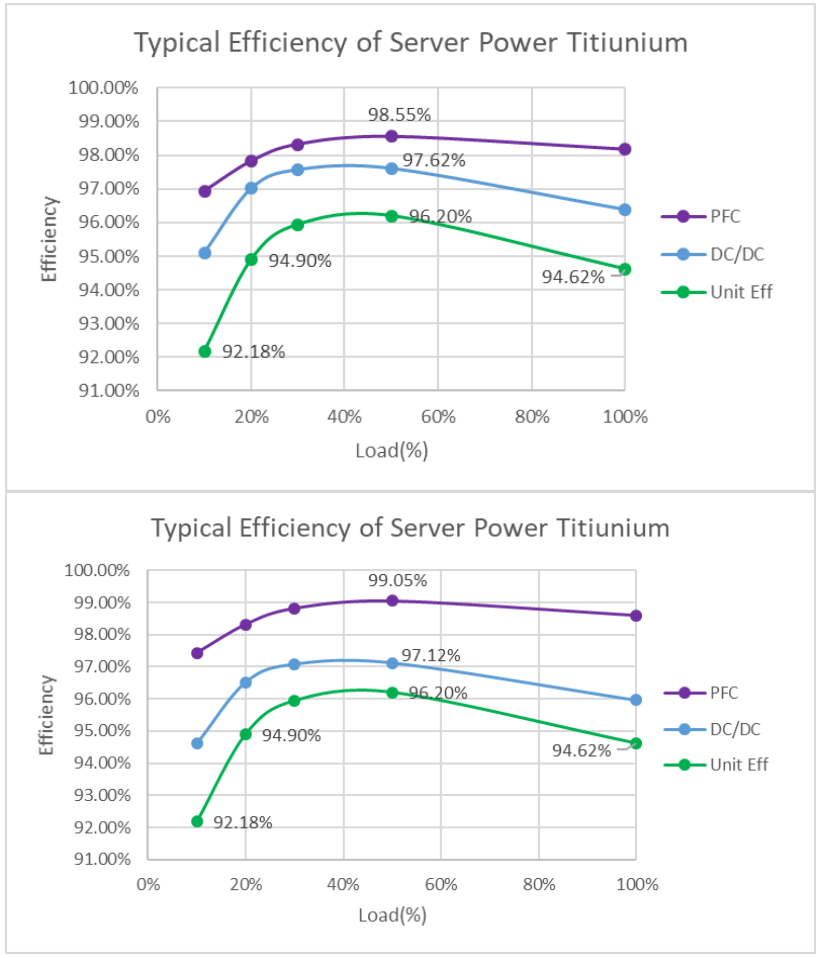
WHY: Maximize output while minimizing energy consumption

SIC ADVANTAGE:

- Increases efficiency
- Reduces size
- Superior thermals



EFFICIENCY STANDARD OF SMPS FOR DATA CENTER



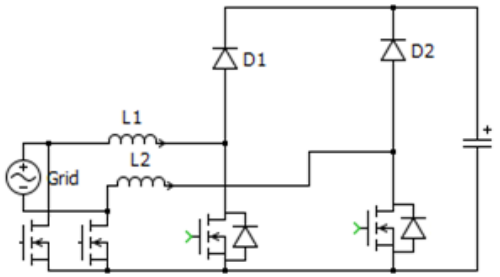
Requirement	Output/Load	Efficiency 10%	Efficiency 20%	Efficiency 50%	Efficiency 100%	Power Factor[1] 10%	Power Factor[1] 20%	Power Factor[1] 50%	Power Factor[1] 100%	80PLUS 115V non-redundant	80PLUS 115V Industrial
Energy Star 3.0	multi	---	90%	92%	89%	---	0.80	0.90	0.95	Platinum	Platinum
	single ≤ 500W	83%	90%	94%	91%	---	0.80	0.95	0.95	Titanium[2]	---
	500W < single ≤ 1000W					0.65	0.80	0.95	0.95	Titanium[2]	---
	single > 1000W					0.80	0.90	0.95	0.95	Titanium[2]	---
Requirement	**Output/Load**	**10%**	**20%**	**50%**	**100%**	**10%**	**20%**	**50%**	**100%**	**230V non-redundant**	**230V redundant**
Lot 9 (1-Mar-2020)	multi	---	88%	92%	88%	---	---	0.90	---	Gold	Gold
	single	---	90%	94%	91%	---	---	0.95	---	Platinum[2]	Platinum
Lot 9 (1-Jan-2023)	multi	---	90%	94%	91%	---	---	0.95	---	Platinum[2]	Platinum
	single	90%	94%	96%	91%	---	---	0.95	---	Titanium	Titanium

80 Plus test type	Icon	115 V internal non-redundant				230 V internal redundant				230 V EU internal non-redundant			
Percentage of rated load		10%	20%	50%	100%	10%	20%	50%	100%	10%	20%	50%	100%
80 Plus			80%	80%	80%						82%	85%	82%
80 Plus Bronze			82%	85%	82%		81%	85%	81%		85%	88%	85%
80 Plus Silver			85%	88%	85%		85%	89%	85%		87%	90%	87%
80 Plus Gold			87%	90%	87%		88%	92%	88%		90%	92%	89%
80 Plus Platinum			90%	92%	89%		90%	94%	91%		92%	94%	90%
80 Plus Titanium		90%	92%	94%	90%	90%	94%	96%	91%	90%	94%	96%	94%

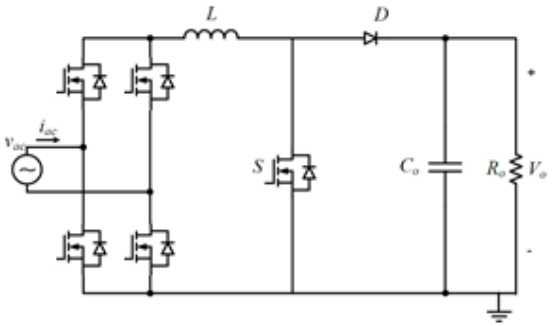
>98.5% PFC peak efficiency is required for 80plus Titanium applications. Two approaches

TOPOLOGIES OF PFC

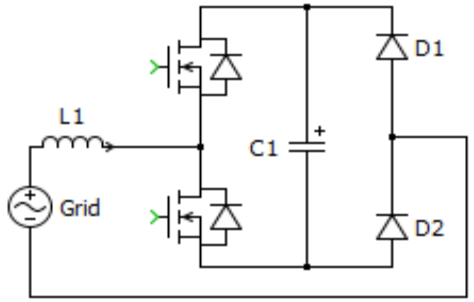
Dual Boost Bridgeless PFC



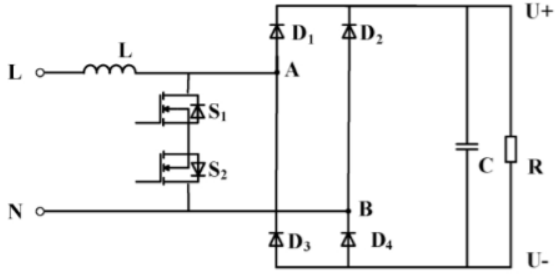
Active Bridge CCM PFC



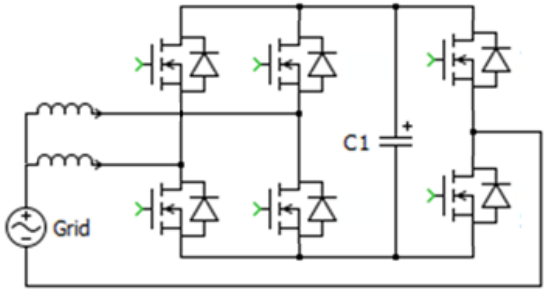
Totem Pole Semi-Bridgeless CCM PFC



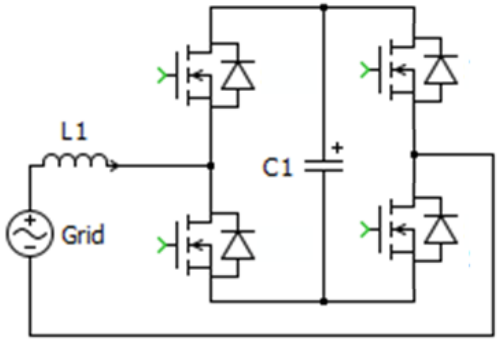
H Bridge PFC



CrM Interleave Totem Pole Bridgeless PFC



Totem Pole Bridgeless CCM PFC



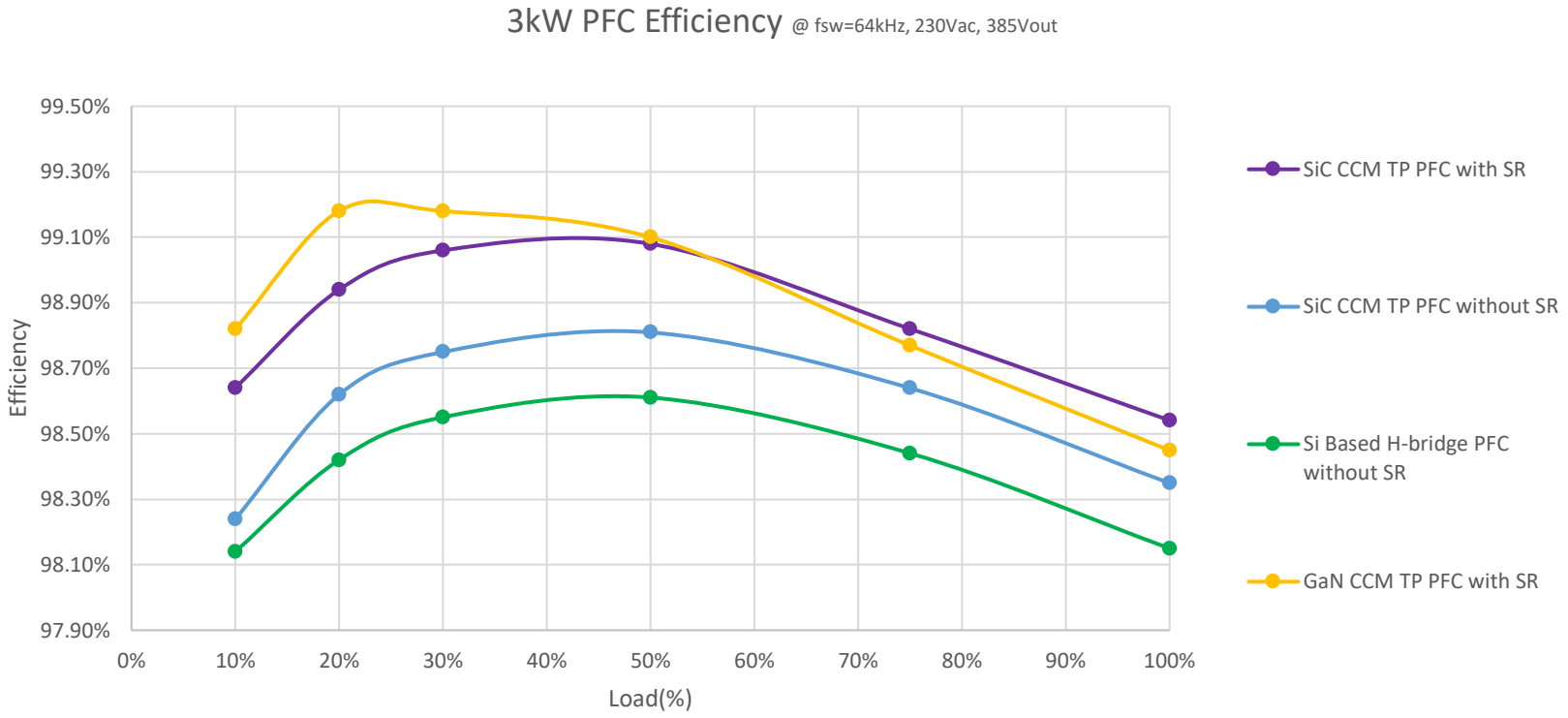
PFC topologies before the adoption of WBG device

COMPARISON OF BRIDGE-LESS PFC SOLUTIONS

	# PFC Choke	# of Power Switch	Power density	Peak Efficiency	Cost
Si Conventional CCM PFC	1	3*	Medium	98.3%	Low
Si Active Bridge CCM PFC	1	6	Medium	98.9%	Highest
Si Dual Boost Bridgeless PFC	2	6	Lower	98.6%	Medium
Si Dual Boost Bridgeless PFC SR	2	6	Lower	98.9%	High
Si H Bridge PFC	1	6	High	98.6%	Medium
Si CrM Totem Pole Bridgeless PFC	2	6	Medium	98.9%	Highest
SiC CCM Totem Pole Semi-BL PFC	1	4	Highest	98.8%	Medium
*SiC CCM Totem Pole bridgeless PFC	1	4	Highest	99.1%	High
GaN CCM Totem Pole Semi-BL PFC	1	4	Highest	98.8%	High
GaN CCM Totem Pole bridgeless PFC	1	4	Highest	99.2%	Highest
GaN CRM Totem Pole bridgeless PFC	2	6	Medium	99.1%	Highest

- SiC based CCM totem pole PFC can have higher efficiency and higher power density than Si based H-bridge PFC with similar or even lower cost.

EFFICIENCY COMPARISON OF PFC SOLUTIONS



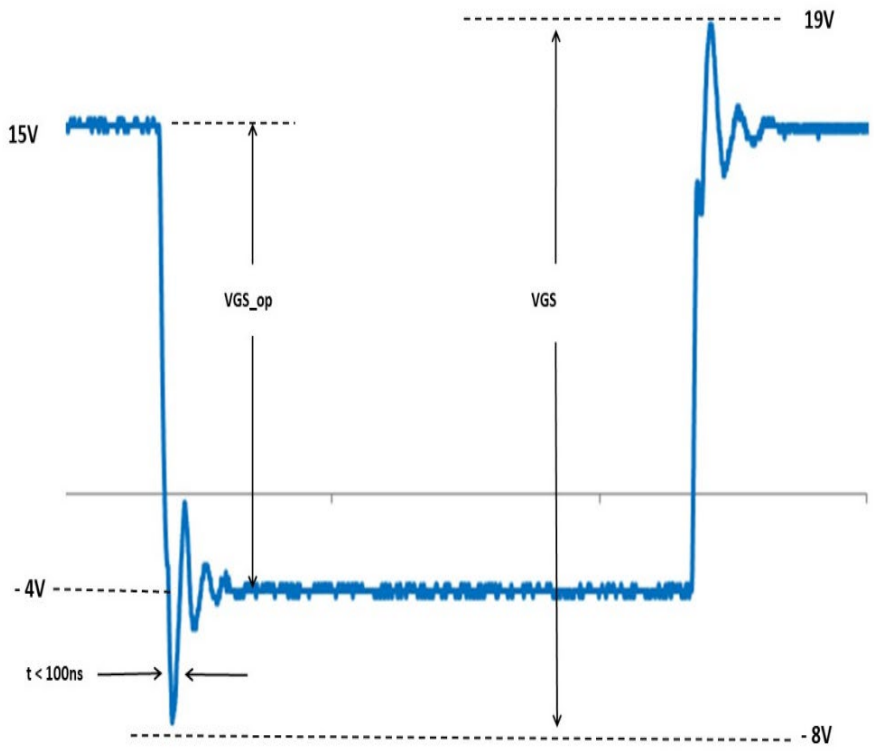
- SiC based CCM totem pole PFC can have higher efficiency than Si based H-bridge PFC.
- GaN has efficiency advantage at light load. But with much higher Rdson over temperature, the efficiency and power delivery capability is compromised at higher power.

→ SiC is the clear choice for the power components for Totem pole PFC especially for high reliability applications.

Tips of Gate Driving with SiC MOSFETs

GATE DRIVE VOLTAGE LEVEL

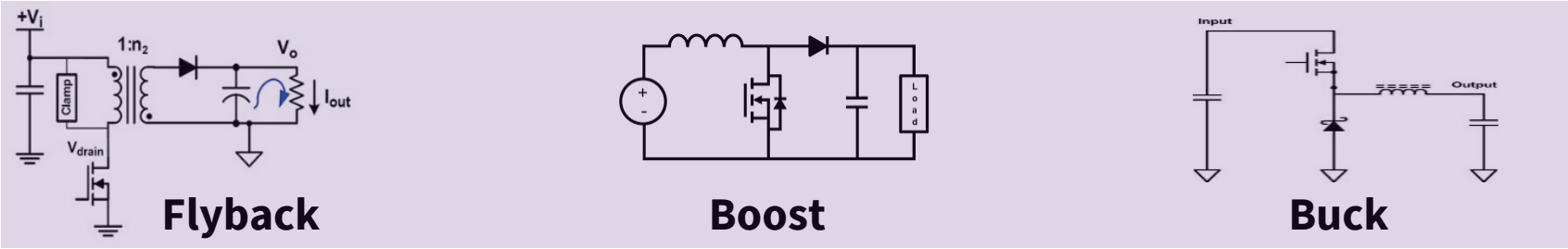
V_{GS}	Gate - Source voltage (Under transient events < 100 ns)	-8/+19	V	Fig. 29
$V_{GS\text{-}op}$	Gate - Source voltage (Recommended operating range)	-4/+15	V	



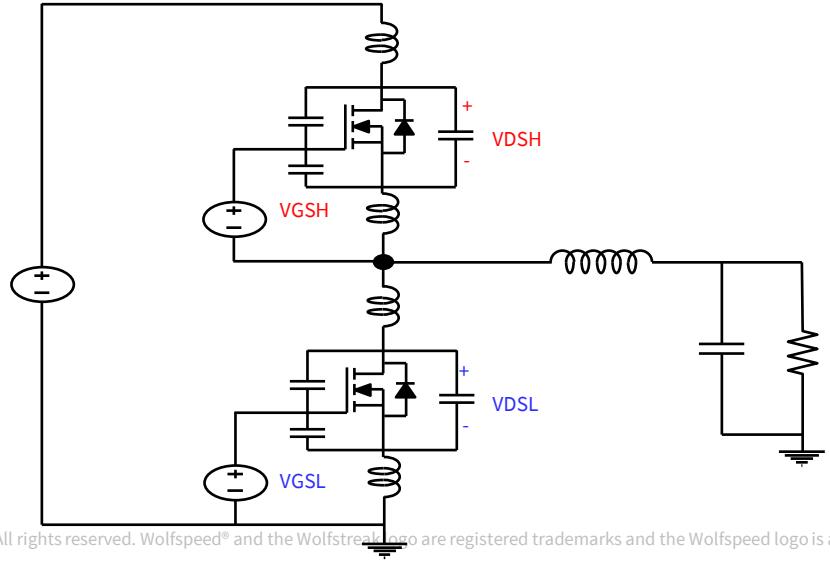
- The first $\mathbf{V_{GS}}$ rating is the absolute max rating. The max $\mathbf{V_{GS}}$ rating allows for ringing and overshoots that will be superimposed on top of the continuous gate drive voltage.
- The second $\mathbf{V_{GS\_OP}}$ rating is the recommended max operating setting for turn-on and turn-off voltage. The max nominal power supply voltage for turn-on is recommended at 15V, and -4V for turn-off. This is recommended value for safe operation and long term reliability.
- For nominal -4V, if considering tolerance +/-5%, the range is -4.2V/-3.8V. For very common -3V, the range will be -3.15V/-2.85V.
- For nominal +15V, if considering tolerance +/-5%, the range is 15.75V/14.25V.
- **Actually, if the layout is optimized, the negative gate bias can be -3V or -2V as long as there is no false turn-on. The benefit of using lower negative gate bias voltage is the Vf of body diode is lower.**

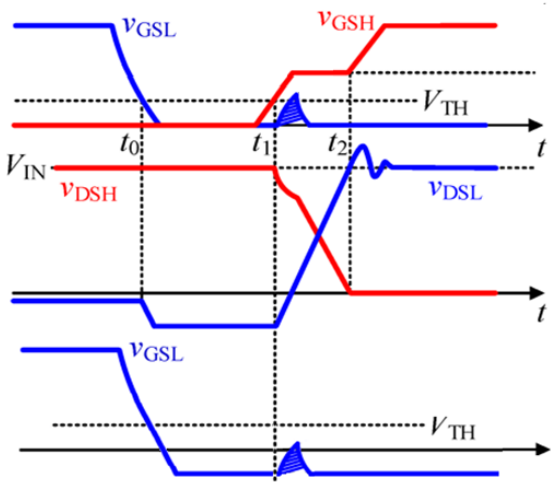
WHY NEGATIVE DRIVING VOLTAGE?

- Wolfspeed Gen3 SiC MOSFETs can safely operate at +15V/0V condition. Adding negative gate bias improves noise immunity, avoiding false turn-on in half bridge configuration.
- In single end power converter such as Flyback, Boost, or Buck converter, it is possible to use 0V turn-off voltage:



- It is recommended to use negative voltage for Totem Pole half bridge topology due to cross talk

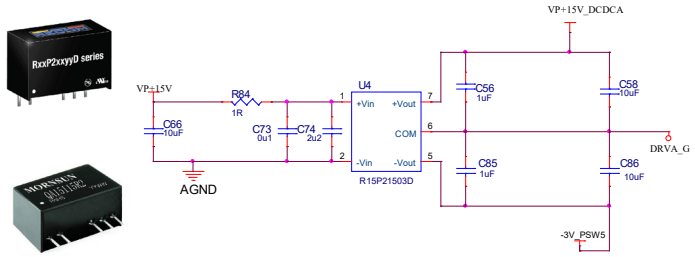




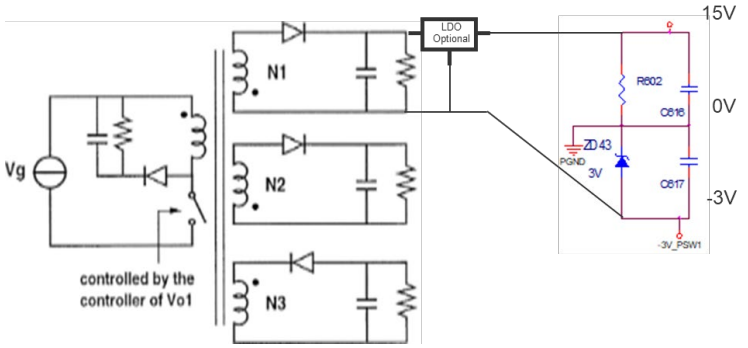
With negative Vgs

POSITIVE & NEGATIVE GATE DRIVER VOLTAGE SOLUTIONS

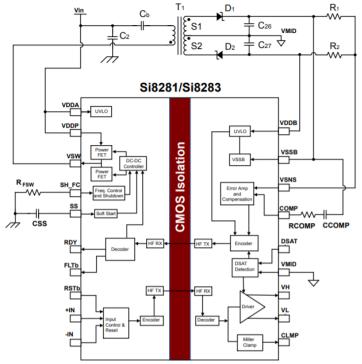
- OPTION 1 – Integrated solution
  - Dedicated +15V/-3V power supply



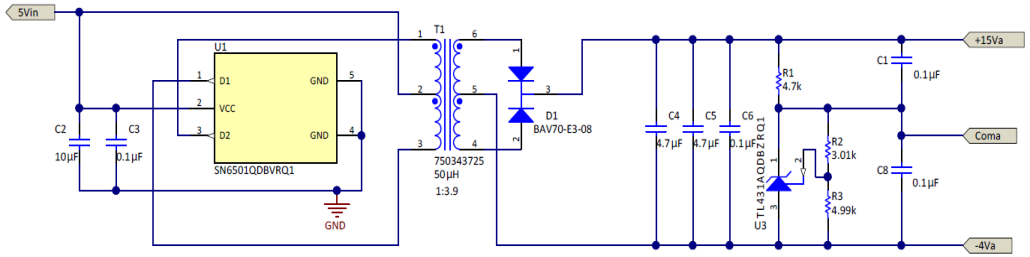
- OPTION 2 – Discrete solution
  - 18V multi-outputs Aux power supply. Generate -3V by resistor and Zener diode



- OPTION 3 – On board In the driver
  - Gate driver IC with built in DC/DC controller (e.g. Si8281)



- OPTION 4 – Build your own
  - Push-Pull Circuit from Texas Instruments TIDA-01605



DESIGN SUPPORT

Electrical simulation

https://www.wolfspeed.com/speedfit

LTspice®
plecs

https://go.wolfspeed.com/all-models

Reference designs

https://www.wolfspeed.com/power/products/reference-designs

Application	Reference design name	Topology
Automotive	6.6 kW Bi-Directional EV On-Board Charger	AC to DC, DC to AC
Automotive	22kW Bi-directional High Efficiency DC/DC Converter	Bi-Directional DC to DC
Automotive & Renewable Energy	22kW Bi-directional High Efficiency Active Front End (AFE) Converter	Bi-Directional AC to DC
Renewable Energy	60 kW Interleaved Boost Converter	DC to DC
Server Power supply	2.2 kW High Efficiency (80+ Titanium) Bridgeless Totem-Pole PFC with SiC MOSFET	AC to DC
Server Power supply	6.6 kW High Frequency DC-DC Converter	DC to DC

THANK YOU