1700V Silicon Carbide (SiC) MOSFETs: Enhancing Power Conversion from Watts to Megawatts

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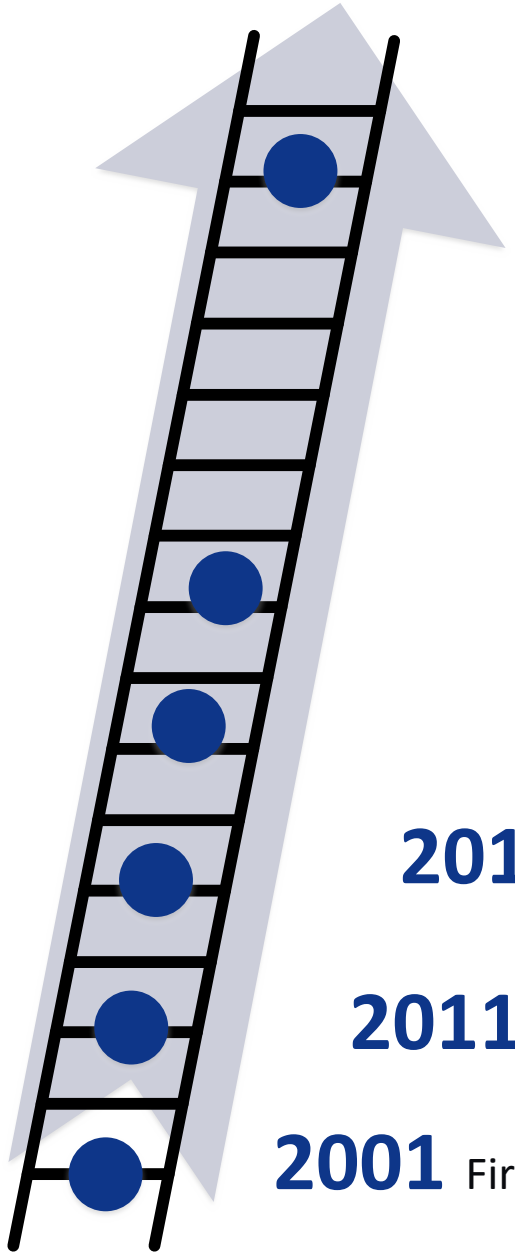
- **1700 V SiC MOSFETs**
  - SiC climbs the voltage scale
  - Features and packaging
- **SiC Versus Silicon**
  - Differences at 1700 V class
- **Application Benefits**
  - Watts, kilowatts, and megawatts
- **Summary**

SiC MOSFETs Climb The Voltage Ladder



2020 and Beyond

Another player releases ***tiny* 1700 V** SiC MOSFET

2-3 other SiC players announce **large-area 1700 V** MOSFETs

Next: 3.3 kV, 6.5 kV, 10 kV?

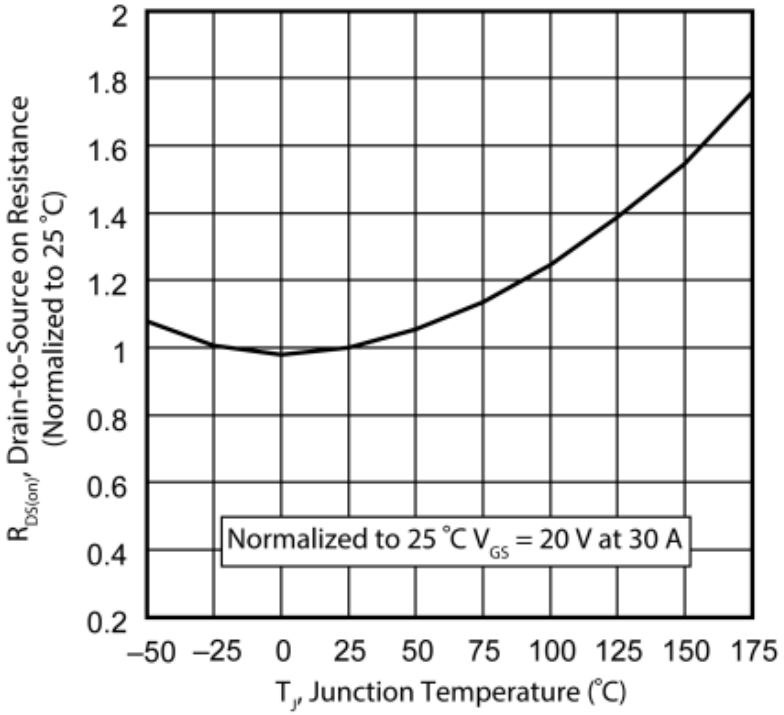
2016 First **1000 V** SiC MOSFET

2015 First **900 V** SiC MOSFET, another player announces ***tiny* 1700 V** SiC MOSFET

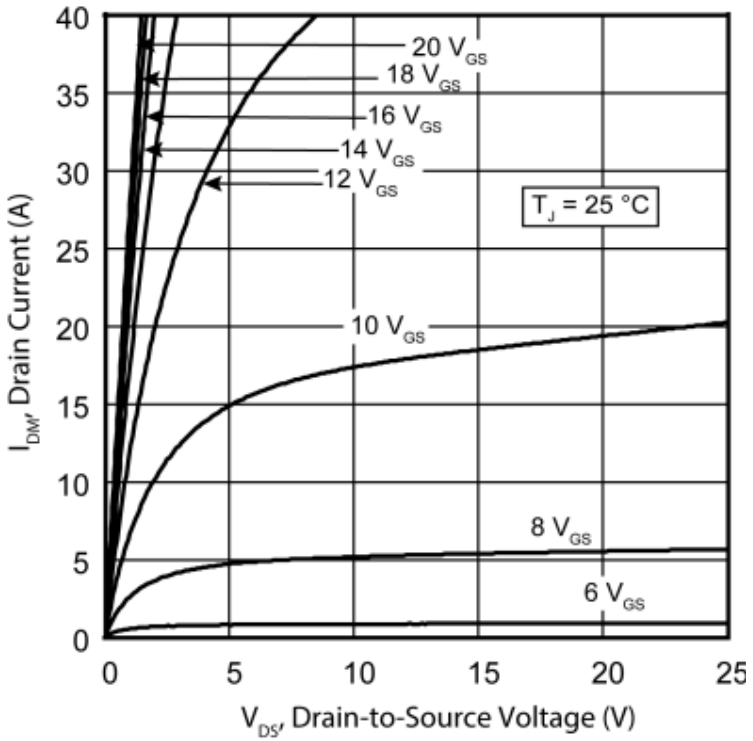
2012 First ***tiny* 1700 V** SiC MOSFET (1400 mΩ)

2011 First **600 V and 1200V** SiC MOSFET

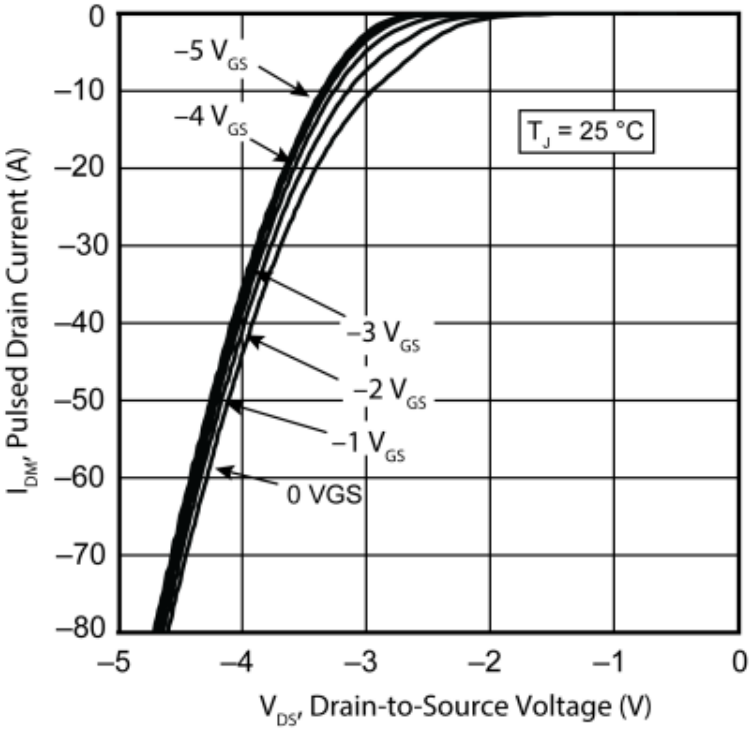
2001 First **600 V** SiC Schottky diode



Low sensitivity of R_{DSon} to T_j

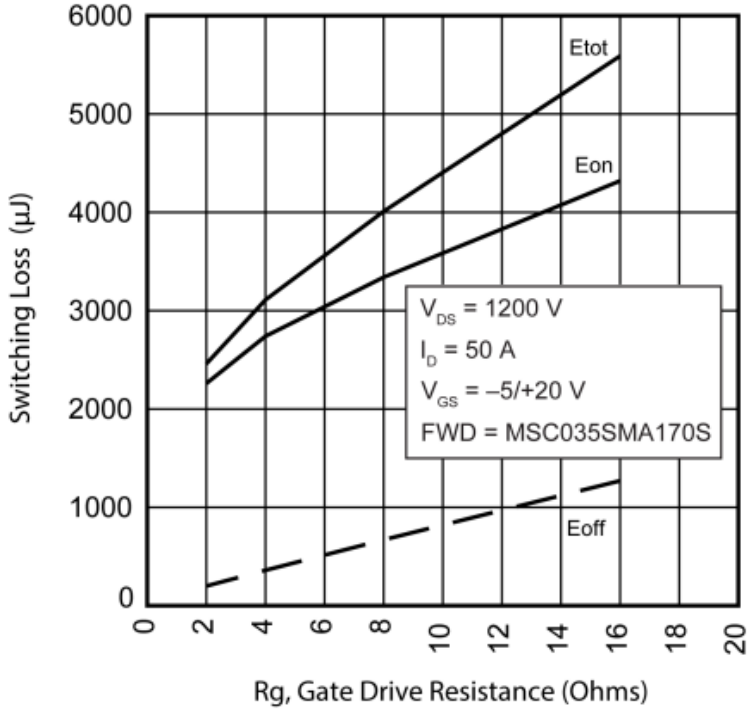


Lower losses at light load

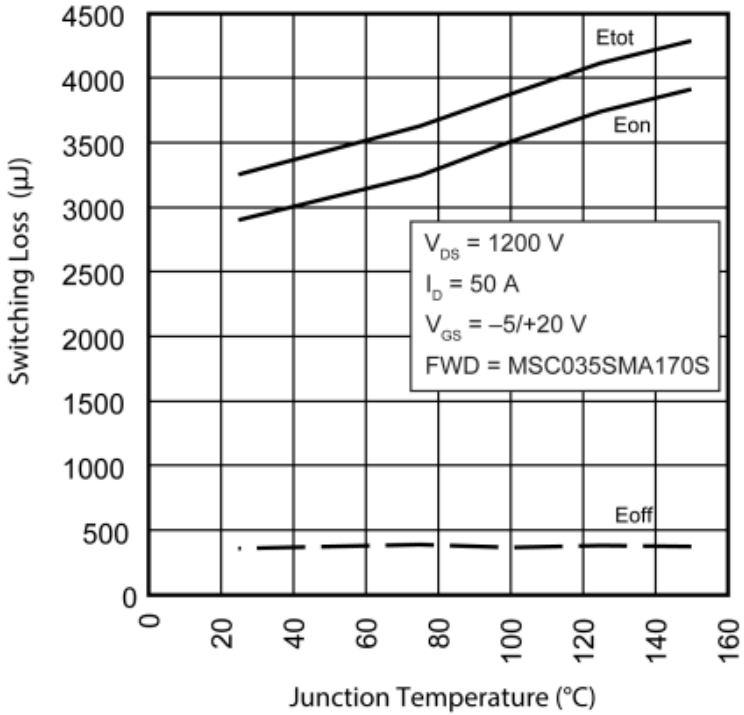


Body diode eliminates need for FWD

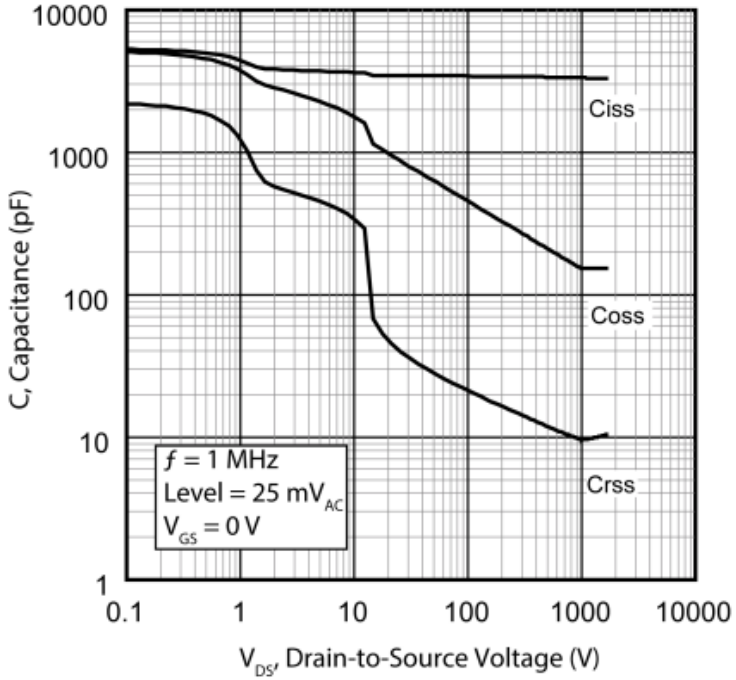
- **Versus silicon SJ MOS:** R_{DSon} of SiC increases 25% at T_j = 100 C; silicon increases 70%
- **Versus silicon IGBT:** Lower light load losses; no need for antiparallel diode



Low switching losses



No dependence of Eoff on Tj
Low dependence of Eon on Tj

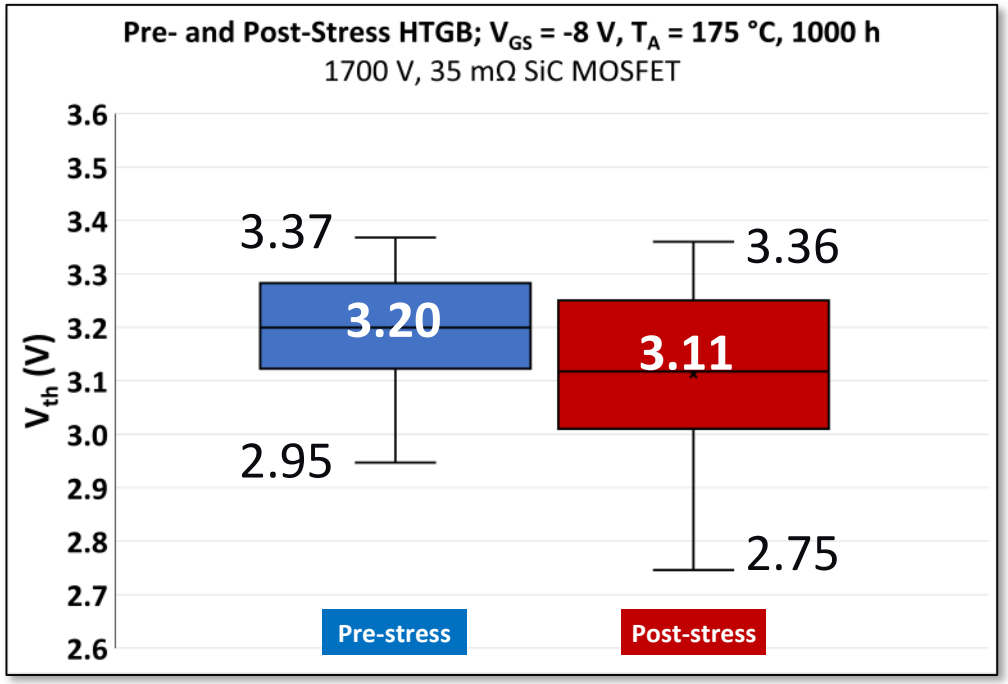


Minimal parasitic capacitance

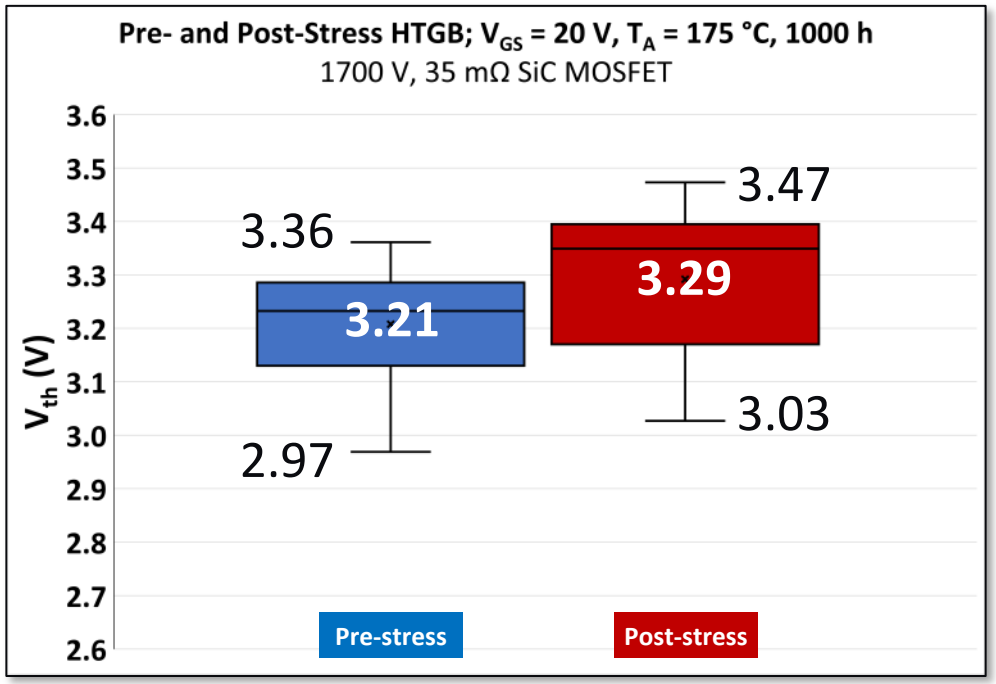
- **Majority carrier device:** Low switching losses with less temperature dependence
- **Small die size:** Low parasitic capacitance for easy, high-speed switching

Stable threshold voltage is **critical**.

Stress: V_{GS} = -8 V | Change: -0.09 V



Stress: V_{GS} = 20 V | Change: +0.08 V



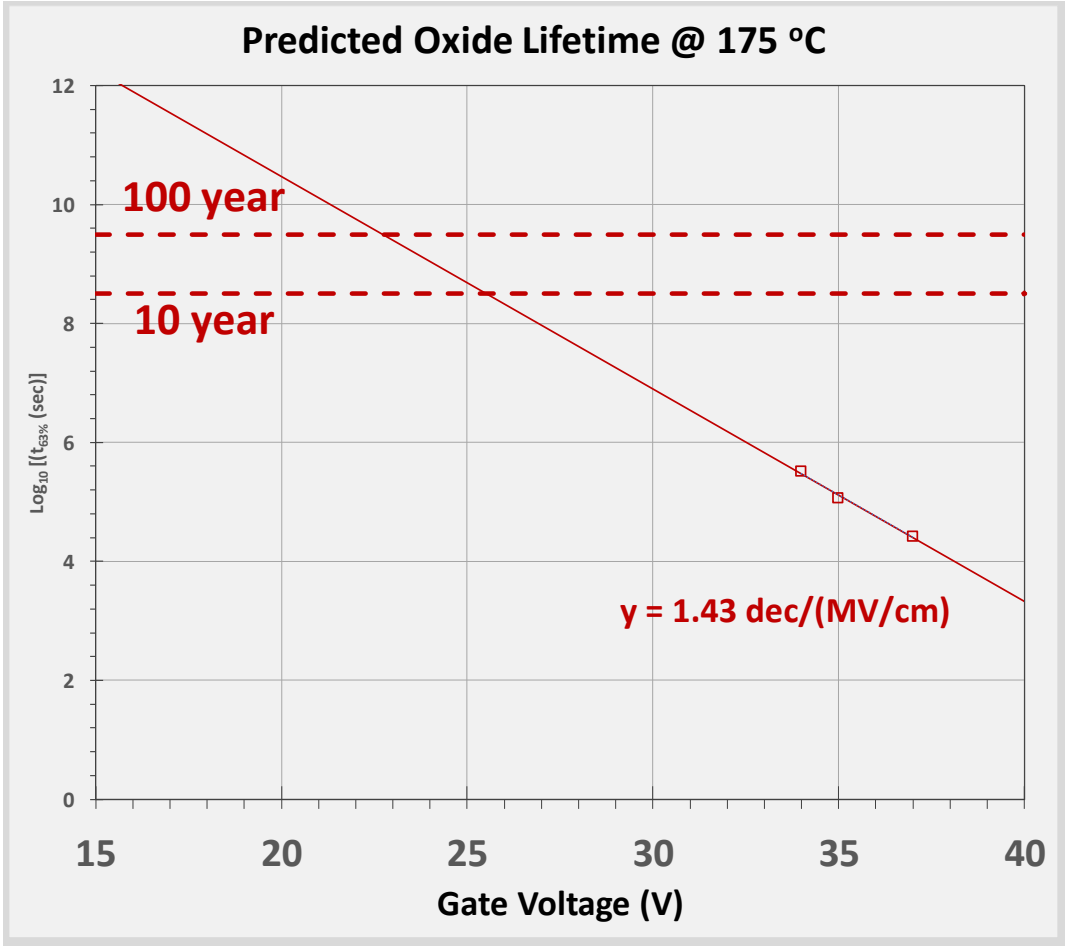
V_{th} measurements before and after 1000 hours of high-temperature gate bias (HTGB) stress show negligible shift.

Long oxide lifetime is **critical**.

i. Oxide failure (breakdown) accelerated with temperature and electric field across the oxide
ii. Failure modes extracted from Weibull plots
iii. Arrhenius equation used to predict oxide lifetime

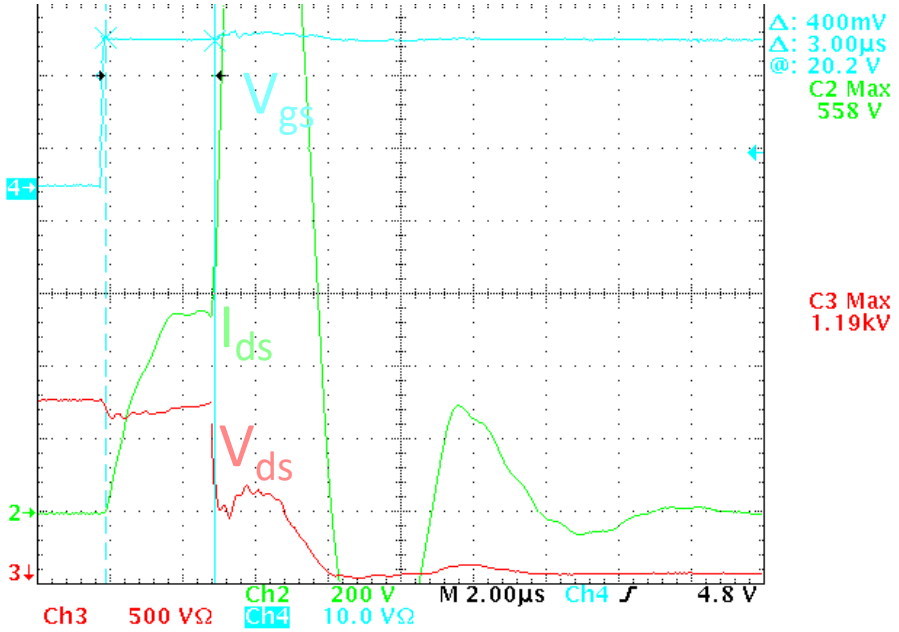
Data from production-grade SiC MOSFETs

Oxide predicted to last more than 100 years at recommended V_{GS} and Tj = 175 C



Short circuit withstand time is **critical**.

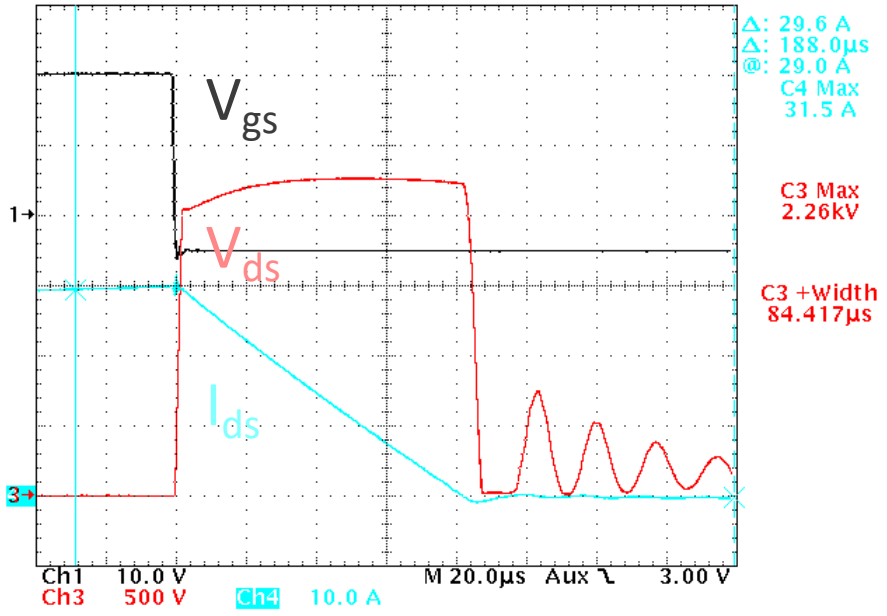
1700 V, 35 mΩ SiC MOSFET
V_{DS} = 1200 V, T_C = 25 C, V_{GS} = 20 V



SCWT > 3 µs, I_{SC} < 650 A

Avalanche ride-through is **critical**.

1700 V, 35 mΩ SiC MOSFET
I_{DS} = 30 A, T_C = 25 C, V_{GS} = 20 V / -5 V



E_{AV} > 4 J, V_{BR} > 2.2 kV

Safely survive system transients with excellent short circuit withstand time and avalanche ruggedness

Customizable module options:

- DCB ceramic: AlN or Si_3N_4
- Baseplate: Cu or AlSiC
- Other topologies possible

MOSFET Modules

Half bridge

SP1
50, 100 A

SP3F
150, 200 A

D3
280, 420 A

Full bridge

SP3F
50, 100 A

SP6C
140, 190 A

Six pack

SP3F
50 A

SP6C
100, 140 A

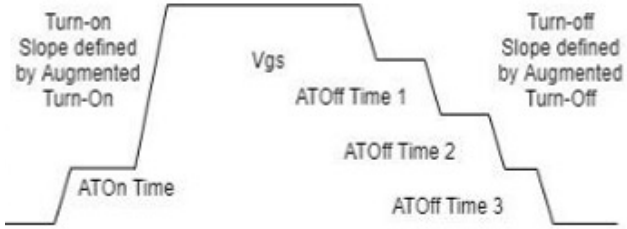
SP6C
280, 420 A

SP6LI
280, 540 A

Ultra-low inductance power modules for high switching performance

Advanced gate drivers for better performance

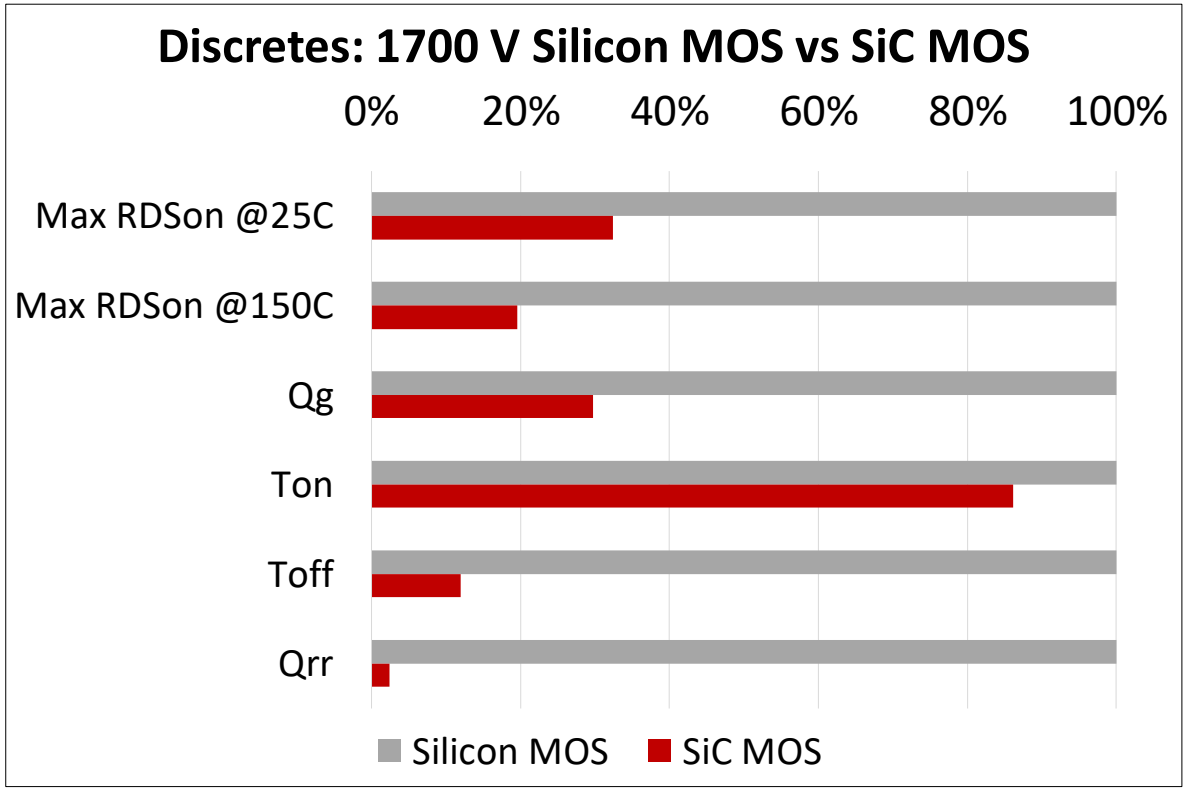
- Augmented switching
- Fully software configurable
- On-the-fly configuration

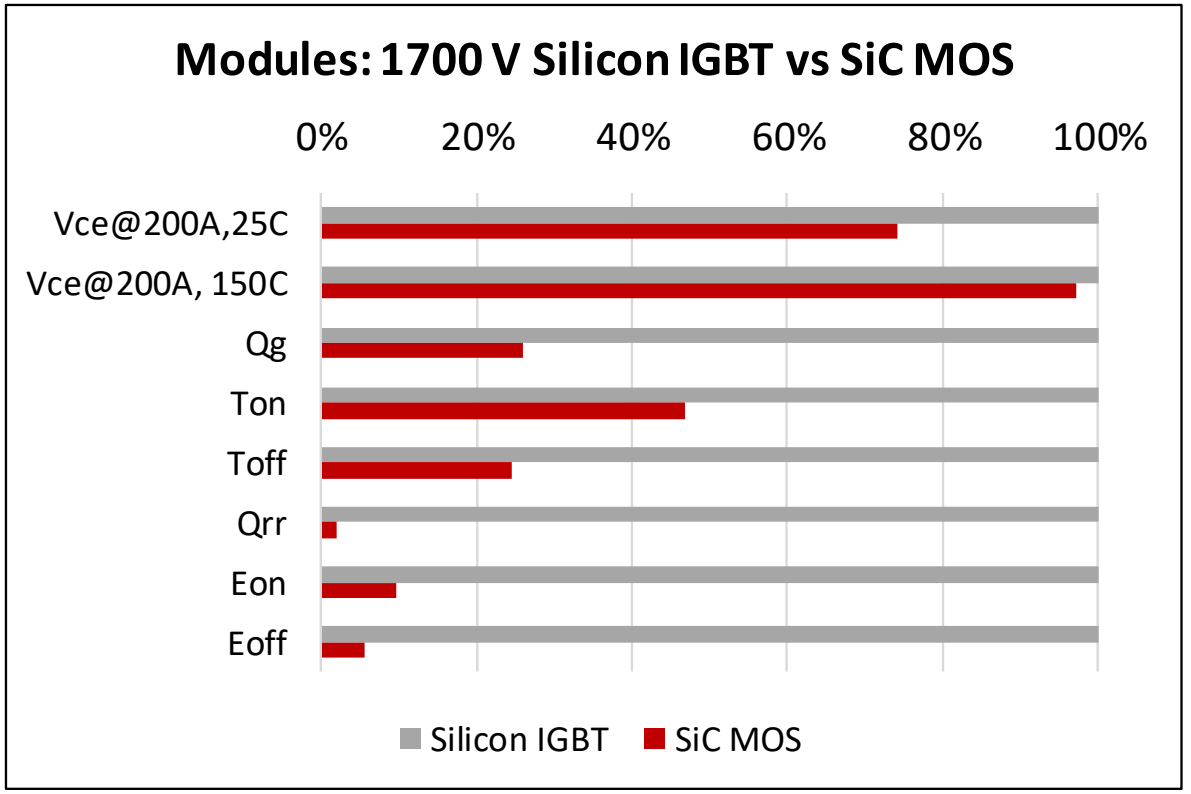


Discrete products also available:

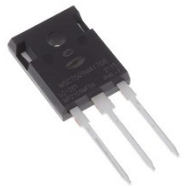
TO-247-3L, TO-247-4L, D2PAK, D3PAK

SiC vs. Silicon | Superior Performance At 1700 V





DISCRETE COMPARISON



More power, cooler operation

70-80% lower R_{DSon} at use-case T_j

95% lower Q_{rr}

Easier to drive

70% lower Q_g

Lower cost, more choice

1700 V SiC MOS is less expensive with more options

MODULE COMPARISON

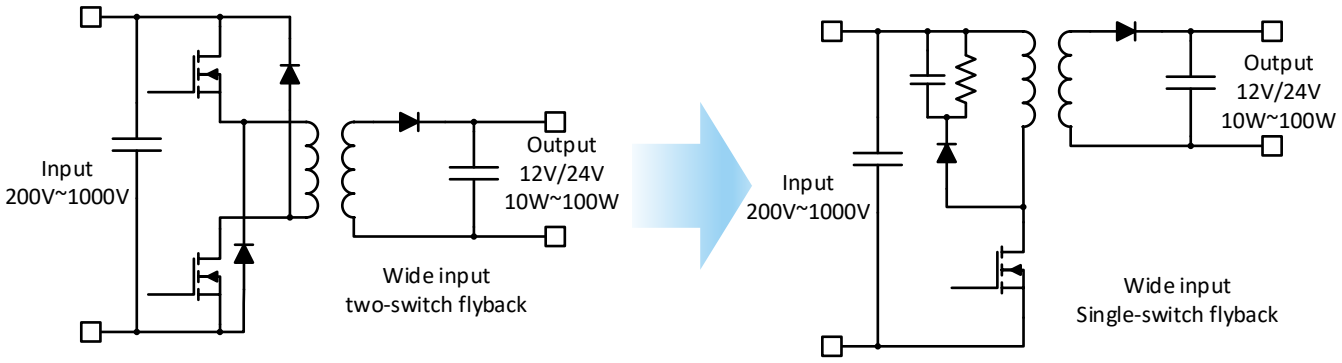
Lower cost of electricity, cooler operation

No knee voltage → lower conduction losses at light load

Smaller, lighter, system

90% lower switching losses allow huge reductions in passives

MORE PROCESSING POWER, LOWER SYSTEM COST



About the AuxPS Application

EVERYWHERE: Appears in almost every power electronics system

CRITICAL: Provides power to all peripherals, from gate drivers to cooling systems

UNIVERSAL: Requires wide range of input voltage

SIMPLE DRIVING: Control IC is used to drive device with 0 V turn-off

Design priorities, ranked

1. Reliability
2. Cost and component availability
3. Efficiency

Benefits of 1700 V SiC MOSFET Over Silicon

Enhanced reliability

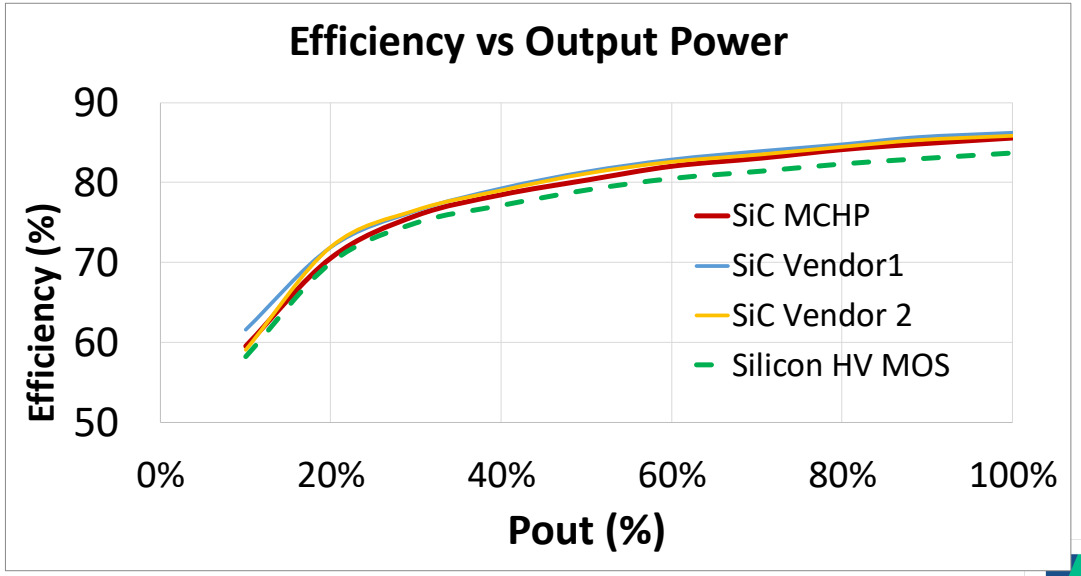
- Simpler circuit topology
- Reduced part count

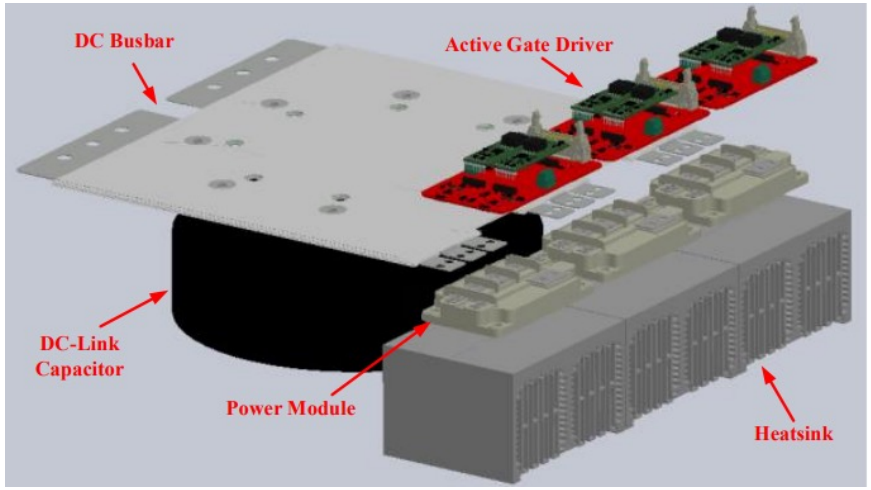
Lower cost, greater availability

- Small-area 1700 V SiC MOSFETs *cheaper than silicon*
- More suppliers of SiC MOSFETs than high-voltage silicon MOSFETs

Efficiency

- Below chart indicates SiC shows improvements, even alongside all other benefits





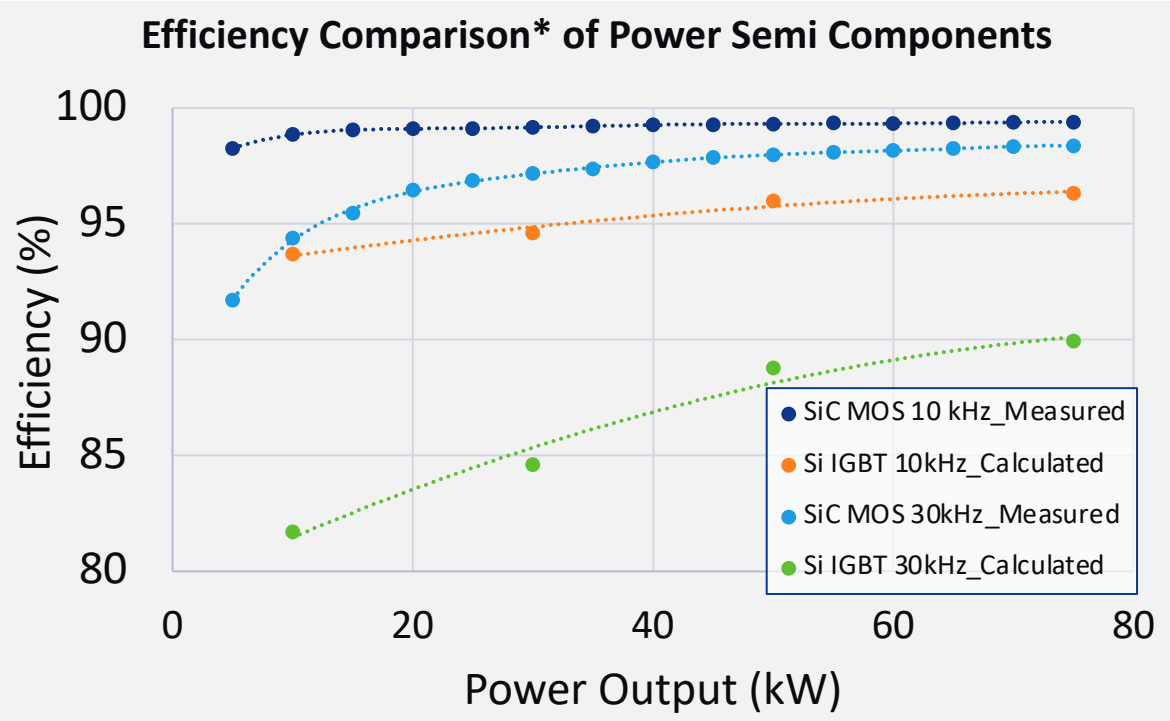
Collaboration with
UNIVERSITY OF ARKANSAS
PESLA
Power Electronic Systems Laboratory at Arkansas

About the application

Multi-kW Three-phase inverter (75 kW in this example)
Three-phase inverters are found in EV traction, EV chargers, solar inverters, UPS, motor drives, and more across a wide range of power

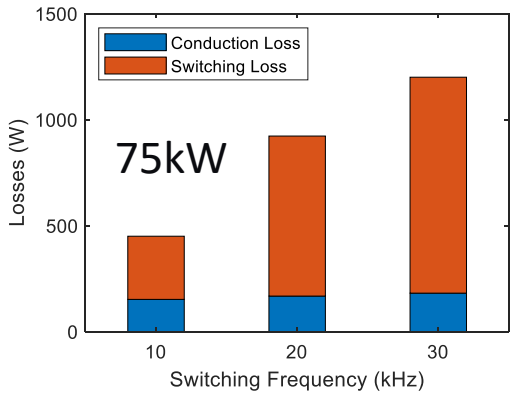
Design priorities, ranked

1. Efficiency
2. Reliability
3. Power density (size, weight reduction)



* Efficiency measurements are for power semiconductors only; passive component losses not included.

Application Benefits | Kilowatts



98.4% efficiency* and **T_j < 50 C**
at full power and 30 kHz

* Efficiency measurements are for power semiconductors only; passive component losses not included.

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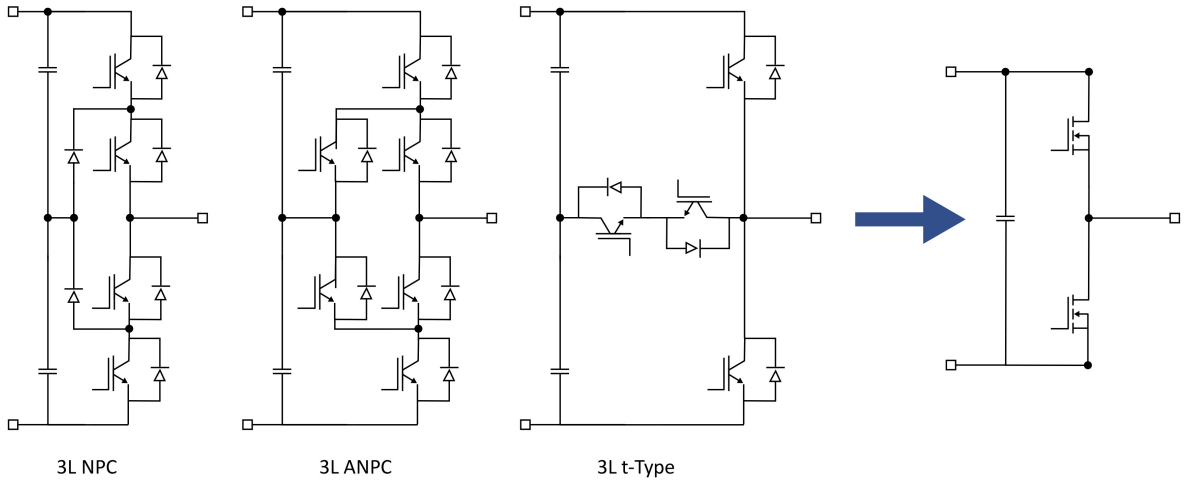


10 parts
Per phase leg
+ 4 drivers

12 parts
Per phase leg
+ 6 drivers

8 parts
Per phase leg
+ 4 drivers

2 parts
Per phase leg
+ 2 drivers

Benefits of 1700 V SiC MOSFET Over Silicon

Greater efficiency

- *Far higher* at identical switching frequencies
- *Substantially higher* when switching SiC at higher frequencies

Enhanced reliability

- Simpler two-level topologies may be used with no penalty in efficiency
- Reduced part count (power devices and drivers) has fewer points of failure

Power density

- Higher switching frequency allows reduction in filter components and output transformers
- Lower losses mean less aggressive thermal management

↘ **LOWER** COMPONENT **COST**
↘ **LOWER** PASSIVES **COST**
↘ **LOWER** SYSTEM **COST**

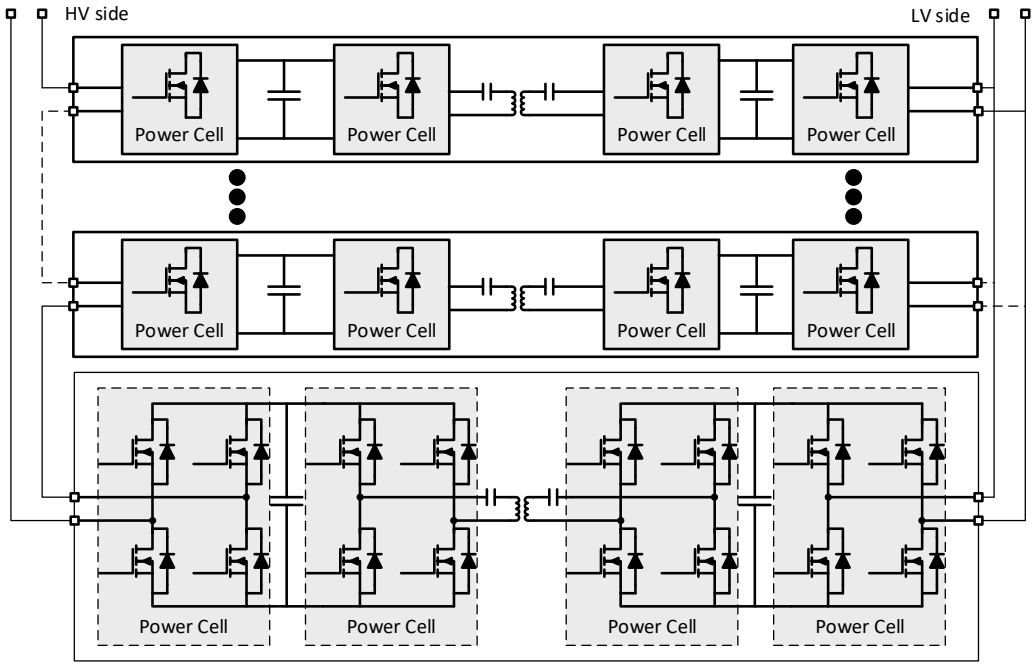
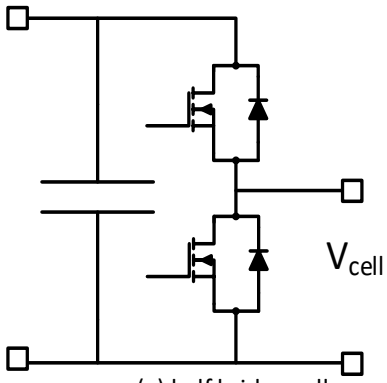
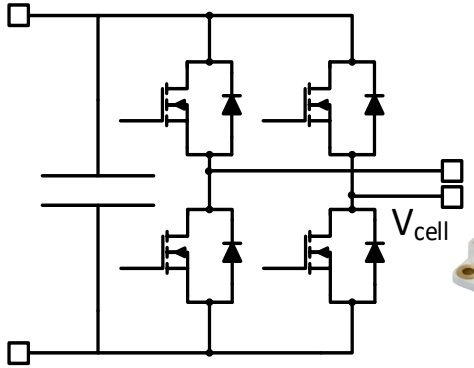


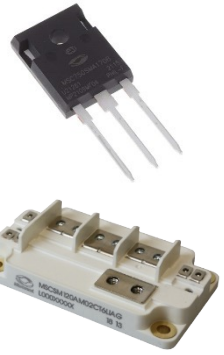
Diagram of a modular multi-level converter.



(a) half bridge cell



(b) full bridge cell



Benefits of 1700 V SiC MOSFET

~~Reduced part count~~ NOT YET…

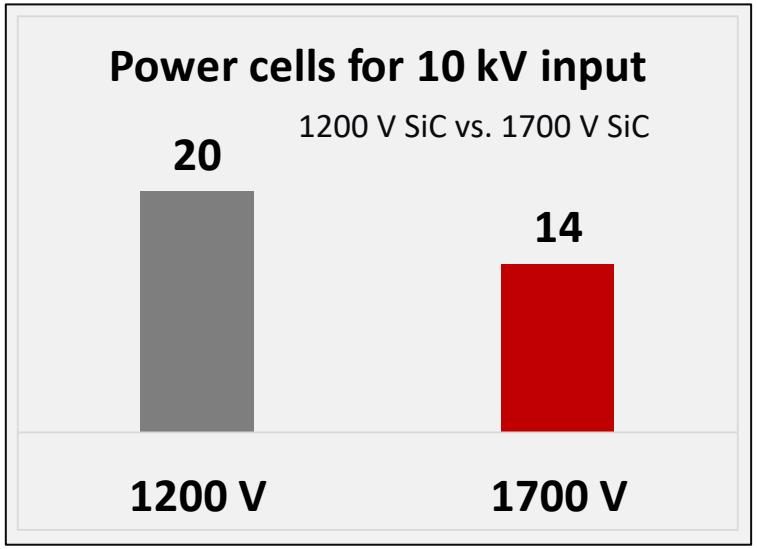
- Silicon IGBTs commercially available at 3.3, 4.5, 6.5 kV

Performance and Size

- Up to 35 percent more power processing capability for the same module current rating
- Higher efficiency and switching frequency shrink size and weight

Compared to 1200 V SiC MOSFETs, one can reduce:

- ↘ Series-connected cell count
- ↘ Number of semiconductor devices
- ↘ Number of gate drivers
- ↘ Points of system failure
- ↘ Wasted power
- ↘ Cost of ownership



Summary

- **SiC power devices continue to climb the voltage ladder**
- **1700 V SiC MOSFETs allow simultaneous improvements in a system's performance, reliability, size, weight, and cost – without compromise**
- **1700 V SiC MOSFETs are commercially available from multiple suppliers**
  - **Microchip offers more than 20 standard catalog part numbers** for 1700 V SiC MOSFET discrete and module products, from 2 A to 540 A
- **Digital gate driver solutions available for all modules**
  - Optimize performance and reduce your time to market, all with the click of a mouse

Thank you for your interest.

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IS11: Power Devices: Performance, Achievements & Road Ahead