

# Bring your inverter to the next level:

## Controlling SiC Modules with Programmable Gate Drivers



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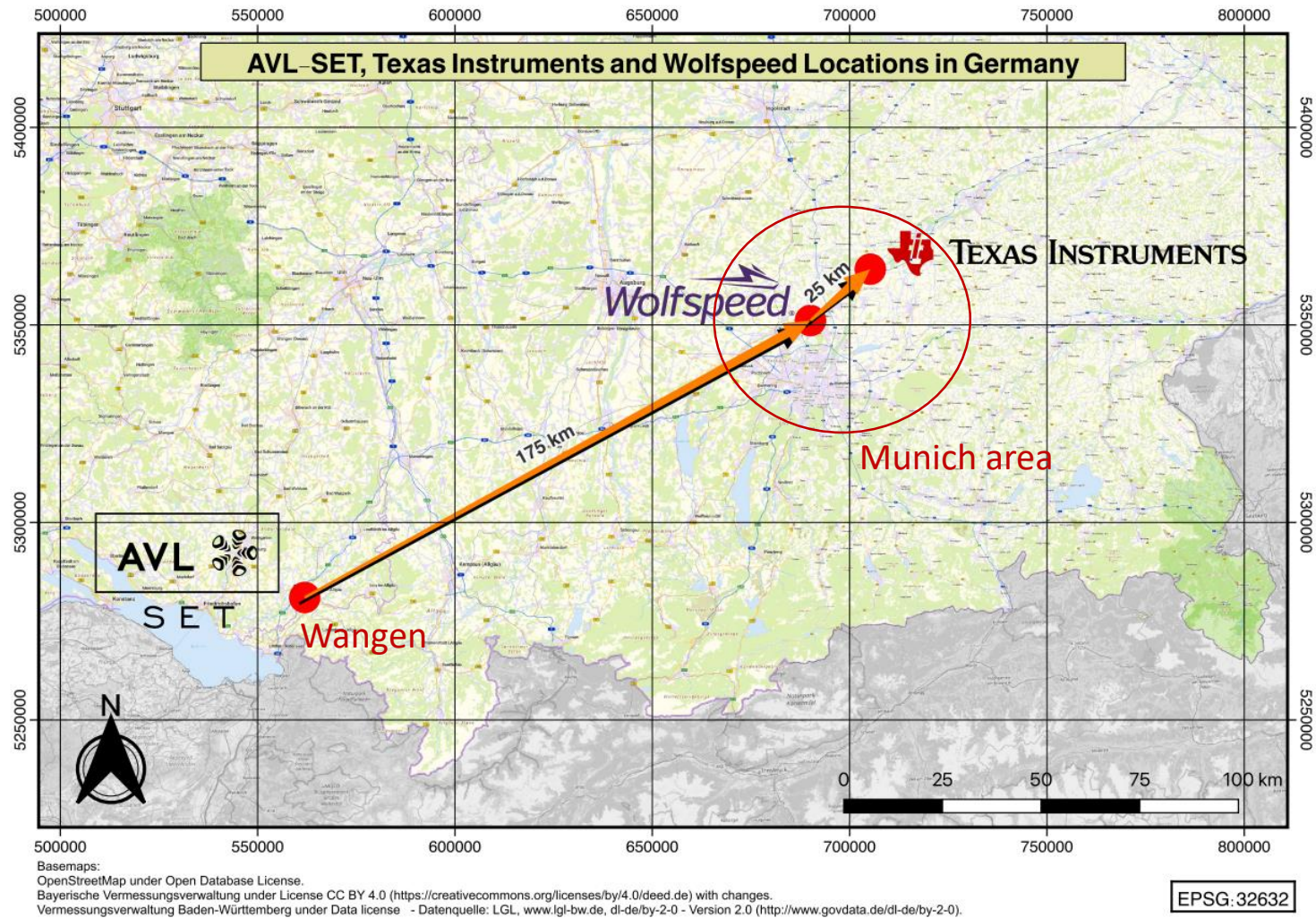
# AGENDA

- Introduction
- Module selection
- Gate driver selection
- Inverter design
  - Inverter stack up
  - Overview
- Real-time variable gate drive strength benefits
- Experimental results
  - Double pulse test
  - Voltage overshoots
  - Efficiency
- Design support
- Conclusion

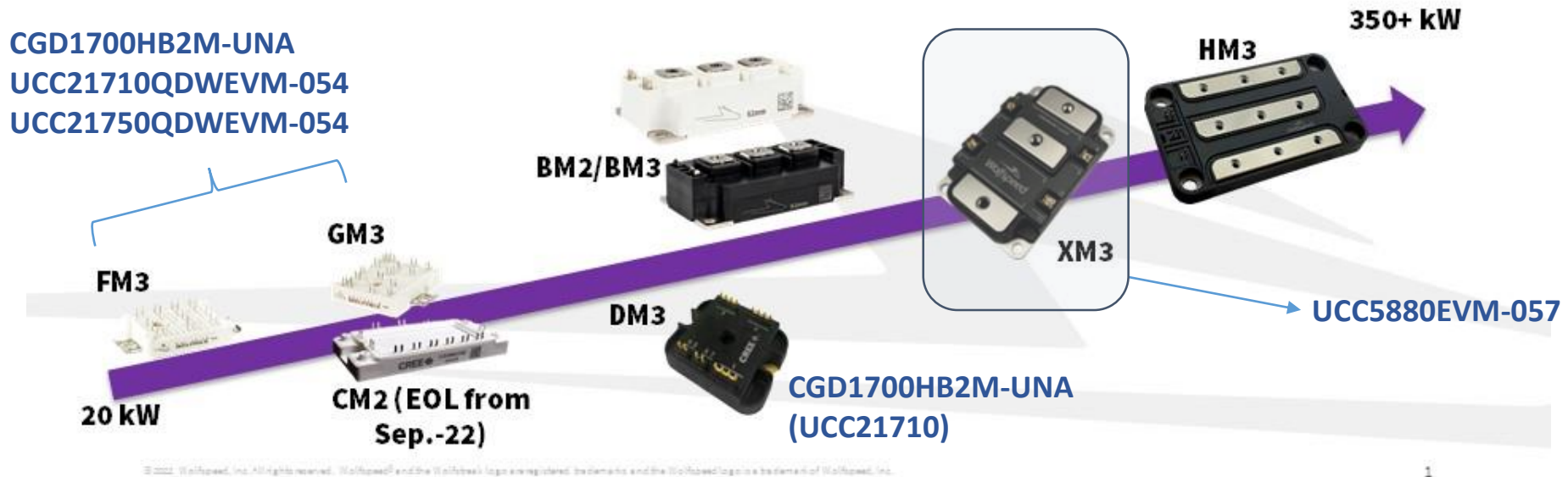
# INTRODUCTION

- Overview of 800V, 300kW SiC-based traction inverter developed by Texas Instruments and Wolfspeed
  - 32kW/L power density and > **2%** improved efficiency in the CLTC drive cycle.
- Foundation to create high-performance, high-efficiency traction inverter systems
  - faster products evaluation and ready to market approach.
- System efficiency improvements enabled by
  - High performance gate driver with variable gate drive strength.
  - Exploiting  $V_{DS}$  overshoot vs switching slope trade-off by changing drive strength on the fly.
- TI's high-control performance MCUs
  - featuring tightly-integrated and innovative real-time peripherals enable effective traction motor control at speeds > 20,000RPM.

# LOCATIONS IN GERMANY



# WHICH MODULE BEST FITS YOUR APPLICATION?



## Industry-Standard Footprints

- FM/GM/BM/CM(EOL)
- Well-Established Footprints Available from Multiple Suppliers
- Low Barrier to Entry from Si or other SiC Suppliers
- Attractive for Highly Cost-Competitive Designs
- **Target Applications: Rail / Traction, PV Inverters, EV Charging Infrastructure, Industrial Test Equipment.**

## Optimized Footprints

- DM/XM/HM
- Platforms Developed by Wolfspeed
- Highly-Differentiated to Push Power Density Metrics
- Attractive for Extreme Performance Driven Designs
- **Target Applications: EV Charging Infrastructure, UPS, Power-Dense Designs.**

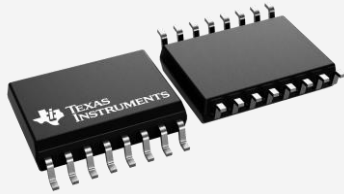
*\*TI gate driver support*



# GATE DRIVER EVOLUTION

## ISO5x5x-Q1

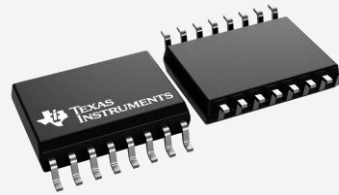
Protection Automotive Gate Driver



ISO5452-Q1 (released)

## UCC217xx-Q1

Protection Automotive Gate Driver



UCC21710-Q1 (released)

## UCC5880-Q1

Programmable Gate Driver



UCC5880-Q1 (released)

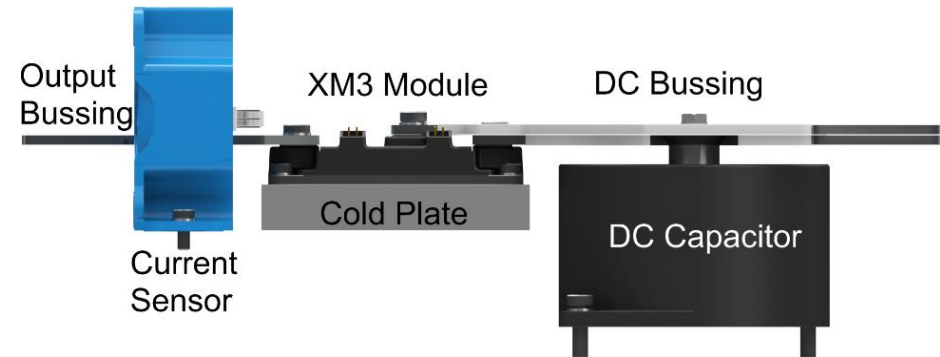
Size & Integration	Integration of <b>Active miller clamp, Fault reporting, SCP, STO, UVLO</b>	Integration of <b>Analog to PWM sensor</b>	<b>Reduction of FuSa external circuitry and PCB area by integration of FS features: ASC (primary and secondary side), 2STO, 10-bit ADC, Active Miller Clamp, Vgs threshold</b>
Efficiency	2.5A/-5A gate drive strength <b>with split output</b>	<b>Efficient solution</b> through $\pm 10\text{A}$ gate drive strength	<b>2%** efficiency gain</b> by adaptive gate drive strength up to $\pm 20\text{A}$
BOM cost	Effective solution for <b>driving IGBT and MOSFET</b>	Most <b>cost-effective</b> solution for <b>non-FS applications</b>	<b>Cost reduction</b> for functional safety applications <b>through integration</b>

*\*\*Based on real tests done by TI and Wolfspeed*

Non-confidential



# TIDM-02014 STACK UP



- High-Performance Liquid Cooled Cold Plate
- Low Inductance, High-Ripple Current Film Capacitors = Total Power Loop Inductance of only **12nH**
- Simple Bussing Design
- Highly Integrated Enclosure allows for a very Compact and Lightweight Inverter

# INVERTER HARDWARE

Power modules:  
**EAB450M12XM3**

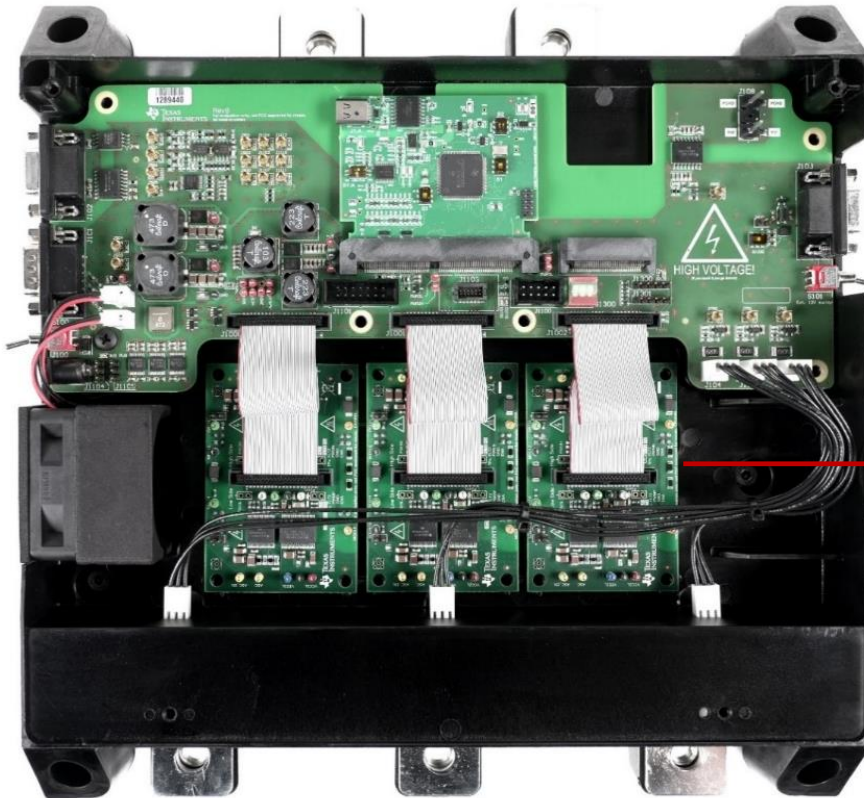
MCU: **AM2634P**  
**TMS320F280039C**

Voltage sense:  
**AMC3330-Q1**

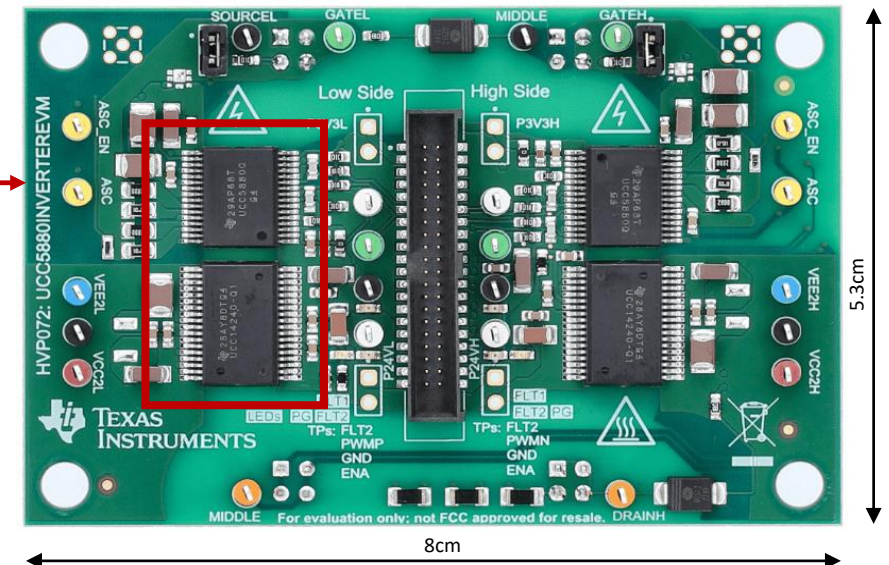
Resolver:  
**ALM2403-Q1**  
**OPA2991-Q1**

CAN:  
**TCAN1044-Q1**  
**ISO1042-Q1**

Pre-regulators:  
**LM74202-Q1**  
**LM5158-Q1**  
**TPS7B869-Q1**

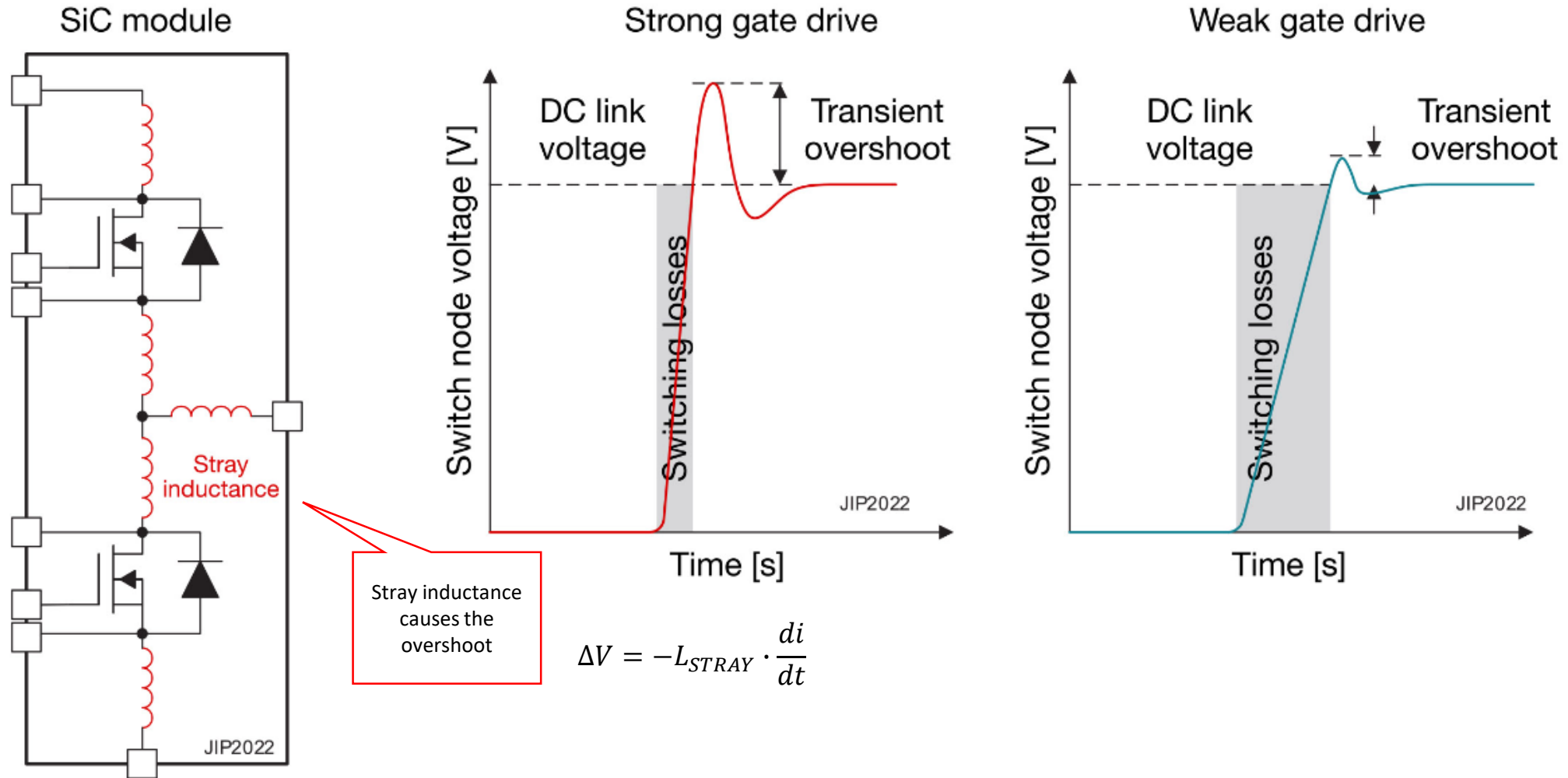


**UCC5880-Q1** 20A Isolated gate driver with adjustable gate drive strengths  
**UCC1424x-Q1** Isolated power module with integrated transformer





# REDUCE OVERSHOOT WITH VARIABLE GATE DRIVE STRENGTH

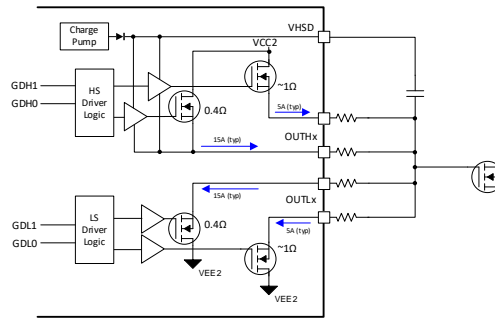


\* Faster transients are rich in harmonics and negatively effect electromagnetic compatibility (EMC)

# HIGH EFFICIENCY WITH XM3 POWER MODULE AND UCC5880-Q1 PROGRAMMABLE GATE DRIVER

## UCC5880-Q1 adjustable gate drive

- ✓ **Three programmable drive strengths**
  - **Dual Output** with 5A, 15A, or 20A capability
- ✓ **“On the fly” drive strength**
  - Enable through **SPI** or **GPIOs**
- ✓ **Improve Vehicle Range**
  - Flexibility to **tune gate drive** based on drive conditions
  - **Reduce VCE overshoot**
  - **Reduce EMI**
  - **Optimize efficiency of inverter**

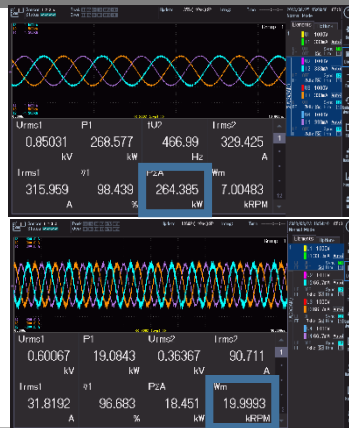


## Reference design high power test

- ✓ **Max power:**
  - 264kW, 466A max phase current, 850V dc bus with 345Nm @7000rpm
  - Max power limited by EME test bench maximum current
- ✓ **Max speed 20krpm**
- ✓ **Highest efficiency**
  - 99.2%
  - 80 Nm @9000 rpm
  - Strong drive(20A)

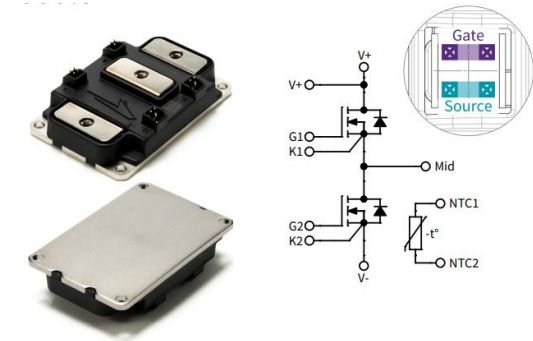
Max tested power

Max tested speed



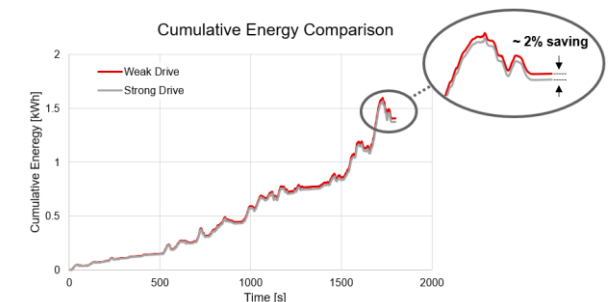
## EAB450M12XM3 power module

- ✓ **1200V, 450A, 2.5mΩ** half-bridge SiC power module
- ✓ **High Power Density**
- ✓ **High Junction Temperature** (up to 175°C)
- ✓ Possibility of the direct bus bar connection without bends -> **low inductance design**
- ✓ Integrated **temperature sensing**
- ✓ Dedicate high-side Kelvin-drain pin enables **gate voltage sensing for gate driver overcurrent protection**



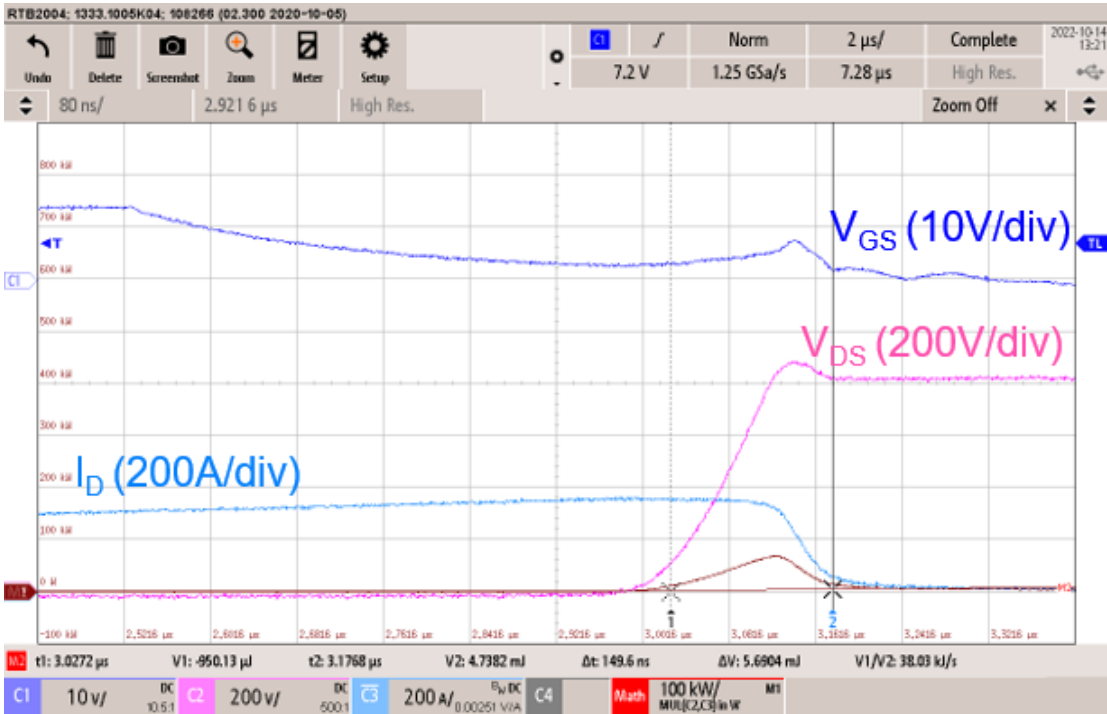
## Vehicle efficiency improvements

- ✓ **CLTC Driving Cycle Efficiency**  
Increase > 2% with adjustable gate driver strength feature
- ✓ **For 72kWh battery this would result in:**
  - -\$140 Battery Cost
  - -9kg Weight
  - -7.5L Battery Volume
- or ---
- +15.5km Operating Range

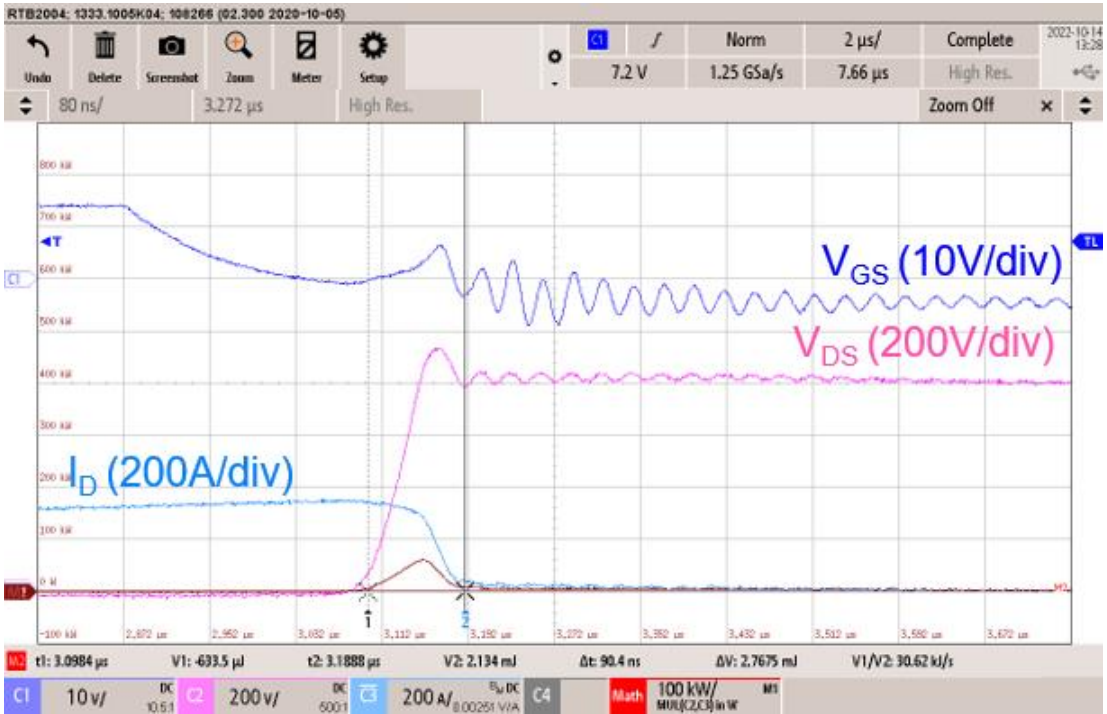


# DOUBLE PULSE TEST | 800V, 380A

## Weak drive (5A)



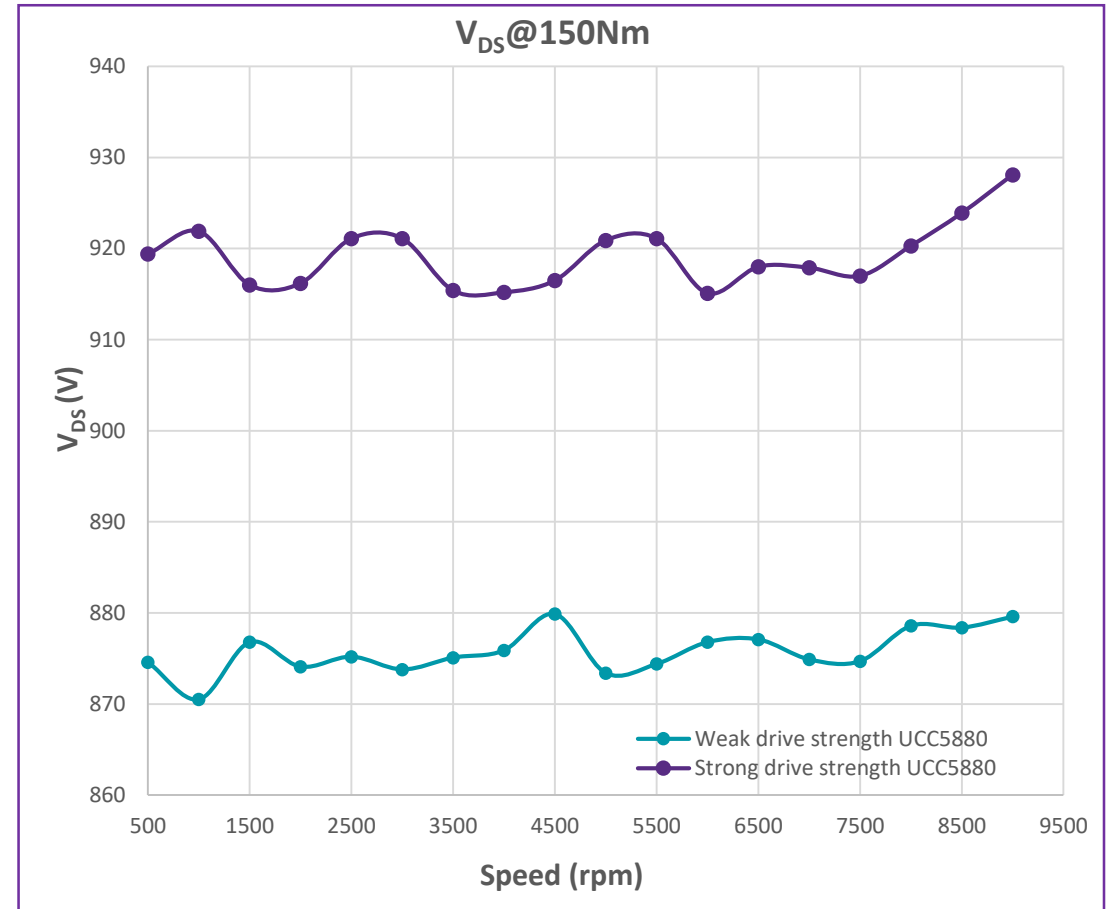
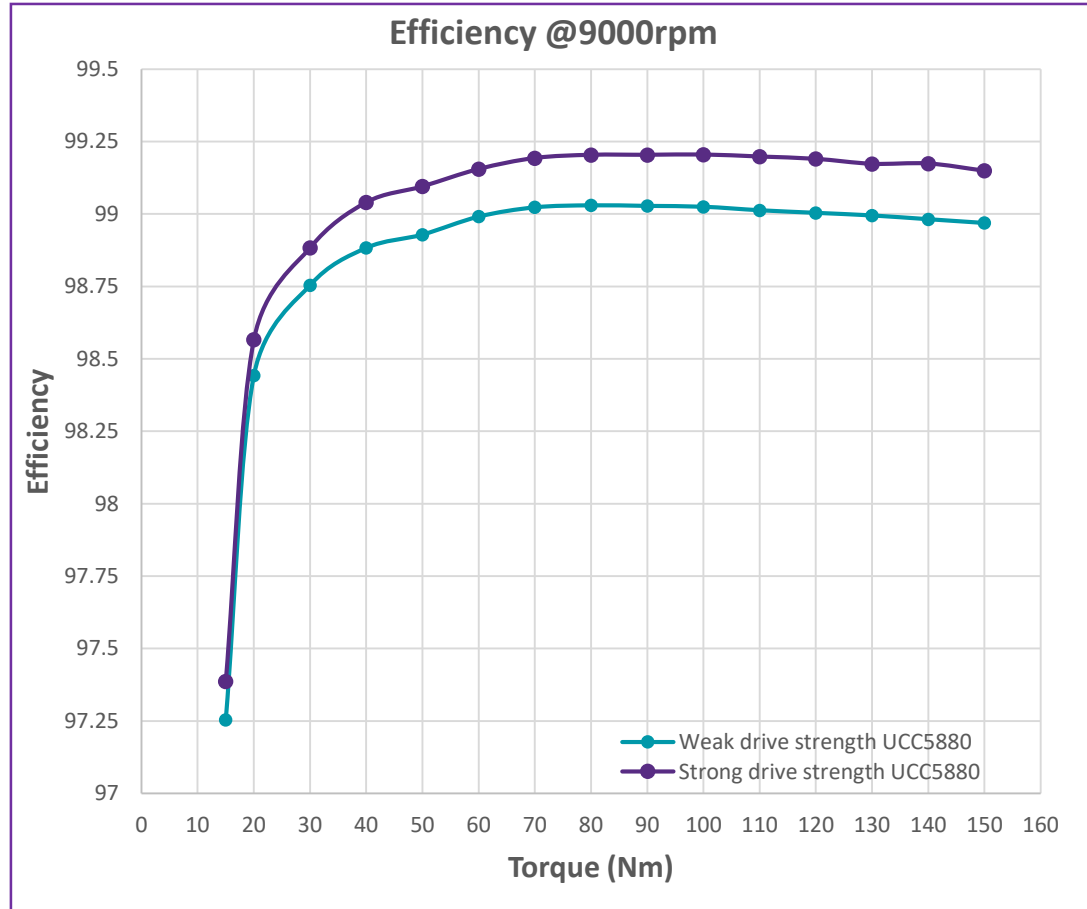
## Strong drive (20A)



PARAMETER	MEASURED VALUE
Turn on Energy	6.4601mJ
Turn off Energy	5.6504mJ
$V_{DS}$ Overshoot	94V

PARAMETER	MEASURED VALUE
Turn on Energy	3.1298mJ
Turn off Energy	2.7675mJ
$V_{DS}$ Overshoot	188V

# PERFORMANCE DATA

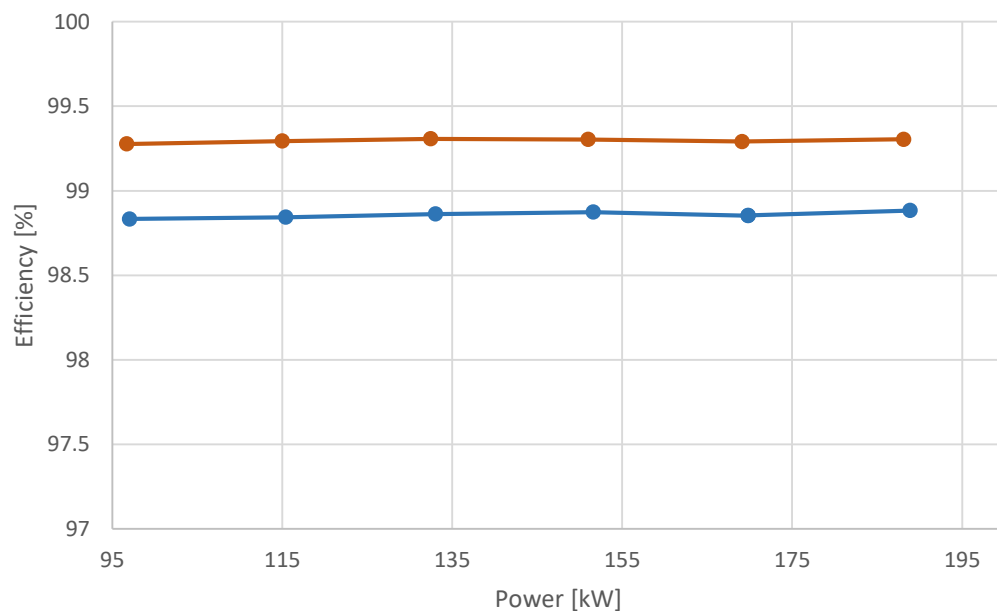




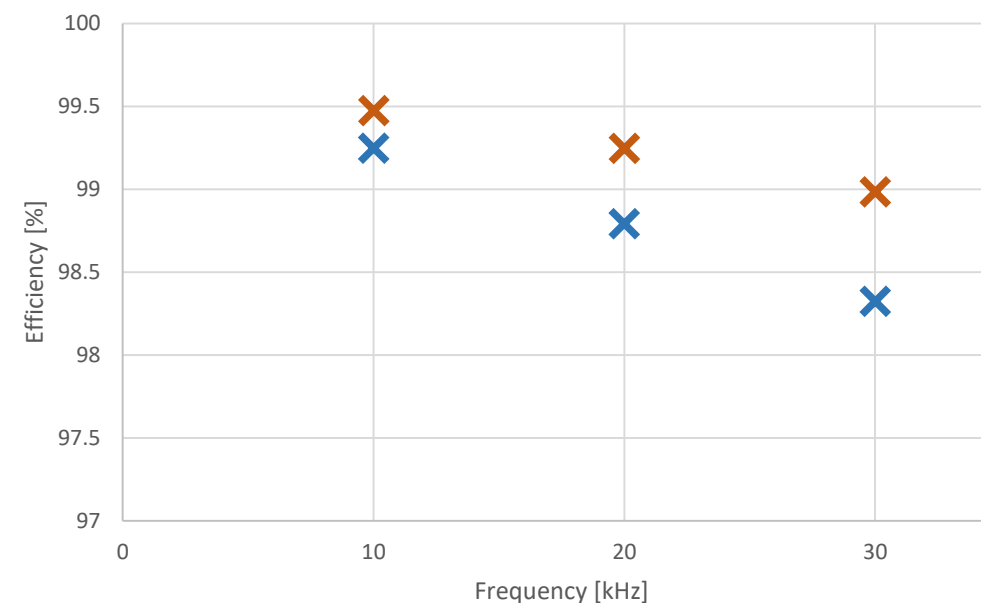
# EFFICIENCY VS SWITCHING FREQUENCIES

Gate drive strength:  
■ strong (20A)  
■ weak (5A)

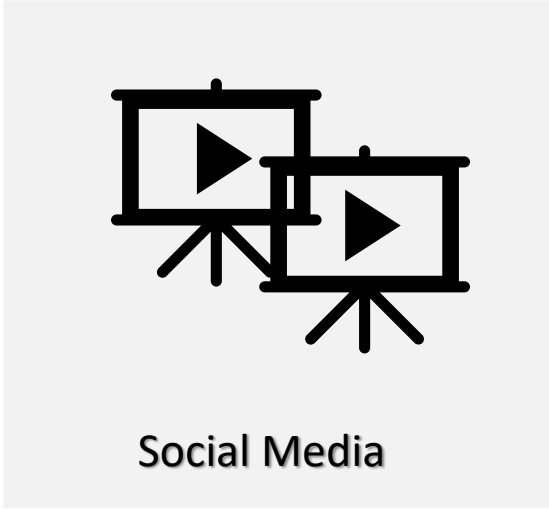
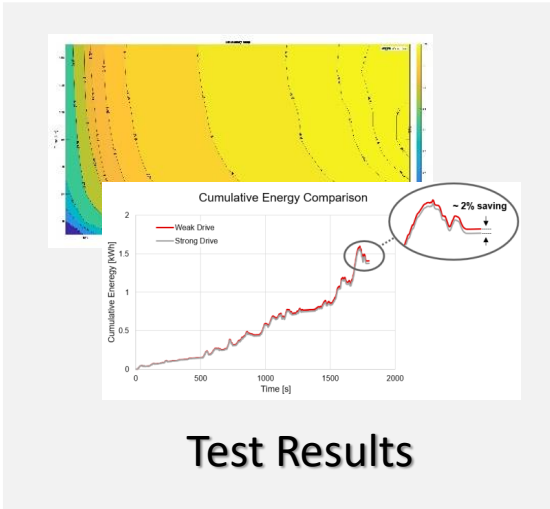
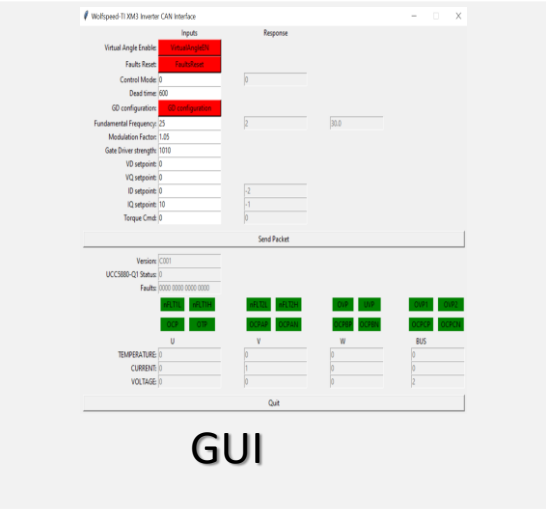
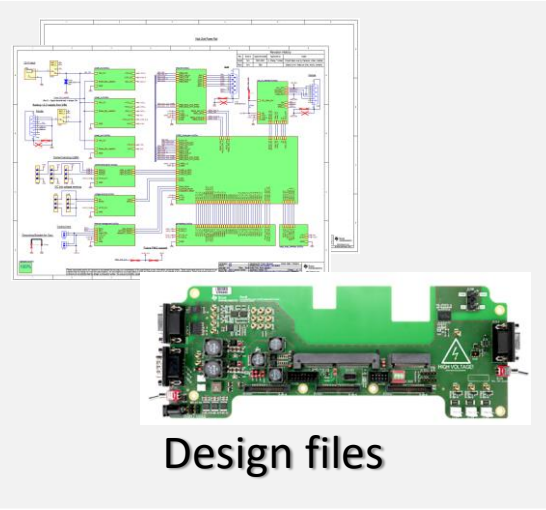
**Speed:** 7500rpm  
**Torque:** from 120 to 240Nm  
**Input power:** from 97 to 208kW  
**Switching frequency:** 20kHz



**Speed:** 7500rpm  
**Torque:** 140Nm  
**Input power:** 110kW



# INDUSTRY-LEADING DESIGN SUPPORT



# SUMMARY

- Highlights key takeaways and system level benefits of the SiC traction inverter reference design including:
- **Systems efficiency improvements** in real time by reducing the  $V_{DS}$  overshoots with an industry-leading performance isolated gate driver with variable gate drive strength feature.
  - Experimental results show > 2% efficiency improvements with a CLTC driving cycle.
- **Size reduction** enabled by
  - Highly-integrated safety driver (UCC5880-Q1) - saves ~21 discrete parts, diagnostics and power module SOH monitoring.
  - Bias with integrated transformer and state of the art isolation technology reduces PCB size, improves CMTI, EMI, and load regulation.
  - XM3 module with half the weight and volume of a standard 62 mm module maximizes power density while minimizing loop inductance and enables simple power bussing.
- **2x increase in speed and motor size reduction** with a faster control loop, low torque ripple, providing smooth speed and torque current profiles.
- **TI's scalable solutions** that enables easy design from platform to platform and between power levels
  - TI's MCU (Arm-based and C2000 high-performance microcontrollers) and broad analog portfolio for specific design needs and specifications.
  - Superior motor control capabilities with increased speed of motor > 20kRPM.

# Thank you for your attention!

