IMPROVE TRACTION INVERTER SYSTEM EFFICIENCY AT LOWER COST

New Product Update

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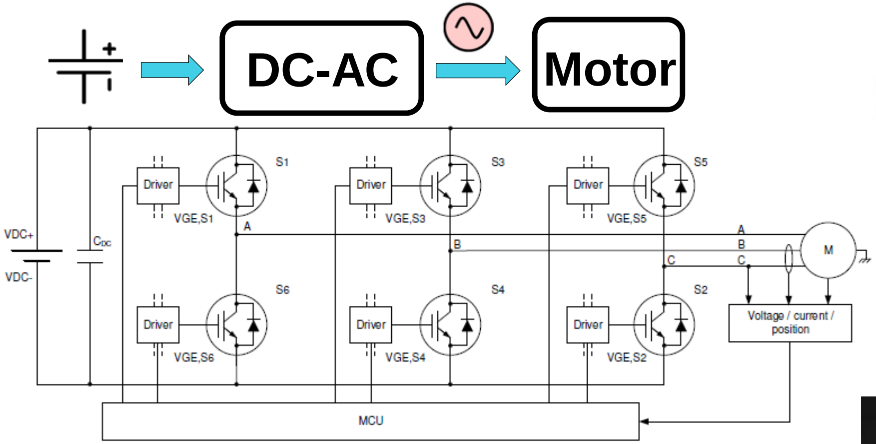
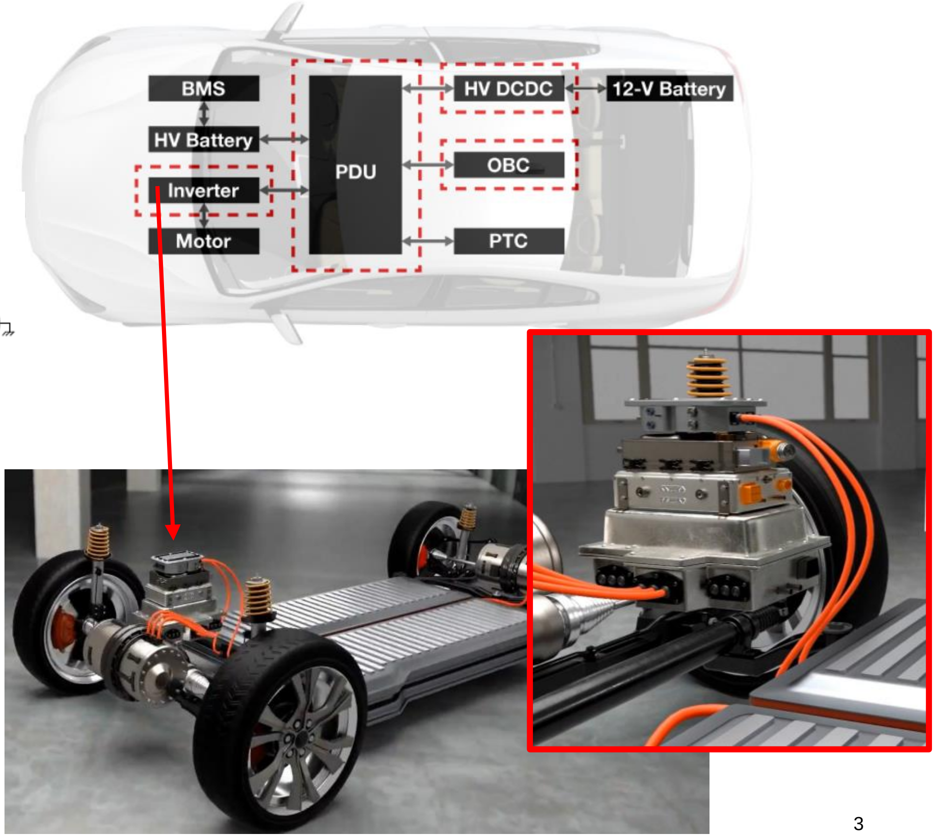
Agenda

- Key traction inverter design considerations
- Isolated gate drivers for EV/HEV traction inverters
- Real-time variable gate drive
  - Traction inverter operating conditions that impact the power switch
  - UCC5880-Q1 value proposition
  - Real-time variable gate drive strength concept and design
  - Experimental test data showing impact of variable drive strength
  - EV benefits
- Design support tools

Introduction of traction inverters in EV/HEV



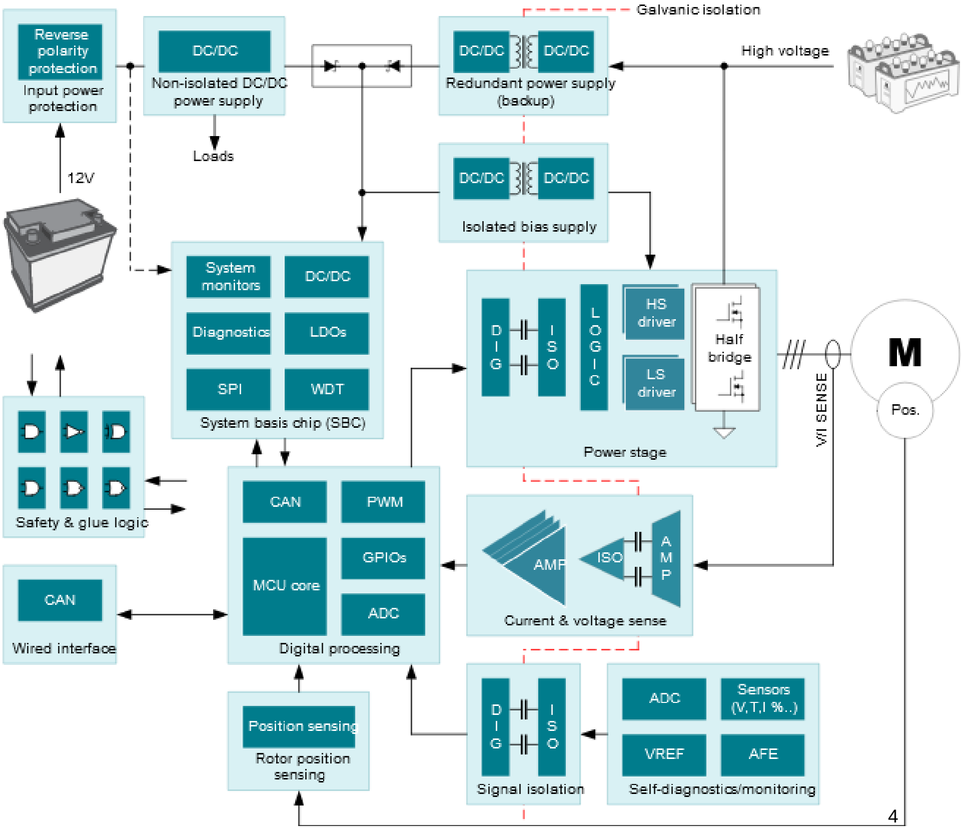
- ➢ Converts DC to AC
- ➢ Controls speed and torque
- ➢ Directly impacts efficiency & reliability



Inverter & motor control: market trends

Technology trends

- **Increased power levels**
  - 100 kW to 500 kW
- **Higher battery voltage**
  - From 400 V to 800 V
- **Higher power density**
  - Up to 50 kW/L
  - System integration
- **Maintaining safety and reliability**



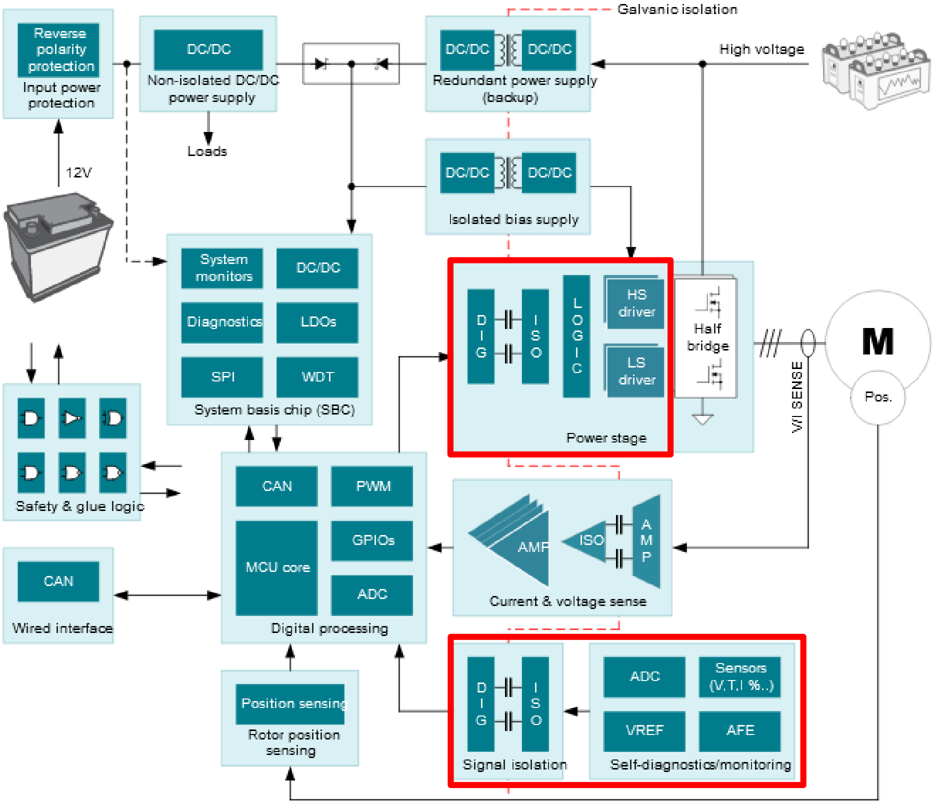
Key traction inverter design considerations

EV goals	Design considerations	Inverter subsystems
• Maximize EV range • Improve EV charging • Make EVs more affordable • Enable safe operation	• Efficiency • Cost • Size • Protection • Reliability	• Controller/MCU • Bias supply • Feedback loop • Bus bars • Gate drive • Power modules (SiC/IGBT)

Increasing integration increases the gate driver impact on the system

<u>Modern gate drivers integrate features such as:</u>

- Isolated ADC sensing
  - Power module temperature sensing
  - DC bus voltage monitoring
- DESAT/Over Current protection
- Bias monitoring (Under voltage and over voltage)
- FET Gate monitoring
- Programable safe state
- Built-in self test
- **Real-time variable gate drive strength**



Major problem & challenges to solve in HEV/EV

Problem: Loading, temperature and battery voltage affect electric vehicle efficiency, EMI, and SiC VDS overshoot impacting battery size, cost, drive range per charge, and reliability.

Design challenge: Implement real-time variable power stage gate drive based on different operating conditions in order to maximize efficiency, while controlling EMI and VDS overshoot

- High Current leads to inductive spikes during transitions
- Low Temperature leads to reduced SOA on VDS
- High Battery Voltage leads to higher voltage spikes as the max spike voltage is directly proportional to the DCLINK voltage

UCC5880-Q1 enables increased efficiency, overshoot control, increased power density and reduced system cost through **real-time variable gate drive strength** and protection and monitoring feature integration

Loading

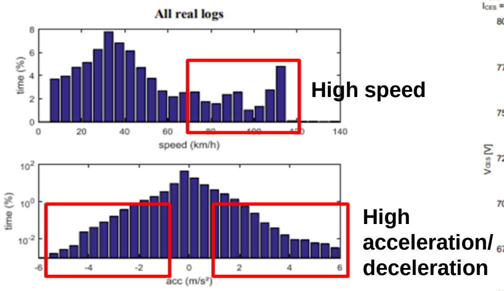
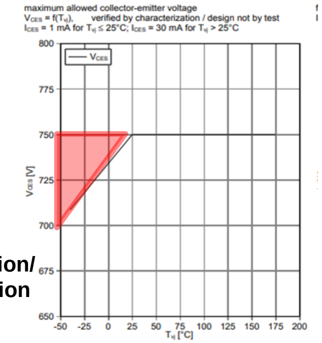
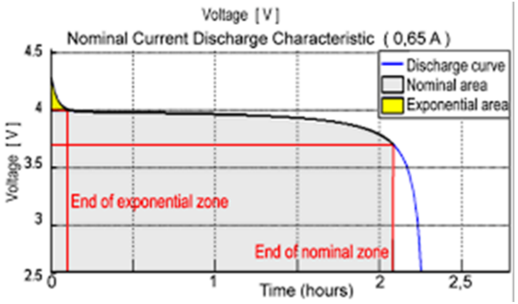


Figure 9. WLTP and real logs speed and acceleration histograms

Temperature



High Voltage



*The **Worldwide harmonized Light vehicles Test Procedure** (**WLTP**)[1] is a global standard for determining the levels of pollutants, CO_2 emissions and fuel consumption of traditional and hybrid cars, as well as the range of fully electric vehicles.

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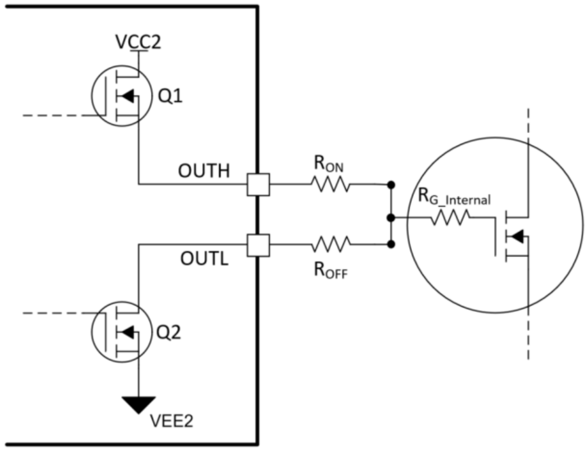
What is variable gate drive strength?

Traditional gate driver output structure

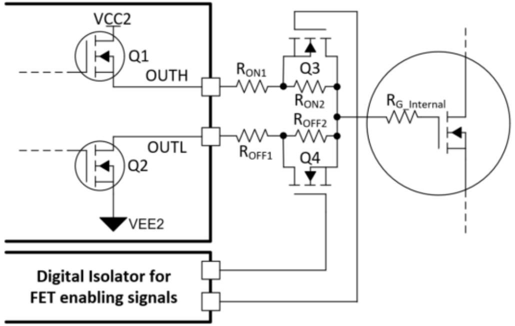


- Single driver power stage, Q1 and Q2
- Drive strength determined by impedance of Q1, Q2, and $R_{G\_Internal}$
- Further determined by R_{ON} and R_{OFF}
- Not real-time variable

Variable gate drive implementation

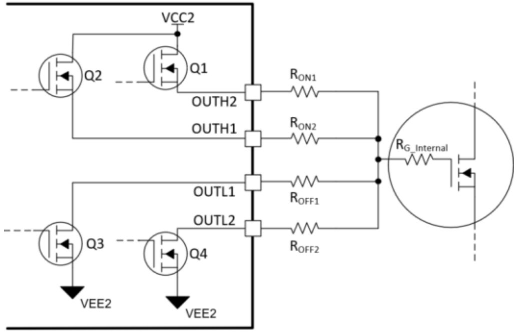
Discrete

- Single power stage
- Adds external components (FETs, digital Isolator, RCs)
- Drive strength adjusted by enabling/disabling Q3 & Q4



Integrated

- **Dual split output power stage**
- Control signals via GPIO or SPI
- **Reduced cost & complexity when compared to discrete**
- Easier control of drive strength over operating conditions



Power switch transient elements

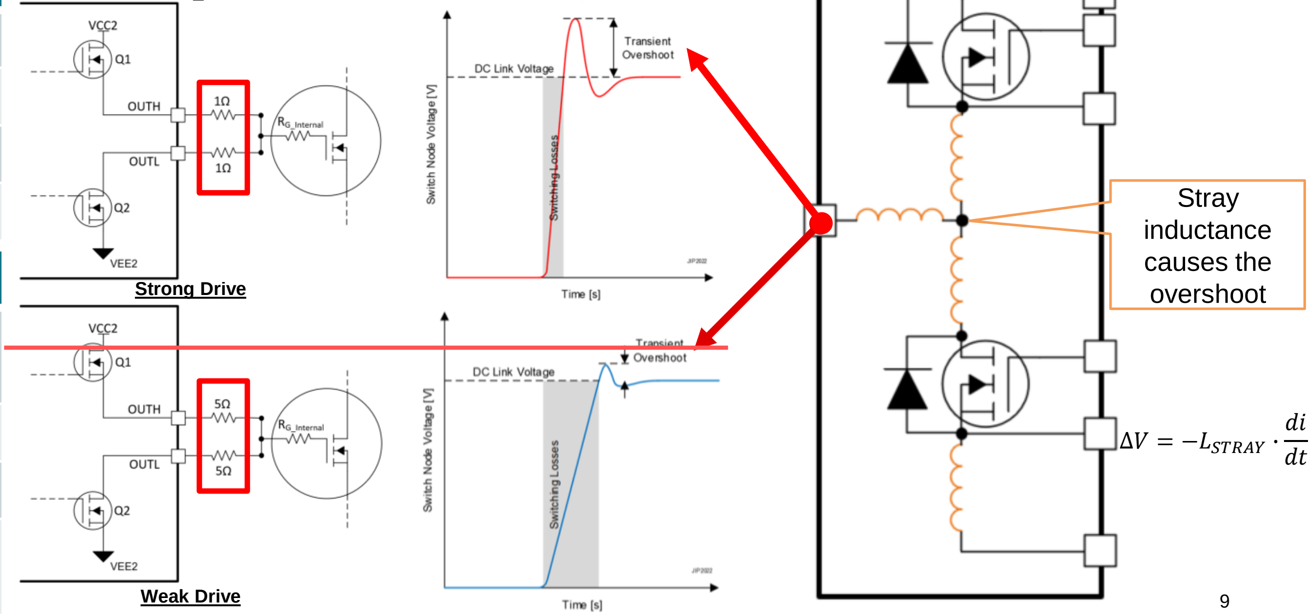
Gate drive strength affects **switching speed (switching losses, VDS/VCE overvoltage)**

- RG sized to prevent VDS overvoltage violation under worst case conditions
  - Not optimal for nominal operating conditions

Test conditions	
Module	CAB450M12XM3
VBUS	800 V
I_{LOAD}	450 A
TJ	25 C (Ambient)

Test results		
Drive strength	Weak drive (5Ω)	Strong drive (1Ω)
E_{ON}(mJ)	40 mJ	16.5 mJ
E_{OFF}(mJ)	39.7 mJ	20.2 mJ
VDS_{PEAK} (V)	1018 V	1157 V

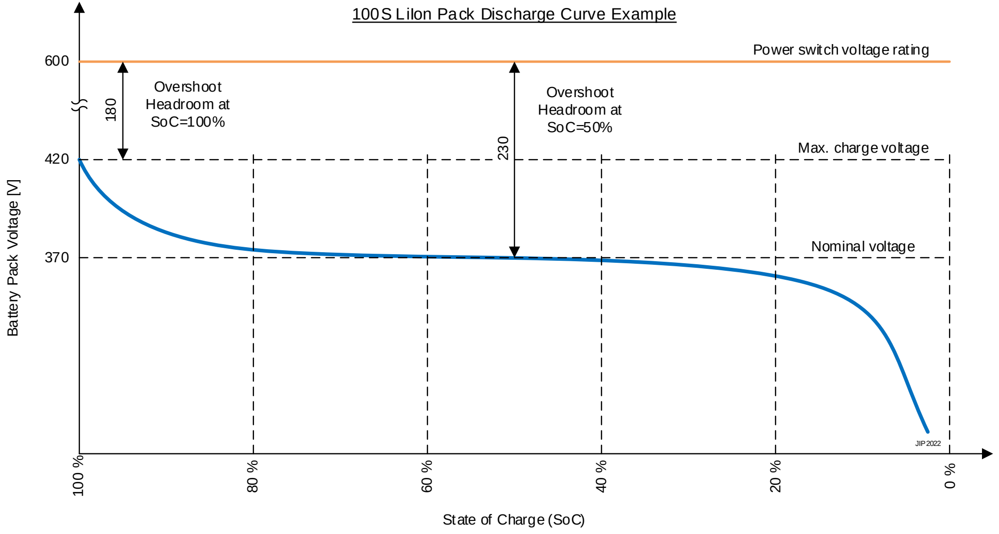
Drive strength **Switch node**



Transient overshoot management and efficiency Optimization

Real-time variable gate drive strength (VGDS) enables optimization of transient overshoot and efficiency

- Fully charged battery pack (SoC from 100% to ~80%) requires ***weak gate drive*** strength to maintain the overshoot within the headroom
- Slightly discharged battery (SoC from 80% to 20%) allows for ***strong gate drive***
- Variable gate drive strength increases system efficiency for approx. ¾ of the charging cycle



UCC5880-Q1 isolated gate driver + UCC14240-Q1 isolated bias for traction inverters

Industry-leading high integration & advanced isolated SiC/IGBT driver + industry's smallest, lightest isolated bias

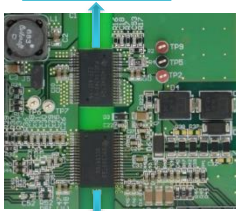
UCC5880-Q1: Isolated driver

- ✓ ± 20A split output drive, dual output
- ✓ Real-time variable drive current
- ✓ 75 ns programmable short-circuit protection
- ✓ >100 V/ns CMTI
- ✓ ISO26262-compliant (ASIL-D)
- ✓ SPI-programmable
- ✓ Reinforced Isolation

UCC14240-Q1: Isolated bias

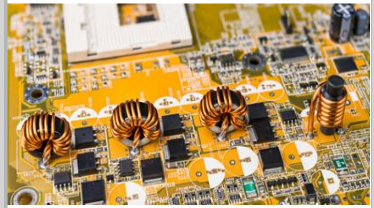
- ✓ 1.5 W - 2 W isolated Bias
- ✓ 3.55 mm height SOIC package
- ✓ ± 1% output accuracy (SiC)
- ✓ Reinforced isolation
- ✓ Over-power/temperature protection
- ✓ Fault communication
- ✓ ISO26262-capable (FS support)
- ✓ >150 V/ns CMTI
- ✓ Vibration & noise immunity

UCC14240-Q1
3.55 mm height
96 mm² area

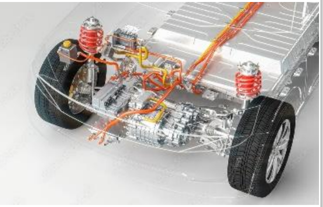


UCC5880-Q1
2.65mm height
77mm² area

Inverter board implications



Inverter system implications



EV / HEV benefits

	Inverter board implications	Inverter system implications	EV / HEV benefits
>2X smaller PCB area, 4mm height Eliminates 30+ discrete components	Highest density, lower cost	Smaller Lighter Lower cost Integrated powertrain	+20 km Longer Range per charge ~$300 battery cost saving
±20A split output (no booster stage) + dual output + real-time variable	Optimized efficiency & overshoot		
No bulky external transformers	Lower weight, vibration immune		
75ns short-circuit protection, ±1% output voltage regulation	SiC protection		
Vgth power switch monitoring	Failure prediction	More reliable Safety standards	Passenger safety
2-channel ADC + SPI + diagnostics	ISO26262 certification		

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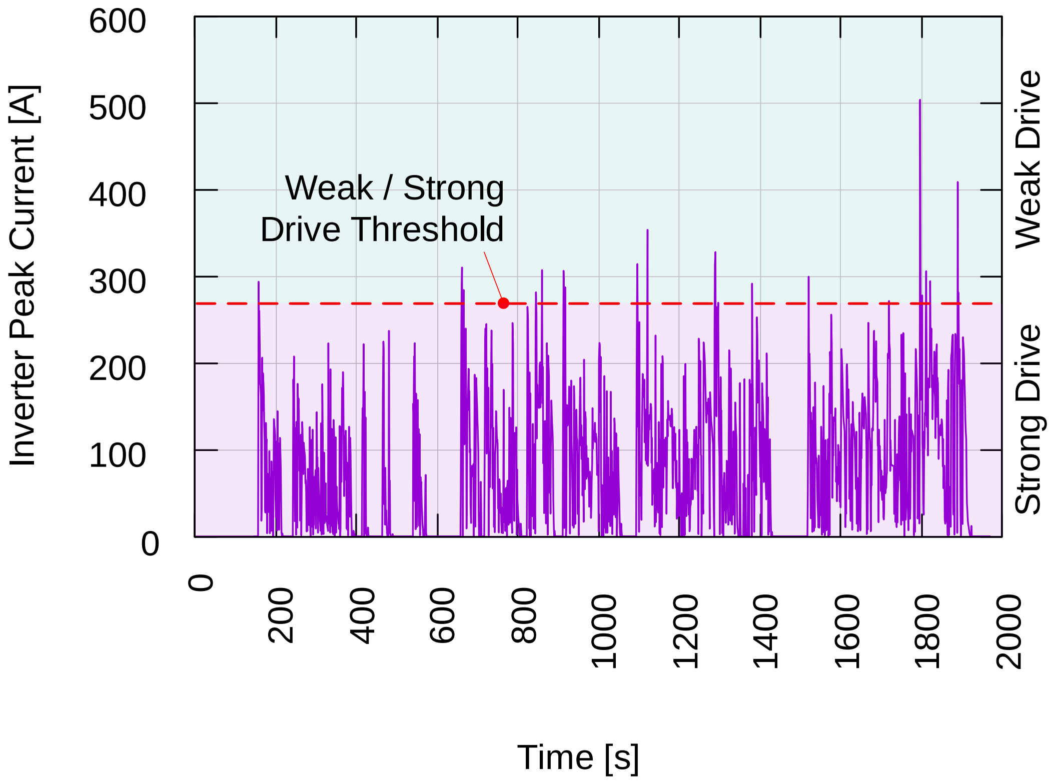
Designing for real conditions



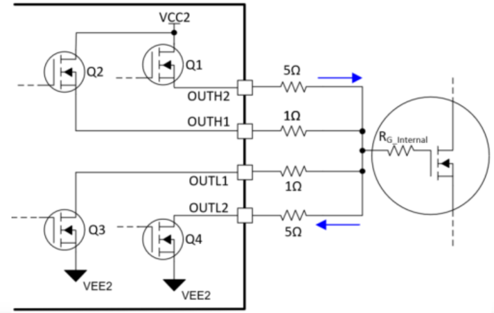
Hardware has to support the highest current peak

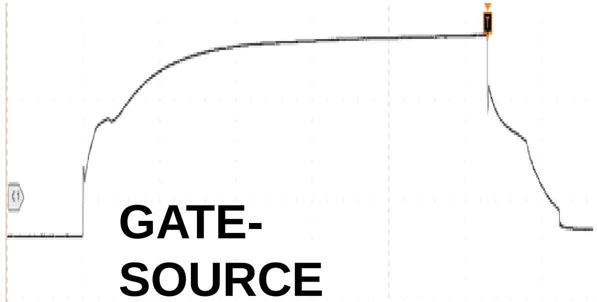
The inverter stays in the strong drive region most of the driving cycle

Gate drive strength selection | Weak vs strong

Weak gate drive strength criteria

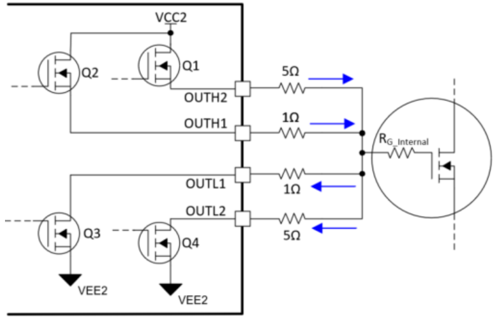
- High load current (di/dt)
- >80% peak battery voltage at max charge
- Cold temperature

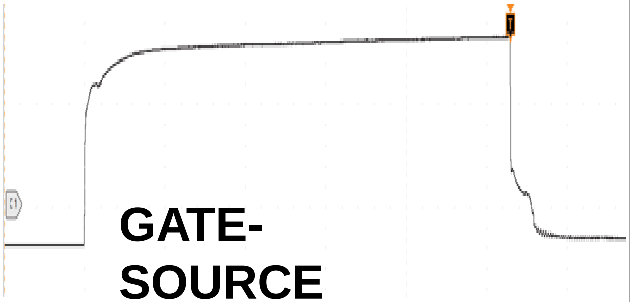




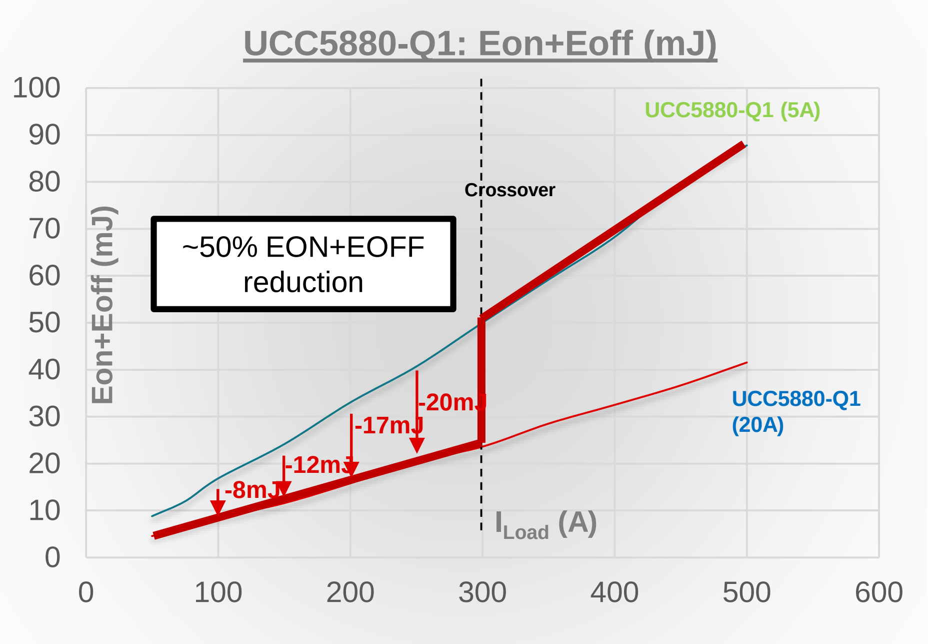
Strong gate drive strength criteria

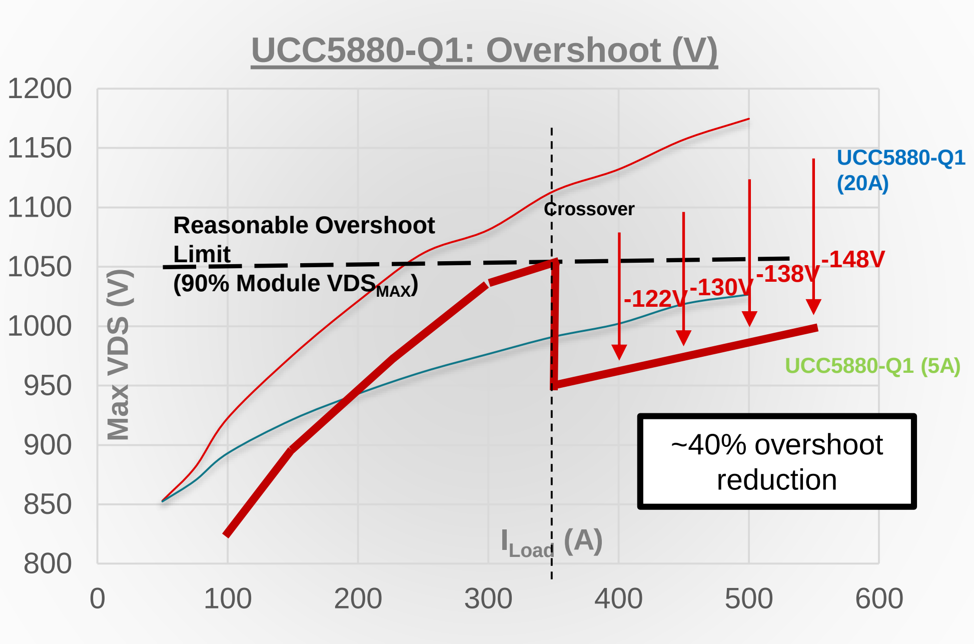
- Low load current
- <80% peak battery voltage at max charge
- Ambient & Hot temperature





Variable drive strength performance



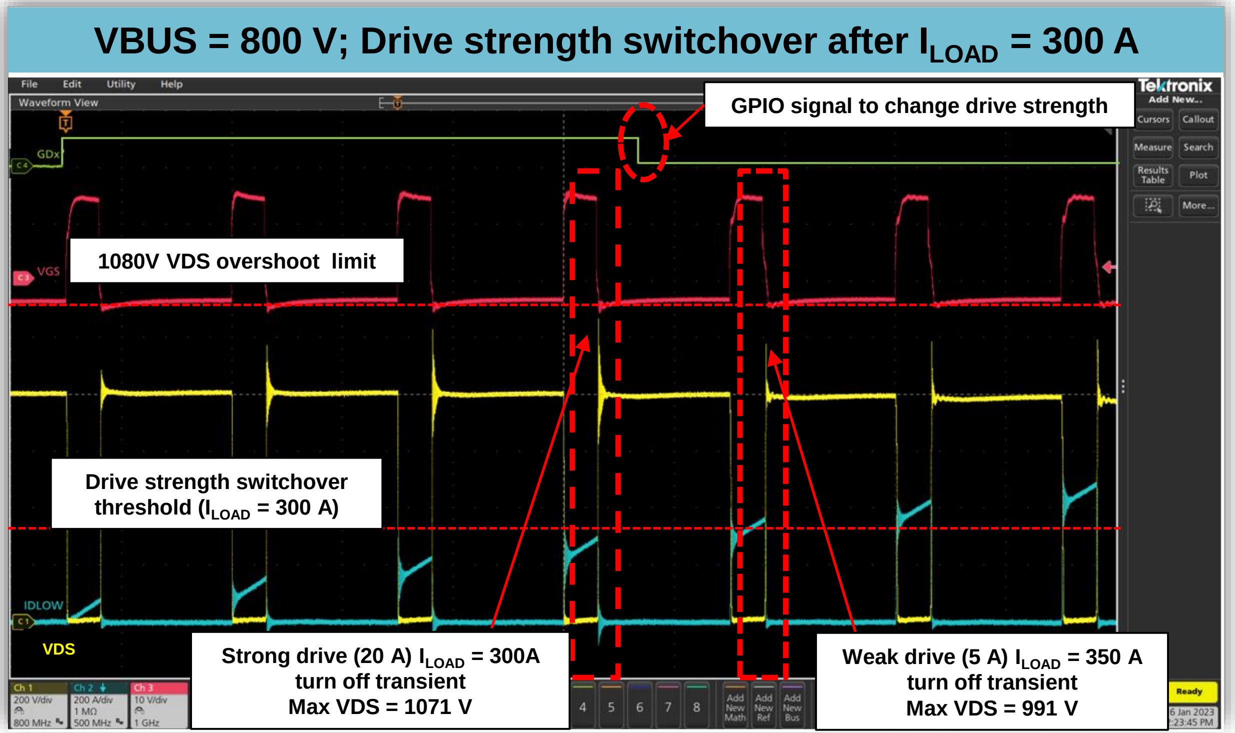


Conclusion

- Traditional output structure must be optimized for worst case overshoot which impacts nominal switching losses.
- Real-time variable drive strength implementation allows optimization of switching losses across full load current range.

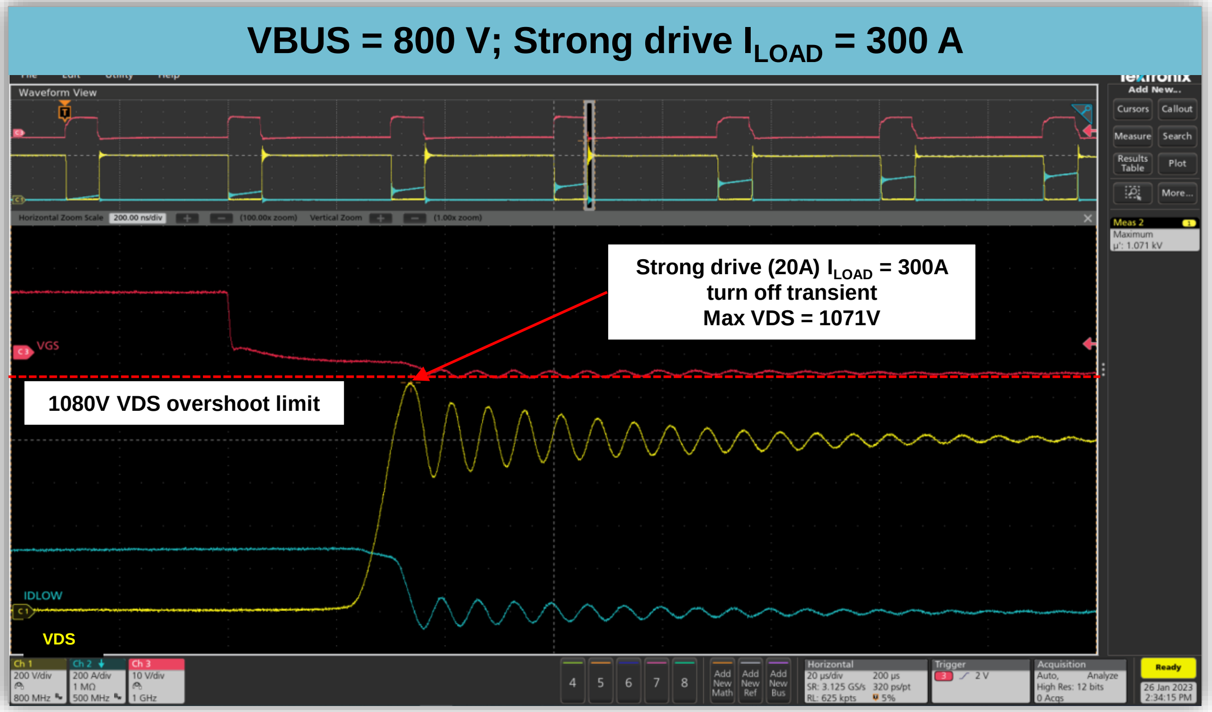
Variable drive strength change reduces VDS overshoot

- Drive strength determined by operating conditions
- Need MCU or hardware logic intervention (SPI or GPIO)
- Changes drive strength **in real time** from one cycle to the next
    - Not intended to shape switching waveform



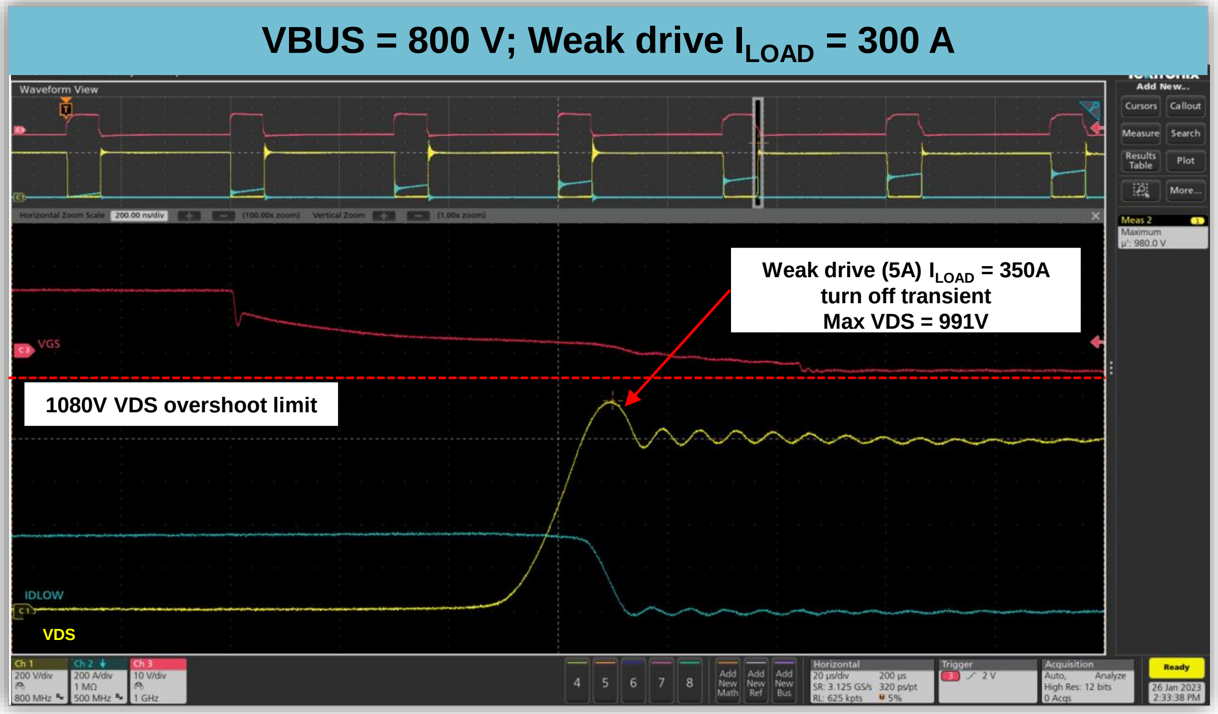
Variable drive strength: Strong drive at 300 A

- Drive strength determined by operating conditions.
- Need MCU or hardware logic intervention (SPI or GPIO).
- Changes drive strength **in real time** from one cycle to the next:
  - Not intended to shape switching waveform



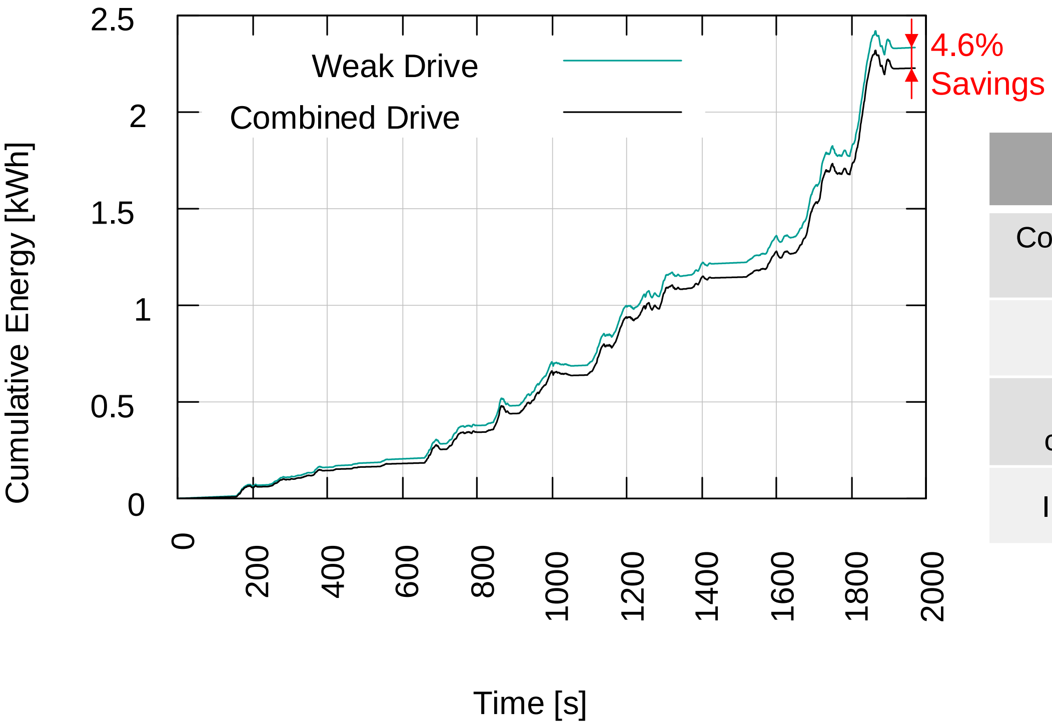
Variable drive strength: Weak Drive at 300A

- Drive strength determined by operating conditions.
- Need MCU or hardware logic intervention (SPI or GPIO).
- Changes drive strength **in real time** from one cycle to the next:
  - Not intended to shape switching waveform



Vehicle Efficiency Improvements

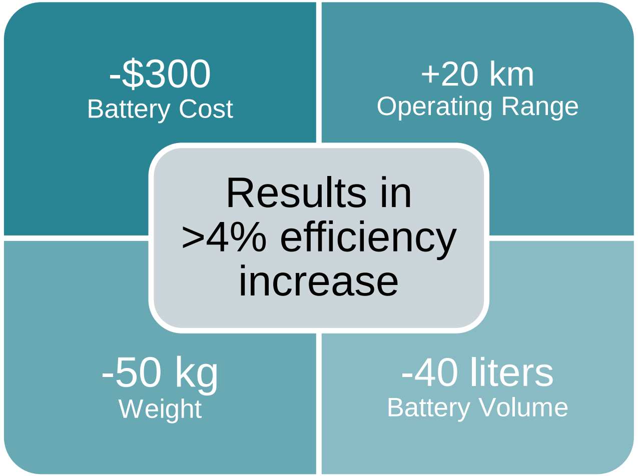
CLTC Driving Cycle with and without the Real-Time Gate Driver Strength Feature (Test Data for a Compact Vehicle)



Parameter	Weak drive	Combined drive	Unit
Consumption per CLTP cycle	2.330	2.224	kWh
Distance	14.94	14.94	km
Average consumption	156	148	W/km
Improvement	-	> 4	%

Vehicle benefits from real-time variable gate drive

- The real-time variable gate driver strength feature significantly improves the light load efficiency
- Typical passenger vehicle operates in light-load conditions most of time



(Assumed 76 kWh usable battery, 470 km range, 162 Wh/km efficiency)

Getting started

You can start evaluating this device leveraging the following:

Resource type	Title	Link to content or more details
Product folder	UCC5880-Q1	https://www.ti.com/product/UCC5880-Q1
Reference design	800V/300kW traction inverter reference design	https://www.ti.com/tool/TIDM-02014
Customer training series or webinar session	Protecting power devices in EV applications	https://www.ti.com/video/6245177995001?context=1134585-1148168-1148181
Technical blog content or white paper	How to maximize SiC traction inverter efficiency with real-time variable gate drive strength	https://e2e.ti.com/blogs_/b/behind_the_wheel/posts/how-to-maximize-sic-traction-inverter-efficiency-with-real-time-variable-gate-drive-strength
Selection and design tools and models	FuSa documents, full datasheet, Simmetrix model, power dissipation calculator	https://www.ti.com/product/UCC5880-Q1
Development tool or evaluation kit	UCC5880-Q1 half-bridge evaluation module for 20-A, isolated, adjustable IGBT/SiC MOSFET gate driver	https://www.ti.com/tool/UCC5880QEVM-057

Visit www.ti.com/npu

For more information on the New Product Update series, calendar and archived recordings

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