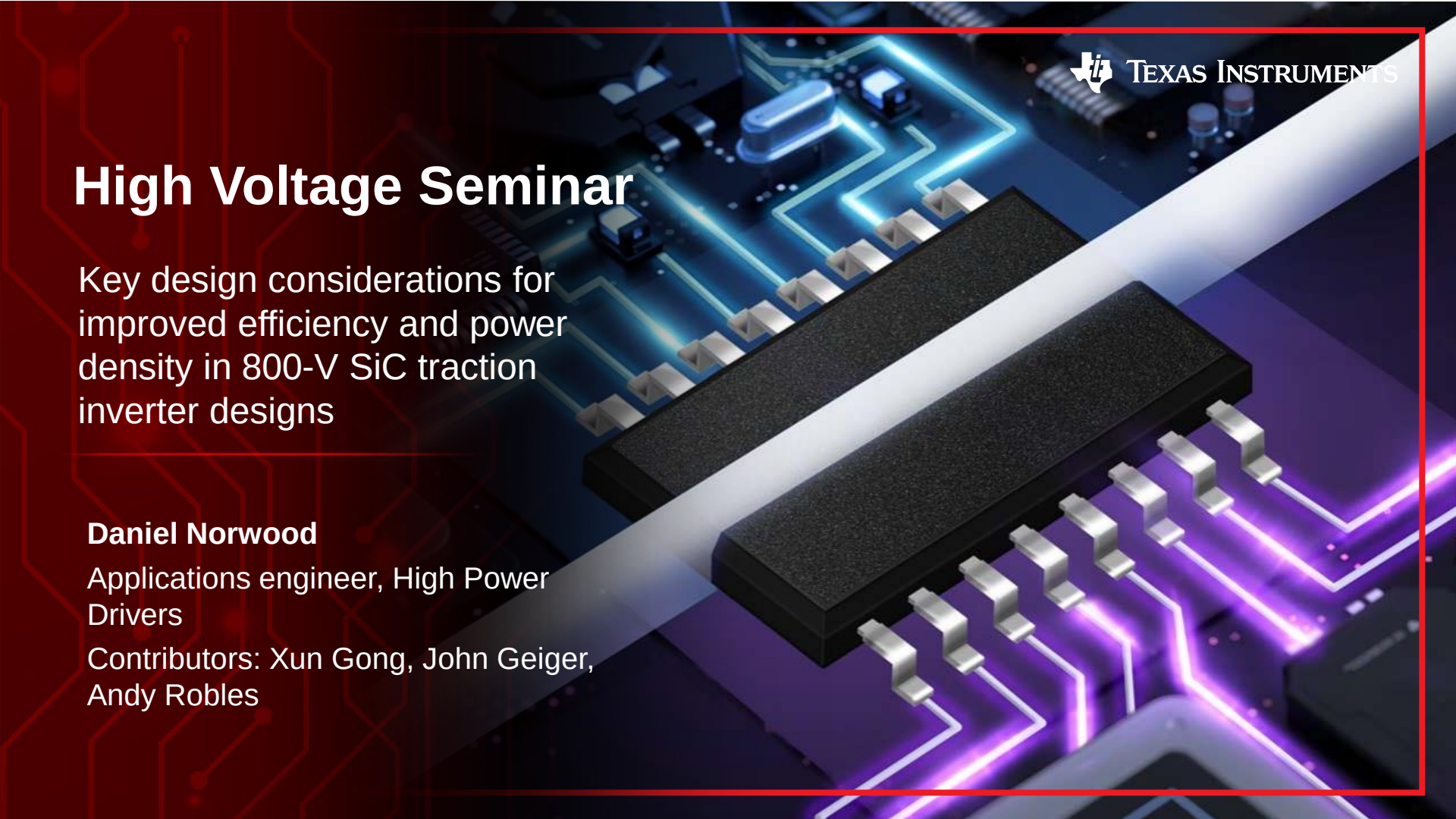


High Voltage Seminar

Key design considerations for improved efficiency and power density in 800-V SiC traction inverter designs

Daniel Norwood

Applications engineer, High Power Drivers

Contributors: Xun Gong, John Geiger, Andy Robles

Agenda

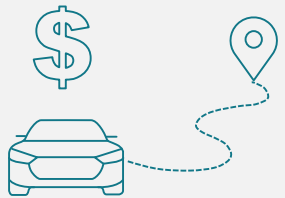
- Traction inverter functionality and trends in EV/HEV
  - Key traction inverter design considerations
- Isolated gate drivers for EV/HEV traction inverters
  - Protection
  - Monitoring
  - Efficiency
- Adjustable gate drive
  - Traction inverter operating conditions that impact the power switch
  - Adjustable gate drive strength concept and design
  - Experimental test data showing impact of adjustable drive strength

Cost and driving range are still hurdles for EV adoption

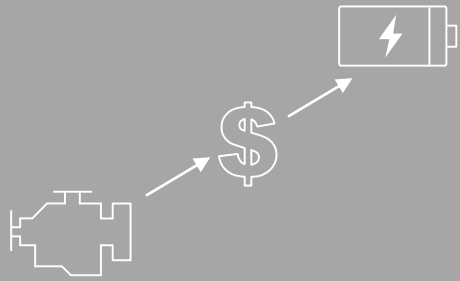
The number of consumers who would consider purchasing an EV varies.

U.S.	Europe	China
Up to **30%**	Up to **60%**	**70%**

EV purchase price and driving range are the biggest hurdles to wider consumer adoption.



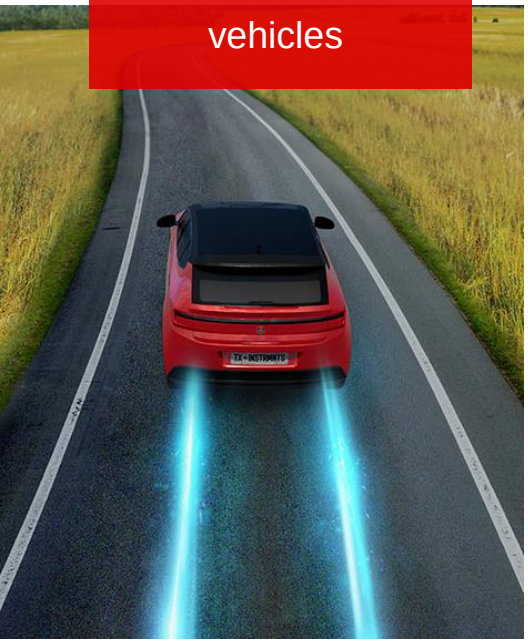
There's a cost gap of about $12,000 between internal combustion-engine vehicles and electric vehicles today.



Source: McKinsey: Making electric vehicles profitable, 2019

Driving vehicle electrification forward

Hybrid and electric vehicles



Our continuous innovation, technology and expertise helps maximize driving range, make EVs more affordable and enable faster charging and safer operation.

Maximize drive range

Maximize drive time with accurate reporting of state of charge and state of health of the battery.

Improve EV charging

Design smaller more efficient systems enabled by high-performance topologies, advanced features and architectures.

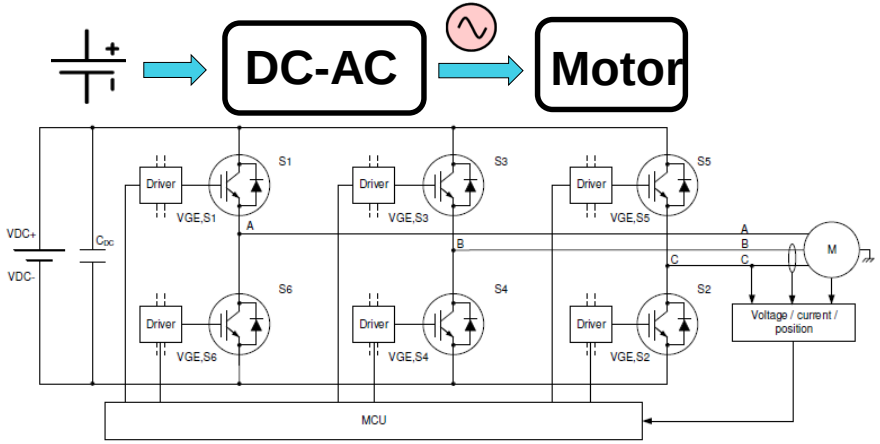
Make EVs more affordable

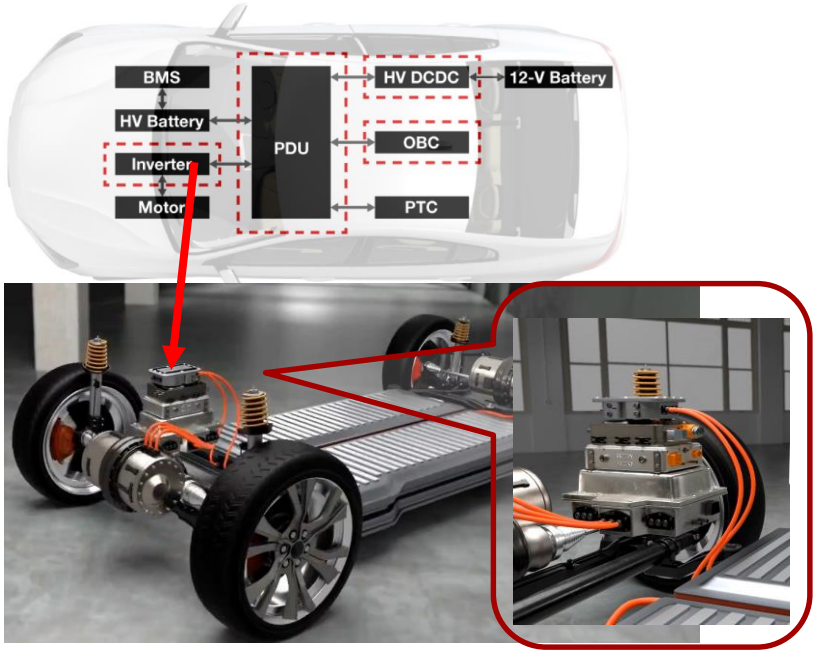
Variety of pin-to-pin compatible, automotive-qualified devices to support different cell chemistries and vehicle architectures.

Enable safe operation

Improve reliability and performance of powertrain systems with optimized thermal management and enhanced electrical safety.

Introduction of traction inverter in EV/HEV



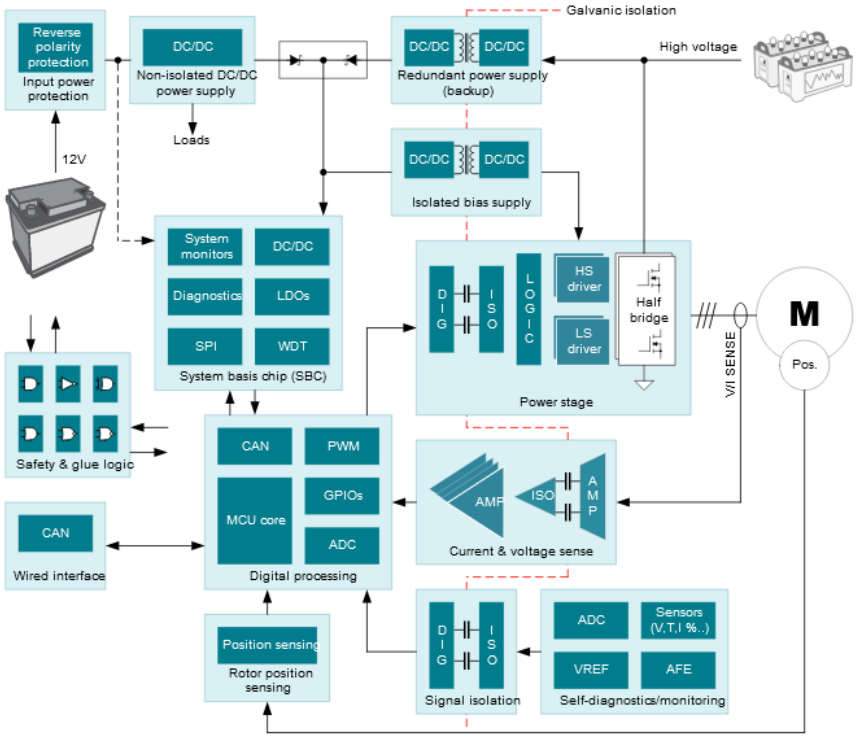


- Converts DC to AC
- Controls speed and torque
- Directly impacts efficiency & reliability

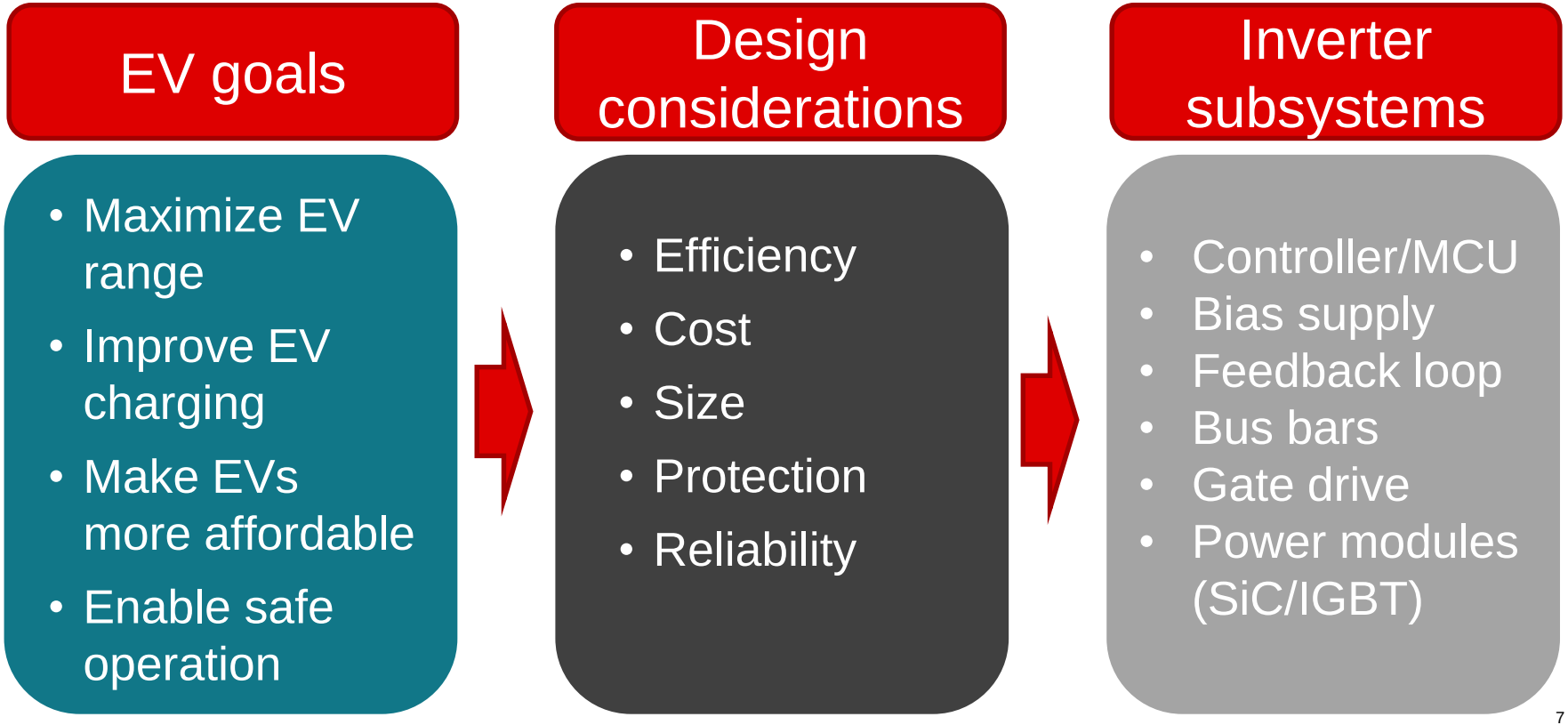
Inverter & motor control: market trends

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**



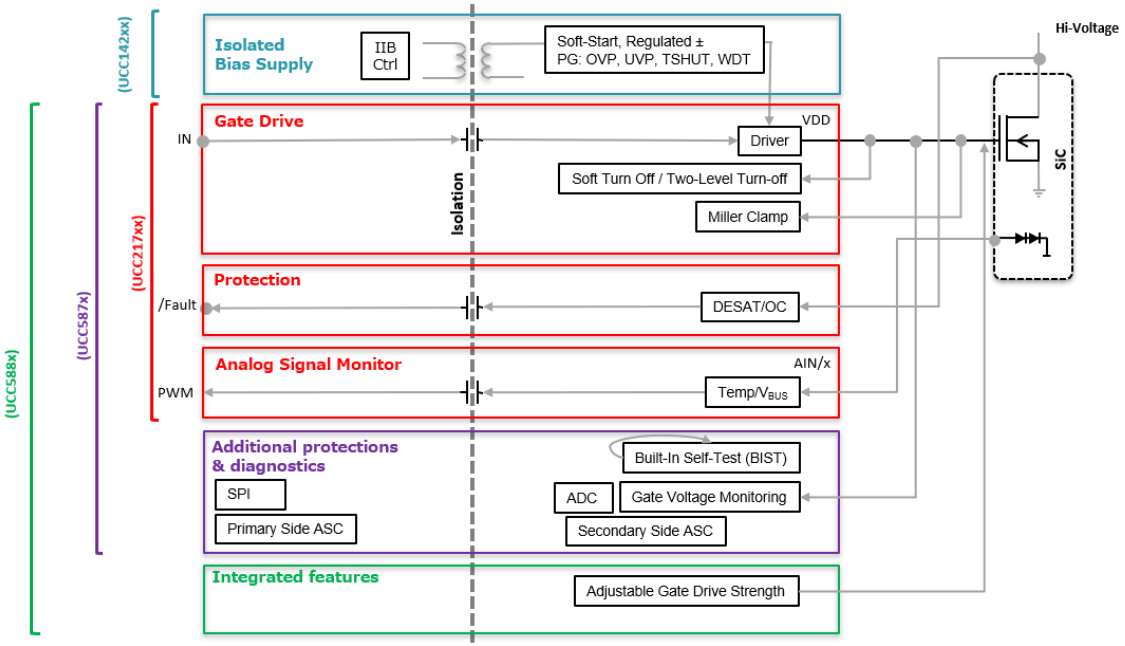
Key traction inverter design considerations



Increasing integration increases the gate driver impact on the system

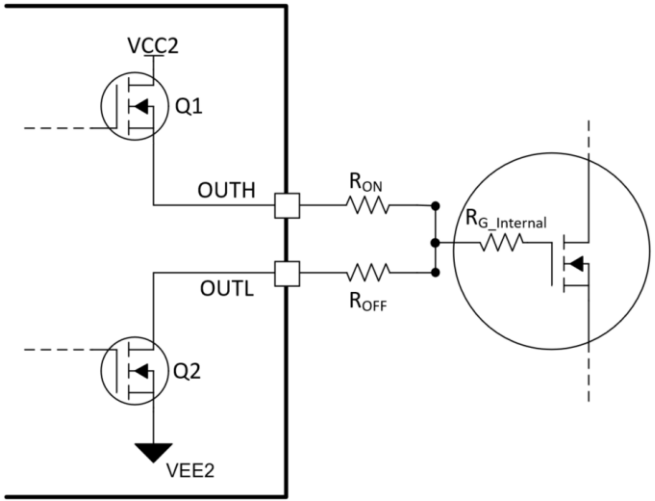
Modern gate drivers integrate features such as:

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



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 adjustable in real time

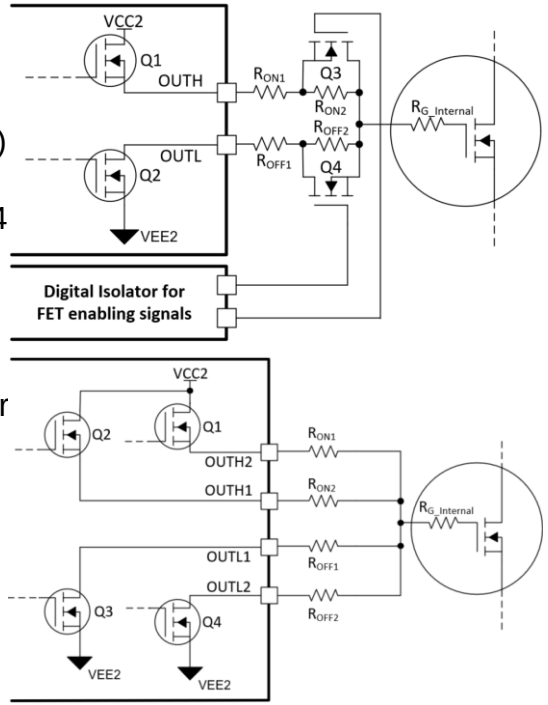
Variable gate drive implementation

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



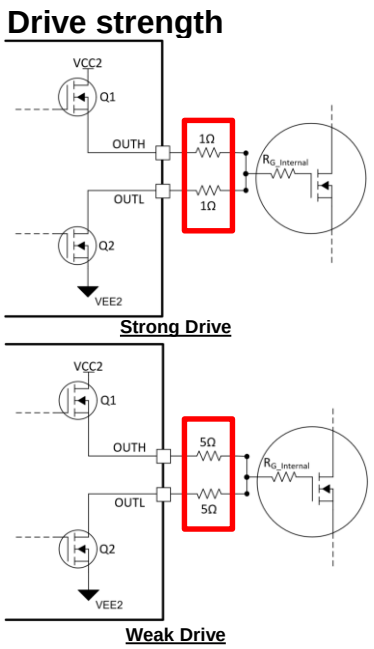
Power switch transient elements

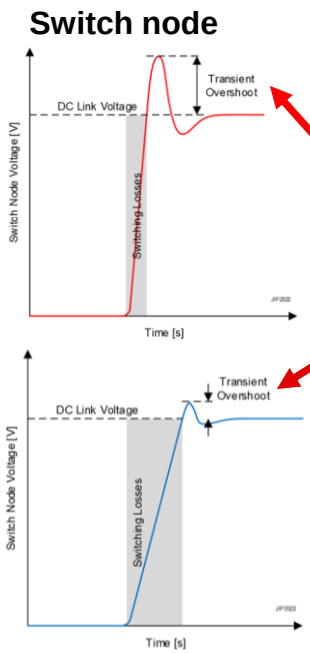
Gate drive strength affects **switching speed (switching losses, VDS/VCE overvoltage)**

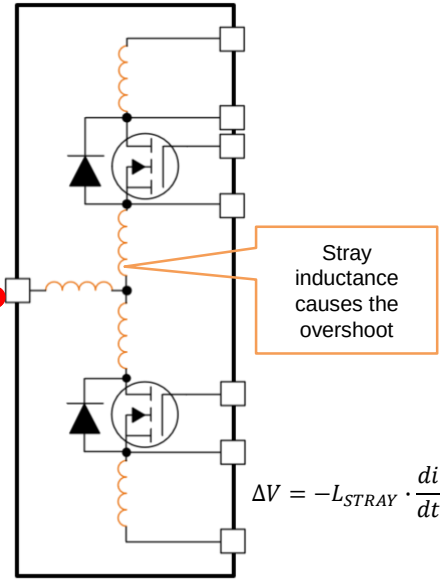
- RG sized to prevent VDS overvoltage violation under worst case conditions
  - Not optimal for nominal operating conditions

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

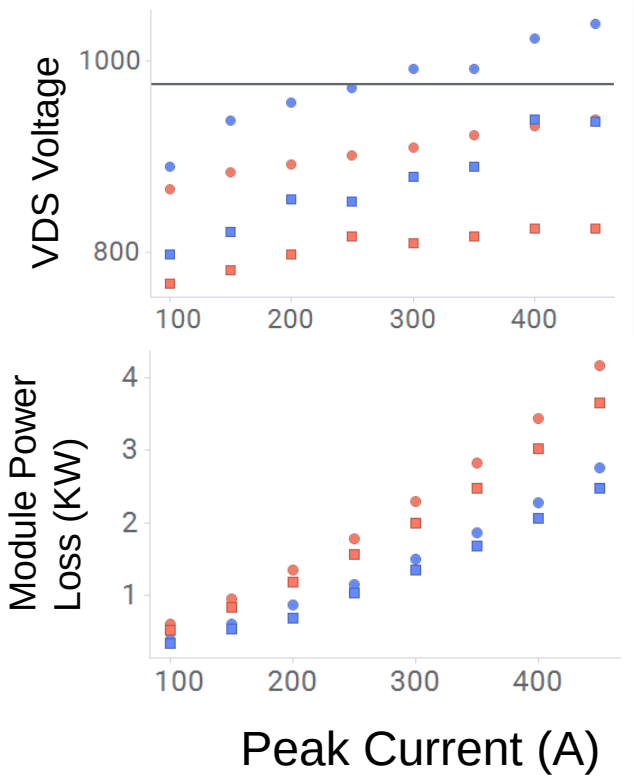




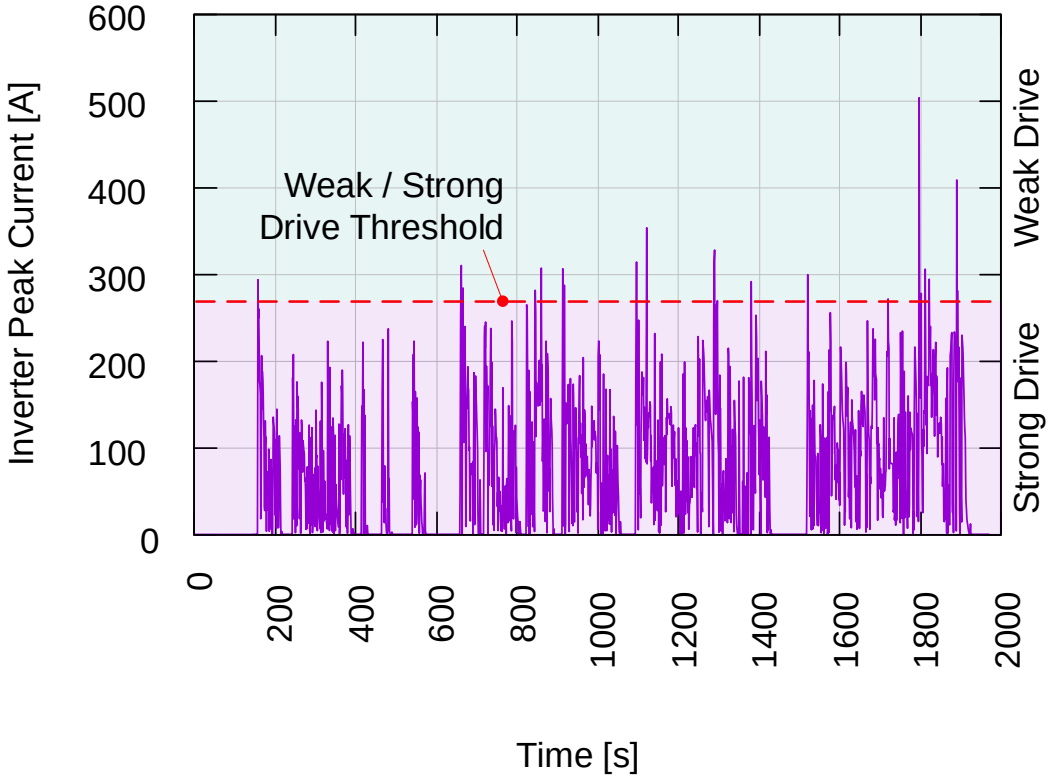


Traction inverter operating conditions

- Load current:
  - Switching losses and voltage overshoot increase as load current increases.
- Battery voltage:
  - Fully charged battery = lower overshoot headroom.
  - More overshoot headroom for majority of battery charge.
- Temperature:
  - Low temperature leads to reduced Safe Operating Area on VDS/VCE.



Designing for real conditions



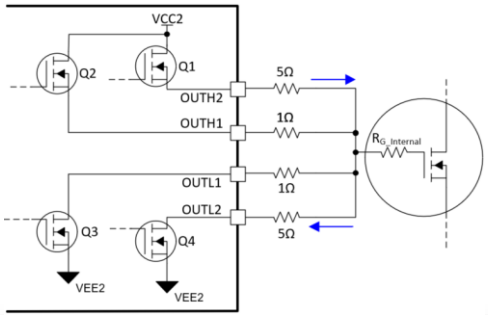
Hardware has to support the highest current peak

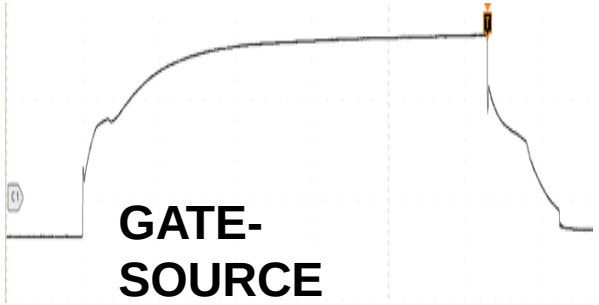
The inverter stays in the strong drive region most of the driving cycle

Gate drive strength selection | Weak vs strong

Weak gate drive strength criteria

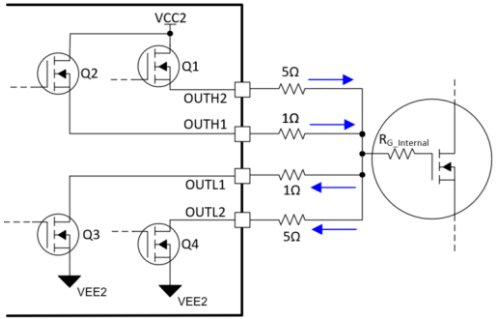
- High load current (di/dt)
- >80% peak battery voltage at max charge
- Cold temperature

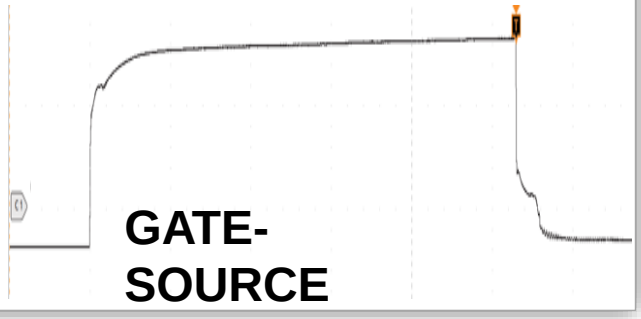




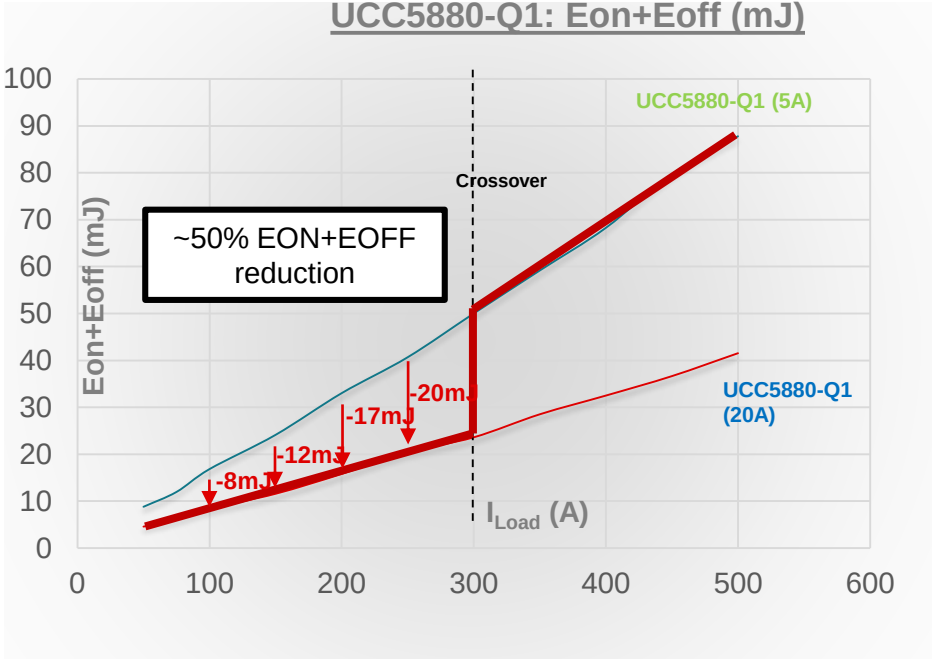
Strong gate drive strength criteria

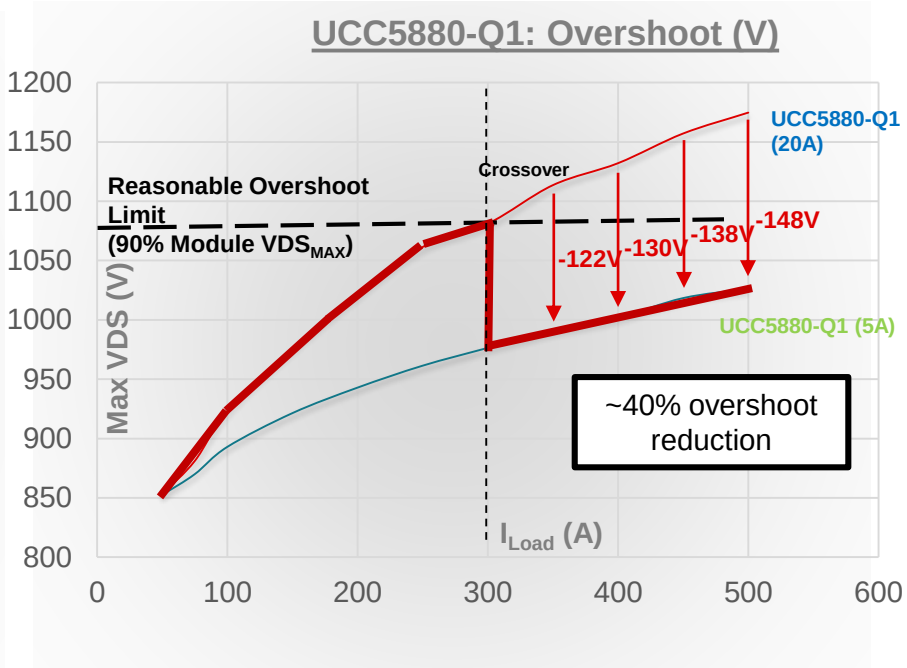
- Low load current
- <80% peak battery voltage at max charge
- Ambient & Hot temperature





Variable drive strength performance



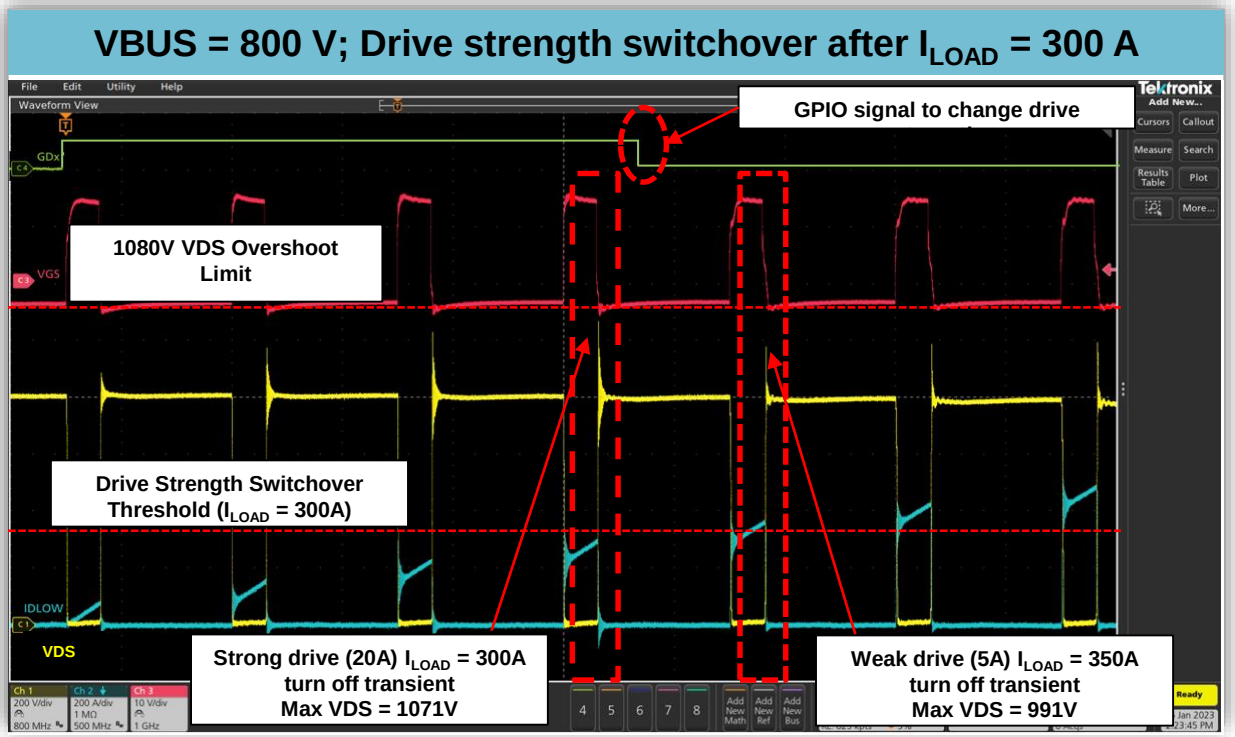


Conclusion:

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

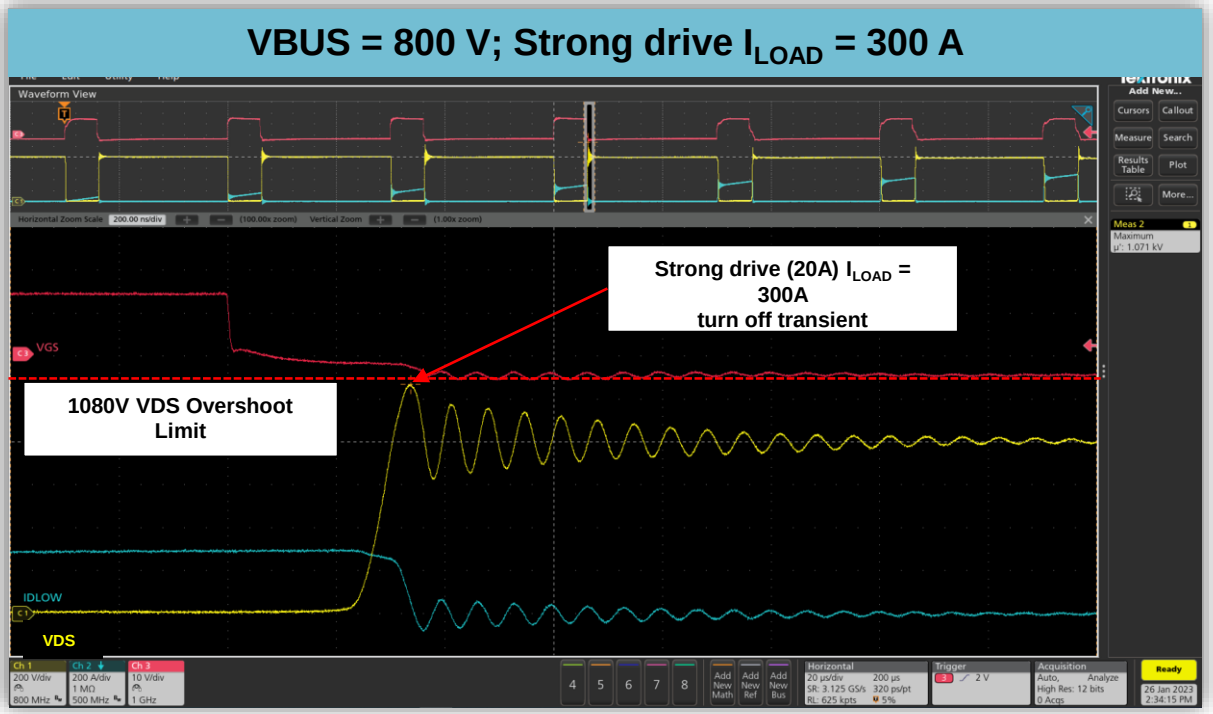
Variable drive strength change reduces VDS overshoot

- Drive strength determined by operating conditions
- Need MCU or hardware logic intervention (SPI or GPIO)
- Changes drive strength **<u>in real time</u>** from one cycle to the next



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



Variable drive strength | Weak drive at 300 A

- Drive strength determined by operating conditions.
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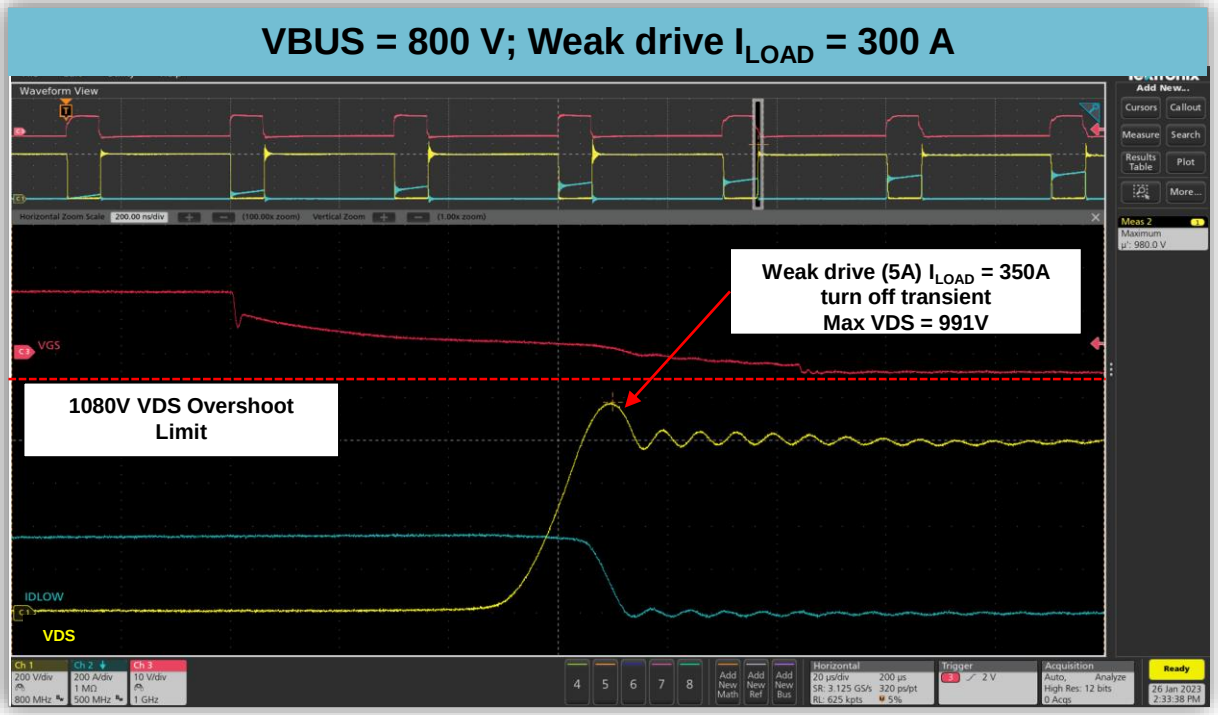
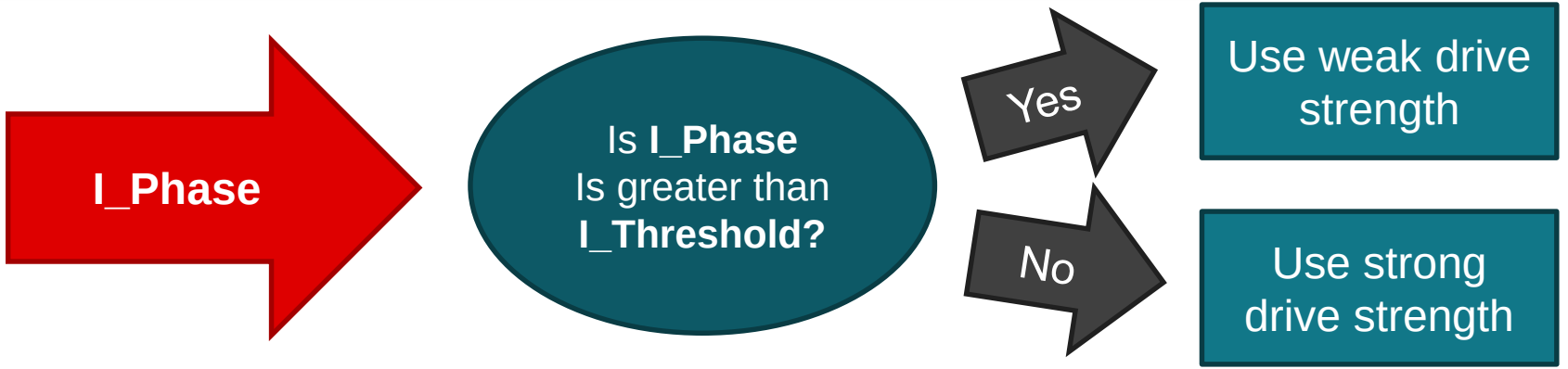


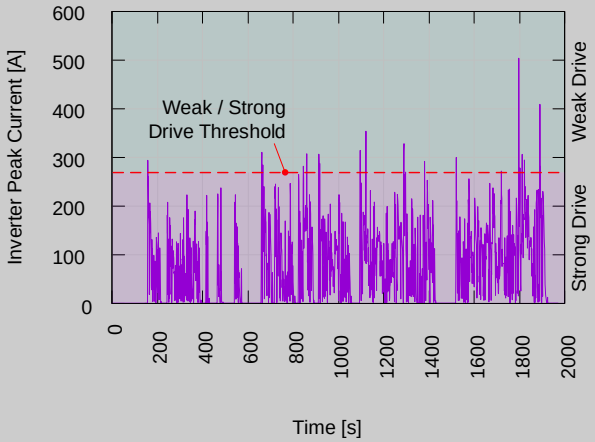
Basic adjustable gate drive control logic

Control parameters

- **I_Phase**: Real time phase current (measured)
- **I_Threshold** : Experimentally determined phase current threshold based on hardware
- **Weak drive strength**: Determined by value of gate resistors on weak drive outputs
- **Strong drive strength**: Determined by value of gate resistors on strong drive outputs

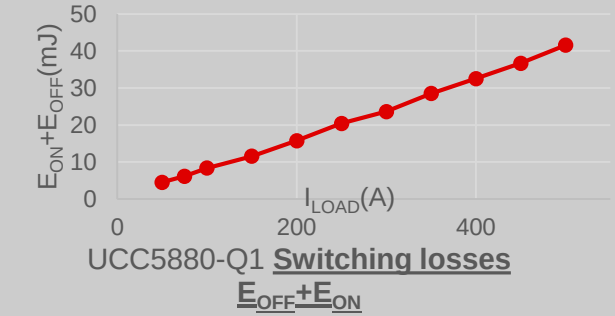


Selecting I_Threshold

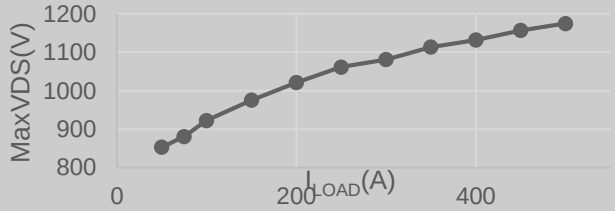


Example phase current across the drive cycle

- Balance switching losses and overshoot
- A lookup table for I_Threshold can be used to account for system conditions such as battery voltage and temperature



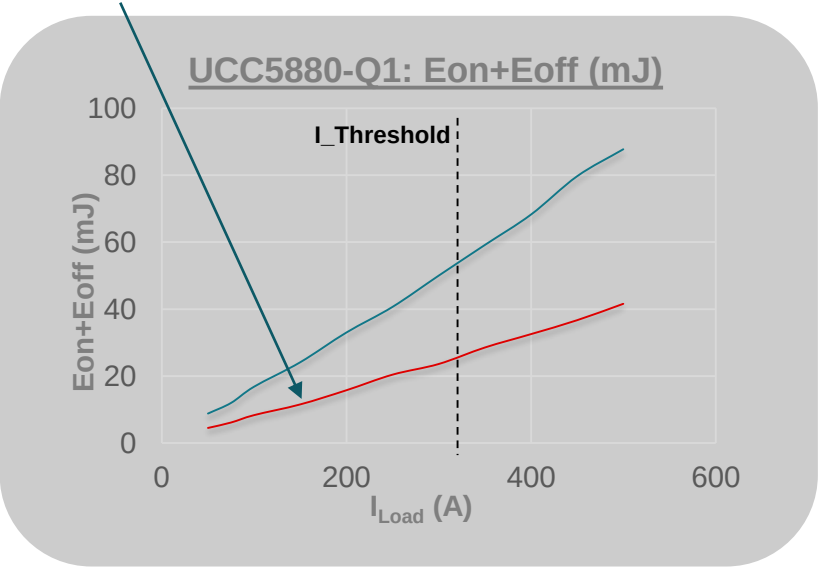
UCC5880-Q1 **Switching losses** $E_{OFF}+E_{ON}$

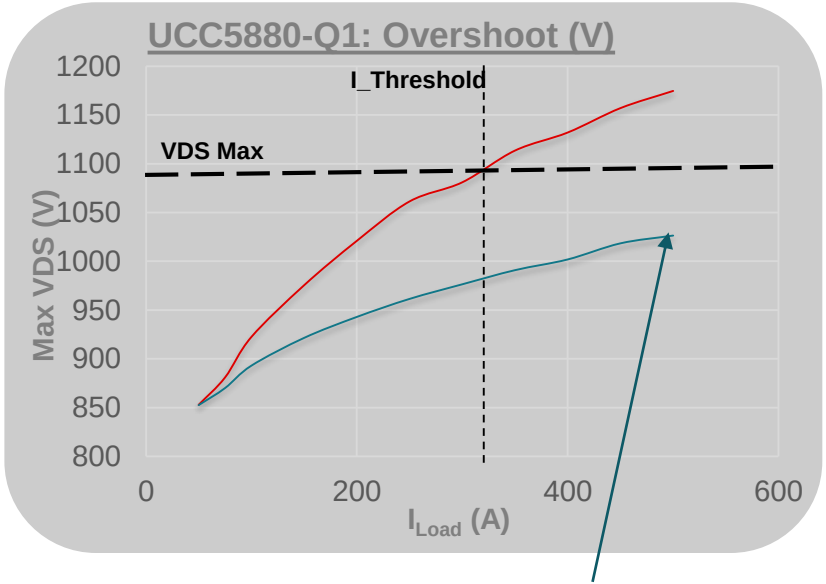


UCC5880-Q1 **Overshoot**

Selecting strong and weak drive strength

Strong drive strength should be chosen to minimize switching losses during typical operating conditions.

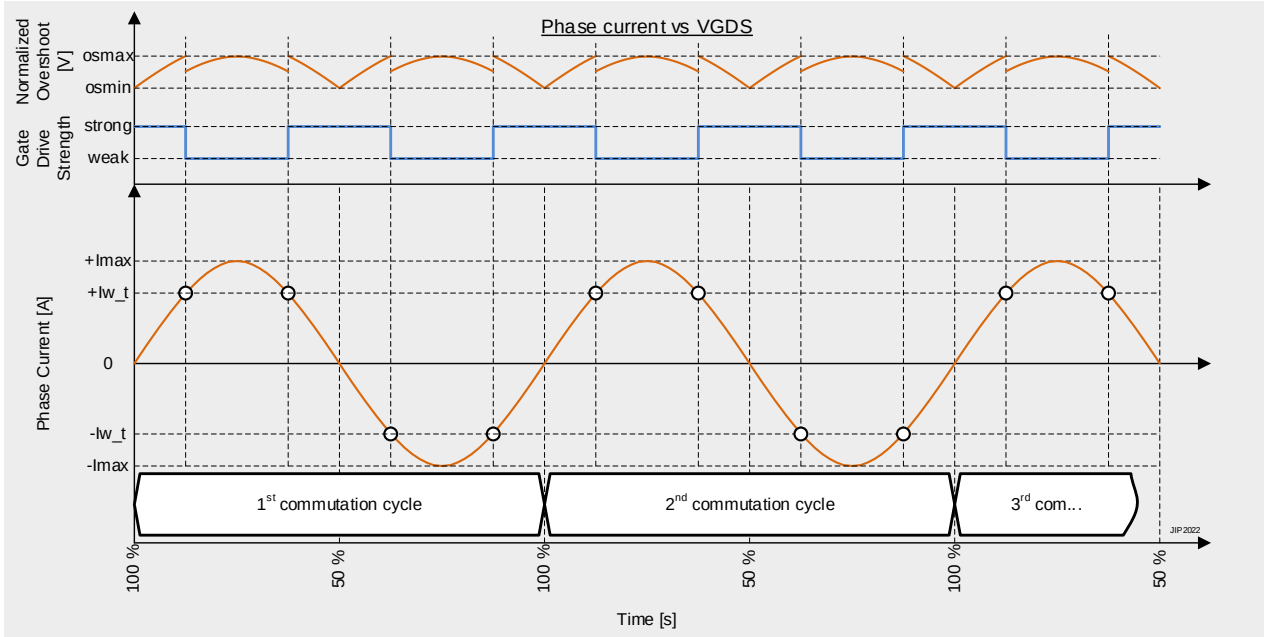




Weak drive strength should be chosen such that in the worst possible conditions the overshoot is just below the designed VDS Max.

Further optimization

- Real-time gate drive control maximizes benefits
- There are still power savings even if the gate drive strength is adjusted at larger intervals



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