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TI POWER

# TI *Live!* BATTERY MANAGEMENT SYSTEMS SEMINAR

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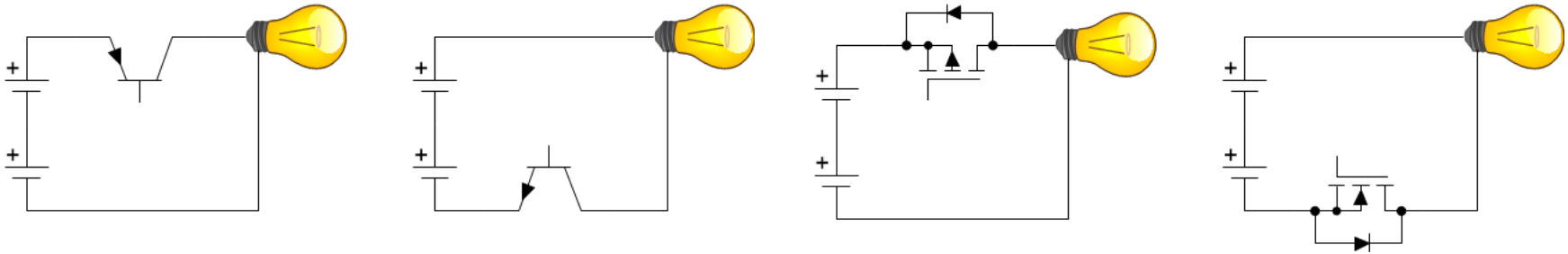
## OPTIMIZING MONITOR USAGE WITH MULTIPLE PARALLEL FETS FOR HIGH POWER APPLICATIONS

# Agenda

- Electronic switching
- Battery protection switching
- High-side vs. low-side switching
- Battery protection FET topologies
- Parallel FET considerations

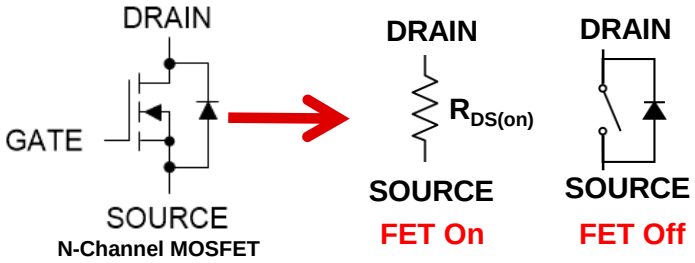
# Electronic switching

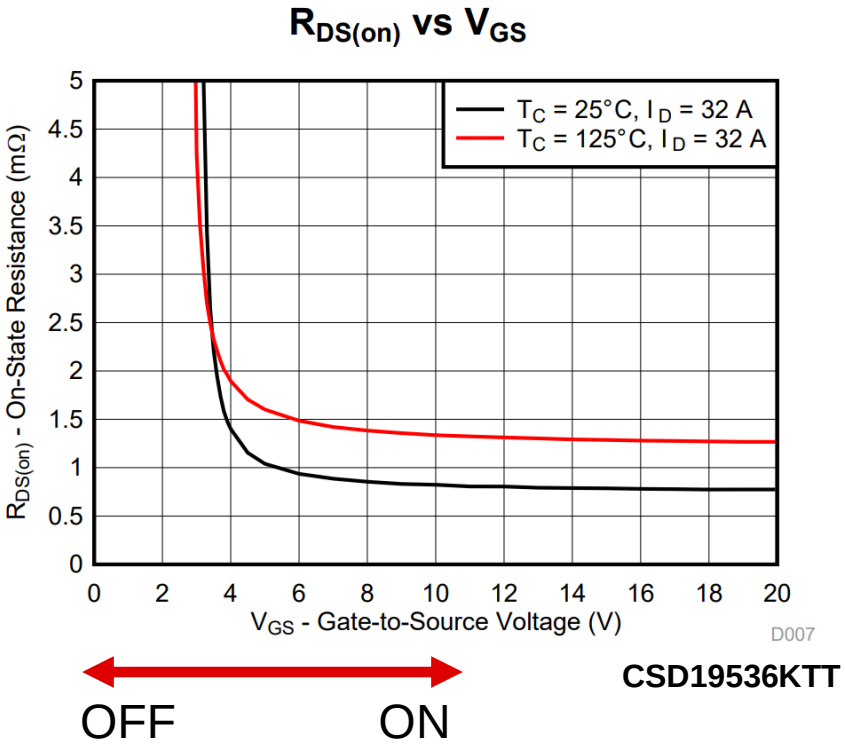
- Electronic switches (simple) will have a polarity
  - BJT is a current-controlled switch
  - FET is a voltage-controlled switch
- FET most commonly used in switching
  - Low drive current
  - Low on-resistance



# FET switching

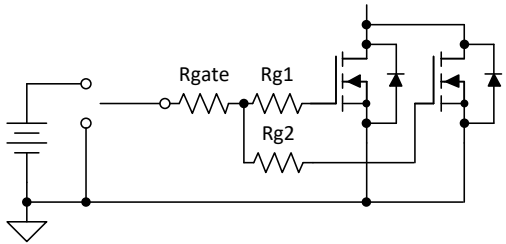
- Want high drive voltage for low $R_{DS(ON)}$
- Must slew through the transition voltage to turn off
- MOSFET blocks current in one direction
  - Behaves as a diode in the other

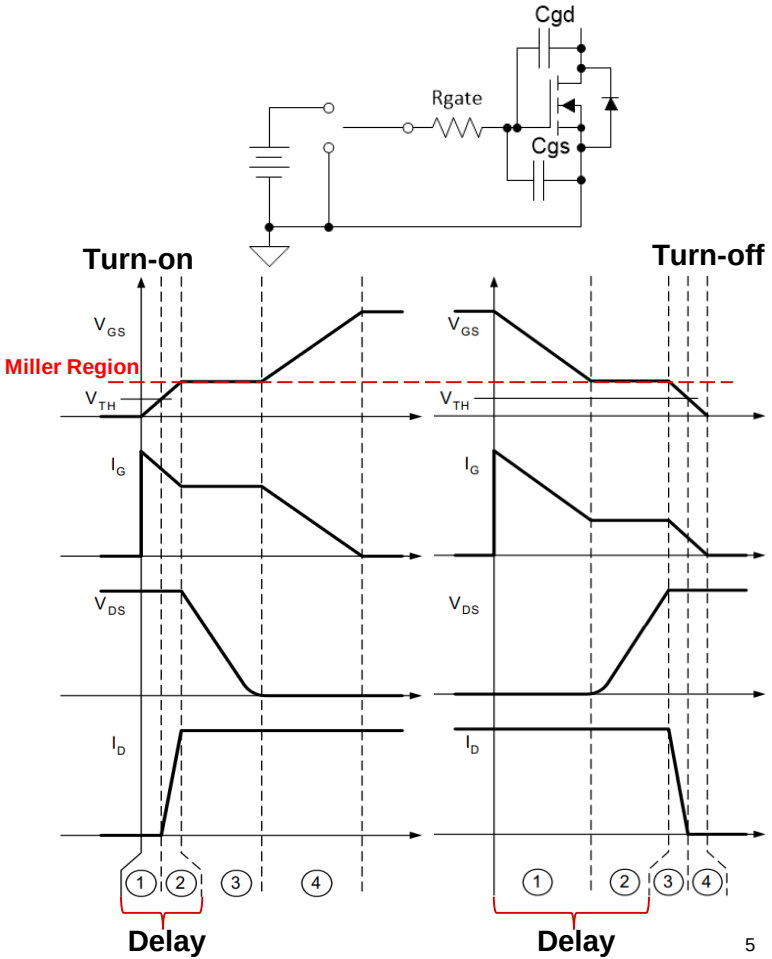


# FET drive

- FET gate is capacitive
  - More input capacitance leads to longer switching
- Miller plateau/region at switching
- Generally parallel well
  - FETs “self-correct” current shared due to Rds(on) temperature dependency
  - Current distributed evenly across FETs
  - May need individual gate resistor or ferrite bead



# FET drive voltage

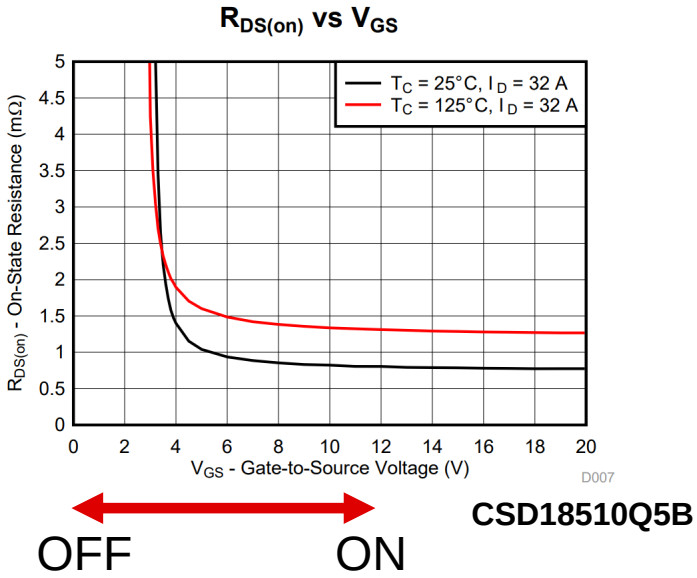
- FETs will vary on-resistance at a specified drive voltage
  - $R_{DS(ON)}$ at $V_{GS}$
- Want lowest $R_{DS(ON)}$ for load switching
- Cannot exceed absolute maximum $V_{GS}$

| | | | | |
|---|---|---|---|---|
| $R_{DS(on)}$ | Drain-to-Source On Resistance | $V_{GS}$ = 4.5 V | 1.2 | mΩ |
| | | $V_{GS}$ = 10 V | 0.79 | |
| $V_{GS(th)}$ | Threshold Voltage | 1.7 | | V |

**Absolute Maximum Ratings**

| $T_A$ = 25°C | | VALUE | UNIT |
|---|---|---|---|
| $V_{DS}$ | Drain-to-Source Voltage | 40 | V |
| $V_{GS}$ | Gate-to-Source Voltage | ±20 | V |

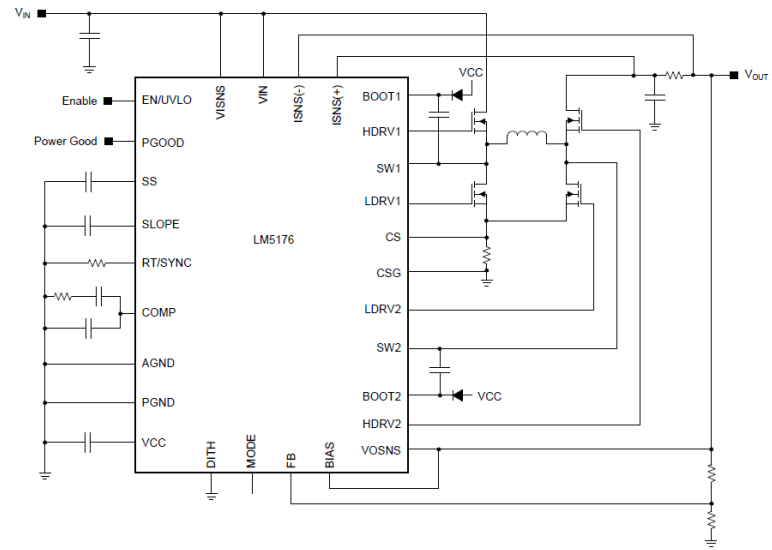
**CSD18510Q5B**

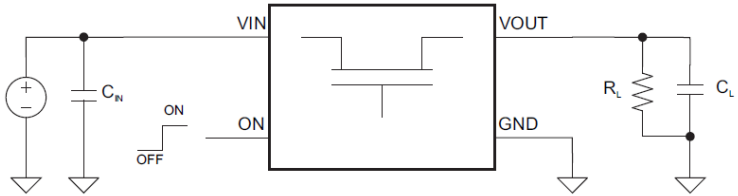



**CSD18510Q5B**

# Types of FET switching

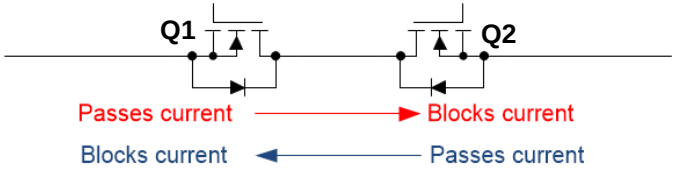
- Power conversion
  - Fast switching
    - kHz to MHz
  - Low on-resistance
  - Want high efficiency
    - Fast switching, high drive currents
- Load switching
  - Infrequent switching
  - Low on-resistance
  - Prefer small loop, may be dictated by physical size
  - Slow switching to avoid exciting system inductance



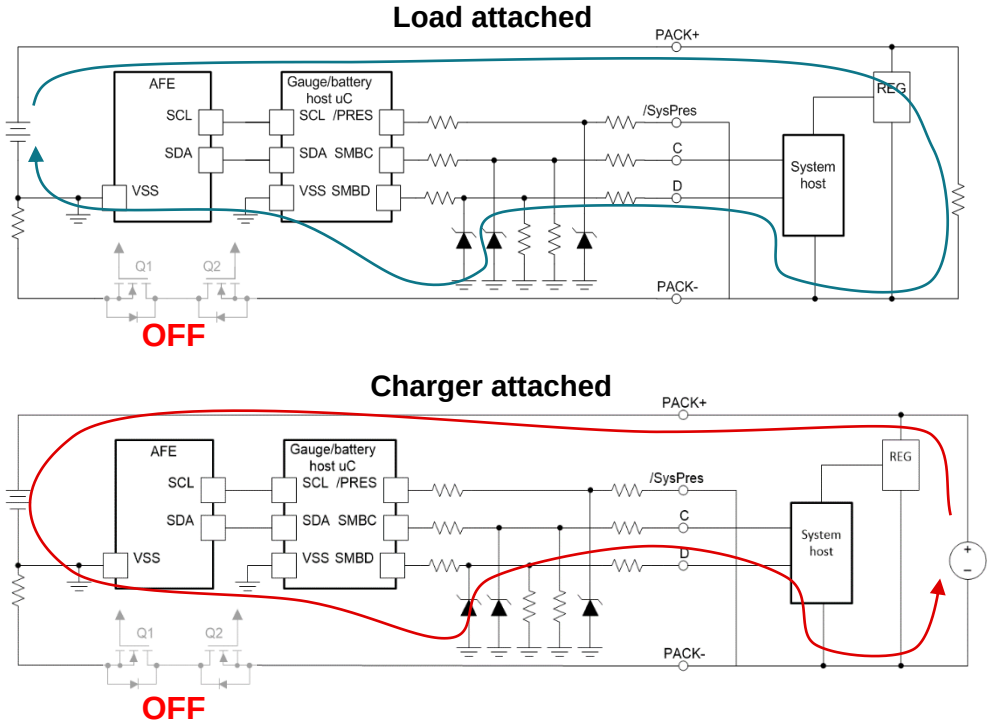
# Protecting a battery with FETs

- Lithium-Ion batteries need to be operated within specified limits
  - Do not over-charge & Do not over-discharge
  - MOSFETs commonly used for protection
- MOSFET is an unidirectional switch
  - Want to drive FETs gate-source voltage to minimize $R_{DS(on)}$
- Two MOSFETs in series controlled independently to avoid a latch
  - At high battery charge, allow discharge
  - At low battery charge, allow charge



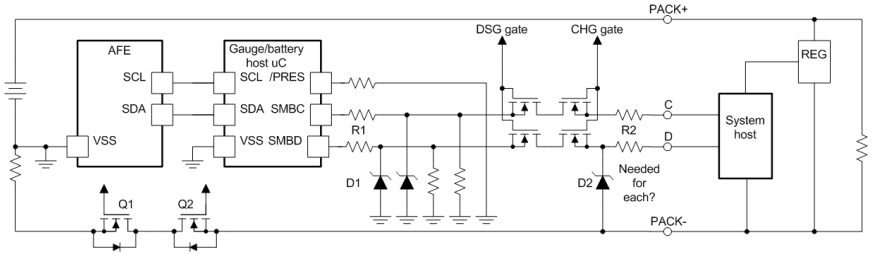
# Low-side switching with N-channel FETs

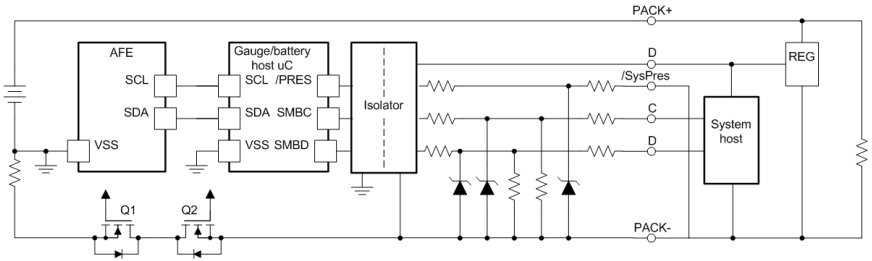
- Low-side switching can be achieved with gate-drive within the battery's voltage
  - Easier to implement
- With direct coupled communication to the battery, low-side switching has some challenges
  - Loss of signal reference
  - Leakage past protection FETs

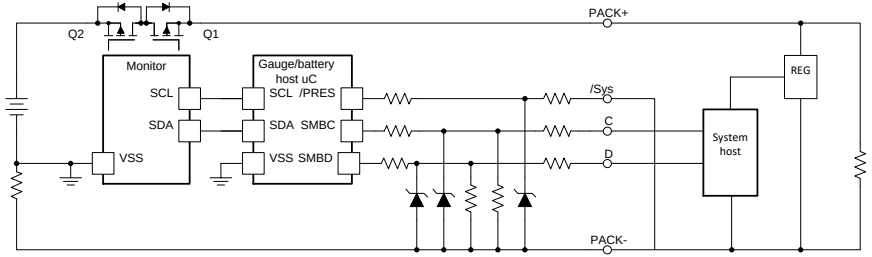


# Mitigating comm & low-side switching issues

- Switch communications
  - Can’t talk to system host
- Isolate communications
  - May be included in some interfaces
- High-side switching

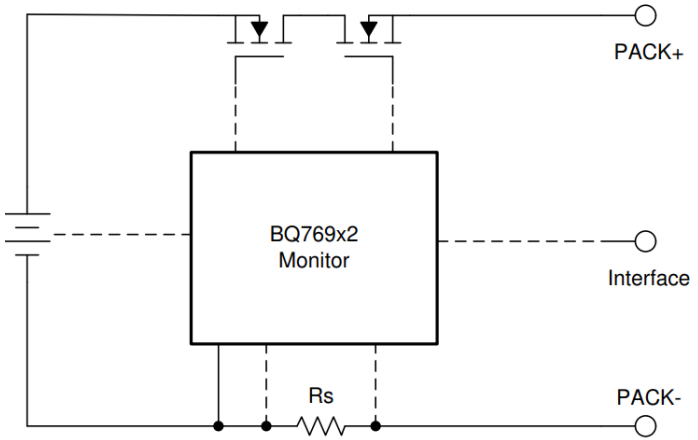


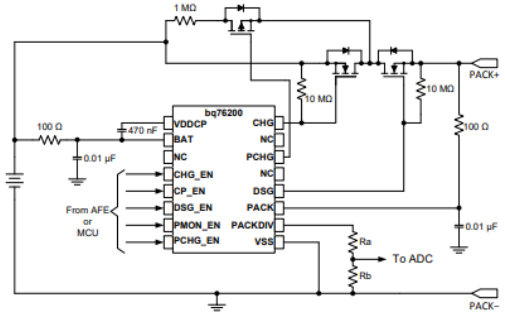
# High-side switching with N-channel FETs

- High-side switching avoids ground disconnection during protection faults.
- Gate driver voltage requires voltage above the battery voltage.
- Charge-pump is needed to drive FETs above battery voltage.
  - BQ769x2 family implements high-side switching with integrated charge-pump

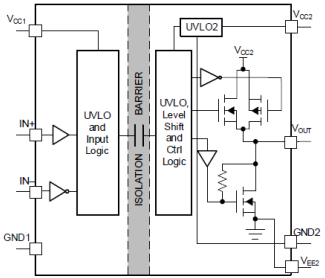


# Changing drive level of the part

- Sometimes part features may not match the drive level required by the system
- High-side BMS output – but low-side switch desired
  - Create level shift to low level
  - Use low-side driver
- Low-side BMS output – but high-side switch desired
  - Use high-side N-channel FET driver
  - High side P-channel
  - Isolated gate driver
    - Requires power supply for both sides



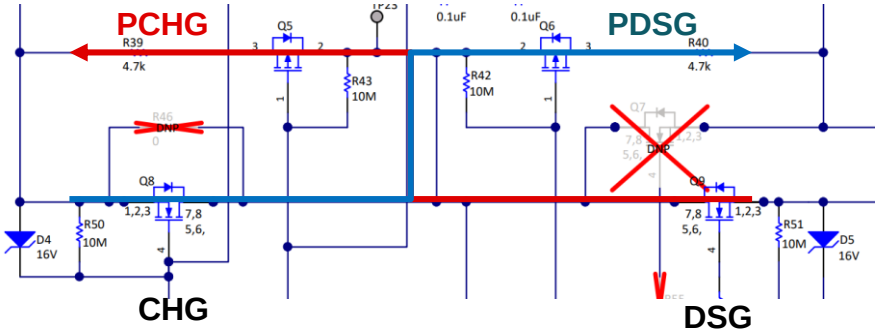

High side N-channel gate driver BQ76200




Isolated gate driver UCC53x0

# Pre-charge & pre-discharge FET switching

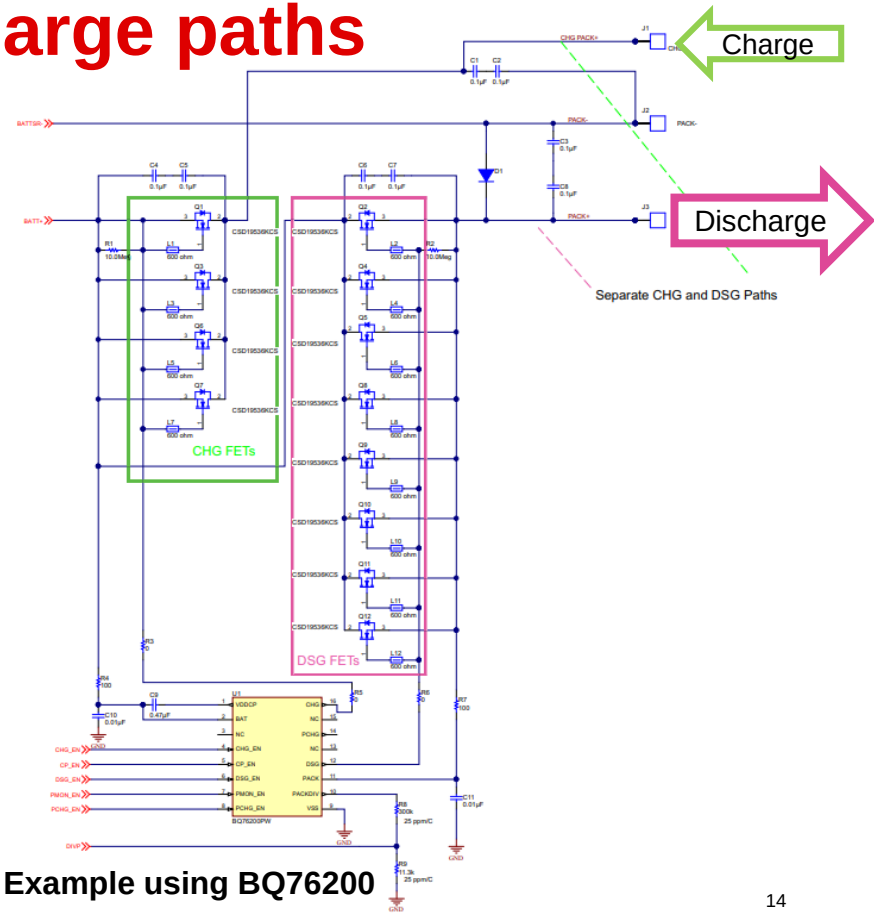
- Depending on the application, reducing current in power path may be desired
  - Reduce inrush current on load during initial power-up
  - Reduce charge current on discharged battery cells
- FETs with added resistance on path used to reduce current in path
- Integrated high-side PCHG and PDSG drivers implemented in BQ769x2 family
  - P-Channel FET drive




BQ76952EVM

# Separate charging and discharge paths

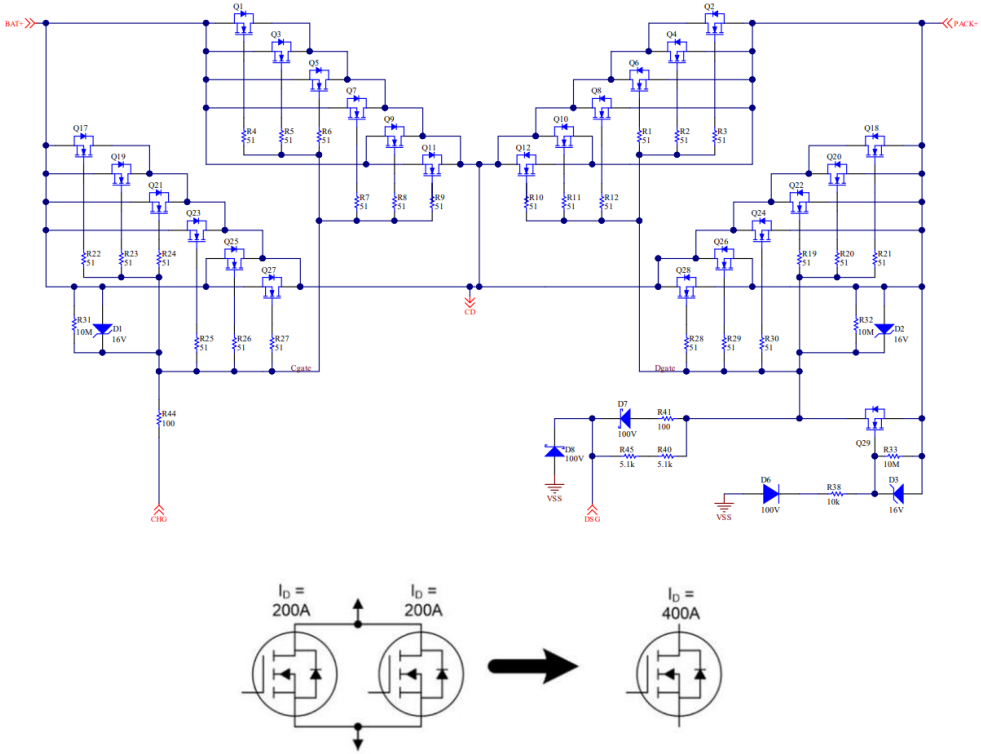
- In some applications there is a large difference between charging and discharge currents
- It may be desired to use small charge FETs and large discharge FETs
  - Cost savings
  - Architecture
- Best if BMS supports it
  - Body-diode protection can cause unintended FETs to turn-on
  - Additional circuitry may be required to prevent leakage currents in parallel paths




**Example using BQ76200**

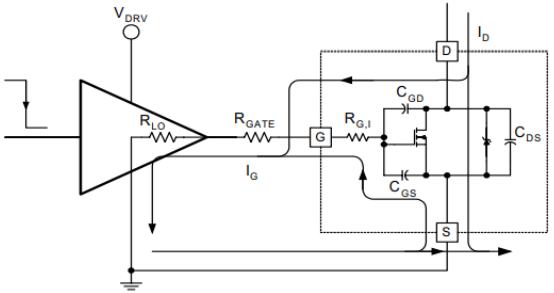
# High-current with multiple parallel FETs

- In high-current cases, parallel FETs can be implemented
  - Allow higher charge/discharge currents
  - Better heat dissipation
- FETs in parallel increase gate capacitance
  - Slower switching
- Parasitic oscillations can occur at the gate of the FETs during switching
  - Individual gate resistance or ferrite bead may need to be added

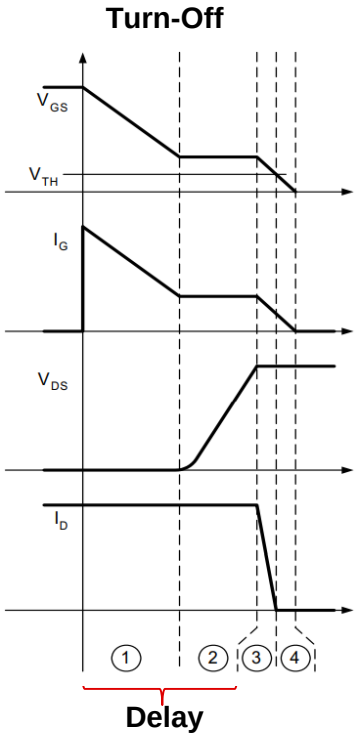


# Parallel FETs effect on switching speed

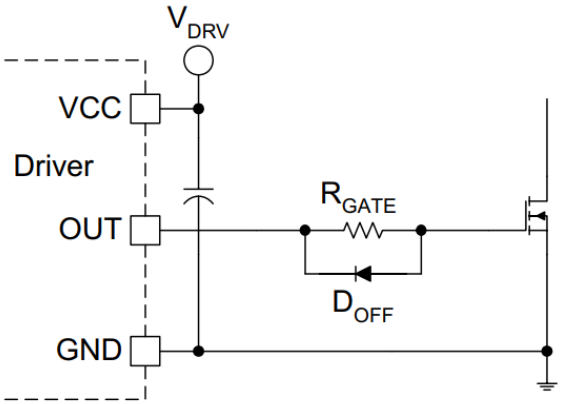
- Gate capacitance is increased in parallel FET implementations
  - Slower switching
  - Turn-off may be too slow
- Gate resistance can slow switching
- BMS gate drive may be limited by the device's design specifications
  - External circuitry can be added to speed switching speed



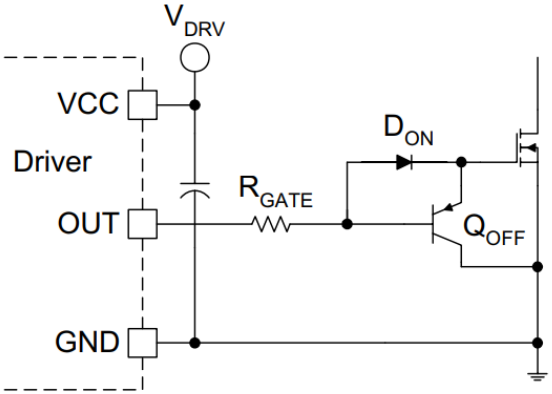

**MOSFET current turn-off path**



# External local turn-off circuits



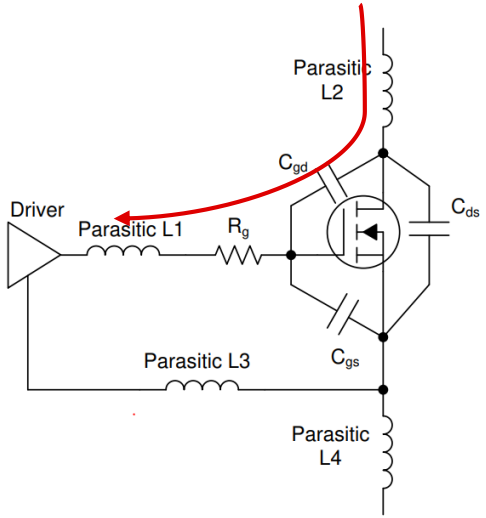

- Add diode that will be forward-biased during turn-off
  - Limited by driver speed




- Current pulled by driver during turn-off will turn-on PNP transistor, giving a faster discharge on MOSFET

# Parasitic oscillations during turn-off

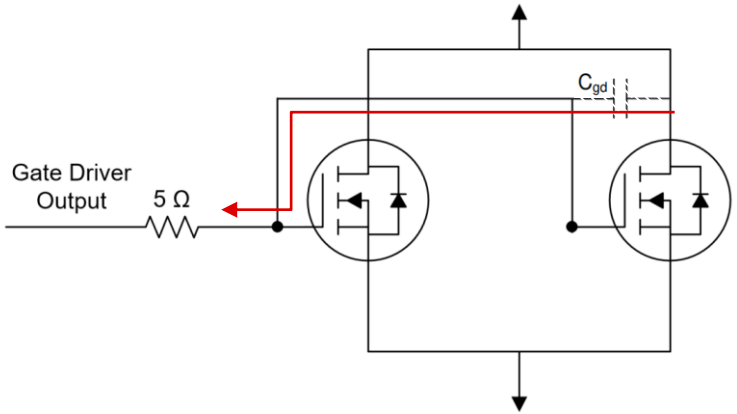
- Power MOSFETs are susceptible to parasitic oscillation
  - Generally have larger gain and capacitances
  - Layout could introduce stray inductances
- During events of fast transients at switching, inverse current can rush through $C_{gd}$ into stray gate inductance
  - Generating RLC resonant circuit
  - Creates a positive feedback loop, which generates oscillations




**Parasitics in gate drive circuit**

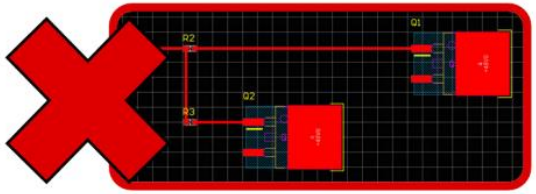
# Parasitic oscillations in parallel FETs

- Variation in electrical characteristics, particularly $V_{TH}$ can lead to different switching timings
  - Lower Vth leads to faster turn-on, slower turn-off
  - Higher Vth leads to slower turn-on, faster turn-off
- One MOSFET will ultimately carry more current due to uneven switching behavior
- During turn-off FETs can cause voltage swing that can couple through parasitic Cgd into the shared gate connection causing oscillations

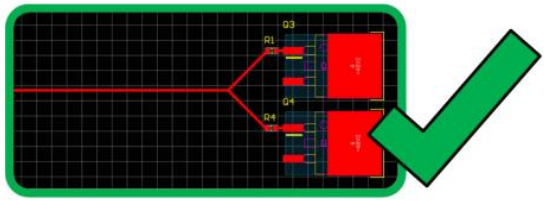


# Mitigating oscillations during turn-off

- Good PCB layout practices
  - Matched gate traces
  - Small turn-off current loops
  - Reduce PCB trace inductances



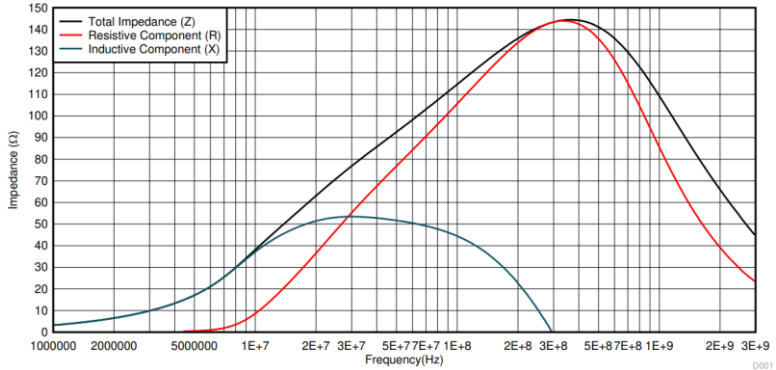

**Bad gate layout**




**Good gate layout**

- Add individual gate resistance/ferrite bead
  - Dampens oscillations
  - Gate resistor can slow switching speed
  - Bead have frequency-dependent impedances
    - Low impedance at low frequency
    - High impedances at high frequencies.

- Choose closely matched FETs
  - Contact FET provider for parallel recommendations.




**Ferrite bead impedance vs frequency**

# Summary

- What drives the BMS requirement?
- FET Topologies for battery protection
  - High-Side
    - Simple Communication
  - Low-Side
    - Simple implementation
  - Pre-charge/pre-discharge
  - Separate discharge/charge paths
- Parallel FETs need additional considerations
  - Individual gate resistor/ferrite beads
  - Good layout practices
  - Select FETs with low difference in electrical characteristics

# Resources

- Multiple FETs with the BQ76952, BQ76942 Battery Monitors
- Parallel Paths with the BQ769x2 Battery Monitor
- FET Configurations for the bq76200 High-Side N-Channel FET Driver
- Fundamentals of MOSFET and IGBT Gate Driver Circuits
- The Use and Benefits of Ferrite Beads in Gate Drive Circuits
- Driving Parallel MOSFETs Using the DRV3255-Q1
- External Gate Resistor Selection Guide

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