

48V Systems: Driving Power MOSFETs Efficiently and Robustly



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In Peter Fundaro's previous [post](#) on 48V automotive systems, he introduced a power-inverter system architecture and configuration as well as the design considerations for MOSFETs and high-side/low-side gate drivers. Integrating all of these parts into a robust system and implementing it efficiently requires a thorough understanding of the loss mechanism of the system, and how to balance the trade-offs. In this post, I will discuss the loss mechanism in a 48V system, the design trade-offs of high- and low-side gate drivers, parasitic inductances/capacitances, and printed circuit board (PCB) layout considerations.

Take a look at the power stage of the 48V inverter system shown in [Figure 1](#). It includes three MOSFET half bridges and corresponding high- and low-side gate drivers.

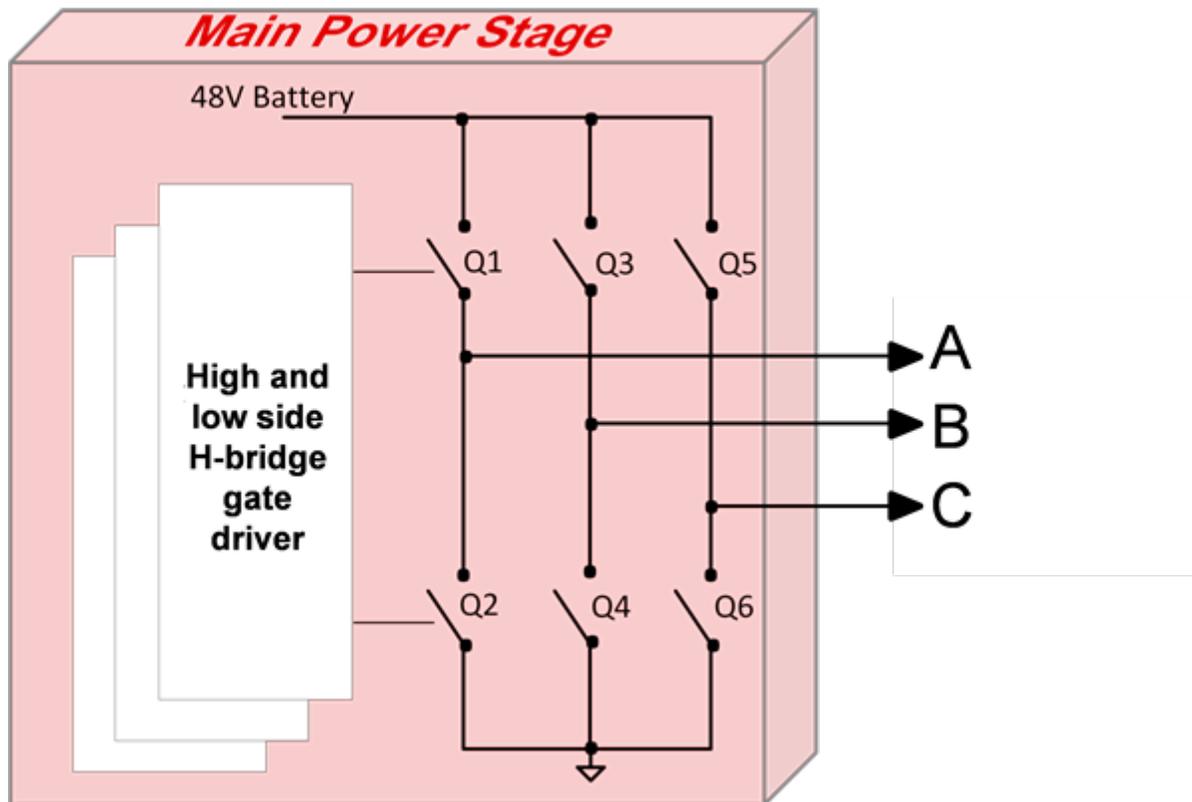


Figure 1. Power Stage of a 48V System Inverter

[Figure 2](#) shows a simplified circuit featuring the configuration of the high- and low-side gate driver and the MOSFET's half bridge for one phase leg in [Figure 1](#). The loss on this power stage dominates the power loss for the whole 48V inverter system, which includes switching loss and conduction loss. Peter's post discussed the trade-off between conduction loss and switching loss. Given selected power MOSFETs and system power ratings, the conduction loss is pre-determined, since the current-ripple-dependent root-mean-square (RMS) current is pre-determined by the motor. Switching loss is dependent on the gate-driver design, however.

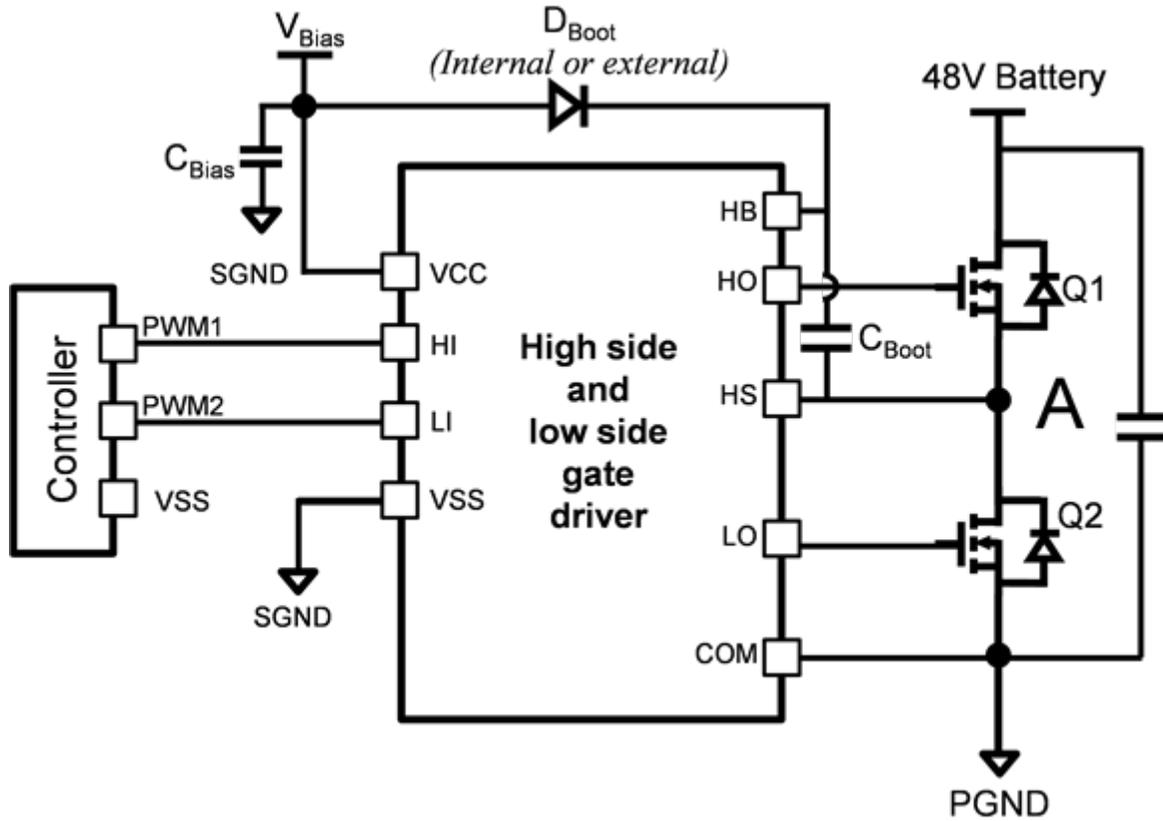


Figure 2. Simplified Circuit for One Phase Leg

Figure 3 shows the simplified piecewise linear switching-loss mechanism for MOSFETs with turn-on, turn-off and turn-on with reverse recovery. The overlapped V_{DS} and I_D , $t_1 \sim t_3$ shown in Figure 3 generates switching energy and is represented by the integration of the product of V_{DS} and I_D , expressed as Equation 1.

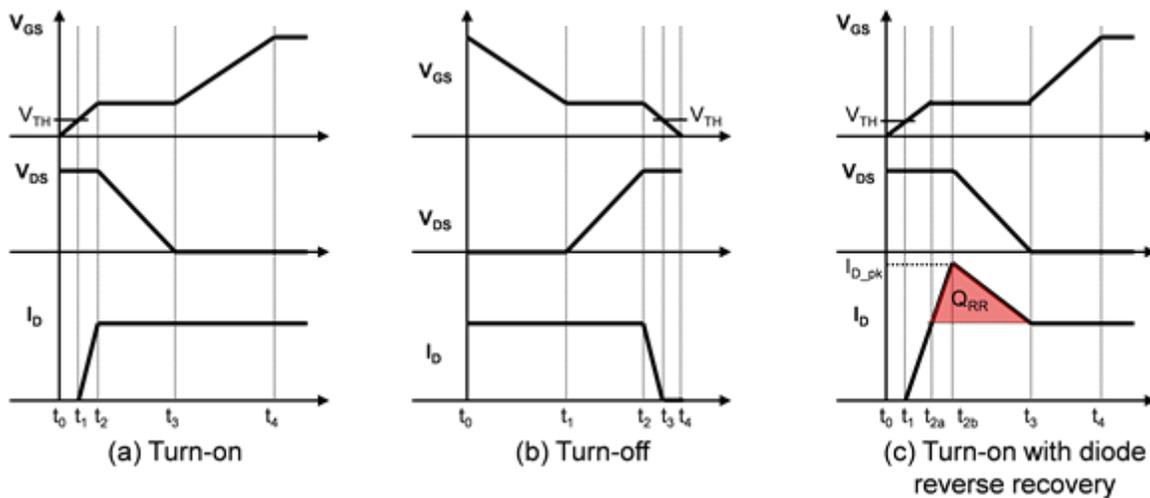


Figure 3. Simplified Piecewise Linear Switching-loss Mechanism

$$E_{on/off} = \int_{t_1}^{t_2} V_{DS}(t) \cdot I_D(t) dt \tag{1}$$

Given a certain switching voltage and current, the switching energy is decided by the driver’s output peak source/sink current, $I_{PK_Source/Sink}$, and the parasitic capacitance of one MOSFET decides the switching period. Equation 2 estimates the interval from $t_{2(b)}$ to t_3 :

$$t_3 - t_{2(b)} = C_{RSS} \cdot \frac{V_{DS}}{I_{PK_Source/sink}} \tag{2}$$

Therefore, the gate peak-current driving capability is very critical to switching loss. Ideally, the higher the gate driver’s current capability, the smaller the loss. But unfortunately, a higher driving current will bring high dv/dt and di/dt and its unfavorable influence on system operation through parasitics. Figure 4 shows a bootstrap high- and low-side driver-application circuit design considering parasitics. Looking at Figure 4, with high dv/dt on the switch node, SW, more noise will be coupled to the primary side through the parasitic capacitance, C_{IO} , in the bootstrap level shifter and junction capacitance of the bootstrap diode (see red shaded path with arrow).

Plus, higher di/dt on the device will cause more noise on the gate-driver loop through the common source inductance, L_{SS} . The voltage drop will always contradict the gate-drive signal by slowing down the driving capability. The voltage drop will also cause significant ringing on the MOSFET’s gate-source pin or over/undershoot on the MOSFET and gate-driver output pin, leading to reliability issues or even damage to the device under test (DUT).

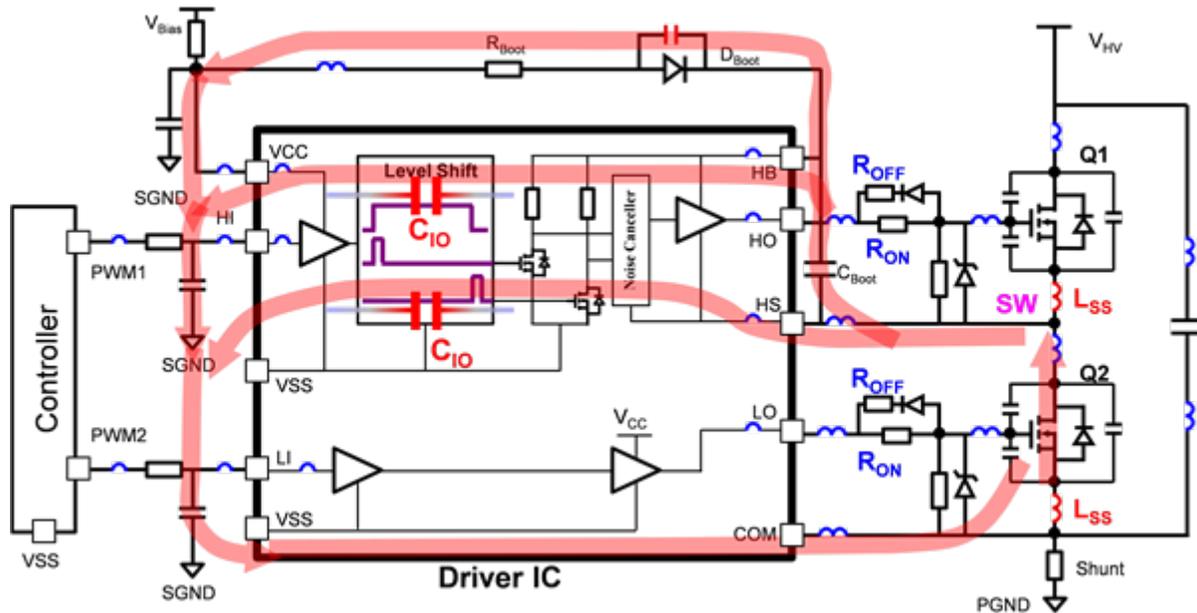


Figure 4. Gate-drive Circuit Considering Parasitics

Considering two active MOSFETs in each phase leg for the 48V system, hard switching and reverse-recovery loss will dramatically increase the switching loss; the major reason is because of the lousy parasitic body diode of the MOSFETs. Importantly, di/dt has a very strong influence on reverse-recovery charge and performance. Higher di/dt leads to a higher reverse-recovery charge and current, which could be 5 to 10 times higher than the rated switching current.

Figure 3(c) shows the piecewise linear turn-on waveform considering reverse recovery. Figure 5 shows an example turn-on/turn-off experimental waveform. As you can see from Figure 5(b), there is significant reverse-recovery current when the switch has a hard turn-on with the parasitic body diode, which not only causes significant current stress and large oscillation on the gate-drive voltage for the switch, but also significantly increases the switching loss. Other unfavorable effects would be electromagnetic interference (EMI), control ground noise, device/driver damage and low reliability.

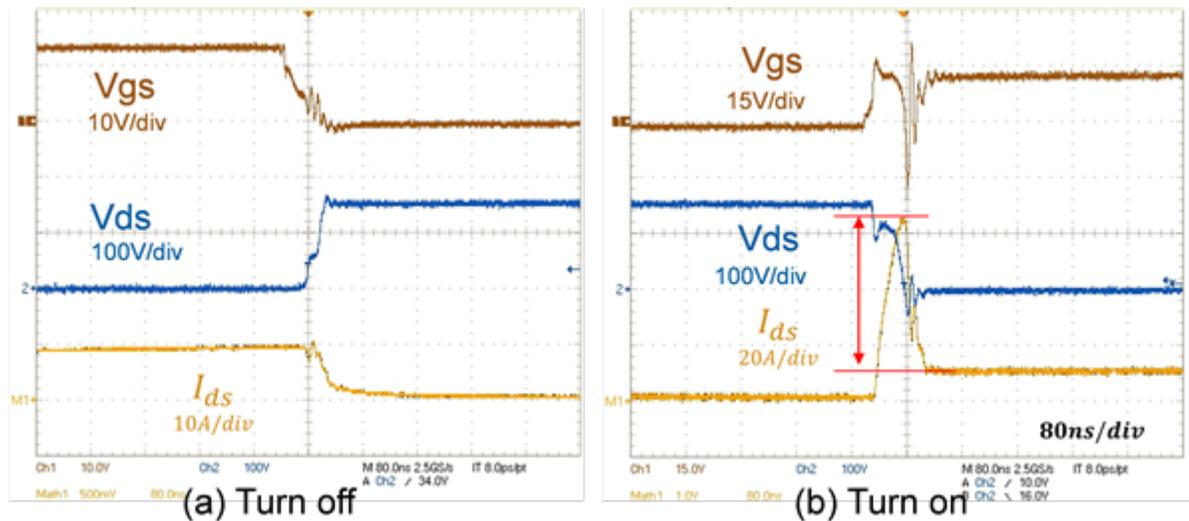


Figure 5. Hard Switching Turn-on/off Waveform

Therefore, proper gate resistance should be sized considering the minimized switching loss, as well as maintaining acceptable dv/dt , di/dt and reverse-recovery performance. One solution to this trade-off is to split the turn-on/turn-off on the gate-driver design (see Figure 4, which has different R_{ON} and R_{OFF}). A smaller R_{OFF} will decrease turn-off loss (make sure that the dv/dt is not over the specifications for the driver) and R_{ON} can control the reverse-recovery performance to an acceptable level.

Figure 6 offers clues about gate-drive resistance and its influence on reverse-recovery current, I_{rr} . Achieving a clean and sharp waveform on the gate drive and minimizing the V_{DS} voltage spikes on the MOSFET requires careful layout. I recommend minimizing the loop inductance for the gate-driver loop, and minimizing the coupling common-source inductance, L_{SS} .

For a 48V system application, TI's [UCC27282-Q1](#) offers 120V, $\pm 3A$ driving capability, which gives you more flexibility to minimize the switching loss. More importantly, its state-of-the-art voltage-slew rate on the HS pin, 50V/ns, combines with a maximum negative voltage on the HS pin of -14V (repetitive pulse), enabling you to further push the driver's peak-current capability while still maintaining robustness. The [UCC27282-Q1](#) also integrates a 120V bootstrap diode with a 0.55V forward-voltage drop and 1.5 Ω of dynamic resistance for a reliable charge transfer to the bootstrap capacitor.

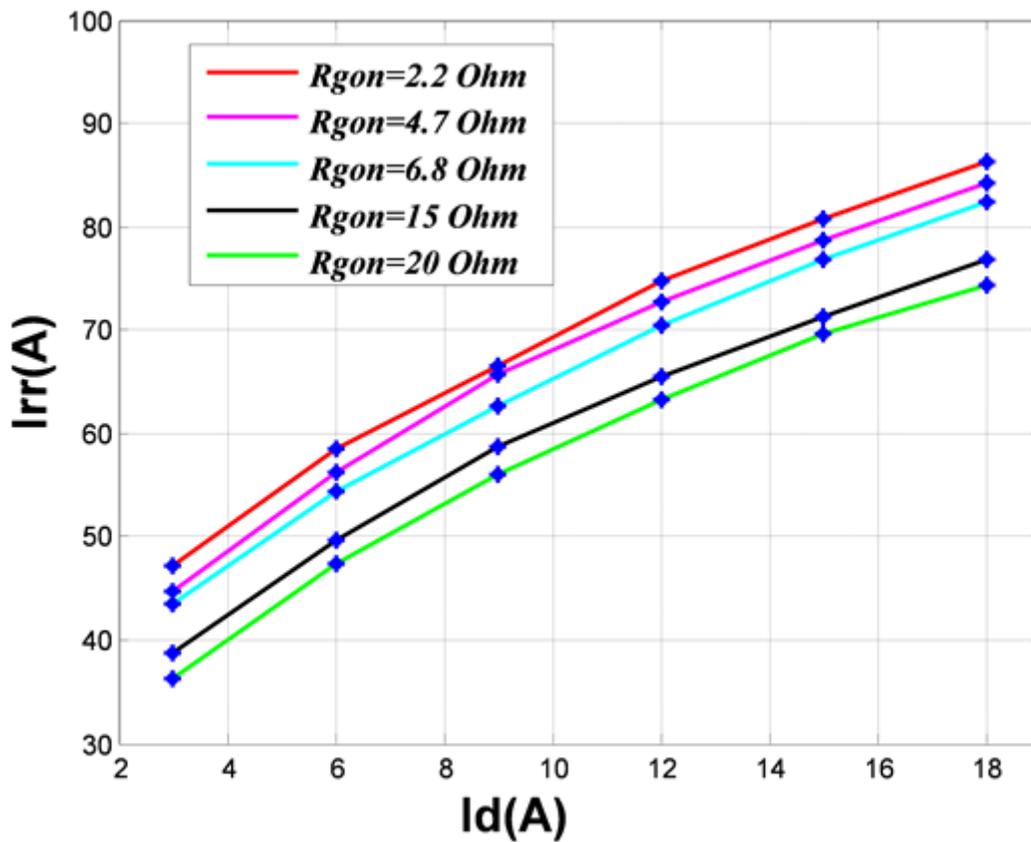


Figure 6. Peak Reverse-recovery Current versus Turn-on Resistance and Id

Additional Resources

- Check out TI's [120V boot 3A peak high-frequency high-side/low-side driver](#).
- Read Laszlo Balogh's article on, "[Design And Application Guide For High Speed MOSFET Gate Drive Circuits](#)"

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