

Motor Driver Slew Rate Considerations for 48V Automotive Systems



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ABSTRACT

Recently, the automotive industry has been undergoing significant changes which are being driven by electrification trends in the market, along with environmental regulations imposed by government bodies. With more OEMs (Original Equipment Manufacturers) working on electric vehicle (EV) projects, the adoption of 48V architecture is being greatly accelerated. Even outside of fully electric vehicles, 48V is being used in mild hybrid vehicles as well.

The inclusion of 48V rails allows the connected systems to operate with lower motor current, which in turn enables the reduction of wire gauge thickness, harness weight, power loss, and PCB size. Ultimately, this helps to reduce the high total cost of the wire harness in these vehicles. The skateboard style of chassis used more commonly in EVs can also benefit from 48V rails by increasing power density and simplifying routing.

In many automotive systems, brushless DC (BLDC) motors are used due to higher efficiency, longer lifespan, reduced EMI, quieter operation and precise controllability. These motors are utilized throughout the vehicle for a variety of purposes, such as braking, steering, shifting, active suspension, pumps, blowers, and more. This shift from the traditional 12V architecture results in changes in the performance of brushless DC (BLDC) motor systems and requires some design reconsiderations.

While there are multiple new system-level considerations at the 48V voltage level, this application note focuses on MOSFET power losses, and how the power losses change when transitioning from 12V to 48V systems.

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1 Introduction

BLDC motors have a variety of functions throughout multiple automotive systems. Traditionally, the most common voltage range for BLDC systems is 12V. With the inclusion of 48V rails to these systems, it is important to understand the resulting effect on MOSFET power losses. It is crucial to manage the sources of power loss in order to mitigate operating heat and preserve battery charge.

This application note discusses the new system level considerations when transitioning to 48V, including conduction losses, switching losses, EMI, and more. For all further examples and calculations, a 960W power level is used for both 12V and 48V, meaning 80A at 12V and 20A at 48V.

2 Power Loss and Thermals in Motor Driver Systems

The BLDC motor converts electrical potential energy into kinetic mechanical energy through electrical commutation of the three phases of MOSFET half-bridges. The MOSFETs delivering power from the battery to the motor are the largest contributors to power loss and thermals in a motor driver system.

Power loss is a critical factor to consider during system design as power loss affects:

User Experience – High heat affects usability and can lead to user discomfort

Device Reliability – High temperature operation can lead to accelerated wear and tear and affect lifetime reliability

Power Efficiency – Decrease battery life, reduce vehicle mileage and increase thermal design challenge

This application note focuses on the two main areas of power loss with MOSFETs: Conduction Losses and Switching Losses.

2.1 Conduction Losses

Conduction losses in MOSFETs occur when current conducts from drain to source. The channel resistance of the MOSFET while conducting, is commonly referred to as on-state resistance, or $R_{ds(on)}$. These losses scale with the square of the current, so motor current becomes the dominating factor in determining conduction losses. Conduction losses during FOC commutation are calculated using the formula:

$$P_{conduction} = 3 \times I_{RMS}^2 \times R_{ds(on)} \quad (1)$$

Example 1

Assume two systems with total power of 960W.

System A = 12V Battery

System B = 48V Battery

$$P = I \times V \quad (2)$$

Based on [Equation 2](#), if the same desired power output for both the 12V and 48V system is assumed, using Ohm's law we can deduce that the 48V system operates with four times less current. Therefore, less current will pass through the MOSFETs, resulting in 16 times less conduction losses in the 48V system based on [Equation 1](#). [Figure 2-1](#) illustrates the losses shown in [Example 1](#).

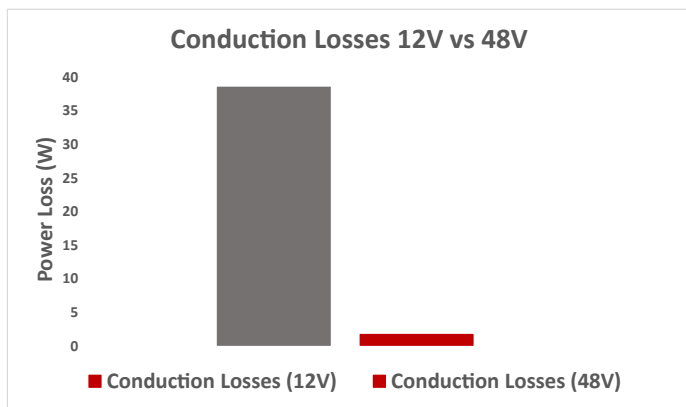


Figure 2-1. Conduction Losses 12V vs 48V

2.2 Switching Losses

Switching losses are another form of power loss related to the energy lost in turning on/off the MOSFETs. These losses are directly proportional to the time needed to fully slew the drain-to-source voltage and the switching frequency of the MOSFET.

The equation for switching loss during FOC commutation is calculated using the formula:

$$P_{switching} = 3 \times I_{RMS} \times V_{peak} \times T_{rise/fall} \times F_{PWM} \quad (3)$$

In 12V automotive systems the conduction losses dominate the total power consumption so switching losses are not the focus point. However, with automotive manufacturers moving towards 48V EV/hybrid systems, the switching losses become a more dominant player in the total losses. This trend in the market shift has led to more engineers optimizing the switching behavior to reduce total power consumption.

The key parameter of focus is the time taken to slew the MOSFET to and from the battery voltage. By reducing the slew time ($\frac{Voltage}{T_{rise/fall}}$), MOSFETs can be switched more efficiently. Reduction in slew time is achieved by increasing the gate current of the motor driver, resulting in a faster slew rate. [Figure 2-2](#) shows the impact of slew rate on switching loss.

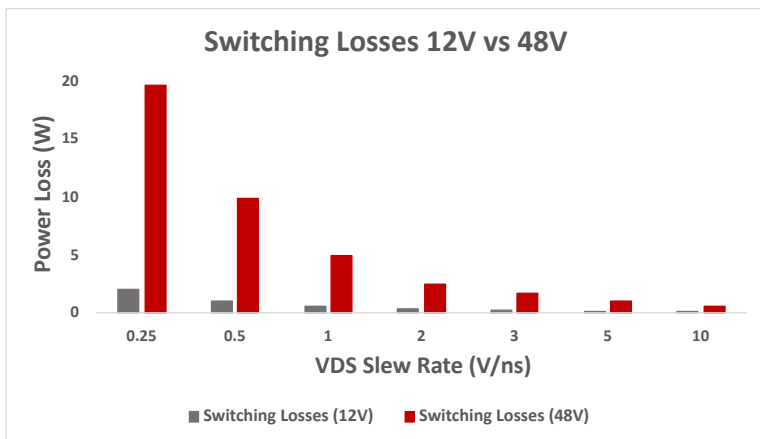


Figure 2-2. Switching Losses 12V vs 48V

2.2.1 Effect of Switching Frequency

Another factor which can heavily impact the amount of switching losses in the system is the frequency of the input PWM signals. The MOSFETs must enter the switching region at both the beginning and end of the respective input pulse (turn off and turn on). With a higher PWM frequency, these pulses happen more often, thus increasing the amount of time each MOSFET spends in the switching region. This means that there is a proportional relationship between the amount of switching losses and the frequency of the input PWM signals (see [Figure 2-3](#)). A common value for the PWM frequency in 48V systems is approximately 20kHz. The reason this value is targeted is because this frequency is high enough to be out of the audible range for humans but is kept low to mitigate switching loss and noise.

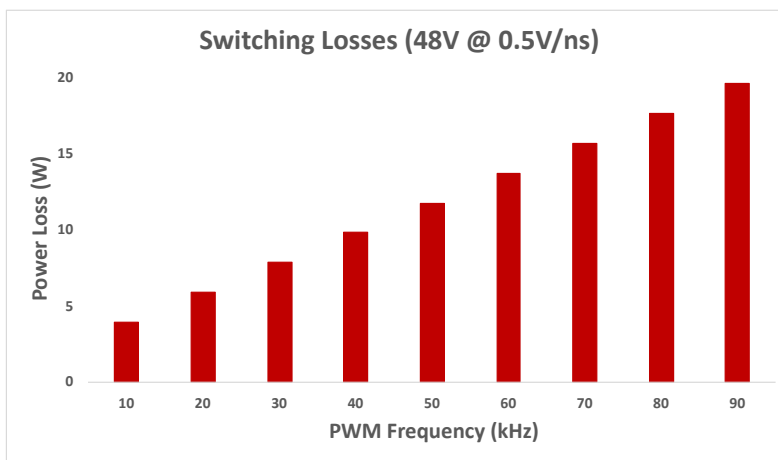


Figure 2-3. Switching Losses (48V at 0.5V/ns)

3 Real World Motor Driver Limitation

In theory operating at the fastest slew rate is the key to optimizing the motor driver system and reducing switching power loss. However, in practice you are limited by the following real-world limitations:

3.1 Electro-Magnetic Interference (EMI) – System Noise Considerations

Faster switching of MOSFETs results in fast voltage transients and these contain high frequency elements which are passed down as EMI. All circuits have parasitic inductances and capacitance, and fast excitations of these L-C components can create resonant circuits which further amplify certain frequencies. These frequencies can cause interference for the rest of the system. Automotive systems have strict EMI frequency ceilings requirements, such as CISPR 25 compliance, thus, posing a limit on the slew rate that can be implemented in the end system.

3.2 Motor Driver Voltage Tolerance

Increasing voltage slew rate results in voltage ringing (overshoots and undershoots) on the gate and source signals of the MOSFETs. The magnitude of the overshoots translates directly with the slew rate (controlled by gate current). See [Figure 3-1](#) for the impact of gate current on slew rate and ringing. The responsibility falls on the system design engineer to ensure that the voltage spikes do not violate the absolute maximum ratings of the motor driver, specifically gate and source pin ratings. Operating above the ratings of the motor driver will affect device performance and reliability leading to unexpected behavior/rapid wear.

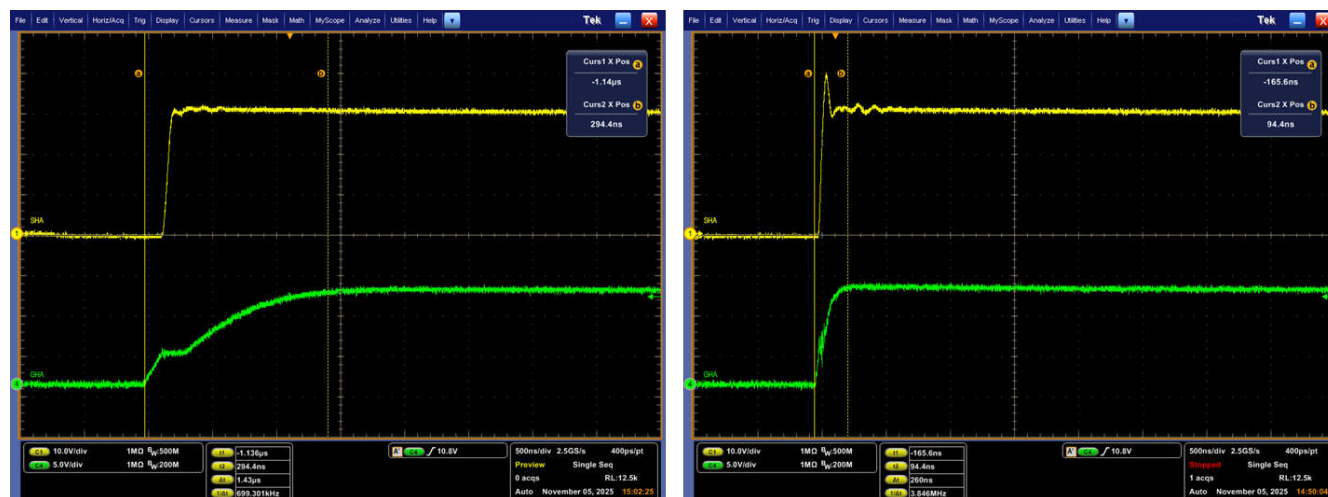


Figure 3-1. Impact of Gate Current on Slew Rate and Ringing : a) Gate Current - 64mA (left) b) Gate Current - 1024mA (right)

Another critical specification often overlooked is the absolute maximum slew rate tolerated by the source node of the motor driver. Many older devices and leading competitor devices have absolute maximum slew rate spec of 1V/us, limiting the switching speed. Also worth noting is that the MOSFET Voltage Drain-to-Source slew is not linear but rather resembles an S curve since this is a capacitor charging analog. This means that the slew rate can be higher than the device rating toward the middle portion. This poses a severe limitation on customers who need to explore faster slew switching times for switching efficiency. Texas Instruments' new 48V driver [DRV8363-Q1](#) was designed specifically with this consideration in mind and offers a max 20V/ns slew rate tolerance on source node. [DRV8363-Q1](#) new ratings increase system robustness to faster slew rate so that the driver does not become the limit for system performance.

Addition of RC snubbers or following proper PCB design practices can reduce the impact of ringing. Ultimately, the system design engineer must consider the EMI limitations and driver voltage ratings before selecting a gate current for the system. There are benefits and tradeoffs on either side including the overall PCB robustness to parasitics that impact the optimal slew rate for the system.

4 Summary

As BLDC systems transition to 48V in automotive systems, it is important to note that MOSFET switching losses are no longer negligible. The shift from conduction dominated to switching dominated losses changes the optimization methods for motor drive systems.

Higher slew rate can help to reduce the switching losses, but it is important to consider the adverse effects of a faster slew rate such as EMI and ringing. If the slew rate is too excessive, the system can be vulnerable to voltage overshoot, capacitive coupling, and even unwanted turn-ons. PCB layout and proper selection of source and sink current settings are critical to optimizing the system. By balancing these factors, designers can create a robust 48V system using [DRV8363-Q1](#), which is not limited by the slew rate capability of the device.

5 References

- Texas Instruments, [DRV8363-Q1 48V Battery Three-Phase Smart Gate Driver with Accurate Current Sensing and Advanced Monitoring](#), data sheet.
- Texas Instruments, [DRV8363-Q1EVM](#), evaluation module.

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