Technical White Paper

Design Trade-offs for 48V Automotive Body Motor Applications

TEXAS INSTRUMENTS

ABSTRACT

The automotive industry is experiencing a shift towards 48V electrical systems, driven by the need for increased efficiency, higher electrical power delivery, and support for advanced features in both traditional and electrified vehicles. While this transition brings many benefits, this also presents several challenges for body motor designs commonly used in applications such as door modules, window lifts, wipers, and power seats. This paper discusses where designers can take advantage of 48V power, and the tradeoffs to be considered.

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1 Introduction

While automotive electrical systems have been based on a 12V nominal lead acid battery system for decades, there is recently a shift towards 48V electrical systems. For body applications, this higher voltage means lower currents for the various actuators that consume high levels of power, such as window lifts, seat adjustments, windshield wipers, pumps, and blowers. Lower currents allow smaller wire cross-sections, reducing cost and weight in the wire harnesses and actuators.

The change from 12V systems to 48V systems requires designers to make new tradeoff decisions for the electronics throughout the vehicle. In the following sections, this document discusses how motor drivers, power management, interface transceivers and other components are affected by this trend.

2 Examples of Using 48V in Body Motor Applications

The following are simplified block diagrams illustrating the implementation of 48V systems in key body motor automotive applications. Note that depending on the specific requirements of each design, other components may be appropriate for that particular application.

2.1 Door Module

In this typical example, a central electronic control unit (ECU) communicates with the door module via the vehicle CAN bus, providing commands for functions like locking, unlocking, and window control. A 48V power supply is used to drive the window lift motor due to its relatively high current. The other functions in the door can remain as 12V actuators, due to the lower current and the cost of redesigning the existing 12V mechanisms. In that case, a 48V-to-12V step-down (buck) regulator is needed to supply 12V to the low-current loads.
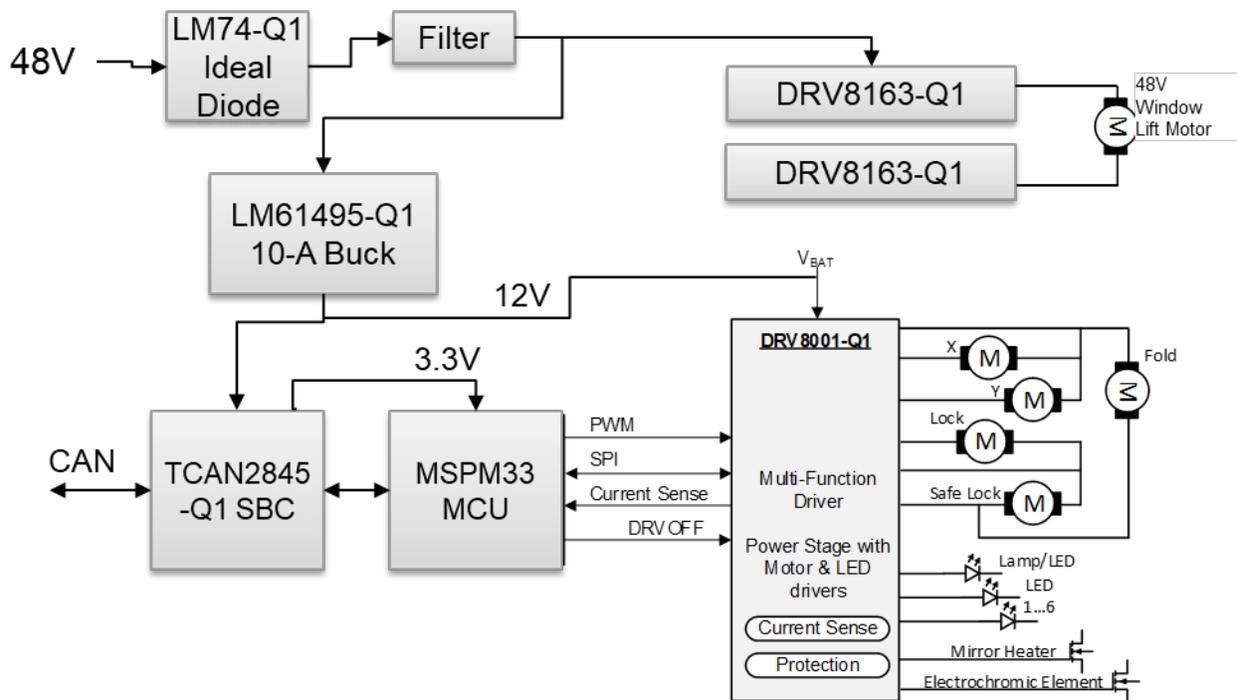

Figure 2-1. Example 48V Door Module Block Diagram

The CAN system basis chip (SBC) is robust to faults up to ±58V on the bus lines, in case the 48V supply is bundled in the same wire harness. The buck converter supplies up to 10A of current at 12V to the multifunction driver, which controls all the lower-power door functions. For the higher-power window lift motor which is powered by the 48V, the half-bridge drivers allow up to 70V on the supply. The ideal diode controller prevents damage due to reverse-voltage faults on the 48V supply line. Coordinating all the communications and functions of the door module is the microcontroller, in this case a 160MHz Arm® Cortex®-M33 MCU with CAN-FD connectivity and enhanced security features preferred for door applications.

2.2 Window Lift

The window lift fumction can be implemented as part of the door module, or can be controlled by a dedicated ECU. The window lift system receives commands to raise or lower the window, and can have advanced features such as speed control to reduce mechanical binding and pinch detection. A 48V power supply drives the DC motor responsible for window movement. A full-bridge driver translates the PWM signals of the MCU into high-current motor-driving voltages, controlling the MOSFETs and, therefore, the operation of the motor.

In this example block diagram, a single DRV8263-Q1 full-bridge driver or two DRV8163-Q1 half-bridge drivers connect directly to the 48V supply to control the brushed 48V window lift motor. Designers can use TI's junction Temperature Calculator tools to evaluate which option is better based on the current profile for the window lift. [6],[7]

A buck converter produces the supply for the TLIN4029A-Q1, which connects to the vehicle's LIN network, and which survives faults up to ±70V.
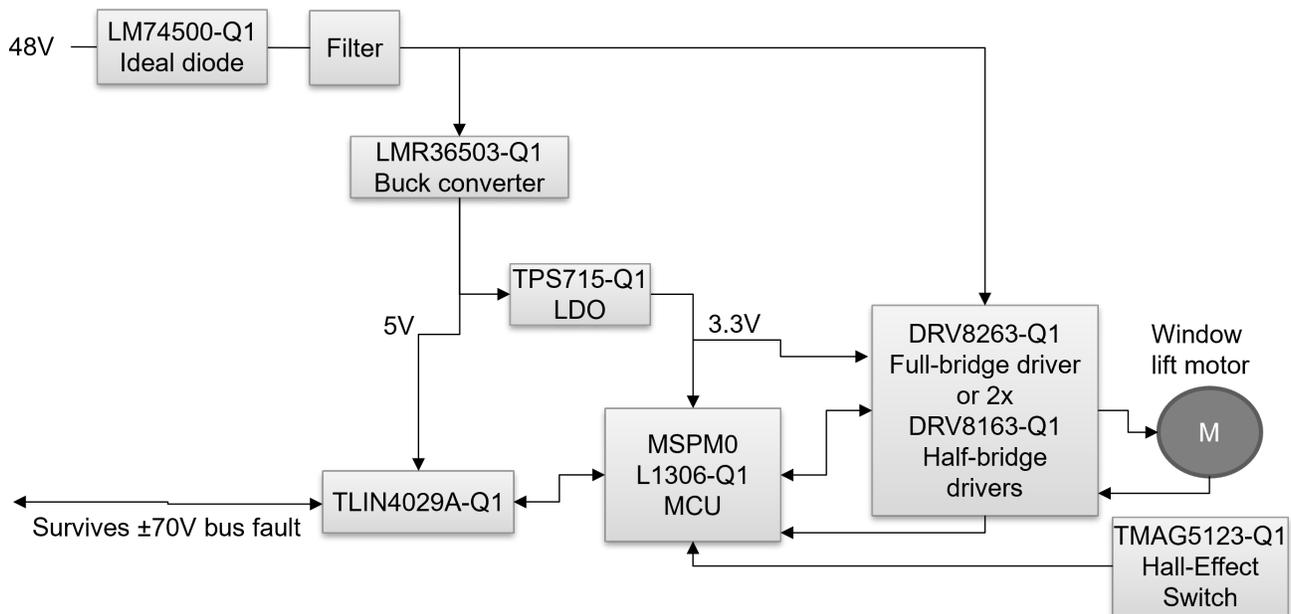

Figure 2-2. Example 48V Window Lift Block Diagram

The low-drop-out (LDO) voltage regulator supplies 3.3V for the microcontroller (MCU), the logic in the motor drivers, and the Hall-effect sensors which give position feedback.

Note that many of the design characteristics of a window lift are similar to other body applications such as power sunroof.

2.3 Wiper

The wiper system, when powered by the 48V rail, uses a rotary motor, either DC brushed or brushless (BLDC), to actuate the wiper mechanism. The driver controls the speed of the motor or drives to the park position based on user settings and optional rain sensor input. Motor current and motion information can be fed back to the MCU for precise control.

Typically front wipers have two speeds, as well as intermittent operation. If the motor is brushed type, it often has two windings, one for each speed. Newer designs may use 48V brushless motors which can be more efficient and long-lived. The speed of a brushless motor can be controlled by adjusting the phasing of the electrically commutated drive voltages.

An example block diagram for a 48V wiper module using a BLDC motor is shown in Example 48V Window Lift Block Diagram.
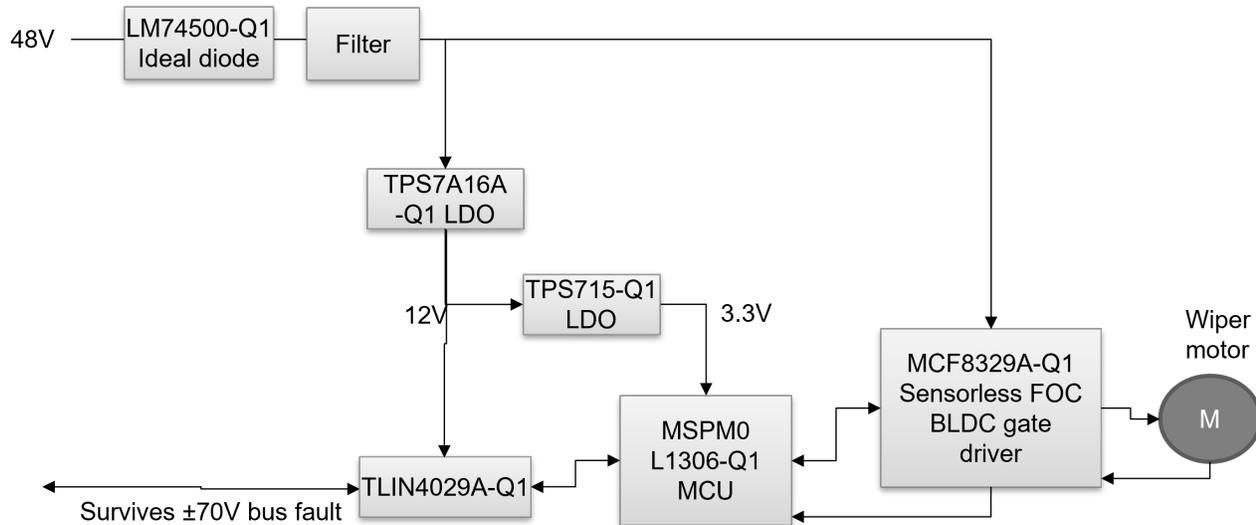

Figure 2-3. Example 48V Windshield Wiper Block Diagram

The MCF8329A-Q1 BLDC gate driver shown in this example includes a 50 mA 3.3V regulator able to supply up to 50mA to external circuits. This regulator is disabled when the chip is in low-power sleep mode, but if the 48V supply to the wiper ECU is switched by an upstream Zone module or power distribution box, the regulator integrated in the MCF8329A-Q1 can be used rather than the TPS7A16A-Q1 regulator.

2.4 Power Seat

Similar to other multifunction body applications, the power seat system utilizes 48V to power the multiple high-power DC motors responsible for seat adjustments. Each motor has a either a dedicated full-bridge driver or shared half-bridge drivers for controlling the movement based on user input from the seat control switches. Similar to the door module, the higher-current motors are the first to transition to 48V, with the low-current actuators remaining on a 12V supply for the time being. Motors driving intermittent functions such as position adjustment typically use brushed motors, while functions that run more continuously, such as seat fans, typically use brushless motors.

Figure 2-4 shows an implementation that drives high-current motors directly from the 48V supply, while lower-current loads remain as 12V loads, requiring a step-down regulator to produce a 12V supply.
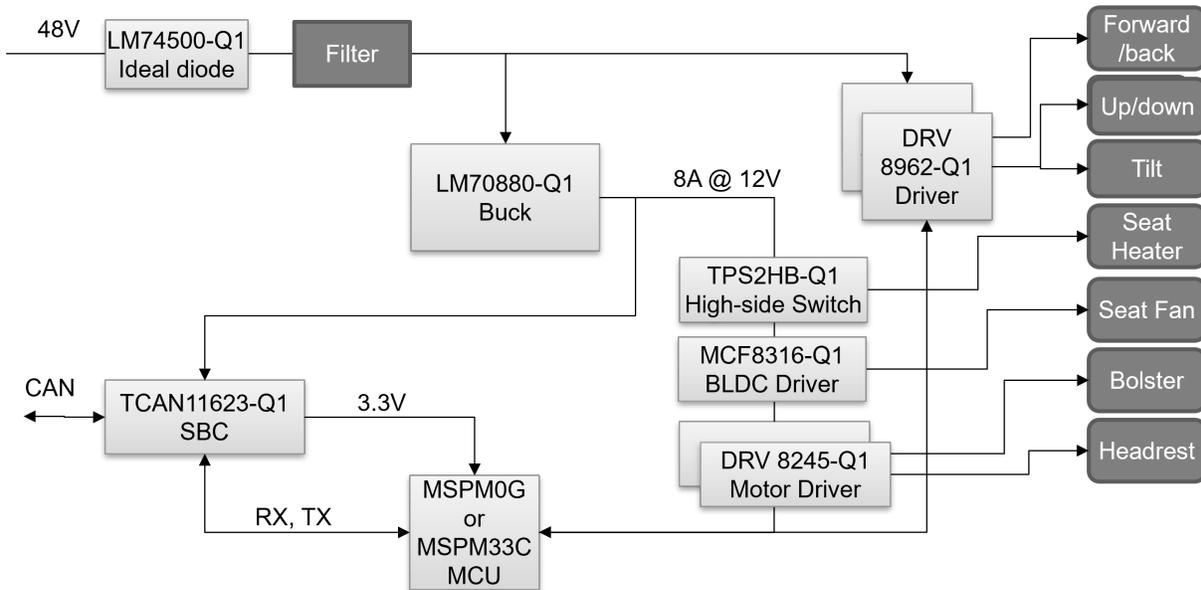

Figure 2-4. Example 48V Seat Module Block Diagram

3 Benefits of 48V Supply

Switching from a 12V supply to a 48V supply has advantages for designers developing body motor applications. Beyond the architecture-level reduction in wire harness cost and weight, these advantages leverage the lower current needed by 48V designs to offer higher integration, smaller board size, and enhanced features.

3.1 Increased Integration of Half-Bridges with 48V

With the adoption of 48V systems, there is a trend towards increased integration of half-bridges within integrated motor driver ICs. Compared to using gate drivers with discrete MOSFETs, integrated driver designs offer:

- Smaller form factor: Integrating multiple half-bridges and control logic into a single package reduces the overall size of the motor driver circuit.
- Reduced complexity: Designing with integrated drivers simplifies the circuit board layout and reduces the number of external components, leading to a more streamlined design.
- Enhanced features: Integrated drivers can incorporate additional features like integrated current sense using current mirrors, temperature sensing of the integrated drive stages, fully-integrated diagnostics, and advanced control algorithms like trapezoidal or Field-Oriented Control (FOC).

3.2 Size Comparison Between 48V Integrated Driver vs 12V Gate Driver

Not only do integrated 48V drivers offer benefits such as reduced complexity, a comparison of size to traditional 12V gate driver implementations reveals interesting trade-offs.

Integrated Drivers: Integrated 48V drivers typically integrate the final drive stage MOSFETs and their gate drive circuitry into a single package. The package size and die cost of motor drivers increases significantly for lower RDS(on) (on-state resistance) values. Thus, due to the lower current requirements, 48V drivers can occupy a smaller board area for similar power capabilities compared to 12V gate driver plus external MOSFET implementations.

One limitation on shrinking the 48V driver package to take advantage of the smaller die size is the requirement that 48V signals must be physically separated from other signals by larger distances than 12V signals. These creepage and clearance specifications bound how small 48V driver packages can be, regardless of reduction in die size due to lower drive currents.

Gate Driver and External FETs: A traditional 12V gate driver combined with external MOSFETs, while potentially taking up more board space for a given RDS(on), allows for greater flexibility in selecting the preferred external FETs for the application, potentially achieving lower RDS(on) and better thermal performance. So designers must consider this in evaluating the benefits and drawbacks of converting from 12V to 48V.

3.3 Example Placement Study

Figure 3-1 shows a board size comparison between two similar designs for a bi-directional brushed DC motor, such as a window lift. This application typically requires a peak power of 300W or less, and typical operating power around 100W.

The left image, a 12V design using the DRV8706-Q1 gate driver and four external n-channel MOSFETs, is preferred for motor currents typical of window lifts, around 20A peak and 8A in steady-state (although intermittent) operation. By choosing appropriate MOSFETs with low RDS(on) values, this design can be extended to higher currents.

The right image, a 48V design using the DRV8263-Q1 integrated full-bridge motor driver, is also preferred for window lift applications, with significant board size savings. The current levels with a 48V supply are less than 10A peak and only a few amps in steady-state operation. Note that beyond the reduction in driver size due to reduced current, the integration of the full-design into a single chip reduces the size of external components, most significantly the elimination of the large shunt resistor.
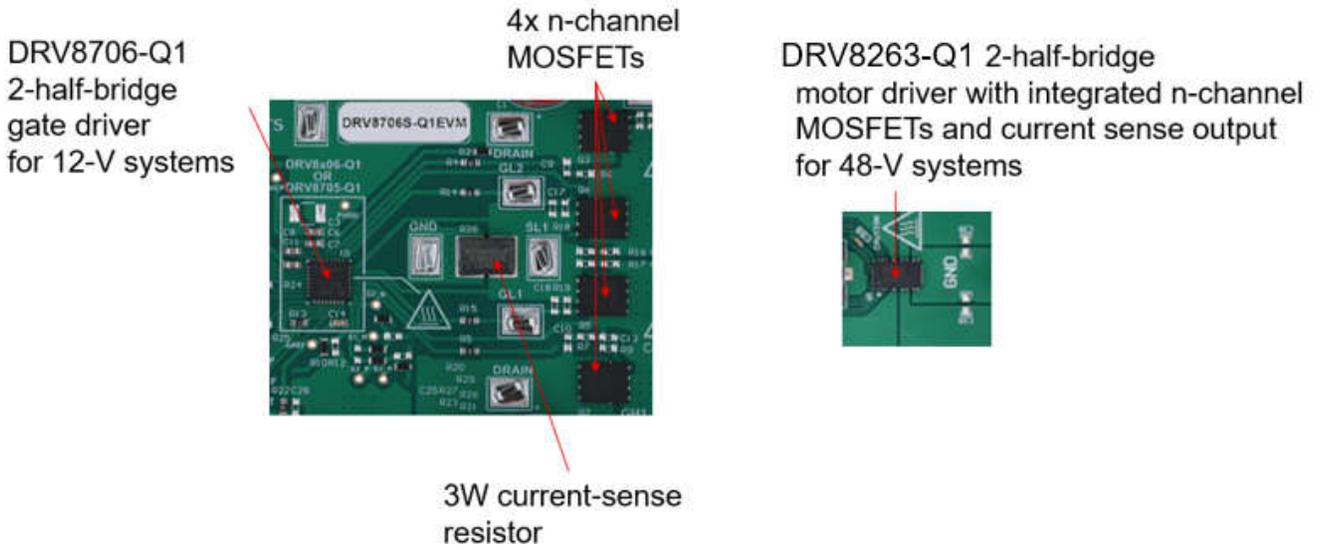
Figure 3-1. Comparison of Board Size for 12V and 48V Full-Bridge Motor Drivers

4 Thermal and EMC Performance Trade-off Considerations

The transition from the conventional 12V electrical system to a 48V system in automobiles, particularly for body motors, presents significant thermal and electromagnetic compatibility (EMC) challenges and trade-offs. While a 48V system offers numerous benefits such as reduced wire harness weight and cost, improved efficiency, and enhanced power for advanced features, this requires a careful consideration of these factors.

4.1 Conduction Losses in the MOSFETs

Consider a specific example where a brushed motor with a continuous power load of 240W is required. For a 12V system, this gives a motor current of 20A, while for a 48V system, the current is only 5A.

For comparison, assume either design requires 99% of the electrical power to be delivered to the motor, so that the losses in the driver must be 2.4W or less. For the 12V system, this means the on-resistance of the driver stage, high-side and low-side transistors, must be less than 6mOhms total.

$$R_{LS+HS} = \frac{P_{loss}}{I_{motor}^2} = \frac{2.4W}{20A^2} = 6m\Omega \tag{1}$$

Motor drivers are not widely available with integrated MOSFETs having this low RDS(on), so gate drivers such as the DRV8706-Q1 with external MOSFETs is the typical design for these requirements.

For the 48V system, the on-resistance of the driver stage, high-side and low-side transistors, can be as high as 96 milliohms for the same allowable power loss in the driver.

$$R_{LS+HS} = \frac{P_{loss}}{I_{motor}^2} = \frac{2.4W}{5A^2} = 96m\Omega \tag{2}$$

Motor drivers for 48V systems such as the DRV8263-Q1 integrate MOSFETs with on-resistance that is typically lower than 96mΩ, allowing a much smaller board size option.

4.2 Switching Losses During PWM

The story is more complicated if pulse-width modulation (PWM) is used to operate the motor at less than full speed. Now switching losses, as well as conduction losses must be considered.

Each time the drive-stage MOSFETs switch on or off, there is a short period of time when the transistor is operated in the linear region, meaning the current is not zero, and the voltage across the channel is greater than when the transistor is fully on. During this time, the power dissipation in the transistor reaches a maximum. The circuit simulation in Figure 4-1 illustrates this as the transistor T1 switches from an off state with no current flowing to an on state. The power dissipation in the transistor is shown as PM1, and reaches a maximum when the current and voltage across the transistor are midway through the transition.
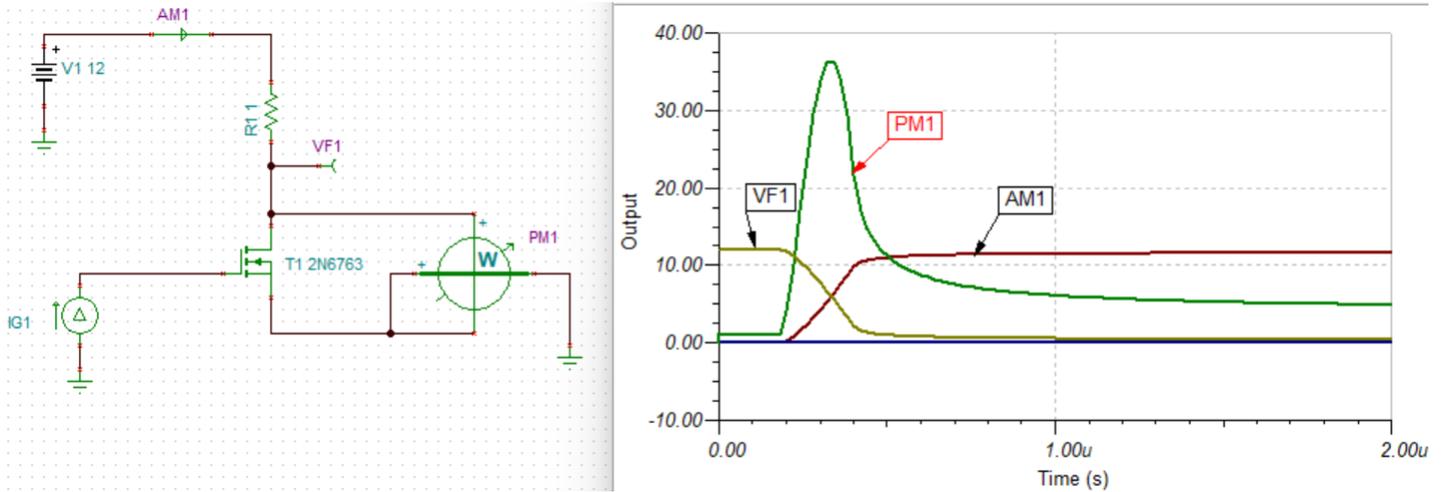

Figure 4-1. Simulation Showing Switching Power Dissipation

Note that before the transistor turns on, the power dissipation is essentially zero, since no current is flowing. After the transistor turns on, in the conduction phase of operation, the power dissipation is the product of the steady-state current and the voltage across the transistor, which is relatively low.

The instantaneous power dissipation in the drive transistors is a product of the voltage across the drain-to-source channel and the current through the channel. A simplified mathematical model of the instantaneous power assumes a linear slope on both the rising and falling transitions. With these simplifications, we can model the power dissipation as:

$$P(t) = V(t) \cdot I(t) \tag{3}$$

$$P(t) = I_{max} \cdot \left(t/t_{rise}\right) \cdot \left(V_{supply} - I_{max} \cdot 2 \cdot R_{DS(on)}\right) \cdot \left(1 - t/t_{rise}\right) + \left(I_{max} \cdot 2 \cdot R_{DS(on)}\right) \cdot \left(I_{max} \cdot t/t_{rise}\right) \tag{4}$$

For an apples-to-apples comparison, we can calculate the power dissipation for equivalent 12V and 48V cases. In both cases we will deliver about 48 Watts to a load during steady-state operation, so the 12V system requires a current of 4A, and the 48V system requires a current of 1A. Select MOSFETs for each case so that during steady-state operation the drive delivers 99.7% efficiency to the load; thus about 160 mW is dissipated in the MOSFETs. So the 12V system uses MOSFETs with RDS(on) of 10mOhms, and the 48V system uses MOSFETs with RDS(on) of 160mOhms In both cases, the maximum instantaneous power dissipated in the MOSFETs is 12W, as shown in Figure 4-2.
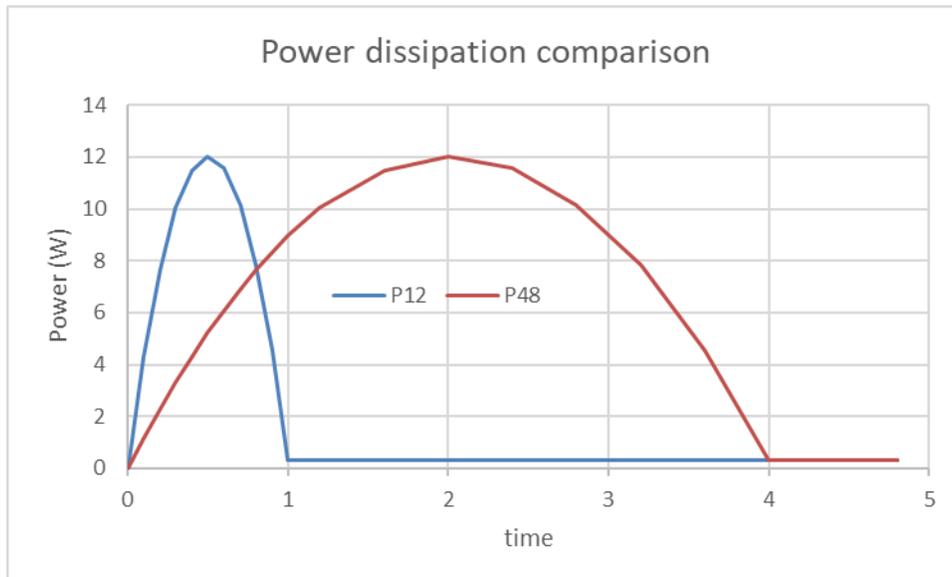
Figure 4-2. Instantaneous Power Dissipation for Equivalent 12V and 48V Systems

The key result is that for equivalent systems in terms of steady-state performance, if the slew rates are equal, the 48V system dissipates the switching power for a duration of 4 times as long as the 12V system. The total energy dissipation is the area under each of the curves in Figure 4-2. It is this energy that can significantly heat the transistors during PWM operation.

Figure 4-3 shows voltage transitions for integrated motor drivers with adjustable slew rates, the DRV8245-Q1 with a 12-V supply and the DRV8363-Q1 with a 48-V supply. Note that the slope is not constant during the rising edge, but the total transition time correlates to the inverse of the slew rate setting. As expected, the rise time of the 48-V device, with a slew rate setting of 19V/us, is about four times longer than the rise time of the 12V device with a slew rate of 20V/us.
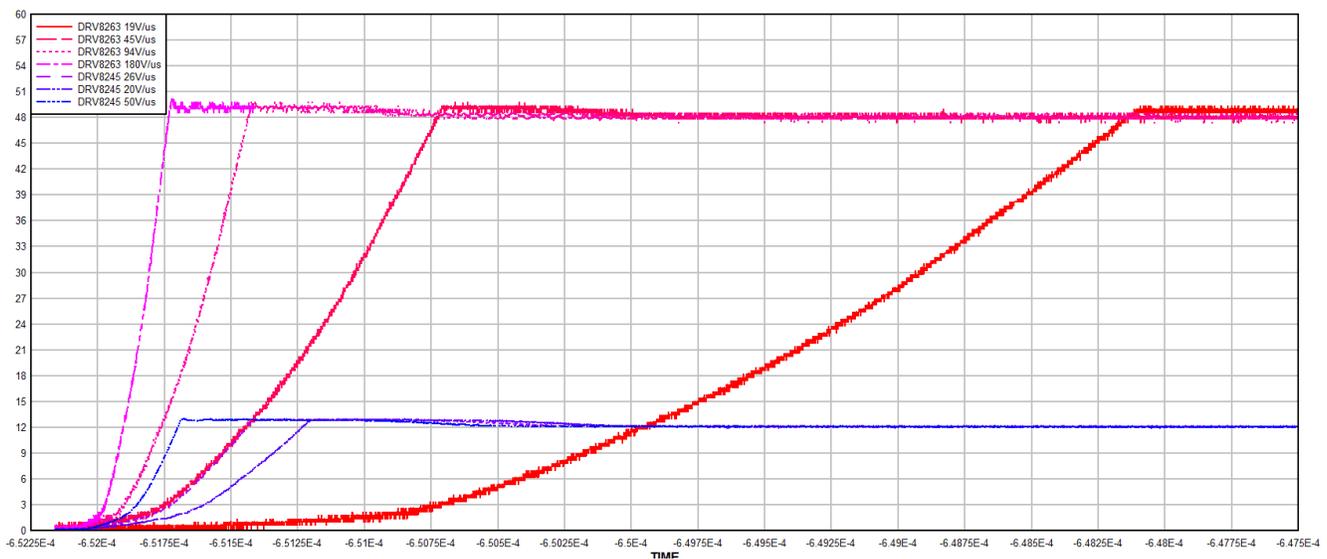

Figure 4-3. Comparison of 12V and 48V Voltage Transitions with Various Slew Rate Settings

To reduce the power dissipation, we want to get through the transition phase quickly. Thus we want a fast slew rate, reducing the rise time and fall time for the drive stage transistors. Adjustable slew rate settings give this flexibility. However, as this document discusses later, fast slew rates impact electromagnetic emissions, due to the larger high-frequency content in fast signal edges.

4.3 Experimental Results Show Effect of Slew Rate on Transistor Temperature During PWM

Experimental results support the theoretical relationship between the slew rate and thermal power dissipation for 12V and 48V supply conditions. The test conditions were PWM switching at 20kHz, with 50% duty cycle. The load was 3Ω in series with 1mH for the 12V device, simulating a motor operating at 24W. For the 48V device, the load was 48Ω in series with 1mH, again simulating a motor operating at 24W. The resulting measurements are shown in Table 4-1 and plotted in Figure 4-4.

Table 4-1. Experimental Measurements of Temperature Rise vs. Slew Rate

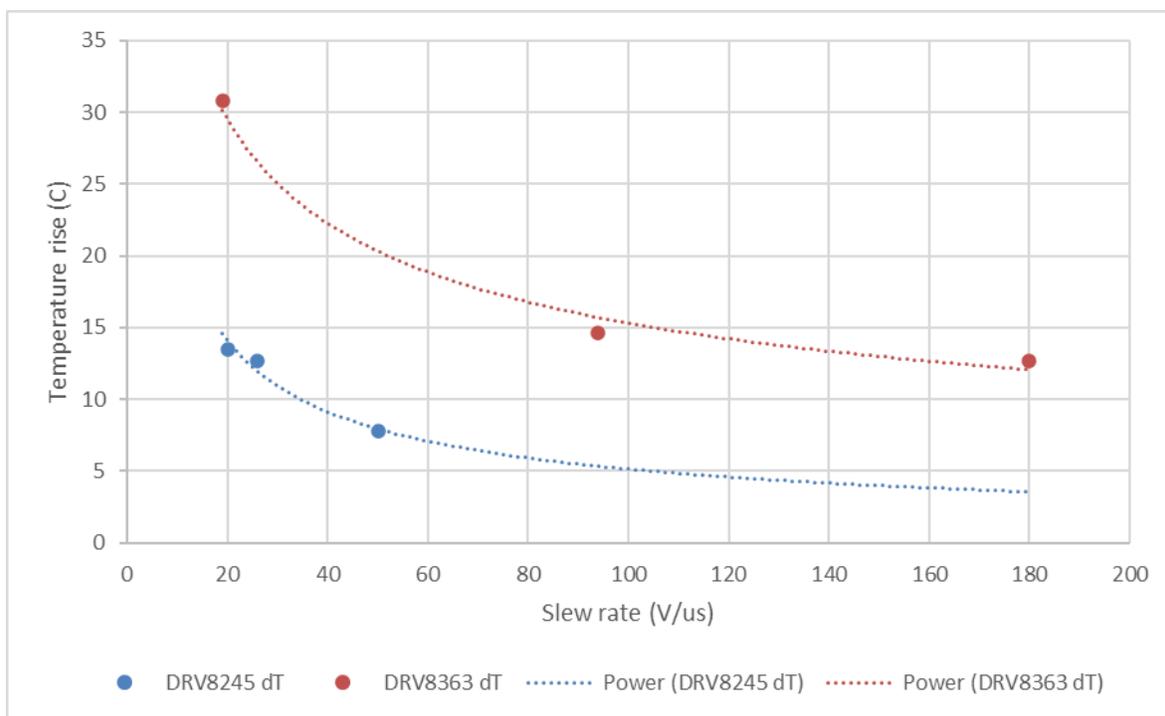| Device	Supply (V)	Slew rate setting(V/us)	Temperature rise (C)
DRV8245	12	20	13.5
DRV8245	12	26	12.7
DRV8245	12	50	7.8
DRV8263	48	19	30.8
DRV8263	48	94	14.6
DRV8263	48	180	12.7

Figure 4-4. Device Temperature Rise vs. Slew Rate, 12V and 48V Devices

The thermal images in Figure 4-5 show the relationship between supply voltage, slew rate, and temperature rise. The temperature rise with a 12V supply and 20V/us slew rate is about 9 C. With the same slew rate, the temperature rise with a 48V supply is about 24 C. To reduce the temperature rise, the slew rate for a 48V supply can be increased; in this case a slew rate of 180V/us gives about the same temperature rise as the case with a 12V supply with 20V/us slew rate.
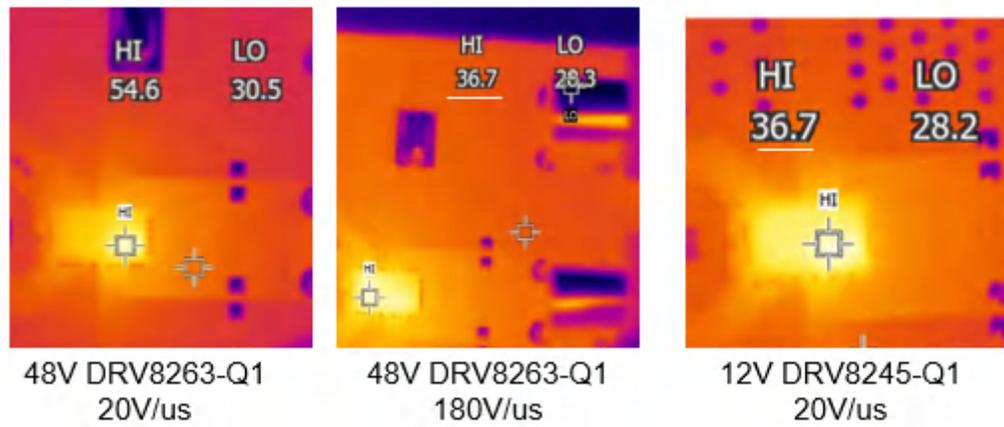
48V DRV8263-Q1 20V/us   48V DRV8263-Q1 180V/us   12V DRV8245-Q1 20V/us

Figure 4-5. Comparison of Driver Temperature, 48V and 12V

The conditions for these measurements are shown in Table 4-2 .

Table 4-2. Test Conditions for Thermal and EMC Measurements

Device	Duty Cycle	Frequency	VM	Load
DRV8245-Q1 VQFN-HR	50%	20kHz	12V	3Ω + 1 mH
DRV8263-Q1 VQFN-HR	50%	20kHz	48V	48Ω + 1 mH

4.4 Fast Slew Rates Impact Electromagnetic Emissions

As we increase the slew rate to reduce power dissipation during switching, an unintended consequence is that the energy in the high-frequency harmonics of the PWM fundamental frequency increases.

If the rising and falling edges are very fast, the PWM voltage can be modeled as a square or rectangular signal, with the well-known harmonics depending on the fundamental period and duty cycle. When the transitions are slower, the PWM voltage is modeled as a trapezoidal signal. From Figure 4-6 we see that a plot of the voltage spectrum envelope has a first roll-off frequency that is determined by the on-time τ which is set by the duty cycle, and a second roll-off frequency that is determined by the rise time $τ_r$, which depends on the slew rate setting.
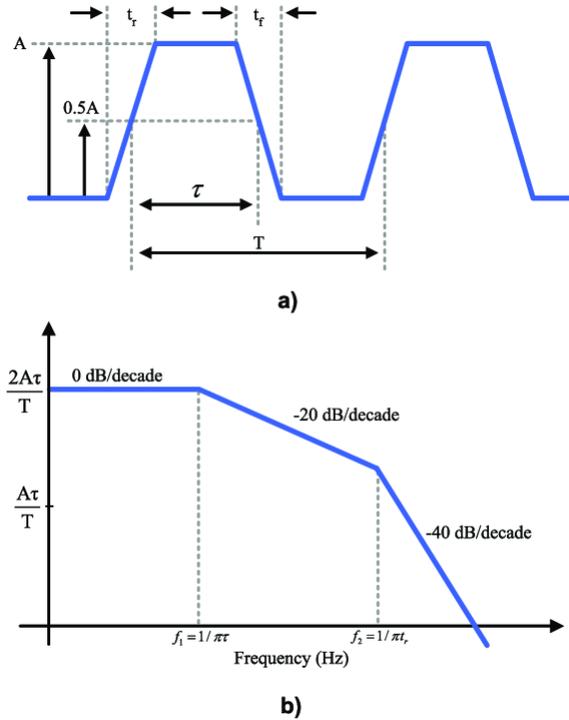

Figure 4-6. Relationship Between Trapezoidal PWM Signal and Harmonic Frequency Envelope [1]

Experimental results illustrating this theoretical relationship between slew rate and emission amplitude are shown in the comparison below. Using the same test conditions as the thermal experiments, we measure the conducted emissions in the 150kHz to 10MHz range, for a 48V motor driver.
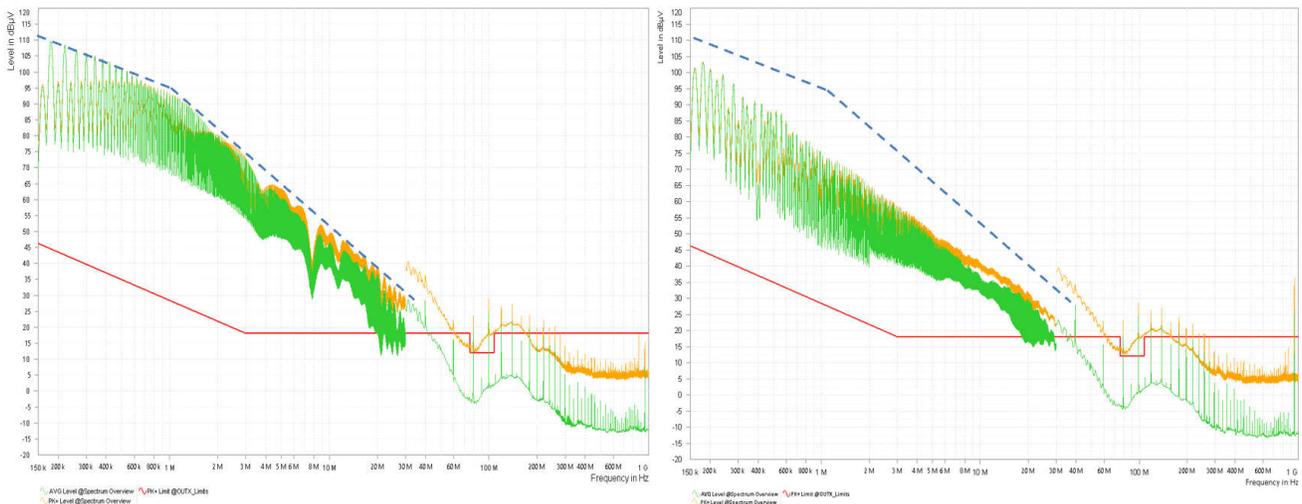

Figure 4-7. Emissions Comparison with Slew Rate 180V/us (Left) and 20V/us (Right)

The plot on the left shows the measured emissions with a slew rate of 180V/us. The right plot shows the emissions with a slew rate of 20V/us. The emissions with a faster slew rate are significantly higher than with a slower slew rate. The dashed line in the plot on the right (slower slew rate) reproduces the envelope of the emissions with the faster slew rate. The reduction in emissions in the 400kHz to 4MHz band is on the order of 20dB.

A similar effect is seen in the radiated emissions of a brushless motor driven by the DRV8363-Q1. The figure below shows two spectra with a BLDC motor operating from a 48V supply. On the left, the gate current to the drive stage MOSFETs is set to 250mA charging and 500mA discharging, giving relatively fast slew rates. On the right plot, the gate current is reduced, resulting in slower transitions, and as expected, the emissions characteristics are improved.
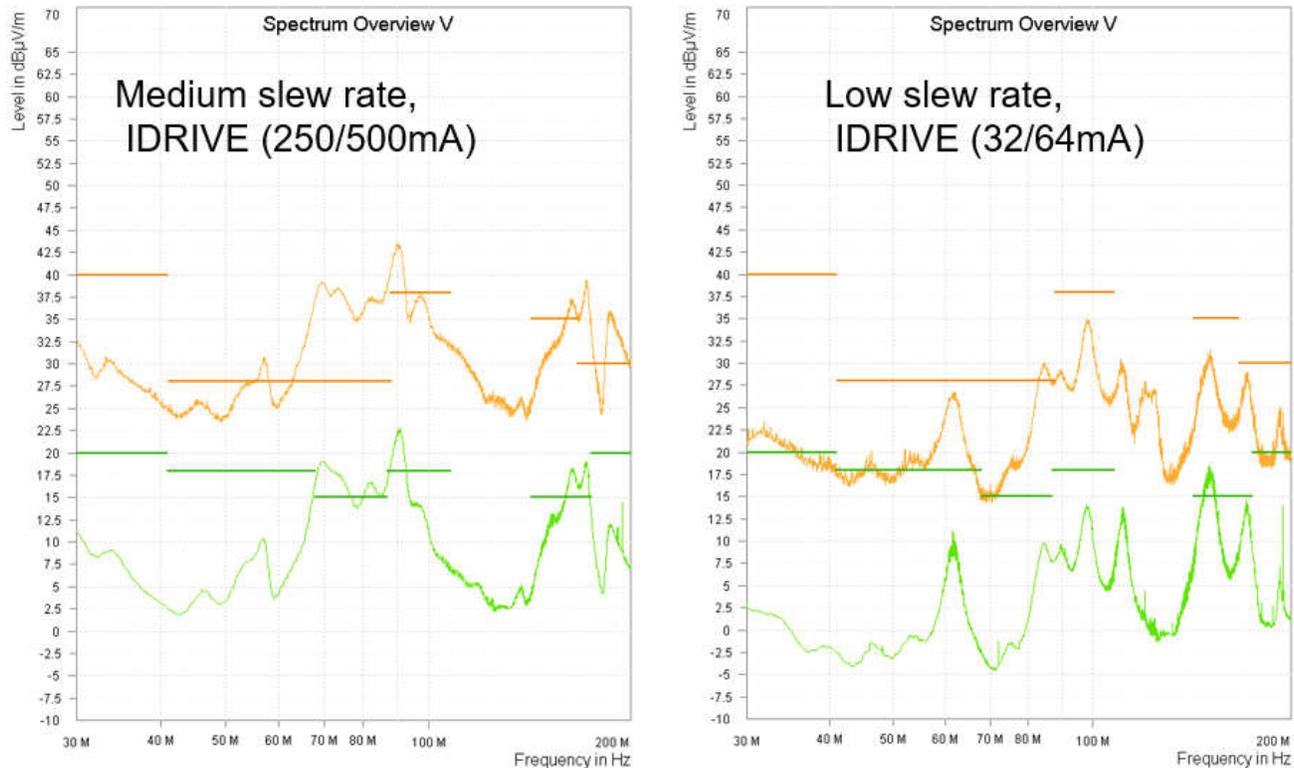

Figure 4-8. Radiated Emissions with BLDC Motor

So, while fast transitions are beneficial to reduce the power dissipation and simplify the thermal design, with regard to electromagnetic compatibility, slower slew rates are more desirable. Designers will find a balance by considering the overall system including heat dissipation measures and best practices for emissions reductions.

5 Summary

In summary, the transition to 48V systems in automotive applications presents both opportunities and challenges for body motor applications. While increased integration of half-bridges offers benefits in terms of size and complexity, thermal management and EMC performance need careful consideration, especially for applications such as window lifts and power seats. The choice between integrated and gate driver designs depends on specific design priorities and application requirements.

The shift to 48V systems for automotive body motors demands a holistic approach that considers both thermal and EMC aspects throughout the design and development process. Careful selection of components, optimized thermal management strategies, and robust EMC design techniques are essential to reap the benefits of 48V systems while verifying the reliability, safety, and functionality of the overall automotive electrical system.

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7. DRV826X-Q1 Junction Temperature Calculator, DRV826X-Q1-JUNCTION-TEMPERATURE-CALC Calculation tool | TI.com

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Last updated 10/2025