

Application Note

MOSFET Selection for DC Motor Control Applications

(AN-002)

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1.Introduction

One of the most important and quickly growing markets for discrete MOSFETs in the voltage range of 30V to 150V is motor control. An unprecedented need for dependable, small, and effective motor drive solutions has been fuelled by the growth of battery-powered tools, home appliances, electric cars, and industrial automation. This application note offers thorough guidance for choosing the right MOSFETs for motor control applications, particularly for brushed DC motors, brushless DC (BLDC) motors, and stepper motors.

The selection of an appropriate MOSFET for motor control differs significantly from power supply applications due to the unique characteristics of motor loads. Motors present highly inductive loads with substantial inrush currents, back-EMF transients, and in many cases, prolonged stall conditions that can stress the switching devices. Compared to power supplies, motor controllers operate at a significant low frequency, making conduction losses and switching losses important criteria for selection. Thus, understanding different cases is essential to select the right MOSFET for applications.

This document is intended for power electronics engineers, motor drive designers, and application engineers who are responsible for selecting and implementing MOSFET-based motor control solutions.

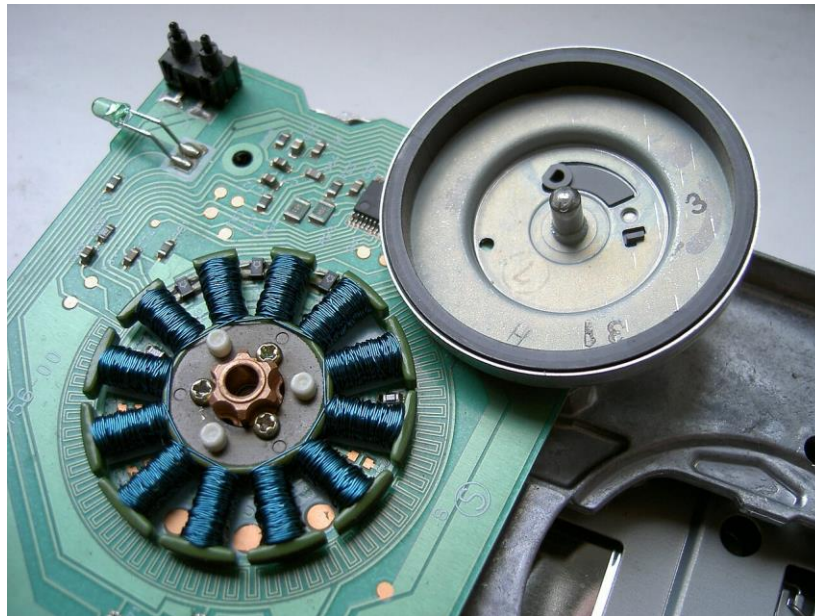


Figure 1: DC Motor in a compact drive disk

2. Fundamental Selection Criteria

2.1 Breakdown Voltage Selection and Margin Analysis

The drain-to-source breakdown voltage (V_{DS}) represents the maximum voltage that the MOSFET can withstand in its off-state before avalanche breakdown occurs. While selecting MOSFETs for motor control applications, the consideration of not just nominal voltage but also various transient conditions.

Transient conditions are important since highly inductive nature of motor windings cause voltage transients for motor controller. When current through an inductor is interrupted, the collapsing magnetic field generates a voltage spike according to the relationship $V = L(di/dt)$. During hard switching events, motor deceleration, and fault conditions, these transients can be substantial. Also, in case of brushed DC motors, significant electrical noise is created due to commutator arcing.

Power electronics designer can take 50% or more above the maximum input voltage margins in power supply design as per traditional approach. However, motor control applications allow for more aggressive margins due to their generally lower switching frequencies. Lower switching frequencies result in slower current transitions and therefore lower di/dt values, which in turn reduce the magnitude of inductive voltage spikes.

Thus, a practical rule of thumb for motor control applications is to maintain approximately a 40% margin between the maximum input voltage and the MOSFET breakdown voltage. This margin can be adjusted by approximately $\pm 10\%$ depending on several factors.

Thumb rule:

In general, MOSFET V_{DS} should be **1.4** times the maximum input voltage. In harsh conditions, MOSFET V_{DS} should be **1.5** times the maximum input voltage.

When the motor control circuit will operate in an environment with well-controlled input voltage and minimal external noise, designers may reduce the margin toward 30%. Conversely, applications operating from automotive electrical systems, which are subject to load dump transients and other electrical disturbances, should maintain margins of 50% or higher. The willingness to implement external passive snubber networks also influences the required margin. A well-designed RC snubber can effectively clamp voltage transients

and allow for more aggressive MOSFET voltage ratings, though this comes at the cost of additional components, PCB space, and design complexity.

Practical Example

Consider a practical example of a cordless power tool operating from a nominal 24V lithium-ion battery pack. The fully charged voltage of such a pack typically reaches 28V, which should be considered the maximum input voltage. Applying the 40% margin guideline yields a minimum required breakdown voltage of 39.2V.

In practice, this would lead to the selection of either a 40V or 60V rated MOSFET, depending on availability and other performance characteristics. The 60V device provides additional margin and may be preferable in noise-prone environments or when snubber circuits are to be avoided.

2.2 Package Selection and Power Density Considerations

Package selection represents perhaps the most critical decision in MOSFET selection for motor control applications. The package fundamentally determines the achievable power density, thermal performance, mounting options, and cost structure of the final design. The package choice depends entirely on the current handling requirements, available PCB space, thermal management strategy, and cost targets of the application.

P Package

The upto 30A current range is suitable for 5mm × 6mm PR packages. This package size has become the de facto standard for battery-powered hand tools, kitchen appliances, vacuum cleaners, and similar consumer products. Sagar Semiconductors' P-PACK 5 x 6 and P-PACK 8 x 8 are optimised for silicon capacity, thermal performance, and PCB footprint. These packages feature a large exposed thermal pad that can dissipate 2W to 5W of heat depending on the PCB thermal design. This heat dissipation is sufficient for many motor control applications when appropriate low-resistance devices are selected.

Through-hole Packages

Beyond 30A, designers face a critical decision point. One option is to parallel multiple MOSFETs to share the current load. This approach works well when PCB space is available and can improve reliability through redundancy. The other alternative is to move to physically larger packages that can accommodate more silicon area and provide superior thermal performance.

Traditional through-hole packages such as the Transistor Outline TO-220 and TO-247 have long been the standard for high-current motor control applications exceeding 30A to 40A. These packages offer several key advantages. First, they can house significantly larger silicon dies than surface mount packages, enabling lower on-resistance and higher current handling capability. Second, they feature metal tabs that can be directly bolted to external heatsinks, allowing heat to be efficiently removed from the system. This is particularly important in high-power continuous-duty applications such as industrial motor drives, where the MOSFET may need to dissipate 10W or more continuously.

The primary disadvantages of through-hole packages are: 1) their larger PCB footprint; 2) the requirement for through-hole manufacturing processes (which are more expensive than pure surface mount assembly); 3) increased parasitic inductance due to the wire bond connections and package geometry; 4) less flexibility in high-density three-dimensional PCB designs.

SMD Packages

To address these challenges of through-hole packages, Surface Mount Devices with packages TO-252 and TO-263 are popular in motor controller designs. These packages have compact PCB footprints and help in reduced expenses for assembly. **Sagar Semiconductors** has TO-252 parts like, [SUN2009](#), and TO-263 parts like [SBN10168](#) in these packages. But these parts still have high parasitic and internal drain-source resistance due to leads.

To overcome these challenges, Transistor Outline Lead-Less (TOLL) and Transistor Outline Lead-less Top (TOLT) packages are popular in the industrial drives. These packages are compact and have often less on-state resistance, proving to be optimal for advanced, compact, and efficient designs. Sagar Semiconductors has TOLL parts like [SLN10379](#), [SLN10449](#), and TOLT part [SLTN10446](#) that are popularly used in the industry, apart from other components.

Current range	Package	Application	Part Numbers
10A - 30A	P-PAK 5X6	Kitchen appliances, Vacuum cleaners	SZN10146
	P-PAK 8X8	Battery-powered hand tools	SZSN04456
>30 A (Cost-effective)	TO-220	Industrial motor drives	SPN2063
	TO-247		SWN6060
>30 A (SMD)	TO-252, TO-263	Industrial/Automotive motor controller	SUN2009 , SBN10168
>30 A (Compact- Lead Less)	TOLL	Industrial/Automotive motor controller	SLN10379
	TOLT		SLTN10446

3. Thermal Management in Motor Control Applications

Thermal management represents one of the most critical aspects of motor control MOSFET selection. The inadequate thermal design is perhaps the most common cause of field failures in power electronics systems. Unlike digital circuits where power dissipation is relatively modest, power MOSFETs in motor control applications can dissipate significant amounts of power continuously. This power must be efficiently removed to maintain junction temperatures within safe operating limits.

3.1 Surface Mount Devices

The fundamental heat flow path depends critically on the package type. Surface mount devices like P-Pack, TO-263, TO-252, and TOLL packages dissipate heat primarily through conduction into the printed circuit board. The exposed thermal pad on the bottom or top of the package makes direct contact with a copper land on the PCB.

From there heat spreads through the copper layers and is ultimately dissipated to the ambient environment through convection and radiation from the board surfaces. The thermal resistance from junction to ambient ($R_{\theta JA}$) for surface mount devices therefore depends as much on the PCB thermal design as on the package itself.

Effective thermal design for surface mount MOSFETs requires substantial copper area surrounding the device. A common mistake is to provide only the minimum copper pad required for the device footprint without adequate heat spreading area. Best practice calls for connecting the thermal pad to large copper pours on multiple layers of the PCB, with numerous thermal vias (typically 0.3mm diameter) providing vertical thermal conduction paths between layers. A typical design might employ 20 to 40 thermal vias under and around a 5mm × 6mm QFN device, with each via providing approximately 0.2°C/W of thermal resistance improvement.

3.2 Through-hole and Top-cooled Devices

Through-hole packages such as the TO-220 and offer a fundamentally different thermal management approach. While these packages do conduct some heat into the PCB through their leads, their primary thermal path is through the metal tab that extends from the package body. This tab can be bolted directly to an external heatsink, which pulls heat away from the PCB entirely. The heatsink then dissipates this heat to ambient air through convection and radiation from its fins. The thermal interface between the MOSFET tab and heatsink is critical and typically requires a thermal interface material (TIM) such as thermal grease, thermal pad, or phase-change material to fill microscopic air gaps and minimize thermal resistance.

Heatsink selection involves balancing thermal performance, cost, size, and weight constraints. The required heatsink thermal resistance can be calculated once the power dissipation is known and the maximum acceptable junction temperature is determined. Forced air cooling with a fan can dramatically reduce the required heatsink size, with typical thermal resistance improvements of 50% to 70% compared to natural convection, though at the cost of increased system complexity, noise, and potential reliability concerns from fan bearing wear.

4. On-state Resistance

The selection of appropriate on-resistance ($R_{DS(on)}$) represents a fundamental trade-off between electrical performance, thermal dissipation, and device cost. In motor control applications, where switching frequencies are relatively modest compared to switch-mode power supplies, conduction losses dominate the thermal performance of the MOSFET. This characteristic simplifies the selection process compared to high-frequency

applications where switching losses must be carefully balanced against conduction losses through selection of appropriate gate charge and switching speed characteristics.

Understanding why conduction losses dominate requires examining typical motor control operating conditions. Consider a brushless motor drive operating at 20 kHz PWM frequency with a 70% average duty cycle driving 20A of motor current. The MOSFET spends 70% of each PWM cycle in its fully on-state, conducting the full motor current through its on-resistance. During this conduction period, the power dissipation is I^2R , which for a device with 5 milliohms resistance at operating temperature would be approximately 2W. The switching transitions occupy only a tiny fraction of the total cycle time - perhaps 100 nanoseconds for turn-on and 100 nanoseconds for turn-off out of a 50 microsecond period, representing 0.4% of the cycle. Even though the instantaneous power during switching may be quite high, the average switching power is modest because the transitions are so brief.

5. Conclusion

For motor control applications, it is important to select MOSFETs after considering packages, voltages, current, and thermal management.

6. See More

- [AN-001 MOSFET Replacement Strategy for BMS Applications](#)