# Understanding Motor Driver Current Ratings

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**ABSTRACT**

There is much misunderstanding about the current ratings used with motor driver ICs, especially as related to the selection of a motor driver part for a specific application. Complicating matters further is that there is no standard way of specifying current ratings, so the exact meaning of the ratings can differ from one vendor to another and in some cases even between different parts from the same vendor. This application report explains the meaning of the different current ratings applied to motor driver parts and specifically explains the ratings found in TI motor driver device datasheets.

**Contents**



**List of Figures**



## 1 Factors Limiting the Maximum Output Current of a Motor Driver

The maximum drive current obtained from a given motor driver IC is limited by a number of factors. The most restrictive of all these conditions limits the amount of current driven. This current level will depend not only on the motor driver IC, but also the PCB construction, ambient temperature, and other factors.

### *1.1 Thermal Limitations*

Even though a motor driver IC is thought of as a switch or set of switches, it is not a perfect switch. Power is dissipated in the motor driver IC, primarily due to resistive losses which are proportional to drive current, as well as from other sources such as internal quiescent power and switching losses.

The precise calculation of this power loss is complex and a subject of its own (refer to the application report *Calculating Motor Driver Power Dissipation*, SLVA504). For the purposes of this discussion, we will simplify the power loss to that which is dissipated in the FET ON-resistance of the power stage, called $R_{DS(ON)}$.

Since the power switch is resistive when it is conducting current, it dissipates power according to Ohm's law: $P = I^2R$, where I is the DC or RMS current flowing to the load and R is the sum of the $R_{DS(ON)}$ of the output switches. In an H-bridge motor driver, when driving current, there are two switches dissipating power; the high-side switch to the supply, and the low-side switch to ground. Note that stepper motor drivers normally have two full H-bridges in the same IC.

This power dissipation causes the temperature of the device to rise. How much the temperature rises is estimated by multiplying the power dissipated (in watts) by the thermal resistance to ambient temperature, referred to as $\theta_{JA}$. The $\theta_{JA}$ value is variable, as it depends on how well the PCB design can dissipate the heat conducted from the IC. Datasheets typically indicate some value for $\theta_{JA}$ based on a standard PCB construction.

If too much current is driven, the device heats up to a point that would endanger the reliability of the device. Almost all motor driver ICs (all motor driver ICs from TI) have a thermal shutdown circuit disabling the outputs when the die temperature reaches a predefined threshold (typically around 150°C for TI parts).

The maximum die temperature before overtemperature shutdown is a limiting factor for how much *DC* or *RMS* current a motor driver IC can deliver. Maximum die temperature is not typically a limitation of the short-term peak current.

In most cases, the thermal limit is the dominant factor in determining the maximum current a motor driver can provide.

This current level is not simple to calculate, as it depends greatly on conditions that the IC manufacturer does not control, like PCB design and ambient temperature.

For further information about thermal considerations, refer to www.ti.com/thermal.

### 1.2 Overcurrent Protection (OCP) Limitations

The motor driver IC is protected from possible damage or degradation due to excessive current by incorporating some form of overcurrent protection (OCP). Many motor driver ICs and all of TI's motor driver ICs have OCP. OCP circuits generally act to limit the output current to a level that is safe for the silicon. See Section 2 for specific information about TI's implementation.

OCP circuits may provide one or both of the following:

- an analog current limit
- disabling an individual FET or the entire device when some preset current level is reached

Attempting to draw more current than is allowed by the OCP circuit results in a fault or shutdown. Because of this, the OCP circuit maximum current becomes a limitation of the peak current drawn from the device. This peak current is important, for example, when considering the start-up current of a stalled DC motor.

Some devices latch in an *off* state after experiencing an OCP event. Other devices automatically re-start after a short delay. Refer to the device datasheet to see in which mode a particular device operates.

A deglitch circuit is implemented to allow a higher current to flow for a very short period of time. This very brief deglitch time is necessary to allow the high peak current needed to charge parasitic capacitance in the load, which may include intrawinding capacitance and also snubber capacitors typically added to DC motors reducing EMI from brush arcing.

### 1.3 Silicon and Package Limitations

The output FETs, signal routing, and IC package of a motor driver are designed to support a finite amount of current. The limitations include:

- safe operating area (SOA) of the output devices
- IC layout considerations such as the maximum current-carrying capability of metal routing, vias, and contacts on the die
- maximum current-carrying capability of the bond wires that connect the die to the package

A device with OCP takes care of each of these limitations; therefore, the designer does not need to be concerned about damaging the device by applying too much load current.

If a motor driver does not have OCP, do not exceed any absolute maximum current ratings, or the device may be destroyed.

## 2 TI Motor Driver OCP Operation

TI motor drivers all implement a robust OCP scheme preventing damage to the IC in the event of excessive output current. TI devices are protected against dead shorts, or soft shorts, between the outputs, as well as between each output and the supply voltage or ground.

TI's OCP implementation typically includes two components:

- A fast-acting analog current limit, typically tens of nanoseconds, to limit the current in the output to a level that is safe for the IC and the package. It does this by operating the output FET in a linear region, dissipating significant power.
- A digital time is started as soon as the current rises above a predefined threshold, the OCP current. When this timer reaches OCP deglitch time, typically a few microseconds, if the current level is still above the threshold, the output is disabled.

TI implements separate OCP circuits for each output FET, so each FET is protected from shorts to either the supply, the ground, or to other outputs. The OCP circuit is independent of any current regulation (current chopping or $I_{TRIP}$) circuitry and does not depend on any external components.

Figure 1 shows a simplified schematic of the analog portion of a typical TI motor driver OCP circuit. A high-side FET is shown; there is a similar circuit for the low-side FET.

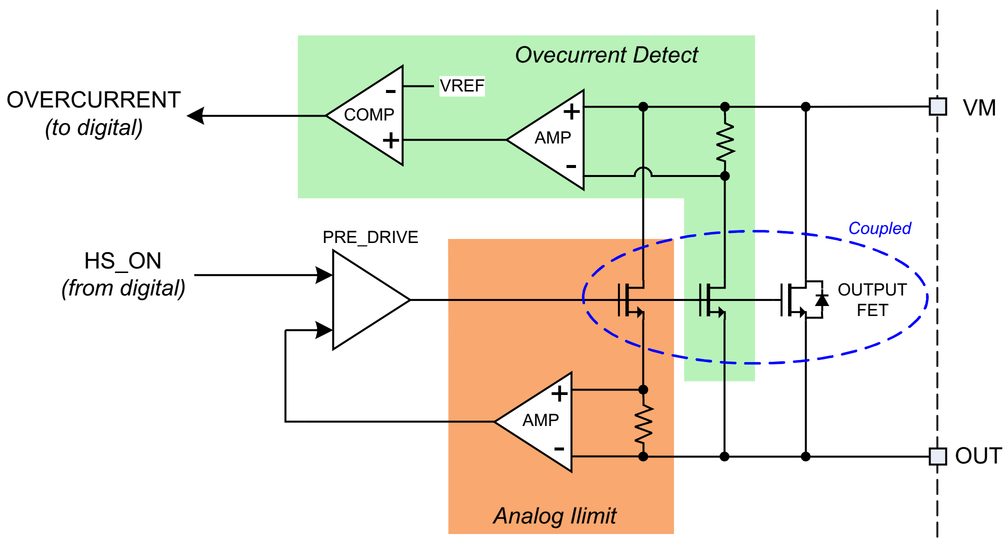


**Figure 1. Simplified OCP Schematic**

Figure 2 shows an oscilloscope capture of a short circuit event using a TI DRV8813 motor driver. In this case, the output was enabled with a direct short across the outputs. The yellow trace is the input signal, the blue trace is the fault-output signal, and the pink trace is the current through the output stage.

Initially, the current rises quickly. After a brief overshoot, which is not a problem for the output stage, the current is limited to approximately 9 A by the analog current limit. In approximately 2.5 µs, as the OCP deglitch time expires, the current is still at the analog current level of 9 A, exceeding the OCP level. In this case, the OCP level is approximately 3 A. At this point, the output is disabled and the current drops to zero. Shortly thereafter, the fault signal is driven low indicating that the OCP event has occurred to the rest of the system.

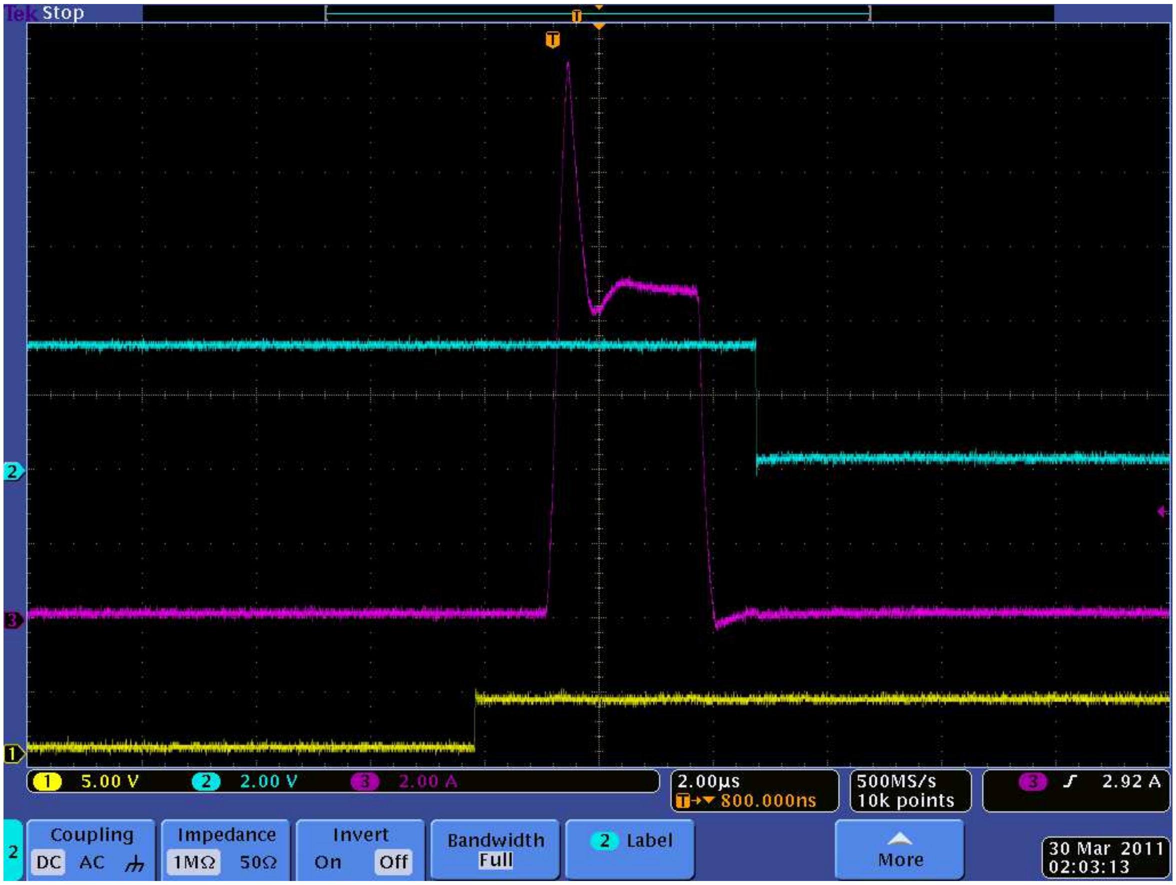


**Figure 2. Oscilloscope Capture of a Short Circuit Event Using TI DRV8813 Motor Driver**

Depending on the individual device, after an OCP event occurs, the device may latch in an off state until some intervention is made by the system (like the application of a reset signal), or the output may automatically re-enable after a delay time.

If the device uses an automatic retry and is operating into a continuous short circuit, the power dissipated by the analog current-limit circuit causes the device to heat up. At some point, the die may reach the overtemperature shutdown temperature. In any case, the device is protected from damage.

## 3 TI Motor Driver Datasheet Ratings

There are several items within a TI motor driver datasheet that relate to the maximum output current. In this section the meanings of these different specifications are explained. As an example, excerpts from TI motor driver datasheets are shown below.

### *3.1 Description*

The description summary on page one of the datasheet, as well as information on ti.com, usually lists the recommended maximum output current for the device:

**FEATURES**

- Dual-H-Bridge Current-Control Motor Driver
  - Capable of Driving Two DC Motors or One Stepper Motor
  - Low MOSFET On-Resistance
- Output Current 1.5-A RMS, 2-A Peak per H-Bridge (at $V_M$ = 5 V, 25°C)

These current specifications are based on thermal limitations as well as OCP current limitations.

In this case, the RMS (or DC) maximum current is calculated as the current that the device can provide at 25°C ambient temperature, when mounted on a standard JEDEC-specified PCB, before it enters overtemperature protection.

This current level *is not attained* at higher ambient temperatures, or on PCB layouts that are not as good at dissipating power as the standard JEDEC PCB. In the actual application, *it may not be possible to drive this much current*. To determine the actual maximum current in a specific application, calculations must be made that take the ambient temperature and PCB thermal resistance into account.

The peak current is limited by the OCP current threshold. The OCP current is specified in the Electrical Characteristics table. Exceeding this current will not damage the device, but it will cause OCP to activate and disable the output.

In some cases, if the $R_{DS(ON)}$ of the FETs is low, the maximum peak and DC or RMS current levels may be identical. In this case, both peak and RMS/DC current is limited by the OCP current, not by thermals. At higher temperatures or on thermally poor PCB constructions, the maximum DC or RMS current decreases, as described above.

## 3.2 Absolute Maximum Ratings

The absolute maximum ratings table lists parameters that can cause damage to the device, if exceeded:

**ABSOLUTE MAXIMUM RATINGS**

| | | VALUE | UNIT |
|---|---|---|---|
| $V_M$ | Power supply voltage range | –0.3 to 11.8 | V |
| | Digital input pin voltage range | –0.5 to 7 | V |
| | xISEN pin voltage | –0.3 to 0.5 | V |
| | Peak motor drive output current | Internally limited | A |
| $T_J$ | Operating junction temperature range | –40 to 150 | °C |
| $T_{stg}$ | Storage temperature range | –60 to 150 | °C |

Note that the peak motor drive output current is not specified as a number, only that it is *Internally limited*. This is because this device has OCP protection; it is not possible to damage the device by drawing too much load current. If the outputs are shorted, the OCP circuit acts to protect the device.

## 3.3 Recommended Operating Conditions

Recommended operating conditions are simply that: conditions that are typically recommended to operate the device within. The device is assured to function correctly within this range.

**RECOMMENDED OPERATING CONDITIONS**
$T_A$ = 25°C (unless otherwise noted)

| | | MIN | NOM | MAX | UNIT |
|---|---|---|---|---|---|
| $V_M$ | Motor power supply voltage range[1] | 2.7 | | 10.8 | V |
| $V_{DIGIN}$ | Digital input pin voltage range | –0.3 | | 5.75 | V |
| $I_{OUT}$ | Continuous RMS or DC output current per bridge[2] | | | 1.5 | A |

(1) Note that $R_{DS(ON)}$ increases and maximum output current is reduced at $V_M$ supply voltages below 5 V.
(2) $V_M$ = 5 V, power dissipation and thermal limits must be observed.

The recommended continuous DC or RMS output current is specified. This recommendation is based on 25°C ambient temperature, on a JEDEC PCB. Pay particular attention to Note 1, stating $R_{DS(ON)}$ increases at higher temperatures, and Note 2, reminding that the power dissipation and thermal limits must be observed. At higher ambient temperatures and/or on a PCB that cannot dissipate power as well as the JEDEC board, this current level *is not attainable* before hitting overtemperature shutdown.

## 3.4 *Thermal Information*

The thermal information table provides data for calculation of how much the temperature of the die rises under a given set of power-dissipation conditions:

**THERMAL INFORMATION**

| THERMAL METRIC | | PWP | RTY | UNITS |
|---|---|---|---|---|
| | | 16 PINS | 16 PINS | |
| $\theta_{JA}$ | Junction-to-ambient thermal resistance | 40.5 | 37.2 | °C/W |
| $\theta_{JCtop}$ | Junction-to-case (top) thermal resistance | 32.9 | 34.3 | |
| $\theta_{JB}$ | Junction-to-board thermal resistance | 28.8 | 15.3 | |
| $\psi_{JT}$ | Junction-to-top characterization parameter | 0.6 | 0.3 | |
| $\psi_{JB}$ | Junction-to-board characterization parameter | 11.5 | 15.4 | |
| $\theta_{JCbot}$ | Junction-to-case (bottom) thermal resistance | 4.8 | 3.5 | |

The $\theta_{JA}$ number for the chosen package gives an estimate of how much temperature rise is expected if the device was mounted on a standard JEDEC PCB. Other data is used to provide an estimate of the thermal resistance on the PCB. For details about this data, please refer to the information at www.ti.com/thermal, including TI application reports IC Package Thermal Metrics (SPRA935A) and Using New Thermal Metrics (SBVA025).

## 3.5 *Electrical Characteristics*

The electrical characteristics tables include specifications showing the maximum current delivered from the motor driver. The first is $R_{DS(ON)}$:

| | | | MIN | TYP | MAX | UNIT |
|---|---|---|---|---|---|---|
| **H-BRIDGE FETS** | | | | | | |
| $R_{DS(ON)}$ | HS FET ON-resistance | $V_M$ = 5 V, $I_O$ = 500 mA, $T_J$ = 25°C | | 200 | | mΩ |
| | | $V_M$ = 5 V, $I_O$ = 500 mA, $T_J$ = 85°C | | | 325 | |
| | | $V_M$ = 2.7 V, $I_O$ = 500 mA, $T_J$ = 25°C | | 250 | | |
| | | $V_M$ = 2.7 V, $I_O$ = 500 mA, $T_J$ = 85°C | | | 350 | |
| | LS FET ON-resistance | $V_M$ = 5 V, $I_O$ = 500 mA, $T_J$ = 25°C | | 160 | | mΩ |
| | | $V_M$ = 5 V, $I_O$ = 500 mA, $T_J$ = 85°C | | | 275 | |
| | | $V_M$ = 2.7 V, $I_O$ = 500 mA, $T_J$ = 25°C | | 200 | | |
| | | $V_M$ = 2.7 V, $I_O$ = 500 mA, $T_J$ = 85°C | | | 300 | |

In this case, the $R_{DS(ON)}$ is specified separately for high-side and low-side FETs, at several power-supply voltages and temperatures. This data is used to estimate the power dissipation inside the device, applying Ohm's law as described in Section 1.1.

The electrical characteristics tables also include information on the OCP and overtemperature shutdown circuits:

| | | | MIN | TYP | MAX | UNIT |
|---|---|---|---|---|---|---|
| **PROTECTION CIRCUITS** | | | | | | |
| $I_{OCP}$ | OCP trip level | | 2 | 3.3 | | A |
| $t_{DEG}$ | OCP deglitch time | | | 2.25 | | µs |
| $t_{OCP}$ | OCP period | | | 1.35 | | ms |
| $t_{TSD}$ | Thermal shutdown temperature | Die temperature | 150 | 160 | 180 | °C |

The OCP trip level ($I_{OCP}$), the maximum amount of current that the device can drive without activating the OCP circuit, is illustrated here. The OCP deglitch time is also listed. If the resulting output current remains above $I_{OCP}$ for at least $t_{DEG}$, then OCP is activated.

This device does automatic re-try in the event of OCP, the device will re-enable the outputs after some period of time. This time is listed here as $t_{OCP}$, the OCP period.

The overtemperature shutdown temperature is also listed in this table. The device shuts down if the temperature, as measured on the die, is exceeded. Typically, the device automatically re-enables itself when the temperature falls to a safe level, 10—40°C below the threshold.

## 4 References

1. *Calculating Motor Driver Power Dissipation* (SLVA504)
2. *IC Package Thermal Metrics* (SPRA935A)
3. *Using New Thermal Metrics* (SBVA025)
4. *PowerPAD Thermally Enhanced Package* (SLMA002G)

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