Application Note

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 note explains the meaning of the different current ratings applied to motor driver parts and specifically explains the ratings found in TI motor driver device data sheets.

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Trademarks

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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 can 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 *Calculating Motor Driver Power Dissipation*, application note). 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 junction-to-ambient temperature, referred to as θ_{JA}. The θ_{JA} value is variable, as it depends on how well the PCB design can dissipate the heat conducted from the IC. Data sheets typically indicate some value for θ_{JA} based on a standard PCB construction.

If too much current is driven, the device heats up to a point that can endanger the reliability of the device. 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).

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 *PCB Thermal Calculator*.

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 data sheet 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 can 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.

1.4 PCB Limitations and Thermal Management Techniques

While thermal limitations exist for the device, several other considerations must be made when designing a printed circuit board (PCB) to meet specified motor driver current ratings.

Thermal management and heat dissipation in PCB design, significantly impact current ratings and motor driver reliability. As motor drivers become more powerful and compact, managing heat is essential in preventing overheating which can make sure operation within safe temperature ranges. Implementing strategic heat dissipation strategies such as proper thermal pad pours and connections, copper thickness, and use of thermal vias can help to enhance PCB performance and improve motor driver current ratings.

1.4.1 Exposed Pad Packages

Certain motor driver packages have exposed pads that are referred to as a thermal pad or PowerPAD™. These thermal pads are located on the bottom of the motor driver and can connect to the landing pad of the PCB. This thermal pad is responsible for most of the device's heat dissipation by creating a low thermally resistive path to dissipate heat away from the die to the landing pad of the PCB. The landing pad is located on the top of the PCB and the size must be the same size or larger than the exposed PowerPad™ of the motor driver. It should also be firmly connected to the bottom ground plane with multiple thermal vias positioned directly underneath.

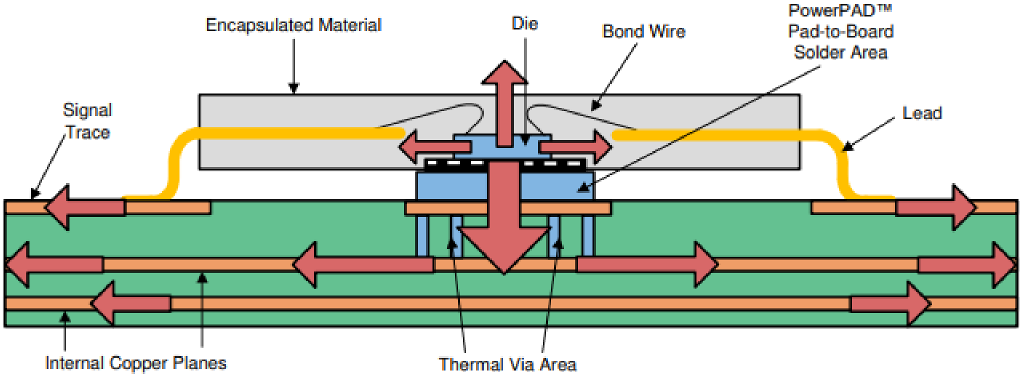


Figure 1-1. Cross Section of Thermal Pad™ Package Mounted to PCB and Resulting Heat Transfer

1.4.2 Continuous Copper Planes

A proper thermal pad connection is critical to provide a low-resistance path to the PCB ground for heat dissipation. These thermal pad connections are made through copper planes that increases the copper area connected to the thermal pad and helps to better dissipate heat. Continuous copper planes make sure effective heat dissipation, preventing overheating and excessive thermal resistance. Interruptions in these planes can lead to higher temperatures both in the device and on the PCB which leads to reduced current carrying capacity.

Connecting the thermal pad to a solid copper plane is crucial for creating a heat exit path from the driver die. To make sure heat flows away from the device, the copper planes must be continuous from the thermal pad to other areas of the board. A best practice is to provide a wide exit path from the copper fill under the driver to a broad, high surface area plane. If these planes are interrupted, the heat exit path becomes constricted, increasing thermal resistance. Higher thermal resistance leads to a greater temperature differential between the thermal pad and the wider surface area on the same plane which can limit motor driver current ratings.

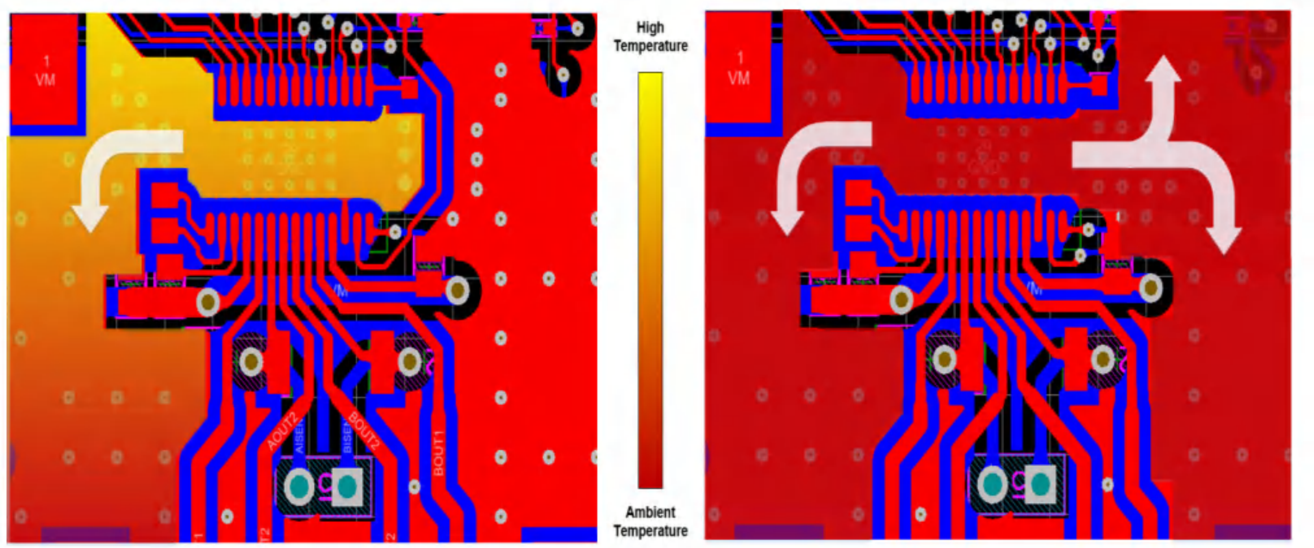
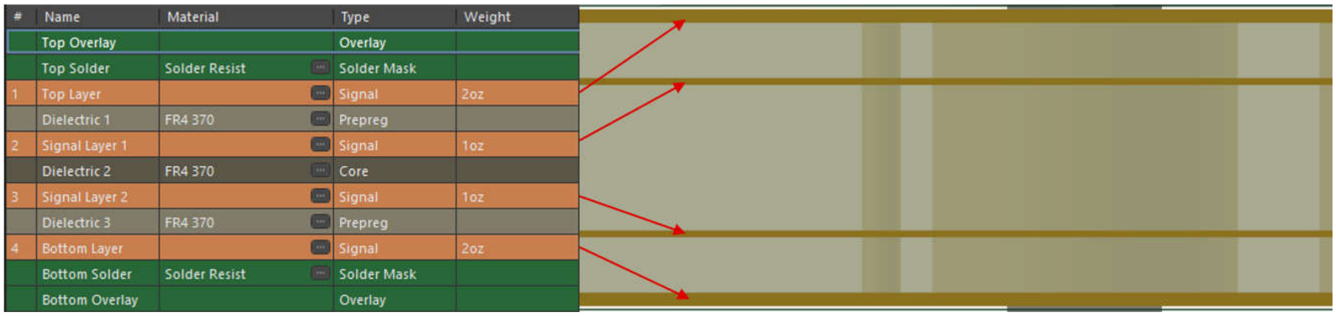


Figure 1-2. Broken Ground vs Continuous Ground Pour Heat Map

1.4.3 Copper Thickness

The thickness of the copper on the plane is crucial for PCB thermal performance. Increasing the copper thickness on the PCB can further decrease the plane's effective thermal resistance. This can enhance the boards ability to conduct and dissipate heat leading to improved reliability and performance, as the traces can be able to safely and efficiently carry more current.

For high-power applications a copper thickness greater than 0.5-oz or 1-oz is recommended to maintain lower operating temperatures. In all TI motor driver EVM designs, the use of 2-oz copper thickness is used on top and bottom layers. In a typical 4-layer PCB design, 2-oz copper on top and bottom layer is used with 1-oz copper for the signal layers in between. A good guideline is if the copper thickness is doubled, the thermal resistance for the same sized plane is halved.



#	Name	Material	Type	Weight
	Top Overlay		Overlay	
	Top Solder	Solder Resist	Solder Mask	
1	Top Layer		Signal	2oz
	Dielectric 1	FR4 370	Prepreg	
2	Signal Layer 1		Signal	1oz
	Dielectric 2	FR4 370	Core	
3	Signal Layer 2		Signal	1oz
	Dielectric 3	FR4 370	Prepreg	
4	Bottom Layer		Signal	2oz
	Bottom Solder	Solder Resist	Solder Mask	
	Bottom Overlay		Overlay	

Figure 1-3. Copper Thickness Example of 4-layer EVM

1.4.4 Thermal Vias

Thermal vias need to establish connections between the top and bottom layer to facilitate heat dissipation from the motor driver to the lower temperature PCB areas on the outer or inner PCB layers while the landing pad/thermal pad interface is dissipating heat on the top layer (device layer). Avoid thermal relief connections as they restrict heat flow, causing increased temperatures around vias. Directly connecting vias minimizes thermal resistance between the via and copper layers. When connecting thermal vias to the internal ground plane, make sure a complete connection around the entire circumference of the plated through hole. Avoid covering the vias with solder mask to prevent excessive voiding. Properly implementing thermal vias can assist with heat dissipation and help with more effective PCB performance and motor driver current ratings.

Though the thermal pad establishes a low-impedance thermal pathway between the die and the top ground plane of the PCB, it's important to assess the thermal impedance of the vias connecting the top and bottom ground planes. The suggestion is to use thermal vias directly beneath the thermal pad, sized at 20 mil in diameter with a hole size of 8 mil which can keep the thermal resistance of the via to a minimum by minimizing solder wicking from the thermal pad.

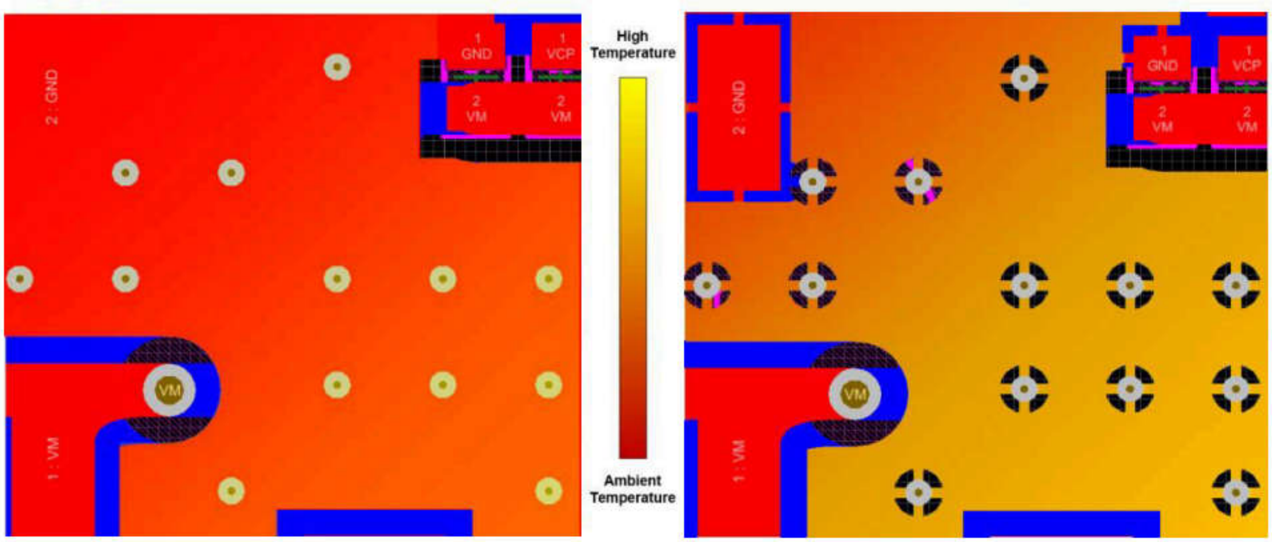


Figure 1-4. Thermal Relief vs Direct-Connect Heat Map

1.4.5 Summary of Thermal Management Techniques

In summary, the thermal pad connection is the most efficient path for dissipating heat from the device die. To optimize this, use continuous top-layer pours from the thermal pad to the ground planes, and utilize 1.5-oz or 2-oz copper when possible for better heat conduction. Additionally, employ direct-connect thermal vias to further enhance thermal management (Figure 1-4). More on board layout best practices for motor drivers can be found at the following link: *Best Practices for Board Layout of Motor Drivers.*, application note.

1.5 Thermal Estimations

Being able to accurately predict junction temperature under certain operating conditions can make sure the motor driver operates within safe thermal specifications and prevent overheating and potential damage. Doing so not only enhances the reliability and lifespan of the motor driver but also maintains a designed for performance by preventing thermal stress related issues. There are several key parameters to consider when calculating the junction temperature of motor drivers such as, ambient temperature, power dissipation, thermal resistance, transient time for loading, PWM or no PWM, and so on. These calculations can further optimize thermal aspects of the design such as heatsink sizing, airflow management, and makes sure the device can be operating below the integrated thermal shutdown protection features.

The DRV824x-Q1 family of devices offers a junction temperature estimation calculator to makes sure the motor driver operates with safe thermal limits. Using the DRV824x-Q1 data sheets, transient thermal resistance tables can be used as a reference for specific transient cases to be used with the thermal calculator.

PART NUMBER	PACKAGE	$R_{\theta JA}$ [°C/W](1)				Current [A](2)					
						without PWM(3)				with PWM(4)	
		0.1 sec	1 sec	10 sec	DC	0.1 sec	1 sec	10 sec	DC	10 sec	DC
DRV8245-Q1	VQFN-HR	4.3	9.2	13.6	30.3	15.8	10.8	8.9	5.9	7.7	4.8
DRV8245-Q1	HTSSOP	3.3	7.1	12.2	29.1	16.1	11.0	8.4	5.4	7.4	4.5

Figure 1-5. Transient Thermal Impedance (RθJA) and Current Capability - Full-Bridge

When using this calculator, the user inputs desired transient current values over a specified time and the calculator outputs a graph of the how the junction temperature changes based on the MOSFETs power dissipation. The MOSFETs power dissipation is composed of two sources, from conduction losses while the MOSFET is on and switching losses during PWM based current regulation. For more details on the total power dissipation formulas, see Calculating Power Dissipation for a H-Bridge or Half Bridge Driver.

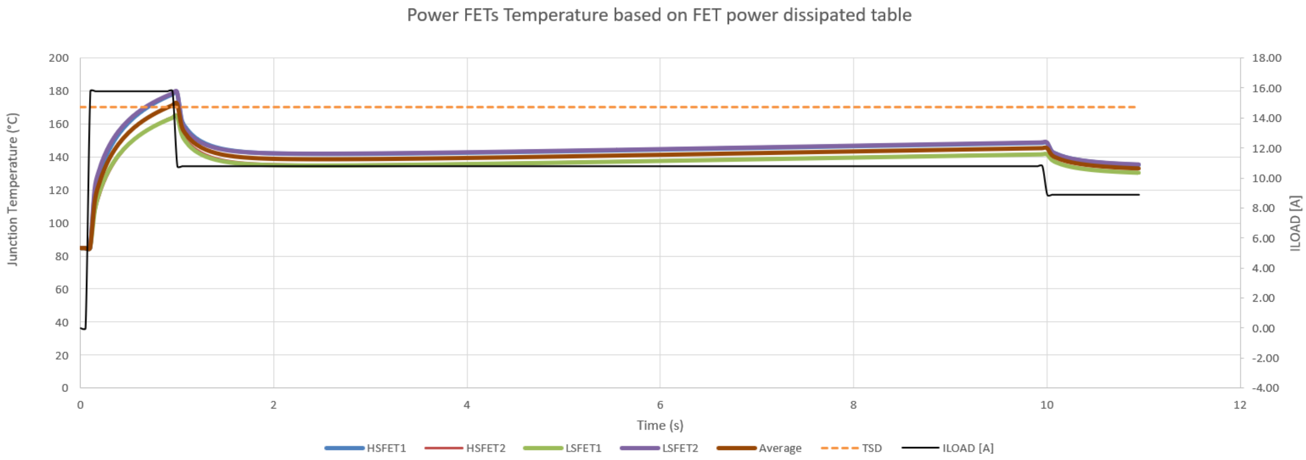


Figure 1-6. Junction Temperature Estimation

The thermal simulation previously is based on using 40mm x 40mm x 16mm, 4-layer PCB using 2 oz Cu on the top and bottom layers, 1 oz Cu on internal planes. With a starting ambient temperature of 85°C and transient current capabilities estimated with only conduction losses (no PWM) used from the data sheet.

Thermal estimations are important to maintain reliability and performance under varying thermal conditions. If the junction temperature exceeds the overtemperature shutdown threshold, the device is outside of safe operating conditions and motor driver operating current must be reduced to lower power dissipation and effectively manage heat. These estimations determine the maximum current the motor driver can handle without overheating.

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 2-1 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.

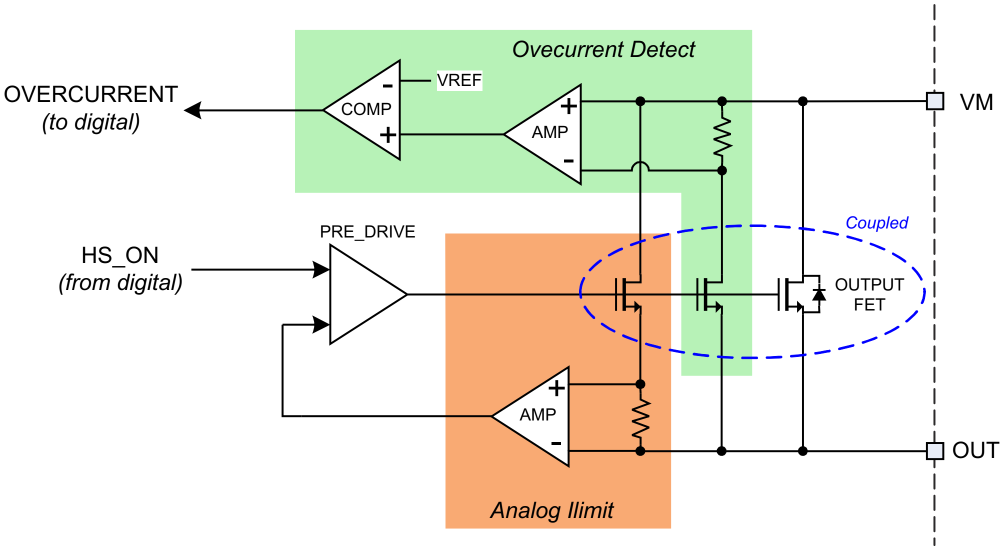


Figure 2-1. Simplified OCP Schematic

Figure 2-2 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.

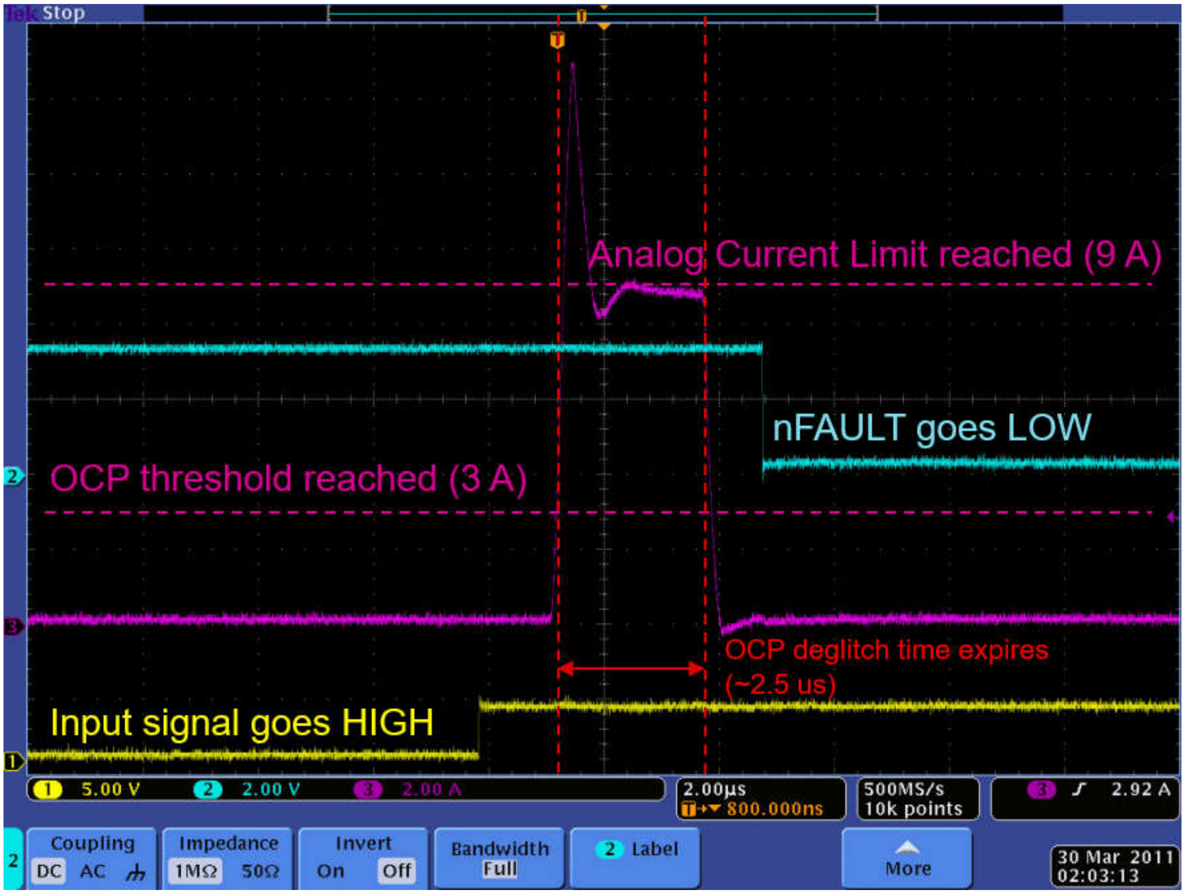


Figure 2-2. Oscilloscope Capture of a Short Circuit Event Using TI DRV8813 Motor Driver

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 Data Sheet Ratings

There are several items within a TI motor driver data sheet 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 data sheets are shown below.

3.1 Description

The description summary on page one of the data sheet, 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 does not damage the device, but can 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 can 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:

Table 3-1. 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.

Table 3-2. 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:

Table 3-3. Thermal Information

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

The θ_{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 PCB thermal calculator, including *IC Package Thermal Metrics*, and *Using New Thermal Metrics*, application notes.

3.5 Electrical Characteristics

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

Table 3-4. Electrical Characteristics H-BRIDGE FETS

			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:

Table 3-5. Electrical Characteristics Protection 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 can re-enable the outputs after some period of time. This time is listed here as t_{OCP}, the OCP period.

The overtemperature shutdown temperature (referred to as *thermal hysteresis* in some data sheets) 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 the device when the temperature falls to a safe level, 10-40°C below the threshold.

4 References

1. Texas Instruments, *Calculating Motor Driver Power Dissipation*, application note.
2. Texas Instruments, *JPEG with Motion Detection on the DM642 EVM*, application note.
3. Texas Instruments, *Using New Thermal Metrics*, application note.
4. Texas Instruments, *PowerPAD Thermally Enhanced Package* application note.

5 Revision History

Changes from Revision * (February 2012) to Revision A (July 2024) **Page**

- Updated the numbering format for tables, figures, and cross-references throughout the document. 1
- Added *PCB Limitations and Thermal Management Techniques* section..3
- Added *Thermal Estimations* section...5
- Updated *Oscilloscope Capture of a Short Circuit Event Using TI DRV8813 Motor Driver* image......................7

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