

# Calculating Motor Driver Power Dissipation

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## ABSTRACT

When selecting a motor driver IC for a particular application, consider the maximum amount of current that must be driven. The thermal characteristics of the IC and PCB are often the limiting factor in how much current a given motor driver provides. To calculate the maximum allowable current in a given application, an estimation of the total motor driver power dissipation is needed. This application report shows how to estimate this power dissipation in DC brush motor and stepper motor applications.

## 1 Sources of Power Dissipation in a Motor Driver

There are a number of sources of power dissipation inside a motor driver IC. Some are obvious, like the power dissipated in the FET ON-resistance, others are more subtle. To make an accurate assessment of the total power dissipation, all sources must be considered.

### 1.1 $R_{DS(ON)}$ Dissipation

The biggest source of power dissipated inside a motor driver IC is the power dissipated in the FET ON-resistance, or  $R_{DS(ON)}$ . The power dissipated in an H-bridge (consisting of a high-side FET and a low-side FET) is calculated with the following:

$$P_{RDS} = (HS-R_{DS(ON)} \times (I_{OUT(RMS)})^2) + (LS-R_{DS(ON)} \times (I_{OUT(RMS)})^2)$$

where  $P_{RDS}$  is the power dissipated in the output FETs,  $HS-R_{DS(ON)}$  is the resistance of the high-side FET,  $LS-R_{DS(ON)}$  is the resistance of the low side FET, and  $I_{OUT(RMS)}$  is the RMS output current being applied to the motor.

Note that  $R_{DS(ON)}$  increases with temperature, as the device heats, the power dissipation increases. This must be considered when calculating the total device power dissipation.

If a device has two H-bridges, like a typical stepping motor driver, you need to add the power dissipated in each H-bridge.

### 1.2 Switching Losses

When an output transitions from high to low or low to high, the output devices traverse a linear region where they are dissipating significantly more power than when fully turned on. This power dissipation is referred to as switching loss.

Switching loss is a function of the following:

- rise and fall times of the output, how quickly the output swings from one extreme to the other
- supply voltage
- output current
- frequency that the output is switching

In some cases, such as a DC motor driver that is only turned on or off (not subjected to PWM speed control or current control), this rate may be so small as to be negligible. On the other extreme, for example a stepper motor driver using current control, the outputs are always being switched at some PWM frequency to maintain current regulation.

As an approximation, switching losses for each output are calculated as follows:

$$P_{SW} = P_{SW\_RISE} + P_{SW\_FALL}$$

where  $P_{SW}$  is the total switching loss (in watts) for one output, and  $P_{SW\_RISE}$  is the power dissipated during the rising edge, and  $P_{SW\_FALL}$  is dissipated during the falling edge.

Expanding on this:

$$P_{SW\_RISE} = \frac{1}{2} \times V_M \times I_{OUT} \times t_R \times f_{SW}$$

and

$$P_{SW\_FALL} = \frac{1}{2} \times V_M \times I_{OUT} \times t_F \times f_{SW}$$

where  $V_M$  is the supply voltage (in volts),  $I_{OUT}$  is the output current (in amps),  $t_R$  is the rise time (in seconds),  $t_F$  is the fall time (in seconds), and  $f_{SW}$  is the switching frequency (in Hz).

The values of  $t_R$  and  $t_F$  are generally listed in the motor driver datasheet.  $f_{SW}$  may be the internal PWM frequency of the motor driver, if the motor driver is performing current regulation (as when driving a stepper motor), or may be an externally applied PWM frequency (as when doing DC motor speed control from a processor).

In an H-bridge, it is possible that one side or both sides of the H-bridge are being switched. For example, with a DC motor driver or a stepper motor using slow decay mode, only one side of the H-bridge is being pulse-width modulated, while the other side remains at a fixed state. A stepper motor driver running in fast decay, however, reverses state at each PWM cycle. Both sides of the H-bridge switch, causing twice as much switching loss.

### 1.3 **Operating Supply Current Dissipation**

Some current is consumed by the motor driver IC. On TI motor driver data sheets, this is usually called  $V_M$  *operating supply current*.

Power dissipated by the operating supply current is calculated using:

$$P_{IVM} = V_M \times I_{VM}$$

### 1.4 **Other Power Dissipation**

Motor drivers may contain other circuits that dissipate power. Many TI motor drivers contain an LDO regulator that is used to provide some reference current, or current to power external loads. You must account for this power dissipation as well.

For an LDO, power dissipation is calculated as follows:

$$P_{LDO} = I_{LDO\_OUT} \times (V_M - V_{OUT})$$

## 2 Example Calculation

Section 2.2 shows an example power dissipation calculation for a DRV8825 motor controller driving a bipolar stepper motor operated with current regulation. Similar calculations are made using other stepper and brush DC motor drivers.

### 2.1 Conditions and Assumptions

When driving a stepper motor using current control, two H-bridges are always conducting current, and are always being switched (to regulate current using PWM). In this example, using a DRV8825 stepper motor controller, we use the following operating parameters:

- $V_M$  (supply voltage) = 24 V
- $I_{OUT} = 1.5$ -A RMS per phase
- Only slow decay is used (so only one side of each H-bridge is switching)
- 2-mA current is drawn from the LDO regulator (V3P3OUT)

For estimation purposes, use the typical 85°C  $R_{DS(ON)}$  number, and the worst-case (maximum) rise and fall times from the datasheet. Other datasheet parameters used are the typical values.

### 2.2 Power Calculation

The total power dissipation is calculated as follows:

$$P_{TOT} = (2 \times P_{RDS}) + (2 \times P_{SW}) + P_{IVM} + P_{LDO}$$

The factor of 2 on the  $P_{RDS}$  and  $P_{SW}$  terms comes from the fact that there are two H-bridges in the DRV8825, each driving one phase of the stepper motor, and one side of each H-bridge is being pulse-width modulated to regulate winding current.

Calculating the components step-by-step, using data from the DRV8825 data sheet:

$$\begin{aligned} P_{RDS} &= (HS-R_{DS(ON)} \times (I_{OUT(RMS)})^2) + (LS-R_{DS(ON)} \times (I_{OUT(RMS)})^2) \\ &= (0.25 \Omega \times (1.5 \text{ A})^2) + (0.25 \Omega \times (1.5 \text{ A})^2) \\ &= 1.125 \text{ W} \end{aligned}$$

$$\begin{aligned} P_{SW} &= P_{SW\_RISE} + P_{SW\_FALL} \\ &= (\frac{1}{2} \times V_M \times I_{OUT} \times t_R \times f_{SW}) + (\frac{1}{2} \times V_M \times I_{OUT} \times t_F \times f_{SW}) \\ &= (\frac{1}{2} \times 24 \text{ V} \times 1.5 \text{ A} \times 200 \text{ ns} \times 30 \text{ kHz}) + (\frac{1}{2} \times 24 \text{ V} \times 1.5 \text{ A} \times 200 \text{ ns} \times 30 \text{ kHz}) \\ &= 0.216 \text{ W} \end{aligned}$$

$$P_{IVM} = V_M \times I_{VM} = 24 \text{ V} \times 5 \text{ mA}$$

$$P_{LDO} = I_{LDO\_OUT} \times (V_M - V_{OUT}) = 2 \text{ mA} \times (24 \text{ V} - 3.3 \text{ V}) = 0.04 \text{ W}$$

Finally,

$$\begin{aligned} P_{TOT} &= (2 \times P_{RDS}) + (2 \times P_{SW}) + P_{IVM} + P_{LDO} \\ &= 2 \times 1.125 \text{ W} + 2 \times 0.216 \text{ W} + 0.12 \text{ W} + 0.04 \text{ W} = 2.84 \text{ W} \end{aligned}$$

This is the approximate amount of power dissipated in the IC.

### 2.3 Die Temperature Estimation

Once you know the power dissipated in the driver, you can estimate the die temperature. Calculate the die temperature using the thermal resistance  $\theta_{JA}$  and the ambient temperature as follows:

$$T_{DIE} = T_{AMB} + (\theta_{JA} \times P_{TOT})$$

In this example, if the DRV8825 were mounted on a JEDEC-standard PCB, the  $\theta_{JA}$  value is 31.6°C/W. The resulting die temperature at a 25°C ambient temperature is:

$$\begin{aligned} T_{DIE} &= T_{AMB} + (\theta_{JA} \times P_{TOT}) \\ &= 25^{\circ}\text{C} + (31.6^{\circ}\text{C/W} \times 2.86 \text{ W}) = 115.4^{\circ}\text{C} \end{aligned}$$

This temperature is well below the overtemperature shutdown temperature of 150°C.

However, an ambient temperature of 70°C produces the following:

$$\begin{aligned} &= 70^{\circ}\text{C} + (31.6^{\circ}\text{C/W} \times 2.8614 \text{ W}) \\ &= 160.4^{\circ}\text{C} \end{aligned}$$

At an ambient temperature of 70°C, the device would enter overtemperature shutdown.

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**NOTE:** When mounted on the application PCB, the actual  $\theta_{JA}$  value is probably different than the  $\theta_{JA}$  value listed on the datasheet for a JEDEC-standard board. Please refer to [www.ti.com/thermal](http://www.ti.com/thermal) for more information on how to determine the  $\theta_{JA}$  value on your PCB.

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### 3 References

1. *Understanding Motor Driver Current Ratings* ([SLVA505](#))
2. [www.ti.com/thermal](http://www.ti.com/thermal)

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