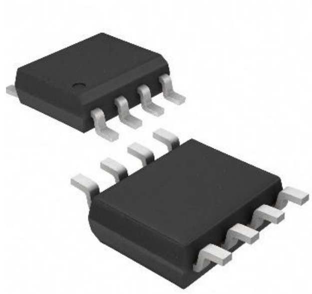
HX8870-S 2.5-A Brushed DC Motor Driver (PWM Control)

General Description

The HX8870-S is a brushed-DC motor driver suitable for printers, appliances, industrial equipment, and small machines. It utilizes an H-bridge configuration with four N-channel MOSFETs for bidirectional motor control up to 2.5 amps.

PWM modulation and selectable current-decay modes allow precise motor speed control. A low-power sleep mode is activated when both inputs are low. Integrated current regulation, based on analog input and motor current sensing, reduces power requirements and stabilizes voltage, especially during startup and stall.

The device is protected from faults and short circuits, including UVLO, OCP, and TSD. It automatically resumes operation once the fault is removed.



SOP-8

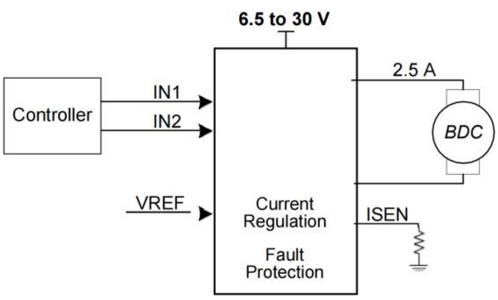
Features

- The H-Bridge Motor Driver can drive DC motors, stepper motor windings, or other loads.
- Operating voltage ranges from 6.5V to 30V.
- RDS(on) is typically 800-mΩ for efficient power.
- Delivers a peak current of 2.5A.
- Integrated current regulation for stable performance.
- PWM interface for precise speed control.
- Low-power sleep mode conserves energy.
- Protection features include UVLO, OCP, TSD, and automatic fault recoverv.

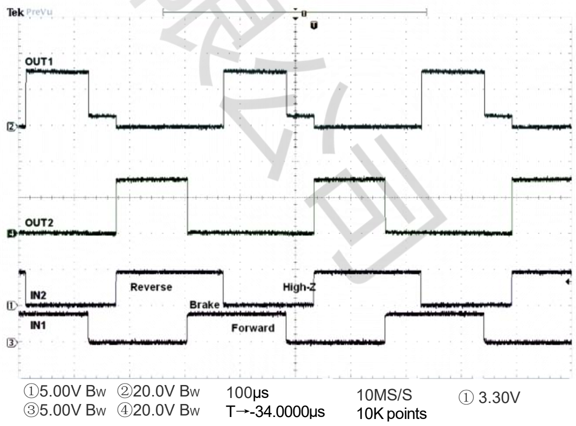
Applications

- Printers
- Appliances
- Industrial Equipment
- Other Mechatronic Applications

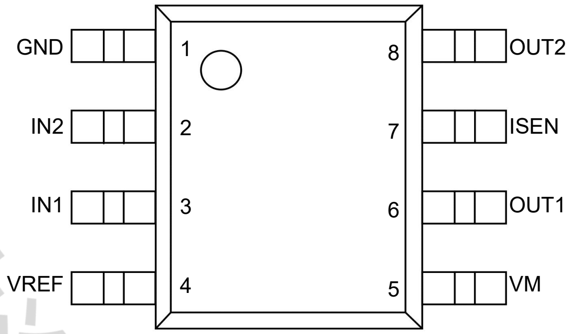
Simplified Schematic



H-Bridge States



PIN CONFIGURATIONS



PIN		TYPE	DESCRIPTION	
NAME	NO.			
GND	1	PWR	Logic ground	Connect to board ground
IN1	3	I	Logic inputs	Controls the H-bridge output. Has internal pulldowns. (See
IN2	2			
ISEN	7	PWR	High-current ground path	If using current regulation, connect ISEN to a resistor
OUT1	6	O	H-bridge output	Connect directly to the motor or other inductive load.
OUT2	8			
PAD	—	—	Thermal pad	Connect to board ground. For good thermal dissipation, use large ground planes on multiple layers, and multiple nearby vias connecting those planes.
VM	5	PWR	6.5-V to 30-V power supply	Connect a 0.1-μF bypass capacitor to ground, as well as
VREF	4	I	Analog input	Apply a voltage between 0.3 to 5 V. For information on current regulation, see the Current Regulation section.

Absolute Maximum Ratings

over operating free-air temperature range (unless otherwise noted)[1]

	MIN	MAX	UNIT
Power supply voltage (VM)	–0.3	30	V
Power supply voltage ramp rate (VM)	0	2	V/μs
Logic input voltage (IN1, IN2)	–0.3	7	V
Reference input pin voltage (VREF)	–0.3	6	V
Continuous phase node pin voltage (OUT1, OUT2)	–0.7	VM + 0.7	V
Current sense input pin voltage (ISEN)[2]	–0.5	1	V
Operating junction temperature, TJ	–40	150	°C
Storage temperature, Tstg	–65	150	°C

Notes

1. Stresses beyond those listed under Absolute Maximum Ratings may cause permanent damage to the device. These are stress ratings
only, which do not imply functional operation of the device at these or any other conditions beyond those indicated under Recommended Operating Conditions. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.
2. Transients of ±1 V for less than 25 ns are acceptable

ESD Ratings

		VALUE	UNIT
V(ESD) Electrostatic discharge	Human-body model (HBM), per ANSI/ESDA/JEDEC JS-001[1]	±3000	V
	Charged-device model (CDM), per JEDEC specification JESD22-C101[2]	±450	

Notes

1. JEDEC document JEP155 states that 500-V HBM allows safe manufacturing with a standard ESD control process'
2. JEDEC document JEP157 states that 250-V CDM allows safe manufacturing with a standard ESD control process.

Recommended Operating Conditions

over operating free-air temperature range (unless otherwise noted)

		MIN	NOM	UNIT	UNIT
VM	Power supply voltage	6.5		30	V
VREF	VREF input voltage	0.3[1]		5	V
VI	Logic input voltage range (IN1, IN2)	0		5.5	V
fPWM	Logic input PWM frequency (IN1, IN2)	0		200[2]	kHz
I peak	Peak output current (3)	0		2.5	A
TA	Operating ambient temperature (3)	-40		125	°C

Notes

1. Operational at VREF = 0 to 0.3 V, but accuracy is degraded
2. The voltages applied to the inputs should have at least 800 ns of pulse width to ensure detection. Typical devices require at least 400 ns. If the PWM frequency is 200 kHz, the usable duty cycle range is 16% to 84%.
3. Power dissipation and thermal limits must be observed

Thermal Information

THERMAL METRIC			UNIT
RθJA	Junction-to-ambient thermal resistance	41.1	°C/W
RθJC(top)	Junction-to-case (top) thermal resistance	53.1	°C/W
RθJB	Junction-to-board thermal resistance	23.1	°C/W
ΨJT	Junction-to-top characterization parameter	8.2	°C/W
ΨJB	Junction-to-board characterization parameter	23	°C/W
RθJC(bot)	Junction-to-case (bottom) thermal resistance	2.7	°C/W

Electrical Characteristics

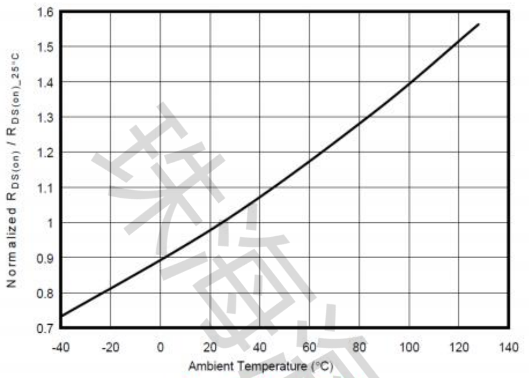
TA = 25°C, over recommended operating conditions (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
POWER SUPPLY (VM)						
VM	VM operating voltage		6.5		30	V
IVM	VM operating supply current	VM = 12 V		3	10	mA
IVMSLEEP	VM sleep current	VM = 12 V			10	μA
tON [1]	Turn-on time	VM > VUVLO with IN1 or IN2 high			4050	μs
LOGIC-LEVEL INPUTS (IN1, IN2)						
VIL	Input logic low voltage				0.5	V
VIH	Input logic high voltage		1.5			V
VHYS	Input logic hysteresis			0.5		V
IIL	Input logic low current	VIN = 0 V	-1		1	μA
IIH	Input logic high current	VIN = 3.3 V		33	100	μA
RPD	Pulldown resistance	to GND		100		kΩ
t PD	Propagation delay	INx to OUTx change		0.7	1	μs
tsleep	Time to sleep	Inputs low to sleep		1	1.5	ms
MOTOR DRIVER OUTPUTS (OUT1, OUT2)						
RDS(ON)	High-side FET on resistance	VM = 24 V, I = 1 A, fPWM = 25 kHz		450	600	mΩ
RDS(ON)	Low-side FET on resistance	VM = 24 V, I = 1 A, fPWM = 25 kHz		350	500	mΩ
t DEAD	Output dead time			220		ns
Vd	Body diode forward voltage	IOUT = 1 A		0.8	1	V
CURRENT REGULATION						
AV	ISEN gain	VREF = 2.5 V	9.4	10	10.4	V/V
tOFF	PWM off-time			25		μs
t BLANK	PWM blanking time			2		μs
PROTECTION CIRCUITS						
VUVLO	VM undervoltage lockout	VM falls until UVLO triggers		6.1	6.4	V
		VM rises until operation recovers		6.3	6.5	
V UV,HYS	VM undervoltage hysteresis	Rising to falling threshold	100	180		mV
IOCP	Overcurrent protection trip level		2.5	3	3.5	A
tOCP	Overcurrent deglitch time			1.5		μs
tRETRY	Overcurrent retry time			3		ms
TSD	Thermal shutdown temperature		150	175		°C
THYS	Thermal shutdown hysteresis			40		°C

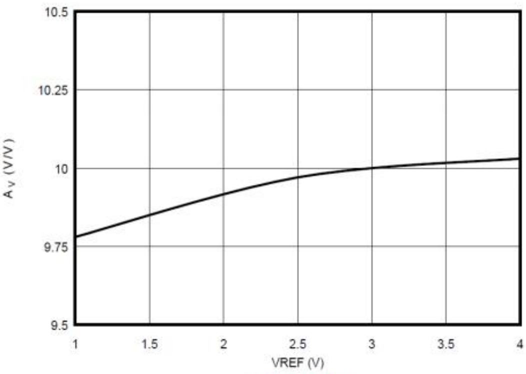
Notes

1. tON applies when the device initially powers up, and when it exits sleep mode.

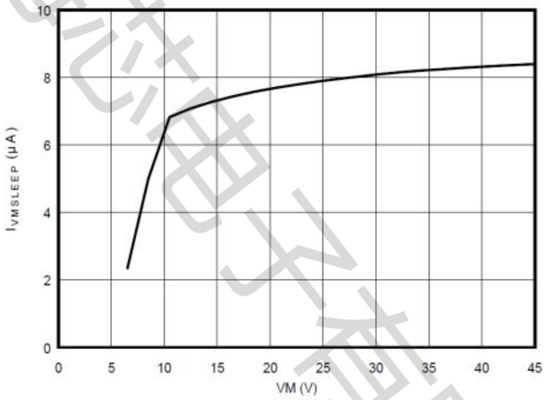
Typical Characteristics



$R_{DS(on)}$ vs Temperature



A_V vs VREF



$I_{VMSLEEP}$ vs VM at 25°C

Detailed Description

Overview

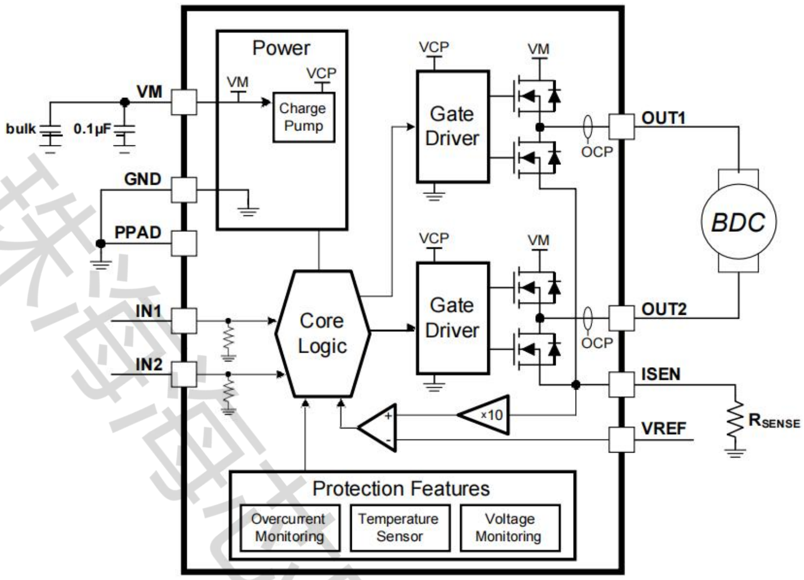
The HX8870-S is an optimized 8-pin device specifically designed for driving brushed DC motors within a voltage range of 6.5 to 30V, capable of handling peak currents up to 2.5A. Its integrated current regulation ensures that the motor current is limited to a predefined maximum level.

The H-bridge driver, comprising four N-channel MOSFETs with a typical Rds(on) of 800mΩ (including both high-side and low-side FETs), is controlled by two logic inputs. A single power input, VM, serves dual purposes: it powers the device and biases the motor winding.

To fully enhance the performance of the high-side FETs, the device integrates a charge pump that boosts the VM internally. Motor speed can be precisely adjusted using pulse-width modulation, with frequencies ranging from 0 to 100 kHz.

Additionally, the HX8870-S features an integrated sleep mode that is activated when both inputs are brought to a low state, allowing for power conservation. The device also includes various protection features that prevent damage in the event of a system fault.

Functional Block Diagram



Feature Description

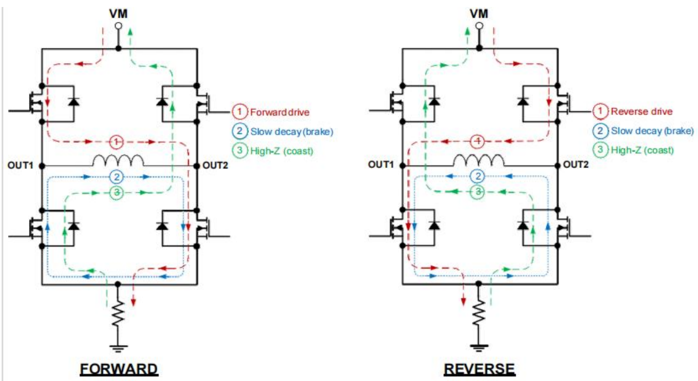
Bridge Control

The HX8870-S output consists of four N-channel MOSFETs that are designed to drive high current. They are controlled by the two logic inputs IN1 and IN2, according to Table 1.

Table 1. H-Bridge Control

IN1	IN2	OUT1	OUT2	DESCRIPTION
0	0	High-Z	High-Z	Coast; H-bridge disabled to High-Z (sleep entered after 1 ms)
0	1	L	H	Reverse (Current OUT2 → OUT1)
1	0	H	L	Forward (Current OUT1 → OUT2)
1	1	L	L	Brake; low-side slow decay

The inputs of the HX8870-S can be configured in two distinct modes: for static voltage operation at 100% duty cycle, or for pulse-width modulation (PWM) to achieve variable motor speed. When utilizing PWM, alternating between driving and braking often yields optimal results. As an example, to propel a motor forward at 50% of its maximum RPM, one would set IN1 to 1 and IN2 to 0 during the driving phase, and subsequently set both IN1 and IN2 to 1 during the braking phase. Additionally, a coast mode is also available, where IN1 and IN2 are both set to 0, enabling rapid current decay. Notably, the input pins can be powered prior to the application of VM.



H-Bridge Current Paths

Sleep Mode

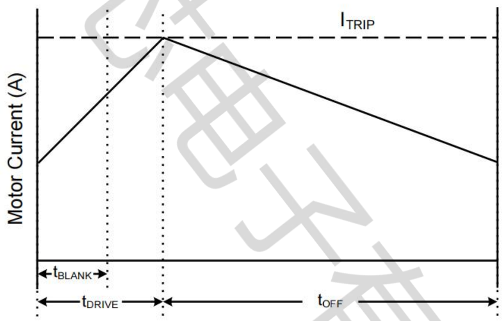
When both IN1 and IN2 are maintained at a low state for a duration of tSLEEP (typically 1 ms), the HX8870-S transitions into a low-power sleep mode. In this mode, the outputs are maintained in a High-Z state, and the device consumes only IVMSLEEP (microamps) of current. If the device is powered on while both inputs remain low, it will immediately enter the sleep mode. Once either IN1 or IN2 is raised to a high state for a minimum of 5μs, the device becomes operational again after a delay of 50μs (tON).

Current Regulation

The HX8870-S regulates the output current based on the analog input VREF and the resistance of an external sense resistor connected to the ISEN pin. This regulation is determined according to the following equation:

$$I_{TRIP}\,(A) \quad \frac{VREF\,(V)}{A_V \times R_{ISEN}\,(v)} \quad \frac{VREF\,(V)}{10 \times R_{ISEN}\,(v)}$$

For instance, when VREF is set to 3.3 V and a sense resistor of 0.15 Ω is used, the HX8870-S effectively restricts the motor current to 2.2 A, regardless of the applied load torque. Guidelines for selecting an appropriate sense resistor can be found in the Sense Resistor section. Once the ITRIP threshold is reached, the device initiates a slow current decay process by activating both low-side FETs. This decay continues for a duration of tOFF, typically 25 μs.

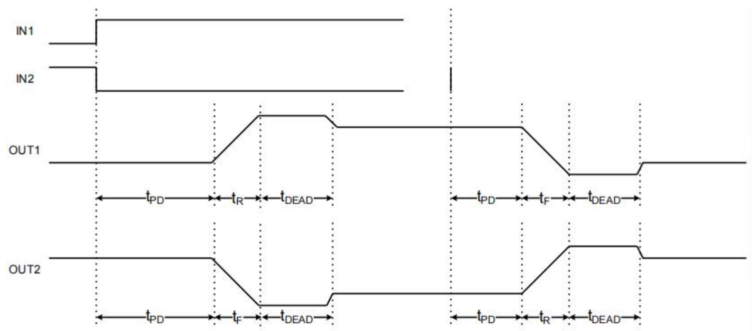


Current Regulation Time Periods

After tOFF has elapsed, the output is re-enabled according to the two inputs INx. The drive time (tDRIVE) until reaching another ITRIP event heavily depends on the VM voltage, the motor's back-EMF, and the motor's inductance.

Dead Time

When there is a transition in the output state, whether from driving high to low or vice versa, a dead time is automatically inserted to prevent shoot-through. This dead time, denoted as tDEAD, represents the duration during which the output is in a High-Z state. If the voltage at the output pin is measured during this tDEAD period, it will be influenced by the direction of the current flow. If the current is exiting the pin, the voltage will be slightly below ground due to the diode drop. Conversely, if the current is entering the pin, the voltage will be slightly above VM due to the diode drop. This diode corresponds to the body diode of either the high-side or low-side FET.



Propagation Delay Time

Protection Circuits

The HX8870-S incorporates comprehensive protection mechanisms against VM undervoltage, overcurrent, and overtemperature conditions.

VM Undervoltage Lockout (UVLO)

If the voltage on the VM pin dips below the undervoltage lockout threshold, all the FETs within the H-bridge will be deactivated. The HX8870-S will resume normal operation once the VM voltage rises above the UVLO threshold.

Overcurrent Protection (OCP)

If the output current surpasses the OCP threshold, IOCP, for a duration longer than tOCP, all the FETs in the H-bridge will be disabled for a period of tRETRY. After this timeout, the H-bridge will be re-enabled based on the state of the INx pins. If the overcurrent condition persists, the cycle will repeat; otherwise, the device will resume normal operation.

Thermal Shutdown (TSD)

If the die temperature exceeds safe operating limits, all the FETs in the H-bridge will be disabled to prevent damage. Once the die temperature has cooled down to a safe level, the HX8870-S will automatically resume operation.

Table 2. Protection Functionality

FAULT	CONDITION	H-BRIDGE BECOMES	RECOVERY
VM undervoltage lockout (UVLO)	VM < VUVLO	Disabled	VM > VUVLO
Overcurrent (OCP)	I OUT> IOCP	Disabled	tRETRY
Thermal Shutdown (TSD)	TJ > 150°C	Disabled	TJ< TSD – THYS

Device Functional Modes

The HX8870-S offers diverse operation modes for driving brushed DC motors.

PWM With Current Regulation

In this mode, the device utilizes all its capabilities. ITRIP is set to a level higher than the normal operating current to ensure a sufficient spin-up time but low enough to maintain the desired current level. Motor speed is adjusted through the duty cycle of one input while the other input remains static. Brake/slow decay is typically activated during the off-time.

PWM Without Current Regulation

When current regulation is not required, the ISEN pin should be directly connected to the PCB ground plane. VREF must still range from 0.3 to 5 V, with higher voltages providing increased noise margin. This mode allows for the highest possible peak current, reaching up to 2.5 A for a few hundred milliseconds (depending on PCB characteristics and ambient temperature). If the current exceeds 2.5 A, the device may trigger overcurrent protection (OCP) or overtemperature shutdown (TSD). In such cases, the device disables itself for approximately 3 ms (tRETRY) and then resumes normal operation.

Static Inputs With Current Regulation

By setting IN1 and IN2 to high and low respectively, a 100% duty cycle drive can be achieved. In this mode, ITRIP is utilized to control the motor's current, speed, and torque capability.

VM Control

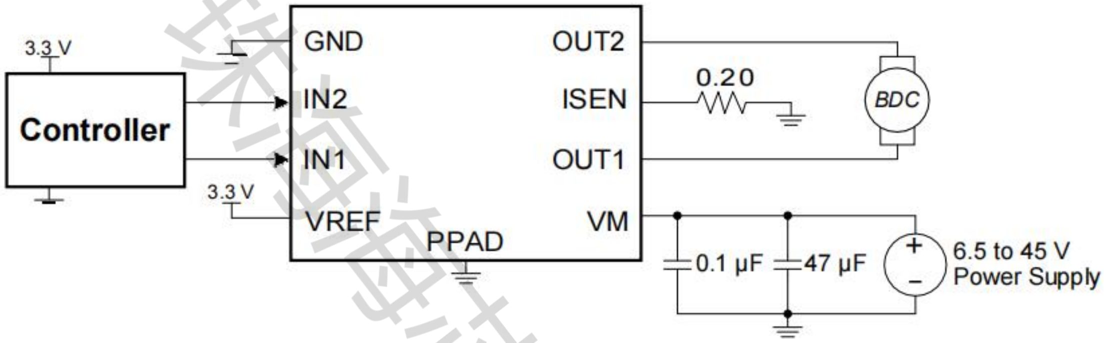
In certain systems, it may be desirable to adjust VM as a means of varying motor speed. For more information on this aspect, please refer to the Motor Voltage section.

Application and Implementation

Application Information

The HX8870-S is typically used to drive one brushed DC motor.

Typical Application



Typical Connections

Design Requirements

Table 3 lists the design parameters.

Table 3. Design Parameters

DESIGN PARAMETER	REFERENCE	EXAMPLE VALUE
Motor voltage	VM	24 V
Motor RMS current	IRMS	0.8 A
Motor startup current	I START	1.5 A
Motor current trip point	ITRIP	2A
VREF voltage	VREF	3.3 V
Sense resistance	RISEN	0.15 Ω
PWM frequency	fPWM	5 kHz

Detailed Design Procedure

Motor Voltage Considerations

The selection of motor voltage is primarily determined by the specified ratings of the chosen motor and the desired RPM. A higher voltage will cause a brushed DC motor to rotate faster, given the same PWM duty cycle applied to the power FETs. Additionally, a higher voltage increases the rate of current change through the motor's inductive windings.

Drive Current Path and Power Dissipation

The drive current follows a specific path, flowing through the high-side sourcing DMOS power driver, the motor winding, and then the low-side sinking DMOS power driver. The power dissipation losses associated with both the source and sink DMOS power drivers can be calculated using the provided equation.

$$P_D = I^2 \left(R_{DS(on)Source} + R_{DS(on)Sink}\right)$$

The HX8870-S has been measured to be capable of 1.5-A RMS current at 25°C on standard FR-4 PCBs. The max RMS current varies based on the PCB design, ambient temperature, and PWM frequency. Typically, switching the inputs at 200 kHz compared to 20 kHz causes 20% more power loss in heat.

Sense Resistor

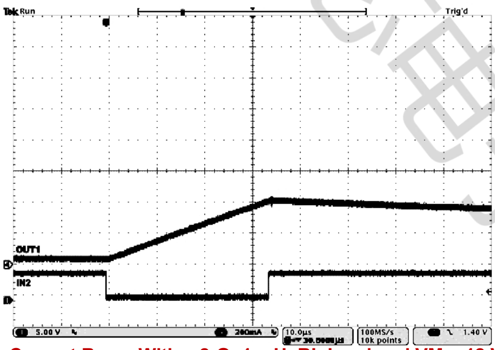
To ensure optimal performance, it is crucial for the sense resistor to possess the following characteristics:

- Surface-mount for efficient heat dissipation
- Low inductance to minimize energy losses
- Sufficient power rating to handle high currents
- Close proximity to the motor driver for reduced wiring inductance

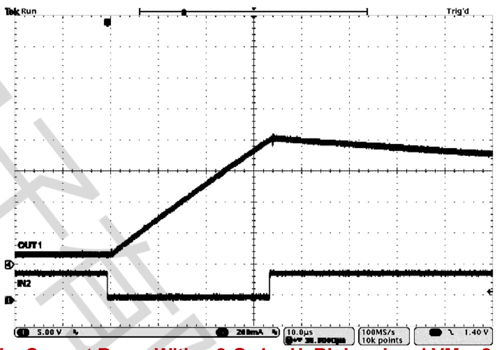
The power dissipated by the sense resistor is calculated as IRMS2 × R. For instance, if the peak motor current is 3 A, the RMS motor current is 1.5 A, and a 0.2-Ω sense resistor is utilized, the resistor will dissipate 1.5A2 × 0.2Ω = 4.5W. Notably, the power dissipation increases rapidly with higher current levels.

Resistors typically have a specified power rating within a certain ambient temperature range, along with a derated power curve for higher ambient temperatures. When a PCB is shared with other heat-generating components, the system designer should incorporate additional margin to ensure reliability. Ideally, the actual sense resistor temperature should be measured in the final system.

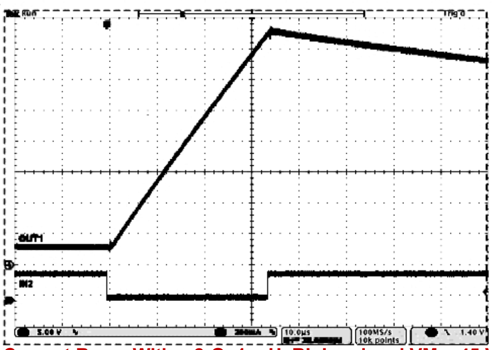
Application Curves



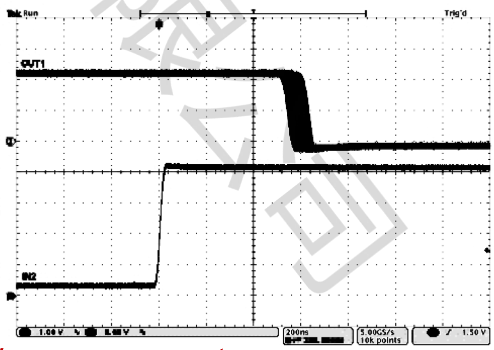
Current Ramp With a 2-Ω, 1 mH, RL Load and VM = 12 V



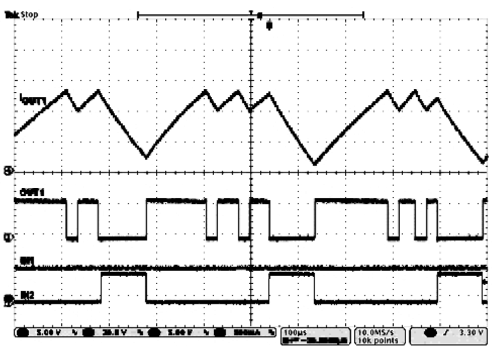
Current Ramp With a 2-Ω, 1 mH, RL Load and VM = 24 V



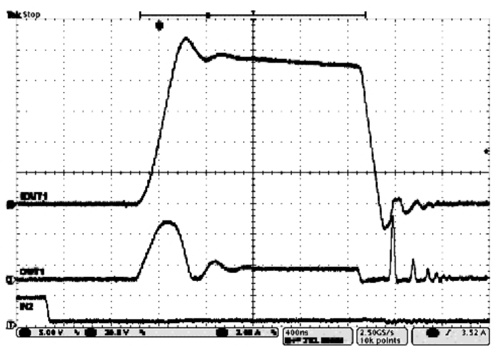
Current Ramp With a 2-Ω, 1 mH, RL Load and VM = 45 V



tPD



Current Regulation With VREF = 2 V and 150 mΩ



OCP With 30 V and the Outputs Shorted Together

Power Supply Recommendations

Bulk Capacitance

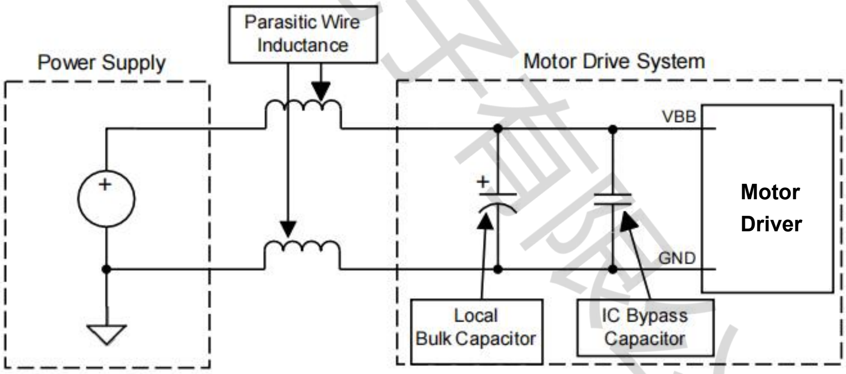
Appropriate local bulk capacitance is a crucial aspect in the design of motor drive systems. While having more bulk capacitance is generally beneficial, it also comes with the disadvantages of increased cost and larger physical size.

Determining the necessary amount of local capacitance involves considering several factors, including:

- The peak current demands of the motor system
- The capacitance and current sourcing capacity of the power supply
- The amount of parasitic inductance between the power supply and the motor system
- The acceptable level of voltage ripple
- The type of motor utilized (brushed DC, brushless DC, stepper)
- The method of motor braking

The inductance present between the power supply and the motor drive system restricts the rate at which the current can change from the power supply. If the local bulk capacitance is insufficient, the system will respond to excessive current demands or dumps from the motor with voltage fluctuations. However, when adequate bulk capacitance is employed, the motor voltage remains stable, and high current can be supplied rapidly.

While the datasheet typically provides a recommended value for bulk capacitance, system-level testing is necessary to determine the appropriate size of the bulk capacitor for optimal performance.



Example Setup of Motor Drive System With External Power Supply

The voltage rating for bulk capacitors should be higher than the operating voltage, to provide margin for cases when the motor transfers energy to the supply.

Layout

Layout Guidelines

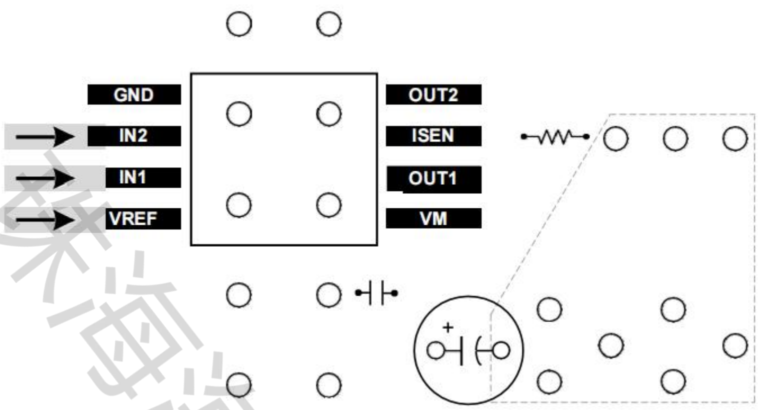
The placement of the bulk capacitor should be optimized to minimize the length of the high-current path through the motor driver device. It is crucial to maximize the width of the connecting metal traces and utilize numerous vias when bridging PCB layers. These measures minimize inductance and enable the bulk capacitor to effectively deliver high current.

Small-value capacitors should be of the ceramic type and placed in close proximity to the device pins. Additionally, the outputs of the high-current device should employ wide metal traces to handle the current efficiently.

Moreover, the thermal pad of the device should be soldered securely to the ground plane on the top layer of the PCB. Multiple vias should be employed to connect this to a larger ground plane on the bottom layer. The utilization of large metal planes and multiple vias aids in dissipating the heat generated by the device due to $I^2 \times RDS(on)$ losses.

Layout Example

Recommended layout and component placement is shown in the following diagram.



Layout Recommendation

Thermal Considerations

The HX8870-S device incorporates a thermal shutdown (TSD) feature, as outlined in the Thermal Shutdown (TSD) section. If the die temperature rises above approximately 175°C, the device automatically shuts down to prevent damage until the temperature falls below the hysteresis level.

Any indication that the device is approaching or entering TSD mode is a warning sign of excessive power dissipation, insufficient heatsinking, or an ambient temperature that is too high.

Power Dissipation

The primary source of power dissipation in the HX8870-S device is attributed to the output FET resistance, RDS(on). To estimate the average power dissipation when driving a load, utilize the equation provided in the Drive Current section.

It is important to note that during startup, the current spikes to levels significantly higher than the normal running current. Therefore, the peak current and its duration must also be taken into account when calculating power dissipation.

Power Dissipation (continued)

The maximum amount of power that can be dissipated in the device is dependent on ambient temperature and heatsinking.

The power dissipation in the HX8870-S is determined by the RMS motor current and the FET resistance (RDS(ON)) of each output.

Power dissipation (IRMS) is calculated using the formula:

$$IRMS = 2 \times (\text{High-side } RDS(ON) + \text{Low-side } RDS(ON))$$

For instance, consider an ambient temperature of 58°C where the junction temperature reaches 80°C. At this ambient temperature, the combined RDS(ON) is approximately 0.72 Ω. With a motor current of 0.8 A as an example, the dissipated power in the form of heat would be:

$$0.8\ A^2 \times 0.72\ \Omega = 0.46\ W.$$

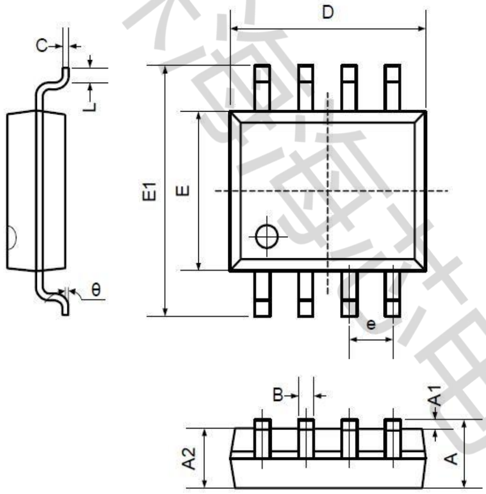
The temperature reached by the HX8870-S depends on its thermal resistance to the air and the PCB. It is crucial to solder the device's PowerPAD to the PCB ground plane, utilizing vias to connect to both the top and bottom board layers. This allows heat to be dissipated into the PCB, thereby reducing the device's temperature. In the given example, the HX8870-S exhibited an effective thermal resistance (RθJA) of 48°C/W. Therefore, the junction temperature (TJ) can be calculated as:

$$T_J = T_A + (P_D \times R_{\theta JA}) = 58°C + (0.46\ W \times 48°C/W) = 80°C$$

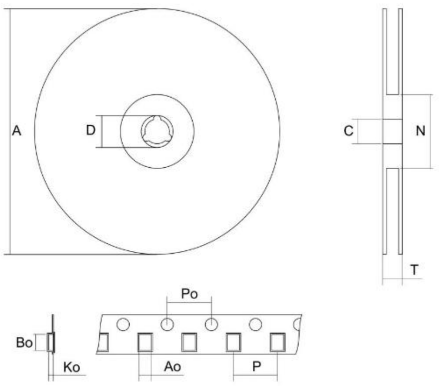
Heatsinking

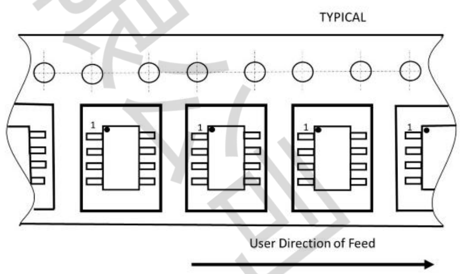
The PowerPAD package incorporates an exposed pad for effective heat removal from the device. For optimal performance, it is imperative to thermally connect this pad to copper on the PCB to facilitate heat dissipation. On multi-layer PCBs with a ground plane, this connection can be achieved by incorporating multiple vias to bridge the thermal pad with the ground plane. In PCBs without internal planes, a copper area can be added on either side of the PCB to enhance heat dissipation. If the copper area is situated on the opposite side of the PCB from the device, thermal vias are utilized to transfer heat between the top and bottom layers.

SOP-8 (Package Outline Dimensions)



Symbol	Dimensions In Millimeters		Dimensions In Inches	
	Min	Max	Min	Max
A	1.350	1.750	0.053	0.069
A1	0.100	0.250	0.004	0.010
A2	1.350	1.550	0.053	0.061
B	0.330	0.510	0.013	0.020
C	0.190	0.250	0.007	0.010
D	4.780	5.000	0.188	0.197
E	3.800	4.000	0.150	0.157
E1	5.800	6.300	0.228	0.248
e	1.270TYP		0.050TYP	
L	0.400	1.270	0.016	0.050
θ	0°	8°	0°	8°





Package Type	package	quantity
SOP-8	Taping	2500

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