

## 4.5-40.0V 4.5A Brushed DC Motor Driver (PWM Control)

### Description

The SA8870C device is a brushed-DC motor driver for robotics, appliances, industrial equipment, and other small machines. Two logic inputs control the H-bridge driver, which consists of four N-channel MOSFETs that can control motors bidirectionally with up to 4.5A peak current. The inputs can be pulse width modulated (PWM) to control motor speed, using a choice of current-decay modes. Setting both inputs low enter a low-power sleep mode.

The SA8870C device features integrated current regulation, based on the analog input VREF and the voltage on the ISEN pin, which is proportional to motor current through an external sense resistor. The ability to limit current to a known level can significantly reduce the system power requirements and bulk capacitance needed to maintain stable voltage, especially for motor startup and stall conditions.

The device is fully protected from faults and short circuits, including undervoltage (UVLO), overcurrent (OCP), and overtemperature (TSD). When the fault condition is removed, the device automatically resumes normal operation.

### Features

- 4.5 to 40.0 V Operating Voltage
- 350-mΩ Typical  $R_{DS(on)}$  (HS + LS)
- 4.5A Peak Current Drive
- PWM Control Interface
- Integrated Current Regulation
- Low-Power Sleep Mode
- H-Bridge Motor Driver
  - Drives One DC Motor, One Winding of a Stepper Motor, or Other Loads
- **Integrated Protection Features**
  - VM Undervoltage Lockout (UVLO)
  - Overcurrent Protection (OCP)
  - Thermal Shutdown (TSD)
  - Automatic Fault Recovery
- ESOP8 Package Available

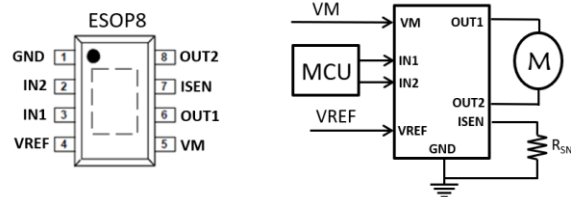
### Applications

- Robotics (Sweeping robot, R/C servo)
- 2-4 Li Battery Motor Applications
- Appliances
- Industrial Equipment
- Any Relevant DC Motor Applications.

### Device Information

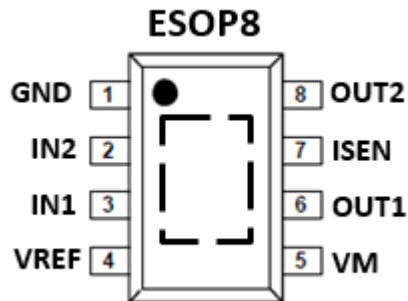
Part No.	Package	Quantity
SA8870C	ESOP8	4000/Reel

## SA8870C Package & Simplified Schematic



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### Pin Configuration and Functions



NO.	NAME	TYPE	DESCRIPTION
1	GND	P	Logic ground. Connect to board ground
2	IN2	I	Logic inputs. Controls the H-bridge output. Has internal pulldowns.
3	IN1	I	Logic inputs. Controls the H-bridge output. Has internal pulldowns.
4	VREF	I	Analog input. Apply a voltage between 0.3 to 5 V.
5	VM	P	4.5 to 36.0V power supply. Connect a 22- $\mu$ F bypass capacitor to ground, as well as sufficient bulk capacitance, rated for the VM voltage.
6	OUT1	O	H-bridge output. Connect directly to the motor or other inductive load.
7	ISEN	P	High-current ground path. If using current regulation, connect ISEN to a resistor (low-value, high-power-rating) to ground. If not using current regulation, connect ISEN directly to ground.
8	OUT2	O	H-bridge output. Connect directly to the motor or other inductive load.
			Thermal pad. Connect to board ground. For good thermal dissipation, use large ground planes on multiple layers, and multiple nearby vias connecting those planes.

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### Absolute Maximum Ratings

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

		MIN	MAX	UNIT
Power supply voltage	VM	-0.3	40.0	V
Logic input voltage	IN1, IN2	-0.3	7.0	V
Reference input pin voltage	VREF	-0.3	6.0	V
Continuous phase node pin voltage	OUT1, OUT2	-0.3	VM+0.7	V
Current sense input pin voltage	ISEN	-0.3	1	V
ESD (HBM)	VM, IN1, IN2, OUT1, OUT2, VREF, ISEN	2		kV
Output current (100% duty cycle)	IOUT	0	4.0	A
Operating junction temperature,	T <sub>J</sub>	-40	150	°C
Storage temperature,	T <sub>stg</sub>	-65	150	°C
Thermal Impedance	θ <sub>JA</sub>		45	°C/W

### Recommended Operating Conditions

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

		MIN	MAX	UNIT
Power supply voltage	VM	4.5	36.0	V
Logic input voltage	IN1, IN2	0	5.5	V
Reference input pin voltage	VREF	0.3	5.0	V
Logic input PWM frequency	f <sub>PWM</sub>	0	200	kHz
Peak output current	IPEAK	0	4.5	A

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### Electrical Characteristics

T<sub>A</sub> = 25°C, over recommended operating conditions (unless otherwise noted)

PARAMETER UNIT		TEST CONDITIONS	MIN	TYP	MAX	UNIT
<b>POWER SUPPLY (VM)</b>						
VM	VM operating voltage		4.5		36	V
I <sub>VM_ON</sub>	VM operating supply current	VM=18V		1.2	2.5	mA
I <sub>VM_OFF</sub>	VM sleep current	VM=18V		1.5	10	uA
T <sub>on</sub>	Turn-on time	VM>V <sub>UVLO</sub> , with IN1 or IN2 high		30	50	us
<b>MOTOR DRIVER OUTPUTS (OUT1, OUT2)</b>						
R <sub>DSON</sub>	High-side & Low-side FET on resistance	VM=18V, LS+HS, I <sub>OUT</sub> =1A		350	500	mΩ
T <sub>DEAD</sub>	Output dead time			200		ns
V <sub>D</sub>	Body diode forward voltage	I <sub>OUT</sub> =1A		0.8	1	V
<b>LOGIC-LEVEL INPUTS (IN1, IN2)</b>						
V <sub>INH</sub>	Input logic high voltage		1.5			V
V <sub>INL</sub>	Input logic low voltage		0		0.5	V
V <sub>IN_HYS</sub>	Input logic hysteresis			0.1		V
I <sub>INH</sub>	Input logic high current	IN=3.3V		33	50	uA
I <sub>INL</sub>	Input logic low current	IN=0V		0	1	
R <sub>PD</sub>	Pulldown resistance	to GND		100	200	KΩ
T <sub>PD</sub>	Propagation delay	INx to OUTx change		20		ns
T <sub>SLP</sub>	Time to sleep	Inputs low to sleep		1.0		ms
<b>CURRENT REGULATION</b>						
A <sub>V</sub>	ISEN gain	VREF=2.5V		10		V/V
T <sub>OFF</sub>	PWM off-time			20		us
T <sub>BLANK</sub>	PWM blanking time			4.0		
<b>PROTECTION CIRCUITS</b>						
V <sub>UVLO_R</sub>	VM rises until operation recovers			3.80		V
V <sub>UVLO_F</sub>	VM falls until UVLO triggers			3.65		
V <sub>UVLO_H</sub>	VM undervoltage hysteresis			0.15		
I <sub>OC</sub>	Overcurrent protection trip level			5.5		A
T <sub>OC</sub>	Overcurrent deglitch time			1.5		us
T <sub>RETRY</sub>	Overcurrent retry time			3.0		ms
T <sub>SD</sub>	Thermal shutdown temperature			160		°C
T <sub>HYS</sub>	Thermal shutdown hysteresis			30		

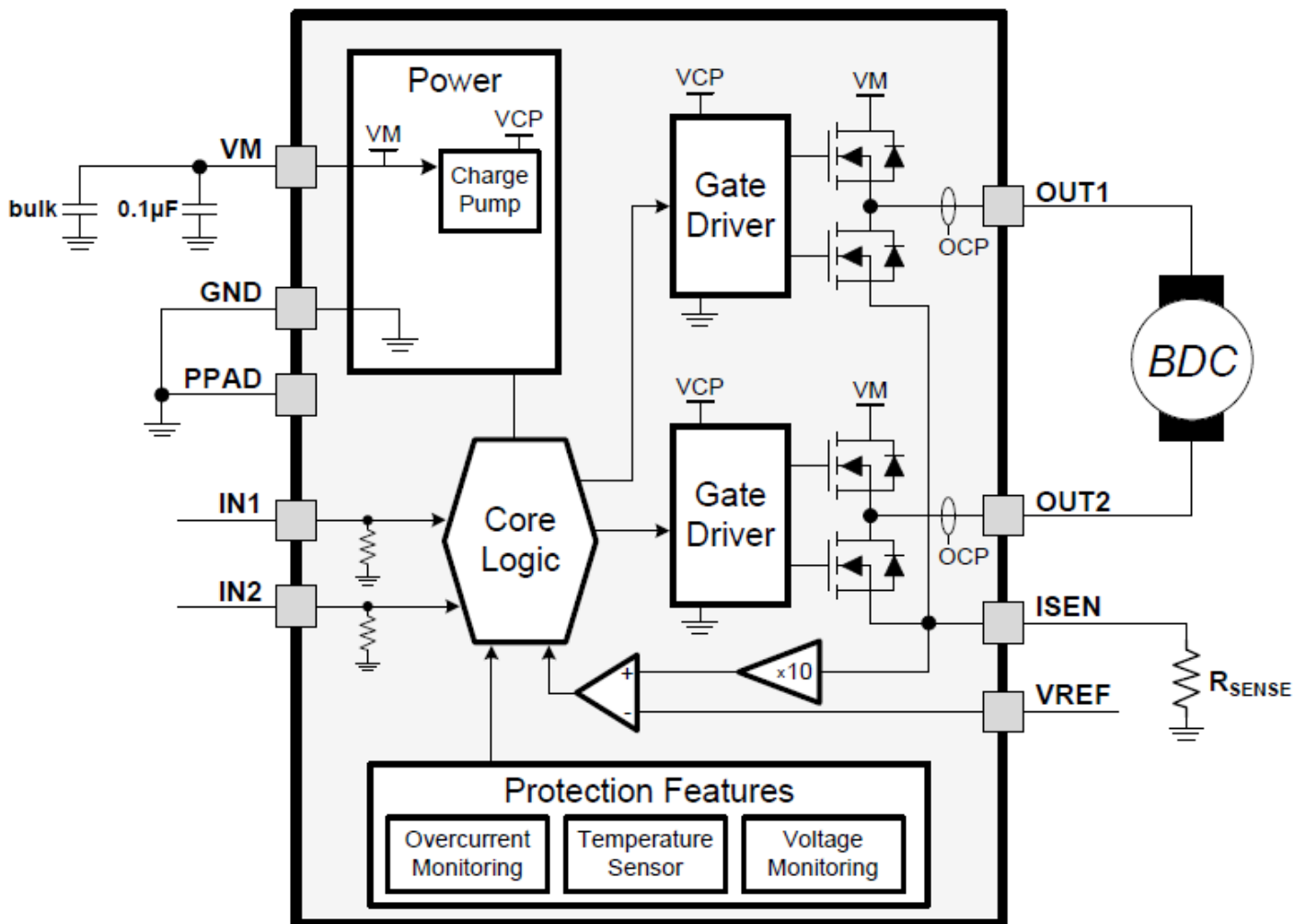
## 4.5-40.0V 4.5A Brushed DC Motor Driver (PWM Control)

### Detailed Description

#### Overview

The SA8870C device is an optimized 8-pin device for driving brushed DC motors with 4.5 to 36.0 V and up to 4.5-A peak current. The integrated current regulation restricts motor current to a predefined maximum. Two logic inputs control the H-bridge driver, which consists of four N-channel MOSFETs that have a typical  $R_{DS(ON)}$  of 400m $\Omega$  (including one high-side and one low-side FET). A single-power input, VM, serves as both device power and the motor winding bias voltage. The integrated charge pump of the device boosts VM internally and fully enhances the high-side FETs. Motor speed can be controlled with pulse-width modulation, at frequencies between 0 to 100 kHz. The device has an integrated sleep mode that is entered by bringing both inputs low. An assortment of protection features prevents the device from being damaged if a system fault occurs.

#### Functional Block Diagram



## 4.5-40.0V 4.5A Brushed DC Motor Driver (PWM Control)

### Feature Description

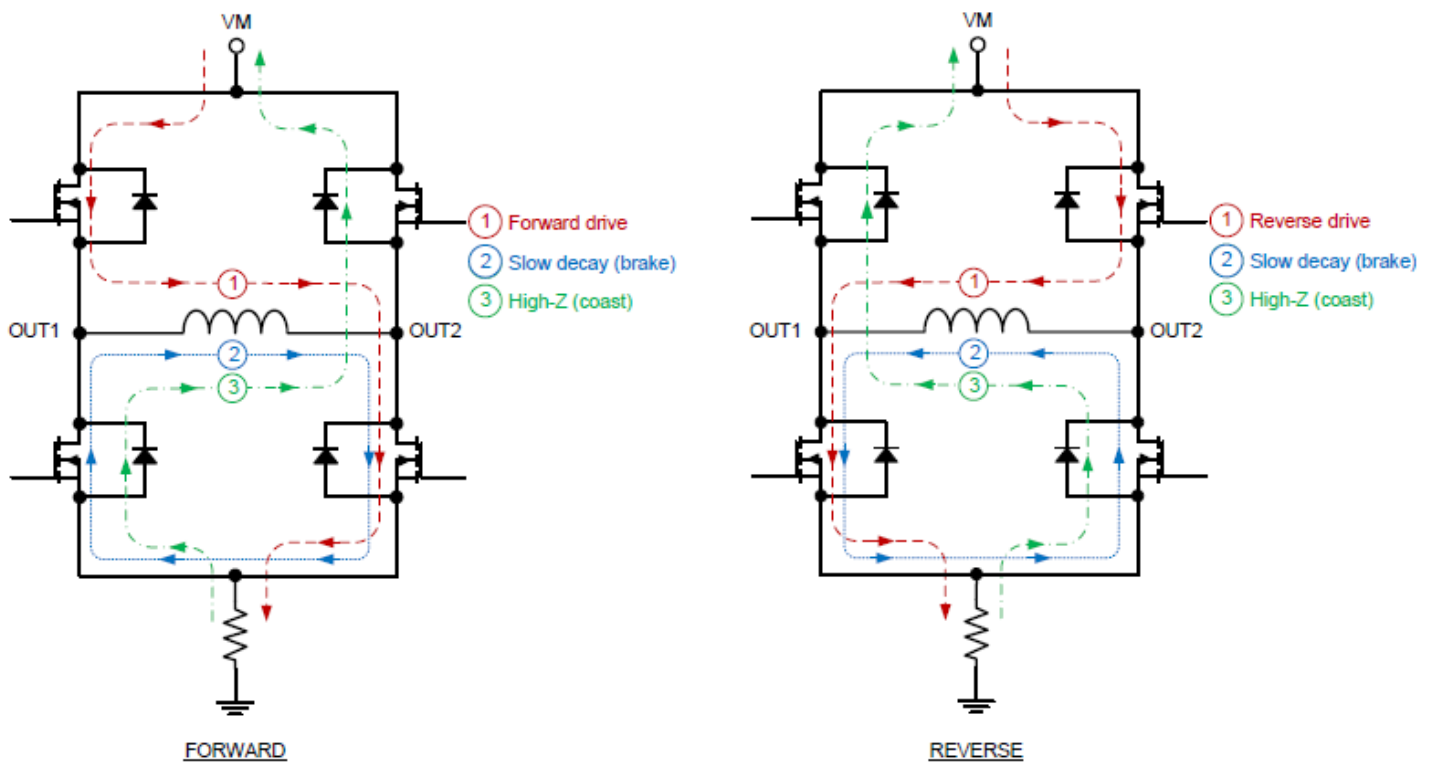
#### Bridge Control

The SA8870C output consists of four N-channel MOSFETs that are designed to drive high current. These outputs are controlled by the two logic inputs IN1 and IN2 as listed in [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 can be set to static voltages for 100% duty cycle drive, or they can be pulse-width modulated (PWM) for variable motor speed. When using PWM, switching between driving and braking typically works best. For example, to drive a motor forward with 50% of the maximum RPM, IN1 = 1 and IN2 = 0 during the driving period, and IN1 = 1 and IN2 = 1 during the other period. Alternatively, the coast mode (IN1 = 0, IN2 = 0) for *fast current decay* is also available. The input pins can be powered before VM is applied.



**Figure 4. H-Bridge Current Paths**

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### Sleep Mode

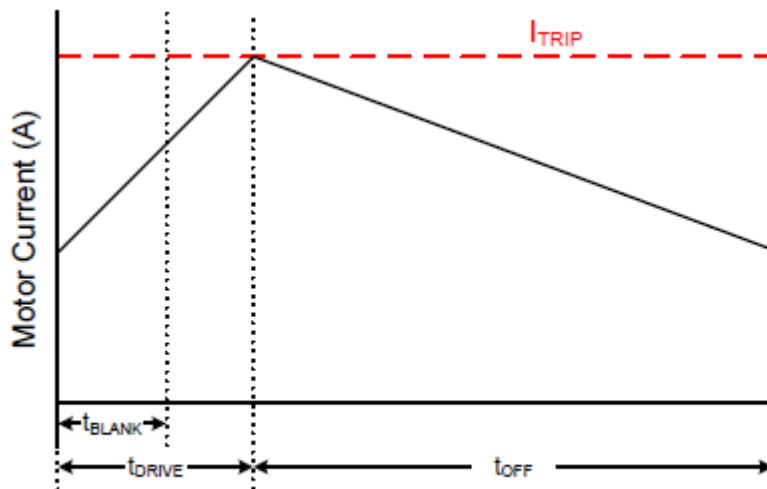
When the IN1 and IN2 pins are both low for time  $t_{SLEEP}$  (typically 1 ms), the SA8870C device enters a low-power sleep mode, where the outputs remain High-Z and the device uses  $I_{VMOFF}$  ( $\mu A$ ) of current. If the device is powered up while both inputs are low, it immediately enters sleep mode. After the IN1 or IN2 pins are high for at least  $5\mu s$ , the device is operational  $50\mu s$  ( $t_{ON}$ ) later.

### Current Regulation

The SA8870C device limits the output current based on the analog input,  $V_{REF}$ , and the resistance of an external sense resistor on the ISEN pin according to [Equation 1](#):

$$I_{TRIP}(A) = \frac{V_{REF}(V)}{A_V \times R_{ISEN}(\Omega)} = \frac{V_{REF}(V)}{10 \times R_{ISEN}(\Omega)}$$

For example, if  $V_{REF} = 3.3 V$  and a  $R_{ISEN} = 0.15 \Omega$ , the SA8870C device limits motor current to 2.2 A no matter how much load torque is applied. For guidelines on selecting a sense resistor, see the [Sense Resistor](#) section. When  $I_{TRIP}$  is reached, the device enforces slow current decay by enabling both low-side FETs, and it does this for a time of  $t_{OFF}$  (typically 20  $\mu s$ ).



**Figure 5. Current-Regulation Time Periods**

After  $t_{OFF}$  elapses, the output is re-enabled according to the two inputs, INx. The drive time ( $t_{DRIVE}$ ) until reaching another  $I_{TRIP}$  event heavily depends on the VM voltage, the back-EMF of the motor, and the inductance of the motor.

### Dead Time

When an output changes from driving high to driving low, or driving low to driving high, dead time is automatically inserted to prevent shoot-through. The  $t_{DEAD}$  time is the time in the middle when the output is High-Z. If the output pin is measured during  $t_{DEAD}$ , the voltage depends on the direction of current. If the current is leaving the pin, the voltage is a diode drop below ground. If the current is entering the pin, the voltage is a diode drop above VM. This diode is the body diode of the high-side or low-side FET.

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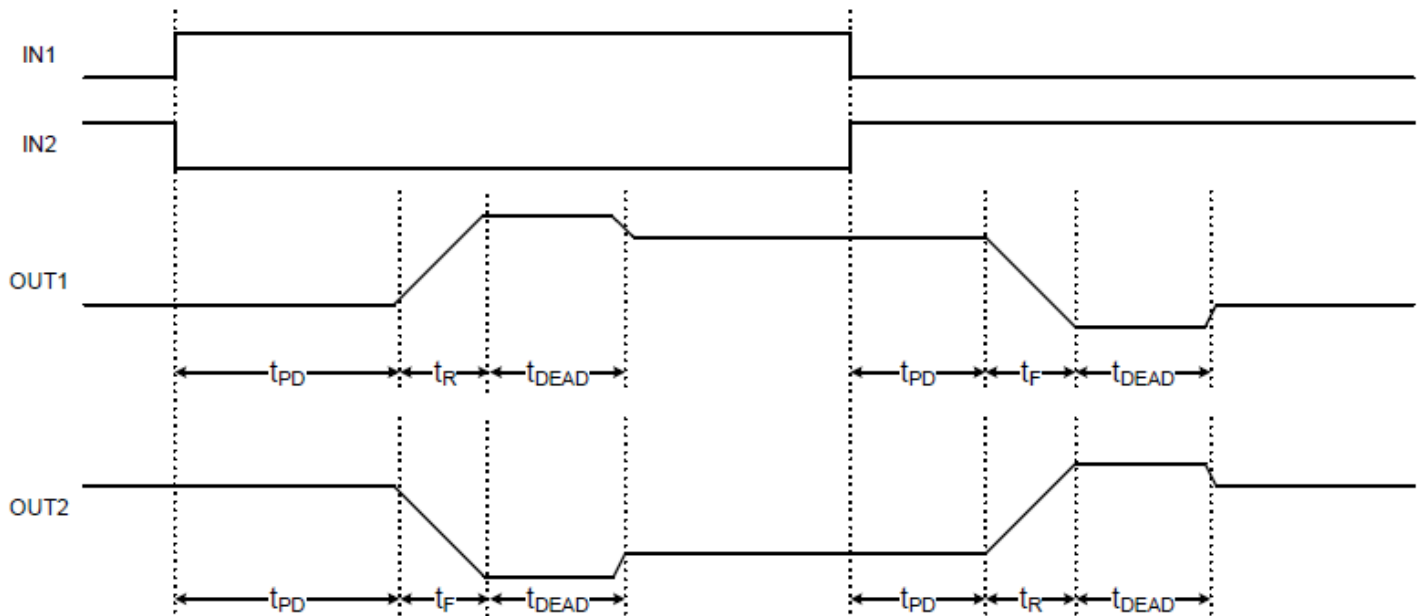


Figure 6. Propagation Delay Time

### Protection Circuits

The SA8870C device is fully protected against VM undervoltage, overcurrent, and overtemperature events.

#### VM Undervoltage Lockout (UVLO)

If at any time the voltage on the VM pin falls below the undervoltage-lockout threshold voltage, all FETs in the H-bridge will be disabled. Operation resumes when VM rises above the UVLO threshold.

#### Overcurrent Protection (OCP)

If the output current exceeds the OCP threshold,  $I_{OCP}$ , for longer than  $t_{OCP}$ , all FETs in the H-bridge are disabled for a duration of  $t_{RETRY}$ . After that, the H-bridge is re-enabled according to the state of the INx pins. If the overcurrent fault is still present, the cycle repeats, otherwise normal device operation resumes.

#### Thermal Shutdown (TSD)

If the die temperature exceeds safe limits, all FETs in the H-bridge are disabled. After the die temperature has fallen to a safe level, operation automatically resumes.

Table 2. Protection Functionality

FAULT	CONDITION	H-BRIDGE BECOMES	RECOVERY
VM undervoltage lockout (UVLO)	$VM < V_{UVLO}$	Disabled	$VM > V_{UVLO}$
Overcurrent (OCP)	$I_{OUT} > I_{OCP}$	Disabled	$t_{RETRY}$
Thermal Shutdown (TSD)	$T_J > 150^\circ\text{C}$	Disabled	$T_J < T_{SD} - T_{HYS}$



## 4.5-40.0V 4.5A Brushed DC Motor Driver (PWM Control)

### Device Functional Modes

The SA8870C device can be used in multiple ways to drive a brushed DC motor.

#### PWM With Current Regulation

This scheme uses all of the capabilities of the device. The ITRIP current is set above the normal operating current, and high enough to achieve an adequate spin-up time, but low enough to constrain current to a desired level. Motor speed is controlled by the duty cycle of one of the inputs, while the other input is static. Brake or slow decay is typically used during the off-time.

#### PWM Without Current Regulation

If current regulation is not required, the ISEN pin should be directly connected to the PCB ground plane. The VREF voltage must still be 0.3 to 5 V, and larger voltages provide greater noise margin. This mode provides the highest-possible peak current which is up to 4.5A for a few hundred milliseconds (depending on PCB characteristics and the ambient temperature). If current exceeds 4.5A, the device might reach overcurrent protection (OCP) or overtemperature shutdown (TSD). If that happens, the device disables and protects itself for about 3ms ( $t_{RETRY}$ ) and then resumes normal operation.

#### Static Inputs with Current Regulation

The IN1 and IN2 pins can be set high and low for 100% duty cycle drive, and ITRIP can be used to control the current of the motor, speed, and torque capability.

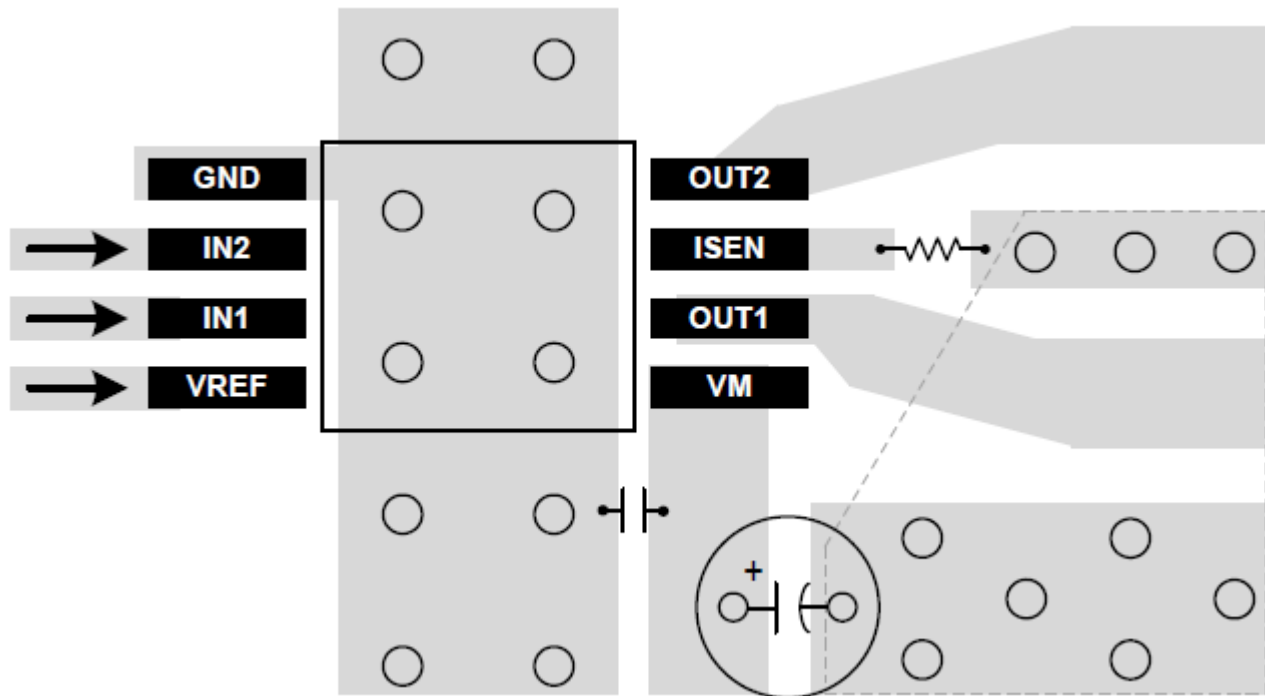
#### VM Control

In some systems, varying VM as a means of changing motor speed is desirable. See the [Motor Voltage](#) section for more information.

#### Layout Example

[The following](#) shows the recommended layout and component placement.

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### Thermal Considerations

The SA8870C device has thermal shutdown (TSD) as described in the [Thermal Shutdown \(TSD\)](#) section. If the die temperature exceeds approximately 160°C, the device is disabled until the temperature drops below the temperature hysteresis level. Any tendency of the device to enter TSD is an indication of either excessive power dissipation, insufficient heatsinking, or too high of an ambient temperature.

### Power Dissipation

Power dissipation in the SA8870C device is dominated by the power dissipated in the output FET resistance,  $R_{DS(on)}$ . Use the equation in the [Drive Current](#) section to calculate the estimated average power dissipation when driving a load.

Note that at startup, the current is much higher than normal running current; this peak current and its duration must be also be considered.

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

#### NOTE

$R_{DS(on)}$  increases with temperature, so as the device heats, the power dissipation increases. This fact must be taken into consideration when sizing the heatsink.

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The power dissipation of the SA8870C device is a function of RMS motor current and the FET resistance (RDS(ON)) of each output.

$$Power \approx I_{RMS}^2 \times (High - side R_{DS(ON)} + Low - side R_{DS(ON)})$$

For this example, the ambient temperature is 58°C, and the junction temperature reaches 66°C. At 58°C, the sum of RDS(ON) is about 0.26Ω. With an example motor current of 0.8 A, the dissipated power in the form of heat is  $0.8 A^2 \times 0.26 \Omega = 0.17 W$ .

The temperature that the SA8870C reaches will depend on the thermal resistance to the air and PCB. It is important to solder the device PowerPAD to the PCB ground plane, with vias to the top and bottom board layers, in order to dissipate heat into the PCB and reduce the device temperature. In the example used here, the SA8870C device had an effective thermal resistance  $R_{\theta JA}$  of 48°C/W, and:

$$T_J = T_A + (P_D \times R_{\theta JA}) = 58^\circ C + (0.17W \times 48^\circ C/W) = 66^\circ C \quad (4)$$

### Heatsinking

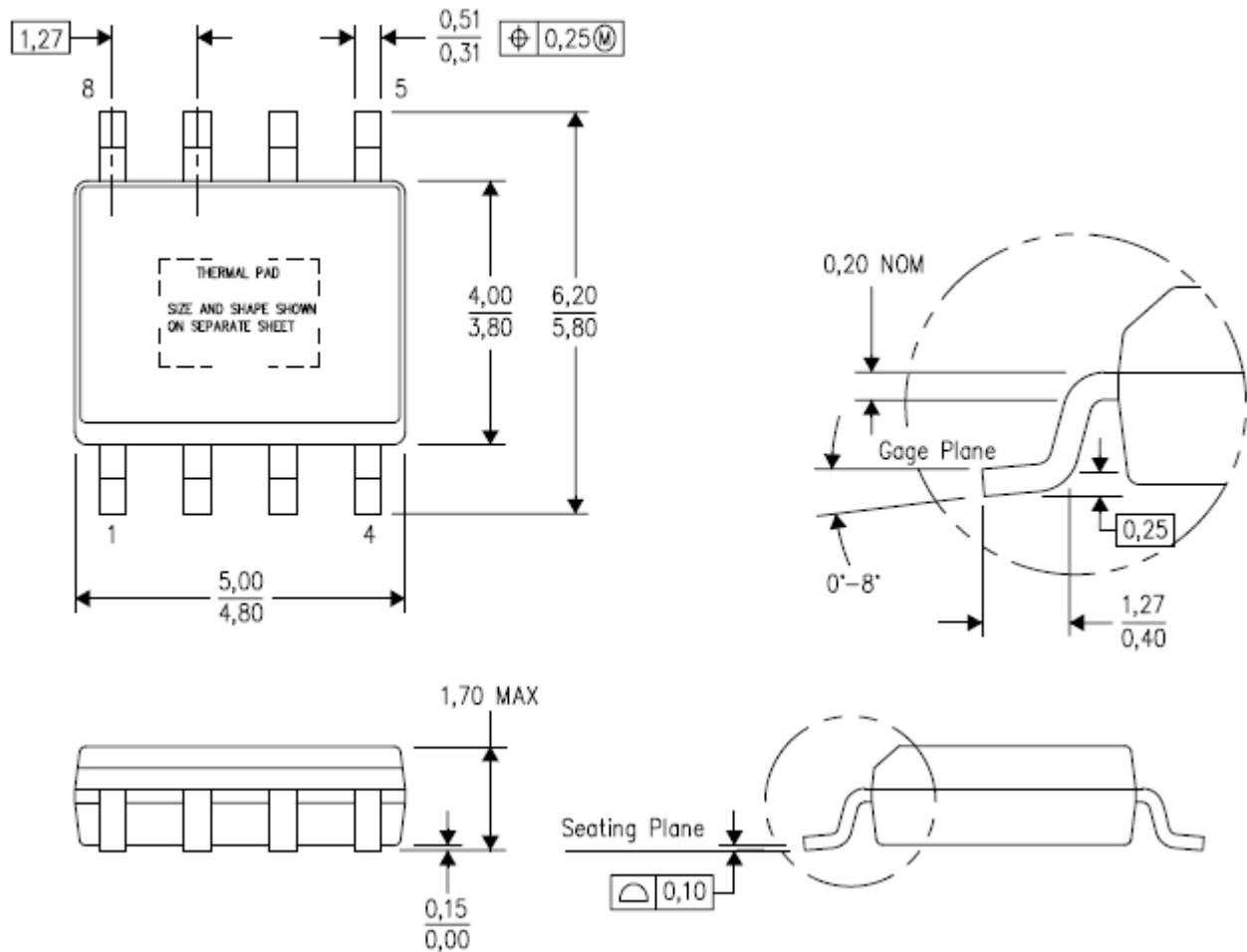
The PowerPAD package uses an exposed pad to remove heat from the device. For proper operation, this pad must be thermally connected to copper on the PCB to dissipate heat. On a multi-layer PCB with a ground plane, this connection can be accomplished by adding a number of vias to connect the thermal pad to the ground plane.

On PCBs without internal planes, a copper area can be added on either side of the PCB to dissipate heat. If the copper area is on the opposite side of the PCB from the device, thermal vias are used to transfer the heat between top and bottom layers.

## 4.5-40.0V 4.5A Brushed DC Motor Driver (PWM Control)

### Package Information

ESOP8



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