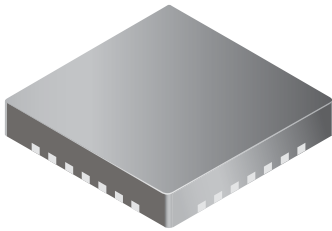


## 3-Phase Brushless DC Motor Pre-Driver

### Features and Benefits

- Drives 6 N-channel MOSFETs
- Synchronous rectification for low power dissipation
- Internal UVLO and thermal shutdown circuitry
- Hall element inputs
- PWM current limiting
- Dead time protection
- FG outputs
- Standby mode
- Lock detect protection
- Overvoltage protection

### Package: 28-contact QFN (ET package)



Approximate Scale 1:1



### Description

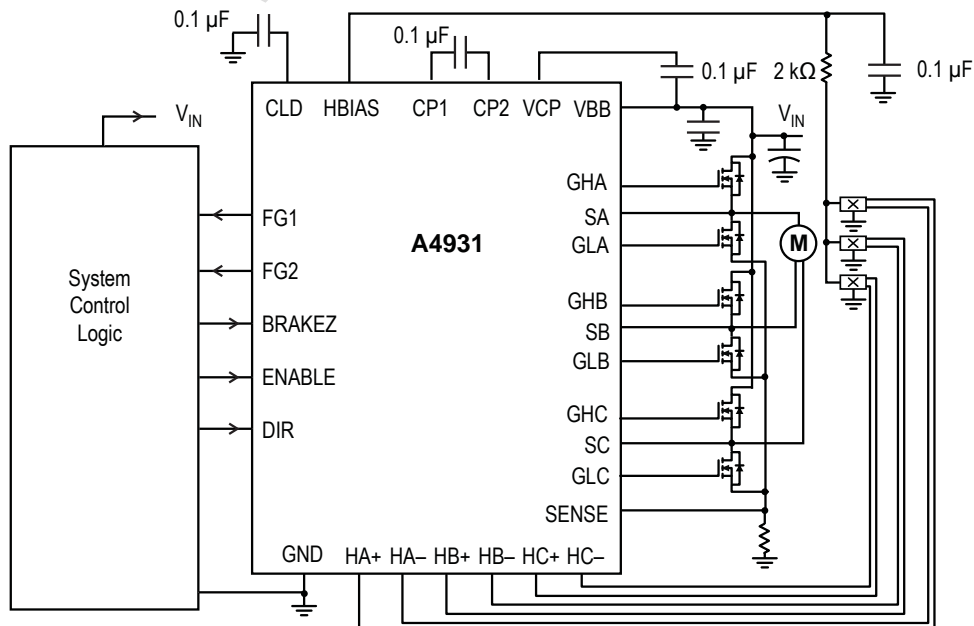
The A4931 is a complete 3-phase brushless DC motor pre-driver. The device is capable of driving a wide range of N-channel power MOSFETs and can support motor supply voltages up to 30 V. Commutation logic is determined by three Hall-element inputs spaced at 120°.

Other features include fixed off-time pulse width modulation (PWM) current control for limiting inrush current, locked-rotor protection with adjustable delay, thermal shutdown, overvoltage monitor, and synchronous rectification. Internal synchronous rectification reduces power dissipation by turning on the appropriate MOSFETs during current decay, thus shorting the body diode with the low  $R_{DS(on)}$  MOSFET. Overvoltage protection disables synchronous rectification when the motor pumps the supply voltage beyond the overvoltage threshold during current recirculation.

The A4931 offers enable, direction, and brake inputs that can control current using either phase or enable chopping. Logic outputs FG1 and FG2 can be used to accurately measure motor rotation. Output signals toggle state during Hall transitions, providing an accurate speed output to a microcontroller or speed control circuit.

Operating temperature range is  $-20^{\circ}\text{C}$  to  $105^{\circ}\text{C}$ . The A4931 is supplied in a  $5\text{ mm} \times 5\text{ mm}$ , 28-terminal QFN package with exposed thermal pad. This small footprint package is lead (Pb) free with 100% matte tin leadframe plating.

### Typical Application



## Selection Guide

| Part Number  | Packing              | Package                                 |
|--------------|----------------------|---|
| A4931METTR-T | 1500 pieces per reel | 5 mm x 5 mm, 0.90 mm nominal height QFN |

## Absolute Maximum Ratings

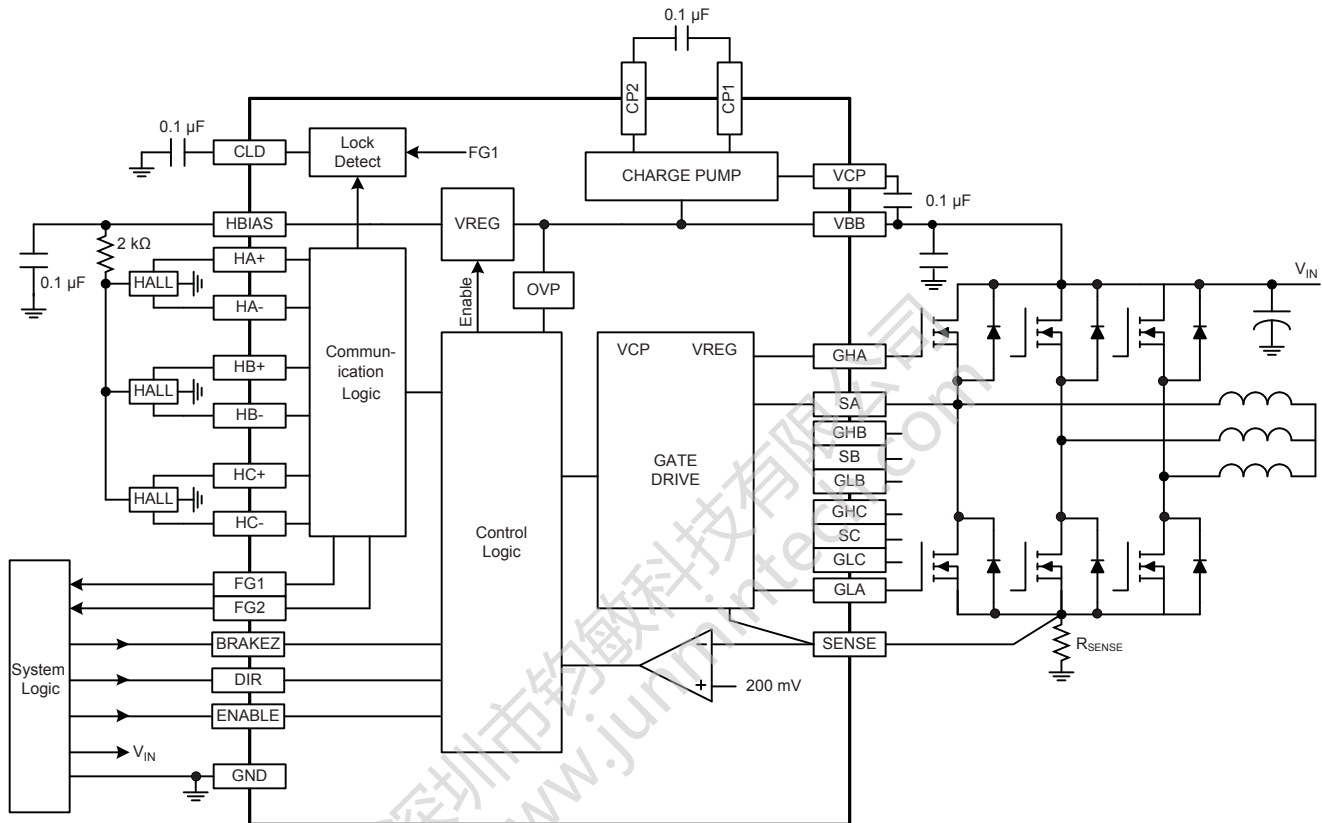
| Characteristic                | Symbol       | Notes          | Rating     | Units |
|-------------------------------|--------------|----------------|------------|-------|
| Load Supply Voltage           | $V_{BB}$     |                | 38         | V     |
| Motor Phase Output            | $S_X$        | $t_w < 500$ ns | -3         | V     |
| Hall Input                    | $V_{HX}$     | DC             | -0.3 to 7  | V     |
| Logic Input Voltage Range     | $V_{IN}$     |                | -0.3 to 7  | V     |
| Operating Ambient Temperature | $T_A$        | Range M        | -20 to 105 | °C    |
| Maximum Junction Temperature  | $T_{J(max)}$ |                | 150        | °C    |
| Storage Temperature           | $T_{stg}$    |                | -40 to 150 | °C    |

## Thermal Characteristics

| Characteristic                                      | Symbol          | Test Conditions*                    | Rating | Units |
|---|-----------------|-------------------------------------|--------|-------|
| Package Thermal Resistance, Junction to Ambient     | $R_{\theta JA}$ | 4-layer PCB based on JEDEC standard | 32     | °C/W  |
| Package Thermal Resistance, Junction to Exposed Pad | $R_{\theta JP}$ |                                     | 2      | °C/W  |

\*For additional information, refer to the Allegro website.

### Functional Block Diagram



### Terminal List

| Number | Name  | Description                    |
|--------|-------|--------------------------------|
| 1      | HA+   | Hall input A                   |
| 2      | HA-   | Hall input A                   |
| 3      | HB+   | Hall input B                   |
| 4      | HB-   | Hall input B                   |
| 5      | HC+   | Hall input C                   |
| 6      | HC-   | Hall input C                   |
| 7      | GND   | Ground                         |
| 8      | HBIAS | Hall bias power supply output  |
| 9      | CP1   | Charge pump capacitor terminal |
| 10     | CP2   | Charge pump capacitor terminal |
| 11     | VBB   | Supply voltage                 |
| 12     | VCP   | Reservoir capacitor terminal   |
| 13     | SENSE | Sense resistor connection      |
| 14     | GLC   | Low side gate drive C          |

| Number | Name   | Description                            |
|--------|--------|--|
| 15     | GLB    | Low side gate drive B                  |
| 16     | GLA    | Low side gate drive A                  |
| 17     | GHC    | High side gate drive C                 |
| 18     | SC     | High side source connection C          |
| 19     | GHB    | High side gate drive B                 |
| 20     | SB     | High side source connection B          |
| 21     | GHA    | High side gate drive A                 |
| 22     | SA     | High side source connection A          |
| 23     | FG1    | FG 1 speed control output (3 Φ inputs) |
| 24     | FG2    | FG 2 speed control output (ΦA input)   |
| 25     | CLD    | Locked rotor detect timing capacitor   |
| 26     | DIR    | Logic input – motor direction          |
| 27     | ENABLE | Logic input – external PWM control     |
| 28     | BRAKEZ | Logic input – motor brake (active low) |

**ELECTRICAL CHARACTERISTICS\*** Valid at  $T_A = 25^\circ\text{C}$ ,  $V_{BB} = 24\text{ V}$ , unless noted otherwise

| Characteristics                     | Symbol         | Test Conditions   | Min. | Typ.     | Max.       | Units             |
|-------------------------------------|----------------|---|------|----------|------------|-------------------|
| Supply Voltage Range                | $V_{BB}$       | Operating   | 8    | –        | $V_{BBOV}$ | V                 |
| Motor Supply Current                | $I_{BB}$       | $f_{PWM} < 30\text{ kHz}$ , $C_{LOAD} = 1000\text{ pF}$ | –    | 5        | 6          | mA                |
|                                     |                | Charge pump on, outputs disabled, Standby mode          | –    | 3        | 3.5        | mA                |
| HBIAS                               | $V_{HBIAS}$    | $0\text{ mA} \leq I_{HBIAS} \leq 24\text{ mA}$          | 7.2  | 7.5      | 7.8        | V                 |
| HBIAS Current Limit                 | $I_{HBIASlim}$ |   | 30   | –        | –          | mA                |
| <b>Control Logic</b>                |                |   |      |          |            |                   |
| Logic Input Voltage                 | $V_{IN(1)}$    |   | 2    | –        | –          | V                 |
|                                     | $V_{IN(0)}$    |   | –    | –        | 0.8        | V                 |
| Logic Input Current                 | $I_{IN(1)}$    | $V_{IN} = 2\text{ V}$                                   | –1   | <1.0     | 1          | $\mu\text{A}$     |
|                                     | $I_{IN(0)}$    | $V_{IN} = 0.8\text{ V}$                                 | –1   | <–1.0    | 1          | $\mu\text{A}$     |
| Input Pin Glitch Reject             | $t_{GLITCH}$   | ENB pin   | 350  | 500      | 650        | ns                |
|                                     |                | DIR, BRAKEZ pins  | 700  | 1000     | 1300       | ns                |
| ENB Standby Pulse Propagation Delay | $t_{dENB}$     | To outputs off  | 2.1  | 3        | 3.9        | ms                |
| HBIAS Wake-up Delay, Standby Mode   | $t_{dHBIAS}$   | $C_{HBIAS} = 0.1\text{ }\mu\text{F}$                    | –    | 15       | 25         | $\mu\text{s}$     |
| <b>Gate Drive</b>                   |                |   |      |          |            |                   |
| High-Side Gate Drive Output         | $V_{GS(H)}$    | Relative to $V_{BB}$ , $I_{GATE} = 2\text{ mA}$         | 7    | –        | –          | V                 |
| Low-Side Gate Drive Output          | $V_{GS(L)}$    | $I_{GATE} = 2\text{ mA}$                                | 7    | –        | –          | V                 |
| Gate Drive Current (Sourcing)       | $I_{Gate}$     | $GH = GL = 4\text{ V}$                                  | 20   | 30       | –          | mA                |
| Gate Drive Pull Down Resistance     | $R_{Gate}$     |   | 10   | 28       | 40         | $\Omega$          |
| Dead Time                           | $t_{dead}$     |   | 700  | 1000     | 1300       | ns                |
| Current Limit Input Threshold       | $V_{REF}$      |   | 180  | 200      | 220        | mV                |
| Fixed Off-Time                      | $t_{OFF}$      |   | 18   | 25       | 37         | $\mu\text{s}$     |
| <b>Protection</b>                   |                |   |      |          |            |                   |
| Thermal Shutdown Temperature        | $T_{JTSD}$     |   | 155  | 170      | 185        | $^\circ\text{C}$  |
| Thermal Shutdown Hysteresis         | $T_{JTSDhys}$  |   | 14   | 15       | 26         | $^\circ\text{C}$  |
| VBB UVLO Enable Threshold           | $V_{BBUV}$     | Rising $V_{BB}$   | 6.2  | 7        | 7.85       | V                 |
| VBB UVLO Hysteresis                 | $V_{BBUVhys}$  |   | 0.4  | 0.75     | 1          | V                 |
| VCP UVLO                            | $V_{CPIUV}$    | Relative to $V_{BB}$                                    | 4.6  | –        | 6          | V                 |
| Lock Detect Duration                | $t_{lock}$     | $C = 0.1\text{ }\mu\text{F}$                            | 1.5  | 2        | 2.5        | s                 |
| VBB Overvoltage Threshold           | $V_{BBOV}$     | Rising $V_{BB}$   | 30   | 33       | 37.5       | V                 |
| <b>Hall Logic</b>                   |                |   |      |          |            |                   |
| Hall Input Current                  | $I_{HALL}$     | $V_{IN} = 0.2\text{ to }3.5\text{ V}$                   | –1   | 0        | 1          | $\mu\text{A}$     |
| Common Mode Input Range             | $V_{CMR}$      |   | 0.2  | –        | 3.5        | V                 |
| AC Input Voltage Range              | $V_{HALL}$     |   | 60   | –        | –          | $\text{mV}_{p-p}$ |
| Hall Thresholds                     | $V_{th}$       | Difference between Hall inputs at transitions           | –    | +10, –10 | –          | mV                |
| Hall Threshold Hysteresis           | $V_{HYS}$      | $T_J = 25^\circ\text{C}$                                | 10   | 20       | 30         | mV                |
|                                     |                | $T_J = -20^\circ\text{C to }125^\circ\text{C}$          | 5    | 20       | 40         | mV                |
| Pulse Reject Filter                 | $t_{pulse}$    |   | –    | 2        | –          | $\mu\text{s}$     |
| <b>FG</b>                           |                |   |      |          |            |                   |
| FG Output Saturation Voltage        | $V_{FG(sat)}$  | $I_{FG} = 2\text{ mA}$                                  | –    | –        | 0.5        | V                 |
| FG Leakage Current                  | $I_{FGlk}$     | $V_{FG} = 5\text{ V}$                                   | –    | –        | 1          | $\mu\text{A}$     |

\*Typical data are for initial design estimations only, and assume optimum manufacturing and application conditions. Performance may vary for individual units, within the specified maximum and minimum limits.

For input and output current specifications, negative current is defined as coming out of (sourcing) the specified device pin.

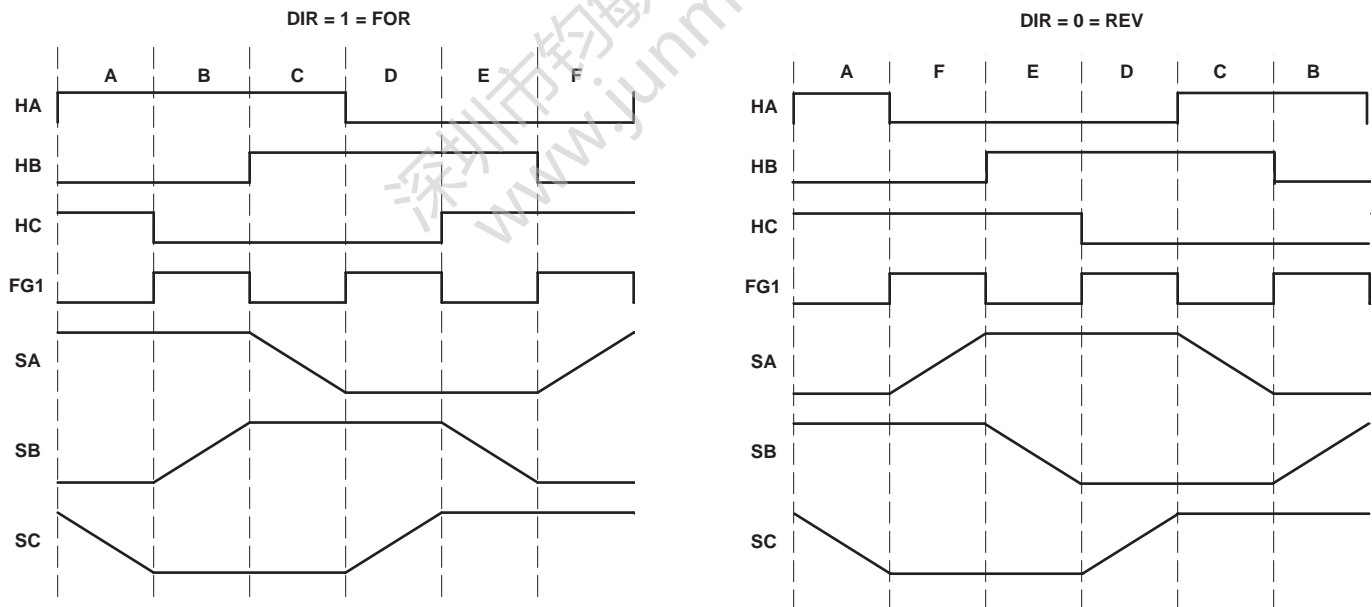
Specifications throughout the allowed operating temperature range are guaranteed by design and characterization.



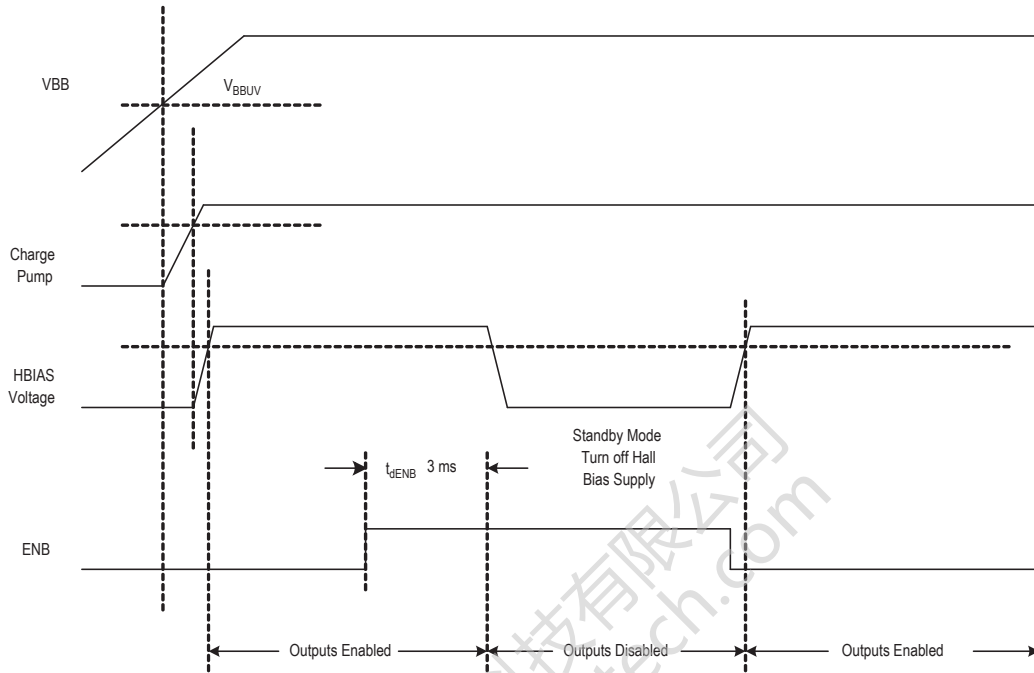
**Logic States Table** (See timing charts, below) X = Don't Care, Z = high impedance

| Condition            |   | Inputs |    |    |        |     | Resulting Pre-Driver Outputs |     |     |     |     |     | Motor Output |    |    |
|----------------------|---|--------|----|----|--------|-----|------------------------------|-----|-----|-----|-----|-----|--------------|----|----|
|                      |   | HA     | HB | HC | BRAKEZ | ENB | GHA                          | GLA | GHB | GLB | GHC | GLC | A            | B  | C  |
| DIR = 1<br>(Forward) | A | +      | -  | +  | HI     | LO  | HI                           | LO  | LO  | HI  | LO  | LO  | HI           | LO | Z  |
|                      | B | +      | -  | -  | HI     | LO  | HI                           | LO  | LO  | LO  | LO  | HI  | HI           | Z  | LO |
|                      | C | +      | +  | -  | HI     | LO  | LO                           | LO  | HI  | LO  | LO  | HI  | Z            | HI | LO |
|                      | D | -      | +  | -  | HI     | LO  | LO                           | HI  | HI  | LO  | LO  | LO  | LO           | HI | Z  |
|                      | E | -      | +  | +  | HI     | LO  | LO                           | HI  | LO  | LO  | LO  | HI  | LO           | Z  | HI |
|                      | F | -      | -  | +  | HI     | LO  | LO                           | LO  | LO  | HI  | HI  | LO  | Z            | LO | HI |
| DIR = 0<br>(Reverse) | A | +      | -  | +  | HI     | LO  | LO                           | HI  | HI  | LO  | LO  | LO  | LO           | HI | Z  |
|                      | F | -      | -  | +  | HI     | LO  | LO                           | LO  | HI  | LO  | LO  | HI  | Z            | HI | LO |
|                      | E | -      | +  | +  | HI     | LO  | HI                           | LO  | LO  | LO  | LO  | HI  | HI           | Z  | LO |
|                      | D | -      | +  | -  | HI     | LO  | HI                           | LO  | LO  | HI  | LO  | LO  | HI           | LO | Z  |
|                      | C | +      | +  | -  | HI     | LO  | LO                           | LO  | LO  | HI  | HI  | LO  | Z            | LO | HI |
|                      | B | +      | -  | -  | HI     | LO  | LO                           | HI  | LO  | LO  | LO  | HI  | LO           | Z  | HI |
| Fault*               |   | +      | +  | +  | HI     | X   | LO                           | LO  | LO  | LO  | LO  | LO  | Z            | Z  | Z  |
| Fault*               |   | -      | -  | -  | HI     | X   | LO                           | LO  | LO  | LO  | LO  | LO  | Z            | Z  | Z  |
| Brake*               |   | X      | X  | X  | LO     | X   | LO                           | HI  | LO  | HI  | LO  | HI  | LO           | LO | LO |

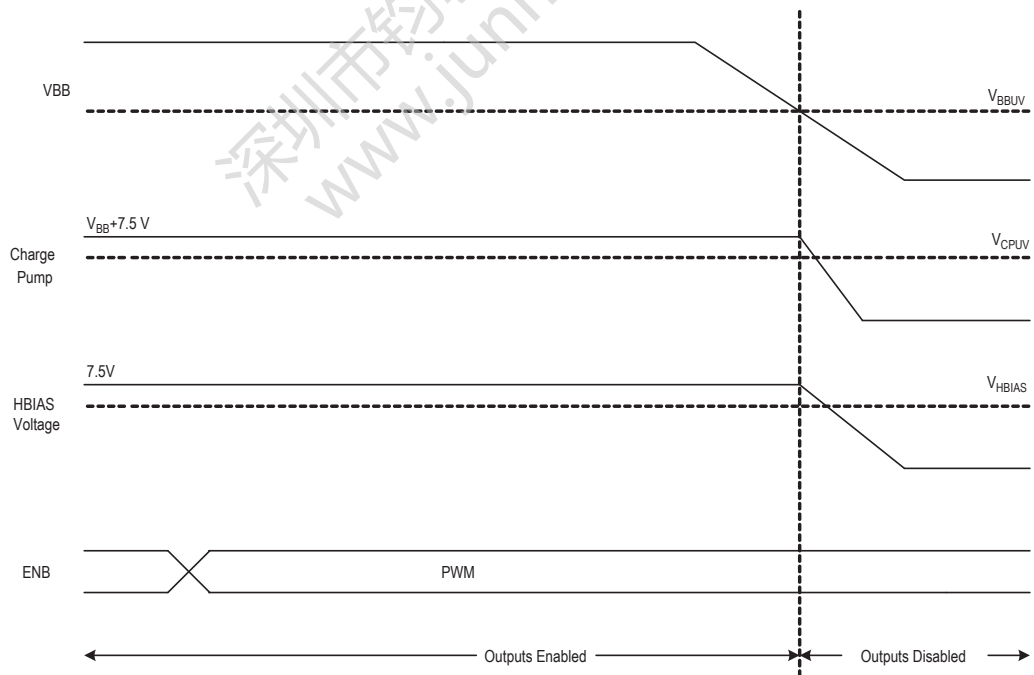
\* DIR = Don't Care



Power-up and Standby Modes Timing Diagram



Power-up and Standby Modes Timing Diagram



## Functional Description

**Current Regulation** Load current is regulated by an internal fixed off-time PWM control circuit. When the outputs of the full bridge are turned on, current increases in the motor winding until it reaches a value,  $I_{TRIP}$ , given by:

$$I_{TRIP} = 200 \text{ mV} / R_{SENSE}$$

When  $I_{TRIP}$  is reached, the sense comparator resets the source enable latch, turning off the source driver. At this point, load inductance causes the current to recirculate for the fixed off-time period.

**Enable Logic** The Enable input terminal (ENB pin) allows external PWM. ENB low turns on the selected sink-source pair. ENB high switches off the appropriate drivers and the load current decays. If ENB is held low, the current will rise until it reaches the level set by the internal current control circuit. Typically PWM frequency is in 20 kHz to 30 kHz range. If the ENB high pulse width exceeds 3 ms, the gate outputs are disabled. The Enable logic is summarized in the following table:

| ENB Pin Setting      | Outputs        | Outputs State                             |
|----------------------|----------------|---|
| 0                    | On             | Drive                                     |
| 1                    | Source Chopped | Slow Decay with Synchronous Rectification |
| 1 for > 3 ms typical | Off            | Disable                                   |

**Fixed Off-Time** The A4931 fixed off-time is set to 25  $\mu$ s nominal.

**PWM Blank Timer** When a source driver turns on, a current spike occurs due to the reverse recovery currents of the clamp diodes as well as switching transients related to distributed capacitance in the load. To prevent this current spike from erroneously resetting the source Enable latch, the sense comparator is blanked. The blanking timer runs after the off-time counter com-

pletes, in order to provide the blanking function. The blanking timer is reset when ENB is chopped or DIR is changed. With external PWM control, a DIR change or an ENB on triggers the blanking function. The duration is fixed at 1.5  $\mu$ s.

**Synchronous Rectification** When a PWM-off cycle is triggered, either by a chop command on ENB or by an internal fixed off-time cycle, load current recirculates. The A4931 synchronous rectification feature turns on the appropriate MOSFETs during the current decay, and effectively shorts out the body diodes with the low  $R_{DS(on)}$  driver. This lowers power dissipation significantly and can eliminate the need for external Schottky diodes.

**Brake Mode** A logic low on the BRAKEZ pin activates Brake mode. A logic high allows normal operation. Braking turns on all three sink drivers, effectively shorting out the motor-generated BEMF. The BRAKEZ input overrides the ENB input and also the Lock Detect function.

It is important to note that the internal PWM current control circuit does not limit the current when braking, because the current does not flow through the sense resistor. The maximum current can be approximated by  $V_{BEMF} / R_{LOAD}$ . Care should be taken to insure that the maximum ratings of the A4931 are not exceeded in the worse case braking situation, high speed and high inertial load.

**HBIAS Function** This function provides a power supply of 7.5 V, current-limited to 30 mA. This reference voltage is used to power the logic sections of the IC and also to power the external Hall elements.

**Standby Mode** To prevent excessive power dissipation due to the current draw of the external Hall elements, Standby mode turns off the HBIAS output voltage. Standby mode is triggered

by holding ENB high for longer than 3 ms. Note that Brake mode overrides Standby mode, so hold the BRAKEZ pin high in order to enter Standby mode.

**Charge Pump** The internal charge pump is used to generate a supply above  $V_{BB}$  to drive the high-side MOSFETs. The voltage on the VCP pin is internally monitored, and in case of a fault condition, the outputs of the device are disabled.

**Fault Shutdown** In the event of a fault due to excessive junction temperature or due to low voltage on VCP or VBB, the outputs of the device are disabled until the fault condition is removed. At power-up the UVLO circuit disables the drivers.

**Overvoltage Protection** VBB is monitored to determine if a hazardous voltage is present due to the motor generator pumping up the supply bus. When the voltage exceeds  $V_{BB0V}$ , the synchronous rectification feature is disabled.

**Overtemperature Protection** If die temperature exceeds approximately 170°C, the Thermal Shutdown function will disable the outputs until the internal temperature falls below the 15°C hysteresis.

**Hall State Reporting** The FG1 pin is an open drain output that changes state at each transition of an external Hall element. The FG2 pin is an open drain output that changes state at each HAX transition.

**Lock Detect Function** The IC will evaluate a locked rotor condition under either of these two different conditions:

- The FG1 signal is not consistently changing.
- The proper commutation sequence is not being followed. The motor can be locked in a condition in which it toggles between two specific Hall device states.

Both of these fault conditions are allowed to persist for period of time,  $t_{lock}$ .  $t_{lock}$  is set by capacitor connected to CLD pin.  $C_{LD}$  produces a triangle waveform (1.67 V peak-to-peak) with frequency linearly related to the capacitor value.  $t_{lock}$  is defined as 127 cycles of this triangle waveform, or:

$$t_{lock} = C_{LD} \times 20 \text{ s}/\mu\text{F}$$

After the wait time,  $t_{lock}$ , has expired, the outputs are disabled, and the fault is latched. These fault conditions can only be cleared by any one of the following actions:

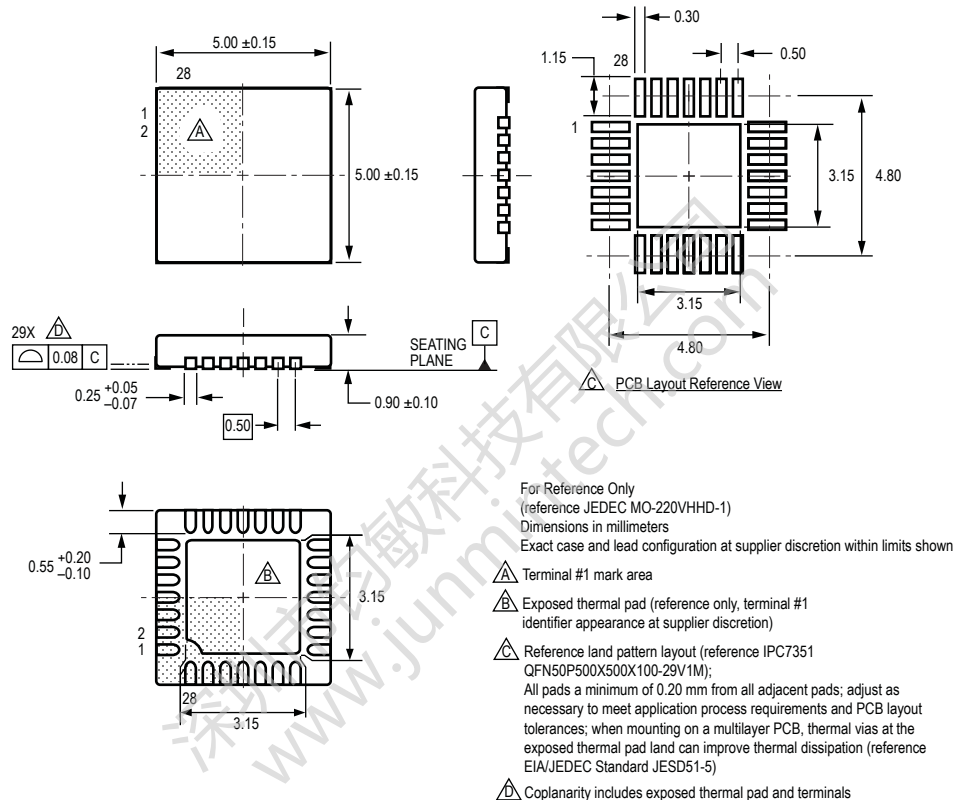
- Rising or falling edge on the DIR pin
- VBB UVLO threshold exceeded (during power-up cycle)
- ENB pin held high for  $> t_{lock} / 2$

The Lock Detect function can be disabled by connecting CLD to GND.

When the A4931 is in Brake mode, the Lock Detect counter is disabled.



## ET Package, 28-Contact QFN



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