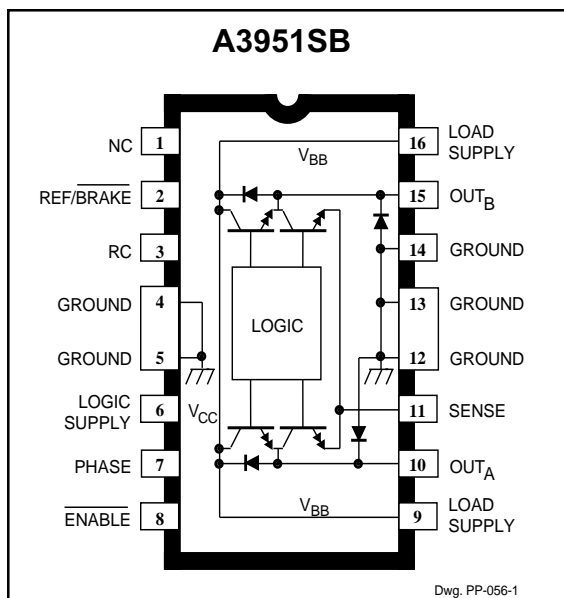


3951

FULL-BRIDGE PWM MOTOR DRIVER



ABSOLUTE MAXIMUM RATINGS

Load Supply Voltage, V_{BB}	50 V
Output Current, I_{OUT}	± 3.5 A
($t_w \leq 20 \mu s$)	± 3.5 A
(Continuous)	± 2.0 A
Logic Supply Voltage, V_{CC}	7.0 V
Logic Input Voltage Range, V_{IN}	-0.3 V to $V_{CC} + 0.3$ V
Sense Voltage, V_{SENSE}	1.5 V
Reference Voltage, V_{REF}	V_{CC}
Package Power Dissipation, P_D	See Graph
Operating Temperature Range, T_A	-20°C to +85°C
Junction Temperature, T_J	+150°C*
Storage Temperature Range, T_S	-55°C to +150°C

Output current rating may be limited by duty cycle, ambient temperature, heat sinking and/or forced cooling. Under any set of conditions, do not exceed the specified current rating or a junction temperature of +150°C.

* Fault conditions that produce excessive junction temperature will activate device thermal shutdown circuitry. These conditions can be tolerated but should be avoided.

Designed for bidirectional pulse-width modulated current control of inductive loads, the A3951SB and A3951SW are capable of continuous output currents to ± 2 A and operating voltages to 50 V. Internal fixed off-time PWM current-control circuitry can be used to regulate the maximum load current to a desired value. The peak load current limit is set by the user's selection of an input reference voltage and external sensing resistor. The fixed off-time pulse duration is set by a user-selected external RC timing network. Internal circuit protection includes thermal shutdown with hysteresis, transient suppression diodes, and crossover-current protection. Special power-up sequencing is not required. The A3951SB and A3951SW are improved replacements for the UDN2953B and UDN2954W, respectively. For new system designs, the A3952SB/SEB/SLB/SW are recommended.

With the ENABLE input held low, the PHASE input controls load current polarity by selecting the appropriate source and sink driver pair. A user-selectable blanking window prevents false triggering of the PWM current control circuitry. With the ENABLE input held high, all output drivers are disabled.

When a logic low is applied to the BRAKE input, the braking function is enabled. This overrides ENABLE and PHASE to turn off both source drivers and turn on both sink drivers. The brake function can be safely used to dynamically brake brush dc motors.

The A3951SB is supplied in a 16-pin dual in-line plastic package with copper heat-sink contact tabs. The lead configuration enables easy attachment of a heat sink while fitting a standard printed wiring board layout. The A3951SW, for higher package power dissipation requirements, is supplied in a 12-pin single in-line power-tab package. In either package style, the batwing/power tab is at ground potential and needs no isolation.

FEATURES

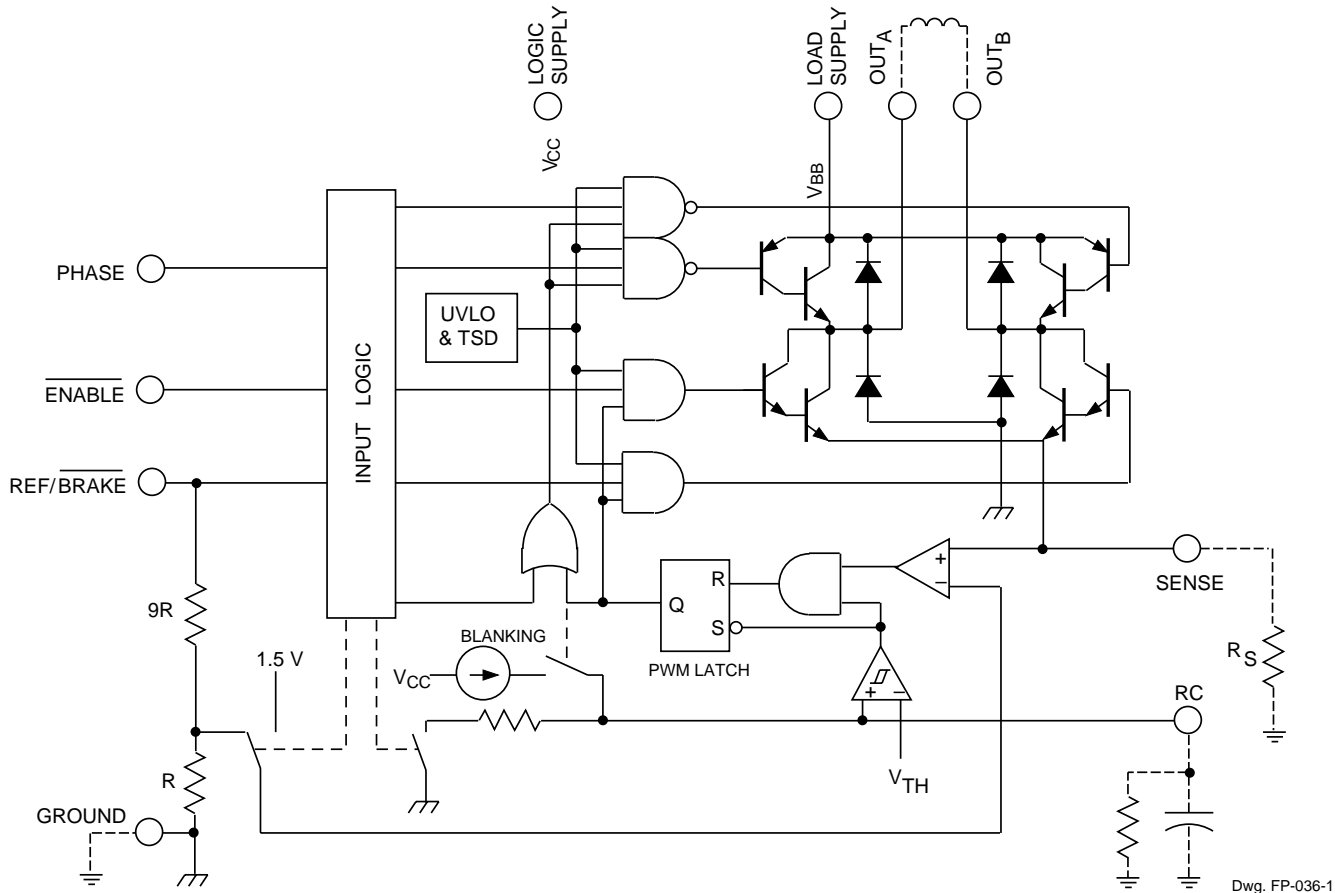
- ± 2 A Continuous Output Current Rating
- 50 V Output Voltage Rating
- Internal PWM Current Control
- Internal Transient Suppression Diodes
- Under-Voltage Lockout
- Internal Thermal Shutdown Circuitry
- Crossover-Current Protection
- Default Brake Current Limit

Always order by complete part number:

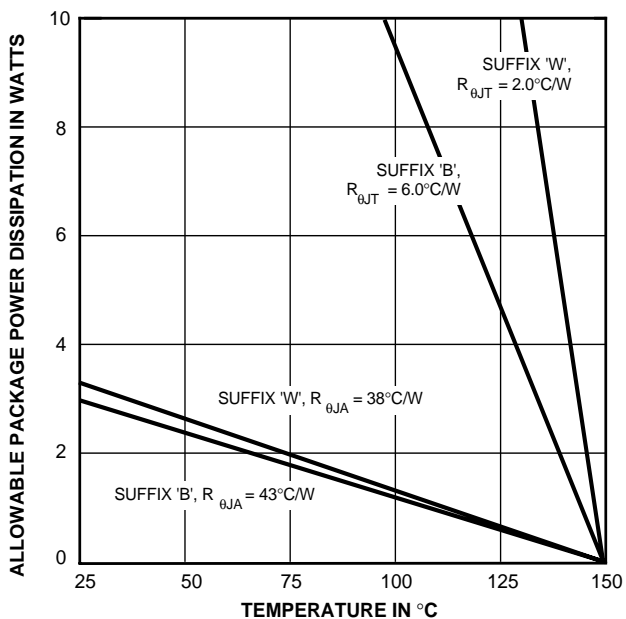
Part Number	Package	$R_{\theta JA}$	$R_{\theta JT}$
A3951SB	16-Pin DIP	43°C/W	6.0°C/W
A3951SW	12-Pin Power-Tab SIP	36°C/W	2.0°C/W

3951 FULL-BRIDGE PWM MOTOR DRIVER

FUNCTIONAL BLOCK DIAGRAM



Dwg. FP-036-1



Dwg. GP-032A

TRUTH TABLE

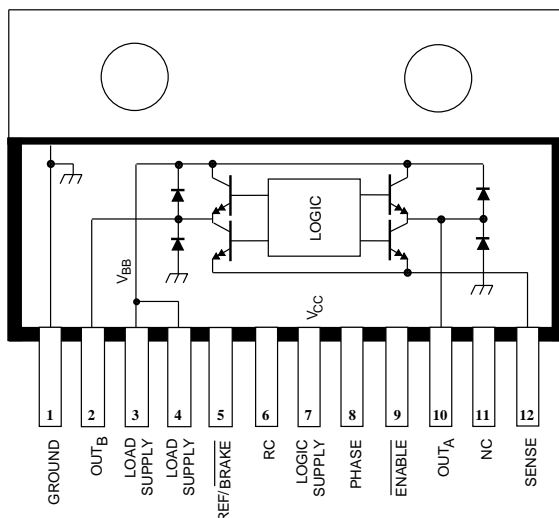
BRAKE	ENABLE	PHASE	OUT _A	OUT _B	DESCRIPTION
H	H	X	Z	Z	Outputs Disabled
H	L	H	H	L	Forward
H	L	L	L	H	Reverse
L	X	X	L	L	Brake, See Note

X = Irrelevant Z = High Impedance (source and sink both off)

NOTE: Includes internal default V_{sense} level for over-current protection.

3951 FULL-BRIDGE PWM MOTOR DRIVER

A3951SW



Dwg. PP-058-1

**ELECTRICAL CHARACTERISTICS at $T_A = +25^\circ\text{C}$, $V_{BB} = 50\text{ V}$, $V_{CC} = 5.0\text{ V}$,
 $V_{REF} = 2.0\text{ V}$, $V_{SENSE} = 0\text{ V}$, $RC = 20\text{ k}\Omega/1000\text{ pF}$ to Ground (unless noted otherwise).**

Characteristic	Symbol	Test Conditions	Limits			
			Min.	Typ.	Max.	Units

Output Drivers

Load Supply Voltage Range	V_{BB}	Operating, $I_{OUT} = \pm 2.0\text{ A}$, $L = 3\text{ mH}$	V_{CC}	–	50	V
Output Leakage Current	I_{CEX}	$V_{OUT} = V_{BB}$	–	<1.0	50	μA
		$V_{OUT} = 0\text{ V}$	–	<-1.0	-50	μA
Output Saturation Voltage	$V_{CE(SAT)}$	Source driver, $I_{OUT} = -0.5\text{ A}$	–	0.9	1.2	V
		Source driver, $I_{OUT} = -1.0\text{ A}$	–	1.0	1.4	V
		Source driver, $I_{OUT} = -2.0\text{ A}$	–	1.2	1.8	V
		Sink driver, $I_{OUT} = +0.5\text{ A}$	–	0.9	1.2	V
		Sink driver, $I_{OUT} = +1.0\text{ A}$	–	1.0	1.4	V
		Sink driver, $I_{OUT} = +2.0\text{ A}$	–	1.3	1.8	V
Clamp Diode Forward Voltage (Source or Sink)	V_F	$I_F = 0.5\text{ A}$	–	1.0	1.4	V
		$I_F = 1.0\text{ A}$	–	1.1	1.6	V
		$I_F = 2.0\text{ A}$	–	1.4	2.0	V
Load Supply Current (No Load)	$I_{BB(ON)}$	$V_{ENABLE} = 0.8\text{ V}$, $V_{REF} = 2.0\text{ V}$	–	2.9	6.0	mA
	$I_{BB(OFF)}$	$V_{ENABLE} = V_{REF} = 2.0\text{ V}$	–	3.1	6.5	mA
	$I_{BB(BRAKE)}$	$V_{BRAKE} = 0.8\text{ V}$	–	3.1	6.5	mA

Continued next page ...

3951 FULL-BRIDGE PWM MOTOR DRIVER

ELECTRICAL CHARACTERISTICS (Continued)

Characteristic	Symbol	Test Conditions	Limits			
			Min.	Typ.	Max.	Units
Control Logic						
Logic Supply Voltage Range	V_{CC}	Operating	4.5	5.0	5.5	V
Logic Input Voltage	$V_{IN(1)}$		2.0	–	–	V
	$V_{IN(0)}$		–	–	0.8	V
Logic Input Current	$I_{IN(1)}$	$V_{IN} = 2.0\text{ V}$	–	<1.0	20	μA
	$I_{IN(0)}$	$V_{IN} = 0.8\text{ V}$	–	<-2.0	-200	μA
Reference Voltage Range	V_{REF}	Operating	2.0	–	V_{CC}	V
Reference Input Current	I_{REF}	$2.0\text{ V} \leq V_{REF} \leq V_{CC}$	25	40	55	μA
Reference Voltage Divider Ratio	–	$V_{REF} = 5\text{ V}$	9.5	10.0	10.5	–
PWM RC Fixed Off Time	t_{off}	$C_T = 1000\text{ pF}, R_T = 20\text{ k}\Omega$	18	20	22	μs
PWM Minimum On Time	$t_{on(min)}$	$C_T = 820\text{ pF}, R_T \geq 12\text{ k}\Omega$	–	1.7	3.0	μs
		$C_T = 1200\text{ pF}, R_T \geq 12\text{ k}\Omega$	–	2.5	3.8	μs
Propagation Delay Time	t_{pd}	$I_{OUT} = \pm 2.0\text{ A}, 50\% E_{IN}$ to $90\% E_{OUT}$ transition:				
		ENABLE on to source driver on	–	2.9	–	μs
		ENABLE off to source driver off	–	0.7	–	μs
		ENABLE on to sink driver on	–	2.4	–	μs
		ENABLE off to sink driver off	–	0.7	–	μs
		PHASE change to source driver on	–	2.9	–	μs
		PHASE change to source driver off	–	0.7	–	μs
		PHASE change to sink driver on	–	2.4	–	μs
	PHASE change to sink driver off	–	0.7	–	μs	
	$t_{pd(pwm)}$	Comparator trip to sink driver off	–	0.8	1.5	μs
Thermal Shutdown Temperature	T_J		–	165	–	$^{\circ}\text{C}$
Thermal Shutdown Hysteresis	ΔT_J		–	15	–	$^{\circ}\text{C}$
UVLO Disable Threshold	$V_{CC(UVLO)}$		3.15	3.50	3.85	V
UVLO Hysteresis	$\Delta V_{CC(UVLO)}$		300	400	500	mV
Logic Supply Current (No Load)	$I_{CC(ON)}$	$V_{ENABLE} = 0.8\text{ V}, V_{REF} = 2.0\text{ V}$	–	20	30	mA
	$I_{CC(OFF)}$	$V_{ENABLE} = V_{REF} = 2.0\text{ V}$	–	12	18	mA
	$I_{CC(BRAKE)}$	$V_{REF} = 0.8\text{ V}$	–	26	40	mA

- NOTES: 1. Typical Data is for design information only.
 2. Each driver is tested separately.
 3. Negative current is defined as coming out of (sourcing) the specified device terminal.

FUNCTIONAL DESCRIPTION

INTERNAL PWM CURRENT CONTROL DURING FORWARD AND REVERSE OPERATION

The A3951SB/SW contain a fixed off-time pulse-width modulated (PWM) current-control circuit that can be used to limit the load current to a desired value. The value of the current limiting (I_{TRIP}) is set by the selection of an external current sensing resistor (R_S) and reference input voltage (V_{REF}). The internal circuitry compares the voltage across the external sense resistor to one tenth the voltage on the REF input terminal, resulting in a function approximated by

$$I_{TRIP} = V_{REF} / (10 \cdot R_S).$$

In forward or reverse mode the current-control circuitry limits the load current. When the load current reaches I_{TRIP} , the comparator resets a latch to turn off the selected sink driver. The load inductance causes the current to recirculate through the source driver and flyback diode (two-quadrant operation or slow decay). See figure 1.

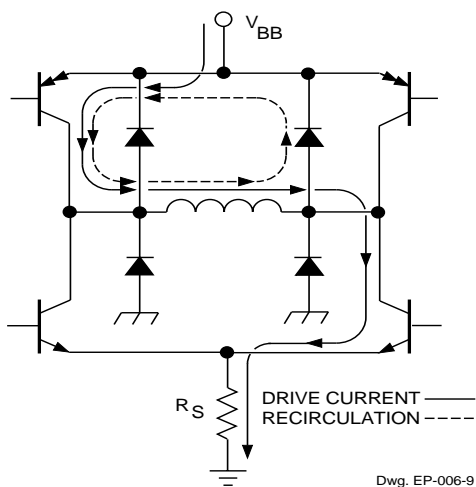
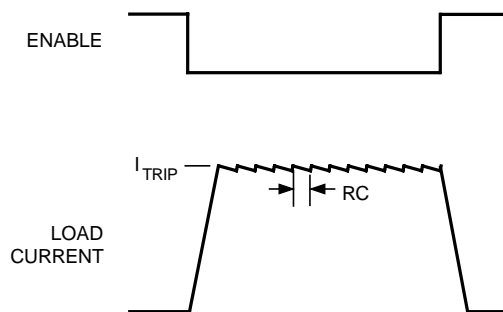


Figure 1 — Load-Current Paths

The user selects an external resistor (R_T) and capacitor (C_T) to determine the time period ($t_{off} = R_T \cdot C_T$) during which the drivers remain disabled (see "RC Fixed OFF Time" below). At the end of the $R_T \cdot C_T$ interval, the drivers are re-enabled allowing the load current to increase again. The PWM cycle repeats, maintaining the load current at the desired value (see figure 2).



Dwg. WP-015-3

Figure 2 — Load-Current Waveform

INTERNAL PWM CURRENT CONTROL DURING BRAKE MODE OPERATION

The brake circuit turns off both source drivers and turns on both sink drivers. For dc motor applications, this has the effect of shorting the motor's back-EMF voltage, resulting in current flow that brakes the motor dynamically. However, if the back-EMF voltage is large and there is no PWM current limiting, then the load current can increase to a value that approaches a locked rotor condition. To limit the current, when the I_{TRIP} level is reached, the PWM circuit disables the conducting sink driver. The energy stored in the motor's inductance is then discharged into the load supply causing the motor current to decay.

As in the case of forward/reverse operation, the drivers are re-enabled after a time given by $t_{off} = R_T \cdot C_T$ (see "RC Fixed Off Time" below). Depending on the back-EMF voltage (proportional to the motor's decreasing speed), the load current again may increase to I_{TRIP} . If so, the PWM cycle will repeat, limiting the load current to the desired value.

Brake Operation

During braking, the peak current limit defaults internally to a value approximated by

$$I_{TRIP} = 1.5 V / R_S.$$

In this mode, the value of R_S determines the I_{TRIP} value independent of V_{REF} . This is useful in applications with differing run and brake currents and no practical method of varying V_{REF} .

3951 FULL-BRIDGE PWM MOTOR DRIVER

Choosing a small value for R_S essentially disables the current limiting during braking. Therefore, care should be taken to ensure that the motor's current does not exceed the absolute maximum ratings of the device. The braking current can be measured by using an oscilloscope with a current probe connected to one of the motor's leads.

CAUTION: Because the kinetic energy stored in the motor and load inertia is being converted into current, which charges the V_{BB} supply bulk capacitance (power supply output and decoupling capacitance), care must be taken to ensure the capacitance is sufficient to absorb the energy without exceeding the voltage rating of any devices connected to the motor supply.

RC Fixed Off Time

The internal PWM current control circuitry uses a one shot to control the time the driver remains off. The one shot time, t_{off} (fixed off time), is determined by the selection of an external resistor (R_T) and capacitor (C_T) connected in parallel from the RC terminal to ground. The fixed off time, over a range of values of $C_T = 820$ pF to 1500 pF and $R_T = 12$ k Ω to 100 k Ω , is approximated by

$$t_{off} = R_T \cdot C_T.$$

When the PWM latch is reset by the current comparator, the voltage on the RC terminal will begin to decay from approximately 3 volts. When the voltage on the RC terminal reaches approximately 1.1 volts, the PWM latch is set, thereby re-enabling the driver.

RC Blanking

In addition to determining the fixed off time of the PWM control circuit, the C_T component sets the comparator blanking time. This function blanks the output of the comparator when the outputs are switched by the internal current control circuitry (or by the PHASE, BRAKE, or ENABLE inputs). The comparator output is blanked to prevent false over-current detections due to reverse recovery currents of the clamp diodes, and/or switching transients related to distributed capacitance in the load.

During internal PWM operation, at the end of the off time, the comparator's output is blanked and C_T begins to be charged from approximately 1.1 V by an internal current source of approximately 1 mA. The comparator output remains blanked until the voltage on C_T reaches approximately 3.0 volts.

Similarly, when a transition of the PHASE input occurs, C_T is discharged to near ground during the crossover delay time (the crossover delay time is present to prevent simultaneous conduction of the source and sink drivers). After the crossover delay, C_T is charged by an internal current source of approximately 1 mA. The comparator output remains blanked until the voltage on C_T reaches approximately 3.0 volts.

Similarly, when the device is disabled via the ENABLE input, C_T is discharged to near ground. When the device is re-enabled, C_T is charged by the internal current source. The comparator output remains blanked until the voltage on C_T reaches approximately 3.0 V.

For most applications, the minimum recommended value is $C_T = 820$ pF $\pm 5\%$. This value ensures that the blanking time is sufficient to avoid false trips of the comparator under normal operating conditions. For optimal regulation of the load current, the above value for C_T is recommended and the value of R_T can be sized to determine t_{off} . For more information regarding load current regulation, see below.

LOAD CURRENT REGULATION WITH THE INTERNAL PWM CURRENT-CONTROL CIRCUITRY

During operation, the A3951S- have a lower limit to the range of PWM current control. This directly relates to the limitations imposed by the V_{REF} input (2.0 V, minimum).

Applications requiring a broader or full range ($\approx 0\%$ to 100%) should utilize the A3952S-, which are recommended for the improvements they bring to new designs.

LOAD CURRENT REGULATION WITH EXTERNAL PWM OF THE PHASE OR ENABLE INPUTS

The PHASE or ENABLE inputs can be pulse-width modulated to regulate load current. Typical propagation delays from the PHASE and ENABLE inputs to transitions of the power outputs are specified in the electrical characteristics table. If the normal PWM current control is used, then the comparator blanking function is active during phase and enable transitions. This eliminates false tripping of the over-current comparator caused by switching transients (see "RC Blanking" above).

3951 FULL-BRIDGE PWM MOTOR DRIVER

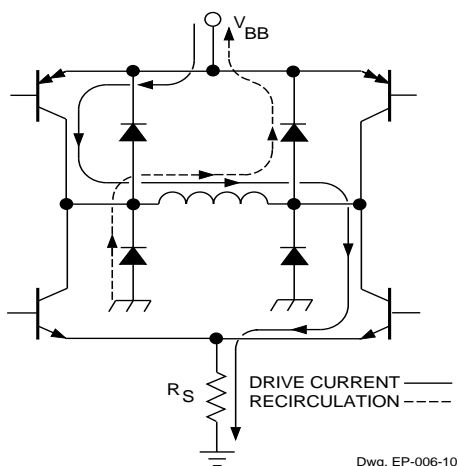


Figure 3 — Load-Current Paths

ENABLE Pulse-Width Modulation

Toggleing the ENABLE input turns on and off the selected source and sink drivers; the load inductance causes the current to flow from ground to the load supply via the ground clamp and flyback diodes (four-quadrant operation or fast decay). See figure 3. When the device is enabled, the internal current-control circuitry will be active and can be used to limit the load current in the normal internal PWM slow-decay or two-quadrant mode of operation.

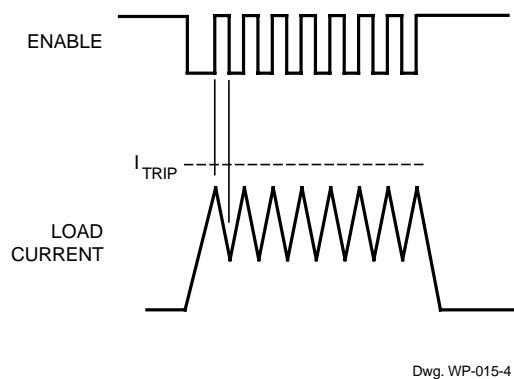


Figure 4 — ENABLE PWM Load-Current Waveform

PHASE Pulse-Width Modulation

Toggleing the PHASE terminal determines/controls which sink/source pair is enabled, producing a load current that varies with the duty cycle and remains continuous at all times. This can have added benefits in bidirectional brush dc servo motor applications as the transfer function

between the duty cycle on the phase input and the average voltage applied to the motor is more linear than in the case of ENABLE PWM control (which produces a discontinuous current at low current levels). See also, “DC Motor Applications” below.

MISCELLANEOUS INFORMATION

An internally generated dead time prevents crossover currents that can occur when switching phase or braking.

Thermal protection circuitry turns off all drivers should the junction temperature reach 165°C (typical). This is intended only to protect the device from failures due to excessive junction temperatures and should not imply that output short circuits are permitted. The hysteresis of the thermal shutdown circuit is approximately 15°C.

If the internal current-control circuitry is not used; the V_{REF} terminal should be connected to V_{CC} , the SENSE terminal should be connected to ground, and the RC terminal should be left floating (no connection).

An internal under-voltage lockout circuit prevents simultaneous conduction of the outputs when the device is powered up or powered down.

APPLICATIONS NOTES

Current Sensing

The actual peak load current (I_{OUTP}) will be greater than the calculated value of I_{TRIP} due to delays in the turn off of the drivers. The amount of overshoot can be approximated as

$$I_{OUTP} \approx \frac{(V_{BB} - ((I_{TRIP} \cdot R_{LOAD}) + V_{BEMF})) \cdot t_{pd(pwm)}}{L_{LOAD}}$$

where V_{BB} is the load/motor supply voltage, V_{BEMF} is the back-EMF voltage of the load, R_{LOAD} and L_{LOAD} are the resistance and inductance of the load respectively, and $t_{pd(pwm)}$ is the propagation delay as specified in the electrical characteristics table.

The reference terminal has an equivalent input resistance of 50 kΩ ±30%. This should be taken into account when determining the impedance of the external circuit that sets the reference voltage value.

3951 FULL-BRIDGE PWM MOTOR DRIVER

To minimize current-sensing inaccuracies caused by ground trace $I \cdot R$ drops, the current-sensing resistor should have a separate return to the ground terminal of the device. For low-value sense resistors, the $I \cdot R$ drops in the PCB can be significant and should be taken into account. The use of sockets should be avoided as contact resistance can cause variations in the effective value of R_S .

Larger values of R_S reduce the aforementioned effects but can result in excessive heating and power loss in the sense resistor. The selected value of R_S must not result in the SENSE terminal absolute maximum voltage rating being exceeded. The recommended value of R_S is in the range of

$$R_S = (0.375 \text{ to } 1.125) / I_{TRIP}$$

Thermal Considerations

For the most reliable operation, it is recommended that the maximum junction temperature be kept as low as practical, preferably below 125°C. The junction temperature can be measured by attaching a thermocouple to the power tab/batwing of the device and measuring the tab temperature, T_T . The junction temperature then can be approximated as

$$T_J \approx T_T + (2 \cdot V_F \cdot I_{OUT} \cdot R_{\theta JT})$$

where V_F is the clamp diode forward voltage and can be determined from the electrical specification table for the given level of I_{OUT} . The value for $R_{\theta JT}$ is given in the package thermal resistance table for the appropriate package.

The power dissipation of the batwing package can be improved by approximately 20% by adding a section of printed circuit board copper (typically 6 to 18 square centimeters) connected to the batwing terminals of the device.

The thermal performance in applications with high load currents and/or high duty cycles can be improved by adding external diodes in parallel with the internal diodes. In internal PWM applications, only the two top-side (flyback) diodes need be added. For external PHASE or ENABLE input PWM applications, four external diodes should be added for maximum junction temperature reduction.

PCB Layout

The load supply terminal, V_{BB} , should be decoupled (>47 μ F electrolytic and 0.1 μ F ceramic capacitors are

recommended) as close to the device as is physically practical. To minimize the effect of system ground $I \cdot R$ drops on the logic and reference input signals, the system ground should have a low-resistance return to the load supply voltage.

See also “Current Sensing” and “Thermal Considerations” above.

Fixed Off-Time Selection

With increasing values of t_{off} , switching losses decrease, low-level load-current regulation improves, EMI is reduced, the PWM frequency will decrease, and ripple current will increase. The value of t_{off} can be chosen for optimization of these parameters. For applications where audible noise is a concern, typical values of t_{off} are chosen to be in the range of 15 to 35 μ s.

DC Motor Applications

In closed-loop systems, the speed of a dc motor can be controlled by PWM of the PHASE or ENABLE inputs, or by varying the REF input voltage (V_{REF}). In digital systems (microprocessor controlled), PWM of the PHASE or ENABLE input is used typically thus avoiding the need to generate a variable analog voltage reference. In this case, a dc voltage on the REF input is used typically to limit the maximum load current.

In dc servo applications that require accurate positioning at low or zero speed, PWM of the PHASE input is selected typically. This simplifies the servo-control loop because the transfer function between the duty cycle on the PHASE input and the average voltage applied to the motor is more linear than in the case of ENABLE PWM control (which produces a discontinuous current at low-current levels).

With bidirectional dc servo motors, the PHASE terminal can be used for mechanical direction control. Similar to when braking the motor dynamically, abrupt changes in the direction of a rotating motor produce a current generated by the back EMF. The current generated will depend on the mode of operation. If the internal two-quadrant slow-decay PWM current-control circuitry is used, the maximum load current generated can be approximated by $I_{LOAD} = V_{BEMF} / R_{LOAD}$ where V_{BEMF} is proportional to the motor's speed. If external four-quadrant fast-decay ENABLE PWM current-control is used, then the maximum load current generated can be approximated by

$$I_{LOAD} = (V_{BEMF} + V_{BB}) / R_{LOAD}$$

3951 FULL-BRIDGE PWM MOTOR DRIVER

For both cases, care must be taken to ensure that the maximum current ratings of the device are not exceeded. The load current will limit at a value

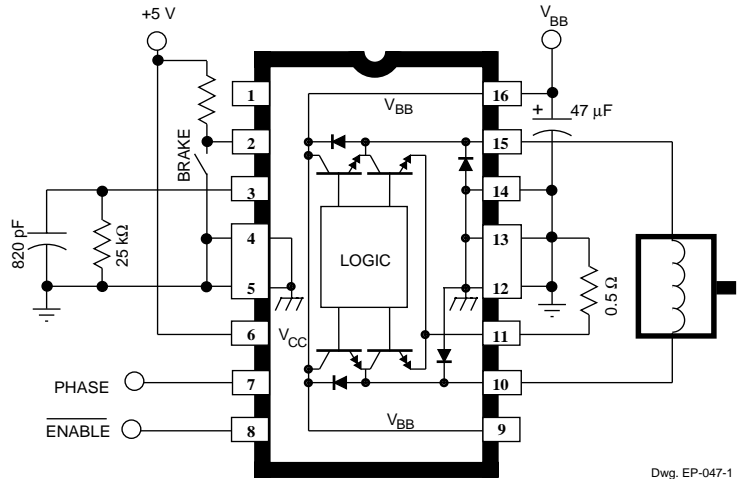
$$I_{LOAD} = V_{REF} / (10 \cdot R_S)$$

CAUTION: When the direction of the motor is changed abruptly, the kinetic energy stored in the motor and load inertia will be converted into current that charges the V_{BB} supply bulk capacitance (power supply output and decoupling capacitance). Care must be taken to ensure the capacitance is sufficient to absorb the energy without exceeding the voltage rating of any devices connected to the motor supply.

See also, the section on brake operation under "Functional Description", above.

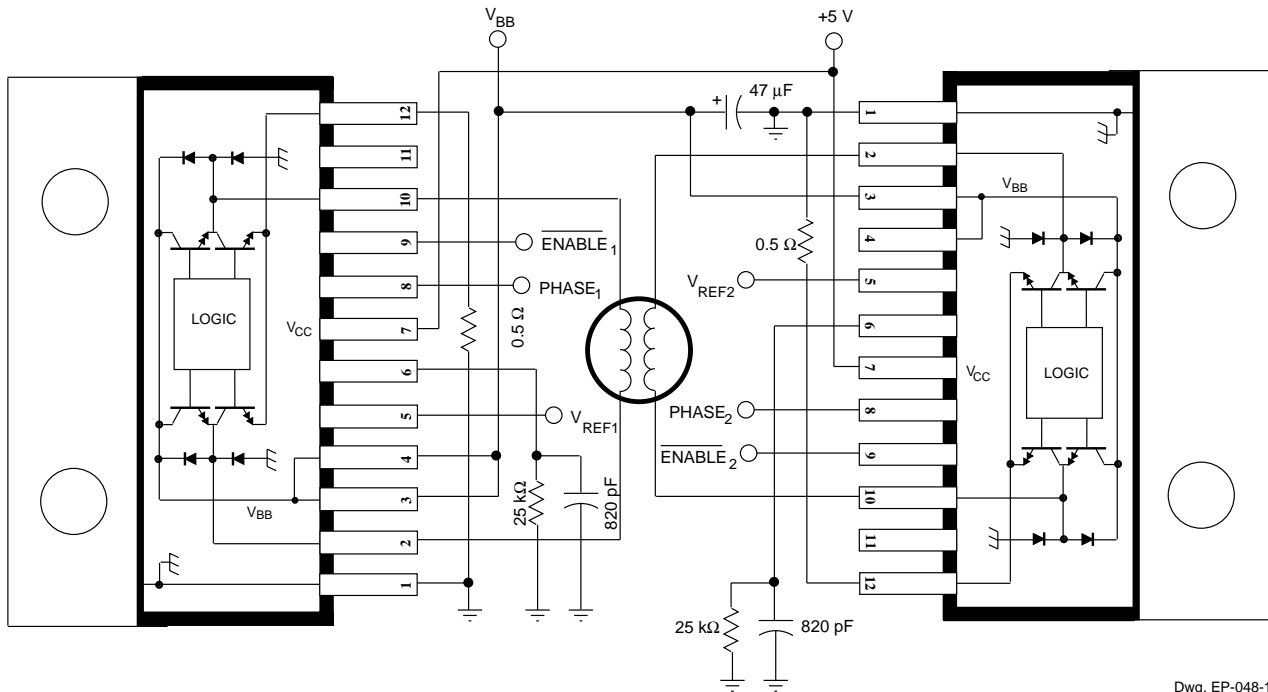
Stepper Motor Applications

The A3951SB and A3951SW may be used for bidirectional control of bipolar stepper motors with continuous output currents to 2 A and peak start-up currents as high as 3.5 A.



Dwg. EP-047-1

Typical DC Servo Motor Application



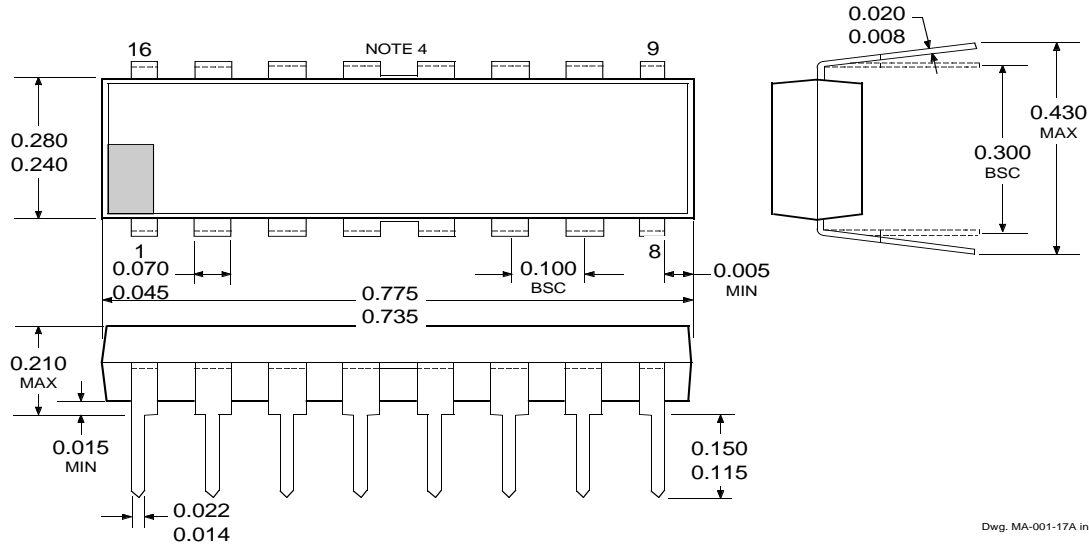
Dwg. EP-048-1

Typical Bipolar Stepper Motor Application

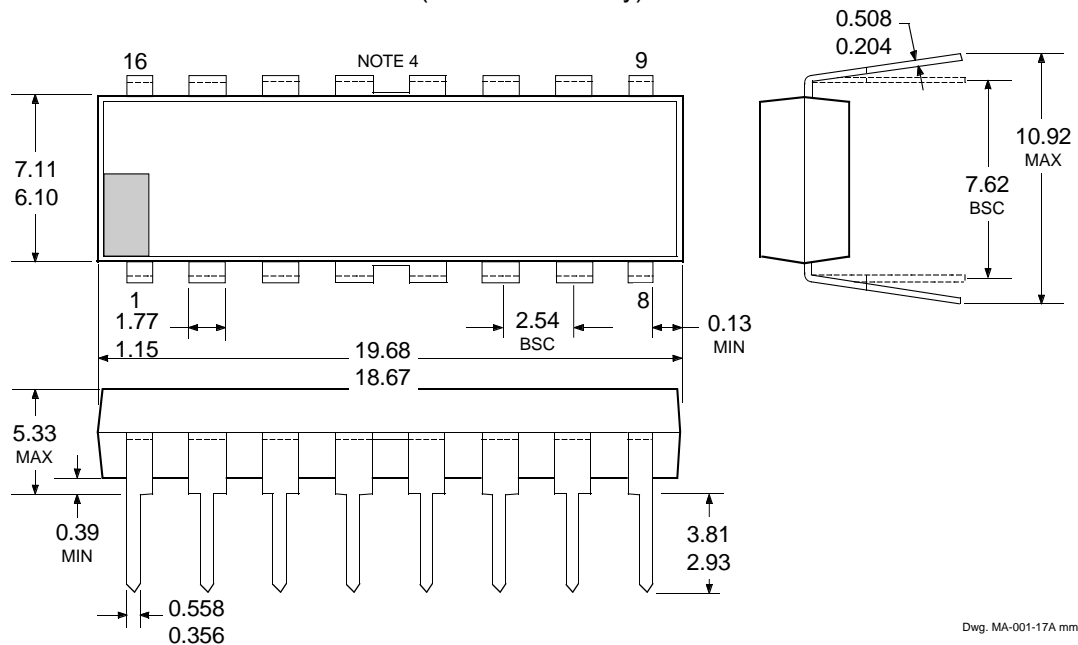
3951 FULL-BRIDGE PWM MOTOR DRIVER

A3951SB

Dimensions in Inches
(controlling dimensions)



Dimensions in Millimeters
(for reference only)

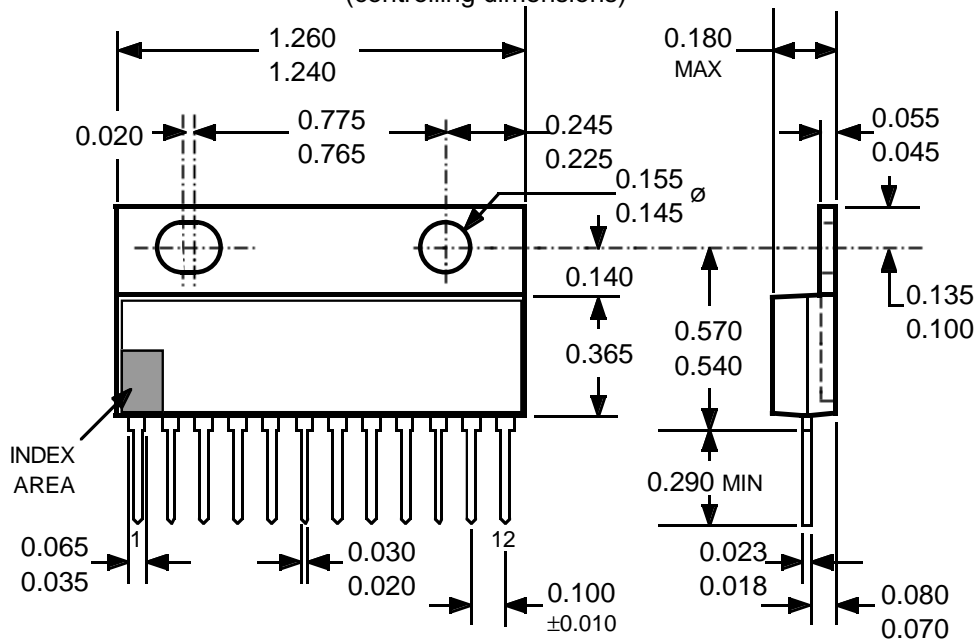


- NOTES: 1. Leads 1, 8, 9, and 16 may be half leads at vendor's option.
 2. Lead thickness is measured at seating plane or below.
 3. Lead spacing tolerance is non-cumulative.
 4. Webbed lead frame. Leads indicated are internally one piece.
 5. Exact body and lead configuration at vendor's option within limits shown.

3951 FULL-BRIDGE PWM MOTOR DRIVER

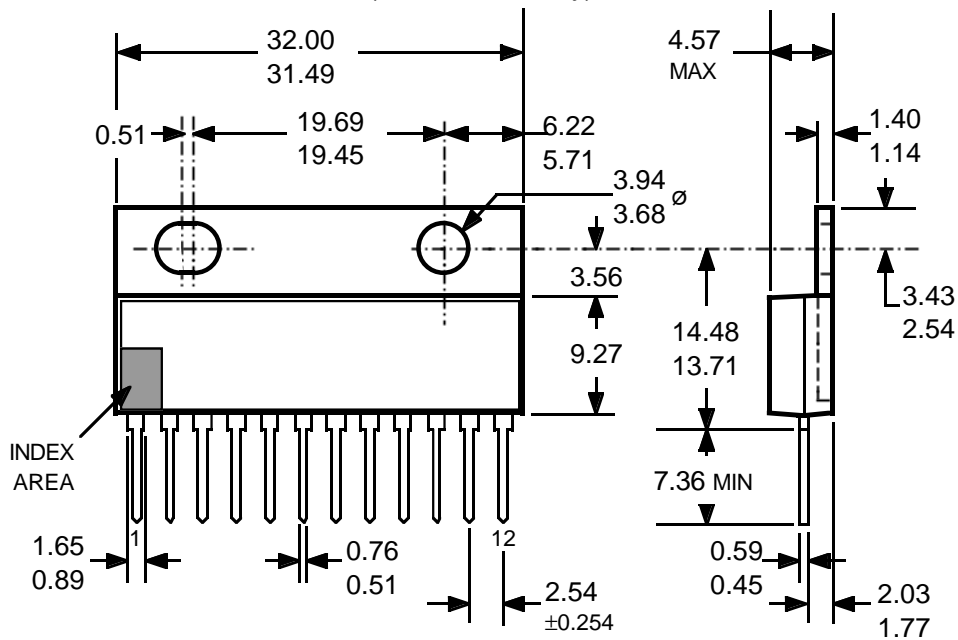
A3951SW

Dimensions in Inches
(controlling dimensions)



Dwg. MP-007 in

Dimensions in Millimeters
(for reference only)



Dwg. MP-007 mm

- NOTES: 1. Lead thickness is measured at seating plane or below.
 2. Lead spacing tolerance is non-cumulative.
 3. Exact body and lead configuration at vendor's option within limits shown.
 4. Lead gauge plane is 0.030" (0.762 mm) below seating plane.

3951 **FULL-BRIDGE** **PWM MOTOR DRIVER**

The products described here are manufactured under one or more U.S. patents or U.S. patents pending.

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