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MOTOROLA

Advance Information

Single IGBT High Current Gate Driver

MC33154

SINGLE IGBT HIGH CURRENT GATE DRIVER

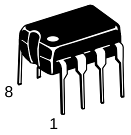
SEMICONDUCTOR TECHNICAL DATA

The MC33154 is specifically designed as an IGBT driver for high powered applications including ac induction motor control, brushless dc motor control, and uninterruptable power supplies. This device also offers a cost effective solution for driving power MOSFETS and Bipolar transistors.

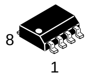
Device protections include the choice of desaturation or overcurrent sensing and an undervoltage lockout to provide assurance of proper gate drive voltage.

These devices are available in dual–in–line and surface mount packages and include the following features:

- High Current Output Stage: 4.0 A Source –2.0 A Sink
- Protection Circuits for Both Conventional and Sense IGBT's
- Current Source for Blanking Timing
- Protection Against Over–Current and Short Circuit
- Under–Voltage Lockout Optimized for IGBT's
- Negative Gate Drive Capability

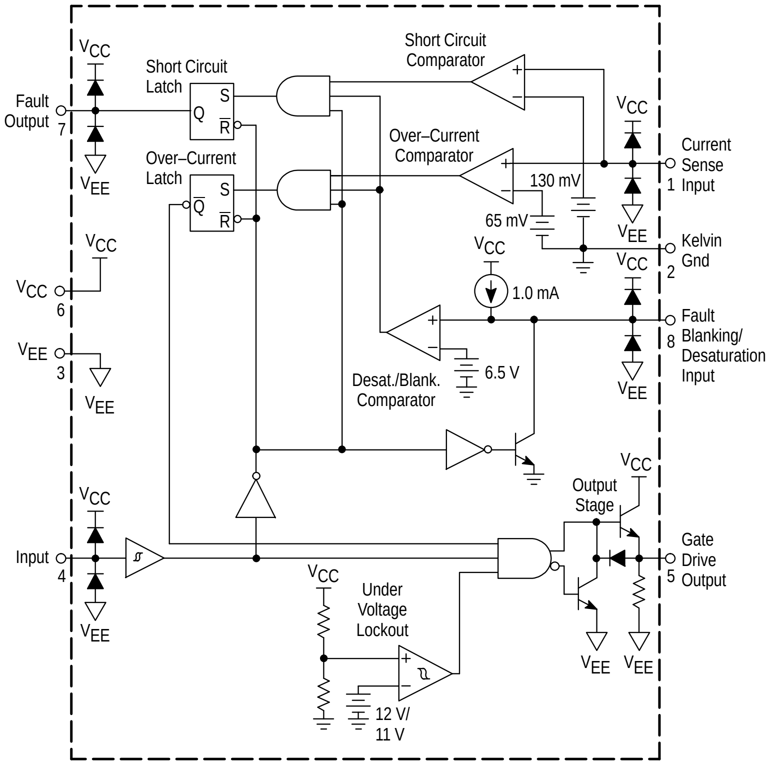


P SUFFIX
PLASTIC PACKAGE
CASE 626

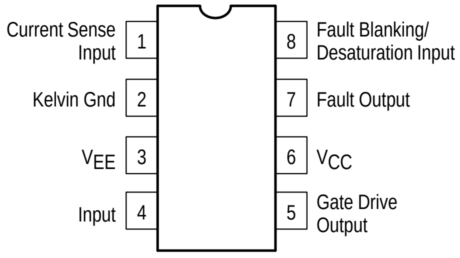


D SUFFIX
PLASTIC PACKAGE
CASE 751
(SO–8)

Simplified Block Diagram



PIN CONNECTIONS



(Top View)

ORDERING INFORMATION

Device	Tested Operating Temperature Range	Package
MC33154D	T_A = –40° to +85°C	Plastic SO–8
MC33154P	T_A = –40° to +85°C	Plastic DIP–8

MAXIMUM RATINGS

Rating	Symbol	Value	Unit
Power Supply Voltage			V
V_{CC} to V_{EE}; $V_{EE} \leq$ KGND $\leq V_{CC}$	$V_{CC} – V_{EE}$	20	
Kelvin Ground to V_{EE} (Note 1)	KGnd – V_{EE}	20	
Input	V_{in}	V_{EE} –0.3 to V_{CC}	V
Current Sense Input	V_{CS}	–0.3 to V_{CC}	V
Fault Blanking/Desaturation Input	V_{BD}	–0.3 to V_{CC}	V
Gate Drive Output	I_O		A
Source Current		4.0	
Sink Current		2.0	
Diode Clamp Current		1.0	
Fault Output	I_{FO}		mA
Source Current		25	
Sink Current		10	
Power Dissipation and Thermal Characteristics			
D Suffix SO–8 Package, Case 751			
Maximum Power Dissipation @ T_A = 50°C	P_D	0.56	W
Thermal Resistance, Junction–to–Air	$R_{\theta JA}$	180	°C/W
P Suffix DIP–8 Package, Case 626			
Maximum Power Dissipation @ T_A = 50°C	P_D	1.0	W
Thermal Resistance, Junction–to–Air	$R_{\theta JA}$	100	°C/W
Operating Junction Temperature	T_J	150	°C
Operating Ambient Temperature	T_A	–40 to +85	°C
Storage Temperature Range	T_{stg}	–65 to +150	°C

NOTES: 1. Kelvin Ground must always be between V_{EE} and V_{CC}.
2. ESD data available upon request.

ELECTRICAL CHARACTERISTICS

(V_{CC} = 20 V, V_{EE} = 0 V, Kelvin Gnd connected to V_{EE}. For typical values T_A = 25°C, for min/max values T_A is the operating ambient temperature range that applies [Note 1] unless otherwise noted.)

Characteristic	Symbol	Min	Typ	Max	Unit
INPUT					
Input Threshold Voltage					V
High State (Logic 1) @ T_A = 25°C	V_{IH}		9.0	10.5	
@ T_A = –40 to +85°C				11.6	
Low State (Logic 0)	V_{IL}	4.5	7.0	–	
Input Current — High State (V_{IH} = 10.5 V)	I_{IH}	–	100	500	µA
— Low State (V_{IL} = 4.5 V)	I_{IL}	–	50	100	
GATE DRIVE OUTPUT					
Output Voltage					V
Low State (I_{Sink} = 1.0 A)	V_{OL}	–	2.0	2.5	
High State (I_{Source} = 2.0 A)	V_{OH}	17	18	–	
Output Pull–Down Resistor	R_{PD}	–	100	200	kΩ
FAULT OUTPUT					
Output Voltage					V
Low State (I_{Sink} = 5.0 mA)	V_{FL}	–	0.2	1.0	
High State (I_{Source} = 20 mA)	V_{FH}	17	18.3	–	
SWITCHING CHARACTERISTICS					
Propagation Delay (50% Input to 50% Output C_L = 15 nF)					ns
Logic Input to Drive Output Rise	t_{PLH} (in/out)	–	200	300	
Logic Input to Drive Output Fall	t_{PHL} (in/out)	–	120	300	
Drive Output Rise Time (10% to 90%) C_L = 15 nF	t_r	–	80	200	ns
Drive Output Fall Time (90% to 10%) C_L = 15 nF	t_f	–	80	200	ns
Propagation Delay					µs
Current Sense Input to Drive Output	$t_{P(OC)}$	–	0.4	1.0	

NOTE: 1. Low duty cycle pulse techniques are used during test to maintain the junction temperature as close to ambient as possible.
T_{low} = –40°C for MC33154 T_{high} = +85°C for MC33154

ELECTRICAL CHARACTERISTICS (continued) (V_{CC} = 20 V, V_{EE} = 0 V, Kelvin Gnd connected to V_{EE}. For typical values T_A = 25°C, for min/max values T_A is the operating ambient temperature range that applies [Note 1] unless otherwise noted.)

Characteristic	Symbol	Min	Typ	Max	Unit
SWITCHING CHARACTERISTICS					
Fault Blanking/Desaturation Input to Drive Output	$t_{P(FLT)}$	–	0.4	1.0	
UVLO					
Start–up Voltage	$V_{CC\ start}$	11.3	12	12.6	V
Disable Voltage	$V_{CC\ dis}$	10.4	11	11.7	V
COMPARATORS					
Over Current Trip Voltage (V_{Pin8} > 7.0 V)	V_{SOC}	50	65	80	mV
Short Current Trip Voltage (V_{Pin8} > 7.0 V)	V_{SSC}	100	130	160	mV
Desaturation Threshold (V_{Pin1} > 100 mV)	$V_{th(FLT)}$	6.0	6.5	7.0	V
Sense Input Current (V_{SI} = 0 V)	I_{SI}	–	–1.4	–10	μA
FAULT BLANKING/DESATURATION INPUT					
Current Source (V_{Pin8} = 0 V, V_{Pin4} ≥ 10.5 V)	I_{chg}	0.8	1.0	1.2	mA
Discharge Current (V_{Pin8} = 15 V, V_{Pin4} = 0 V)	I_{dschg}	0.8	2.5	–	mA
TOTAL DEVICE					
Power Supply Current	I_{CC}				mA
Standby ($V_{Pin\ 4}$ = 0 V, Output Open)		–	9.0	14	
Operating (C_L = 15 nF, f_{in} = 20 kHz)		–	15	25	

NOTE: 1. Low duty cycle pulse techniques are used during test to maintain the junction temperature as close to ambient as possible.
T_{low} = –40°C for MC33154 T_{high} = +85°C for MC33154

Figure 1. Input Current versus Logic Input Voltage

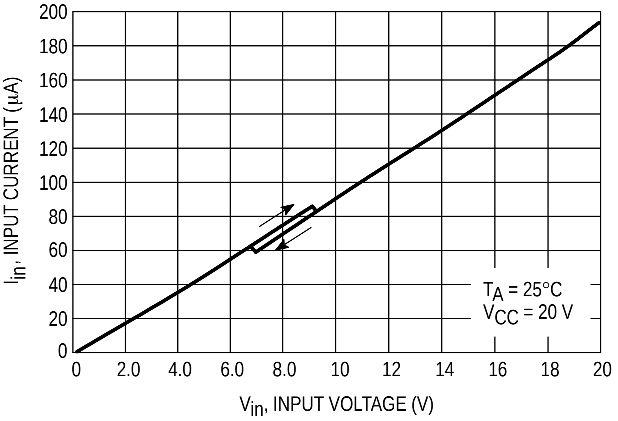


Figure 2. Output Voltage versus Input Voltage

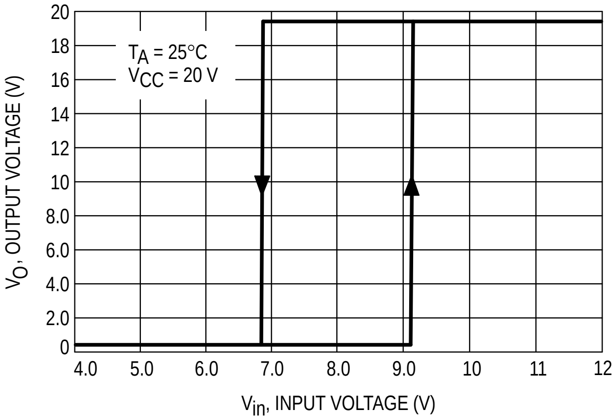


Figure 3. Input Threshold Voltage versus Supply Voltage

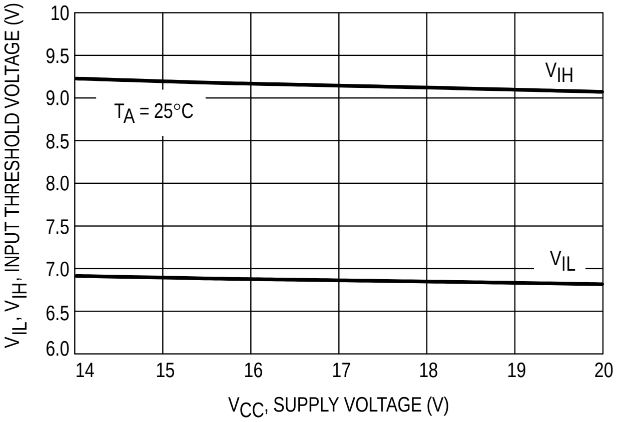


Figure 4. Input Thresholds versus Temperature

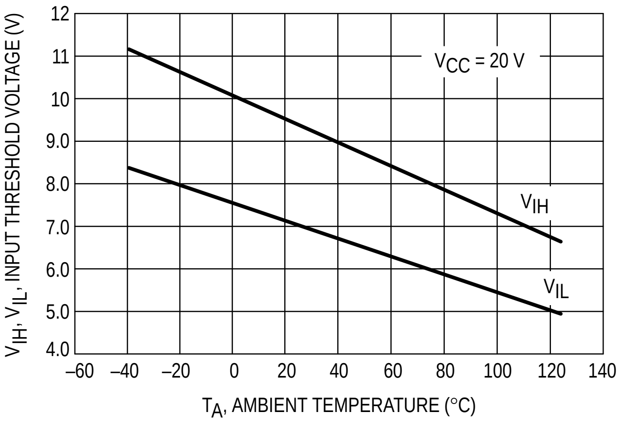


Figure 5. Drive Output Low State Voltage versus Temperature

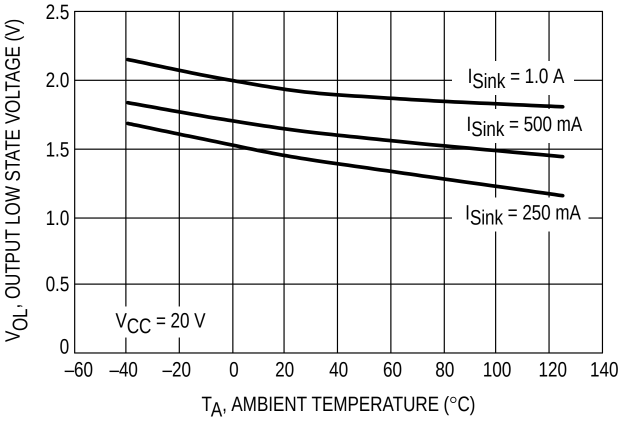


Figure 6. Drive Output Low State Voltage versus Sink Current

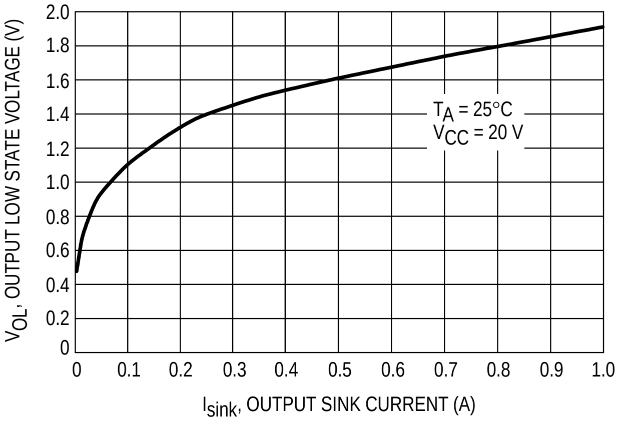


Figure 7. Drive Output High State Voltage versus Temperature

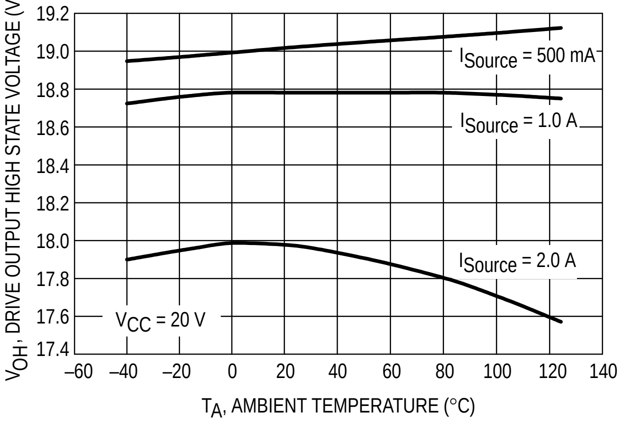


Figure 8. Output Saturation High versus Output Current

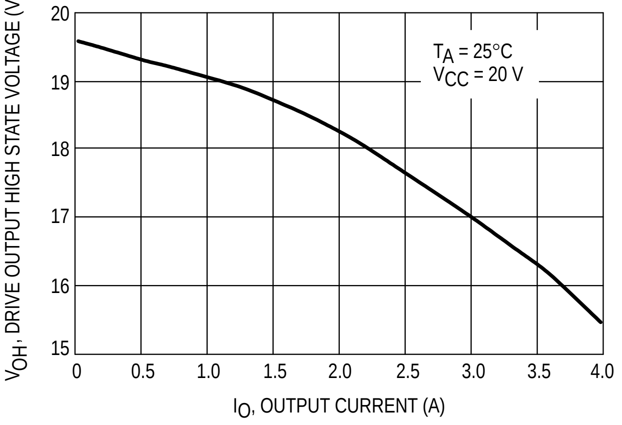


Figure 9. Drive Output Voltage versus Current Sense Input Voltage

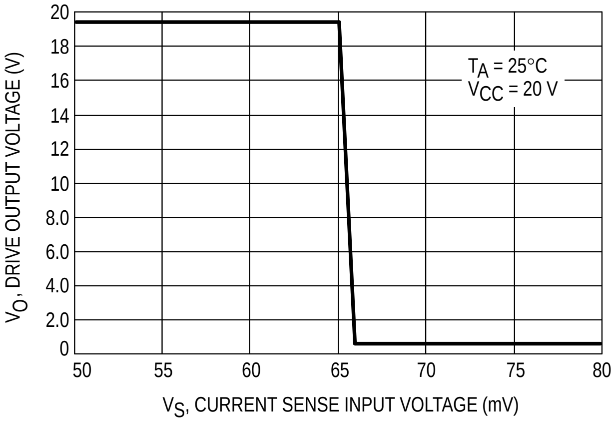


Figure 10. Fault Output Voltage versus Current Sense Input Voltage

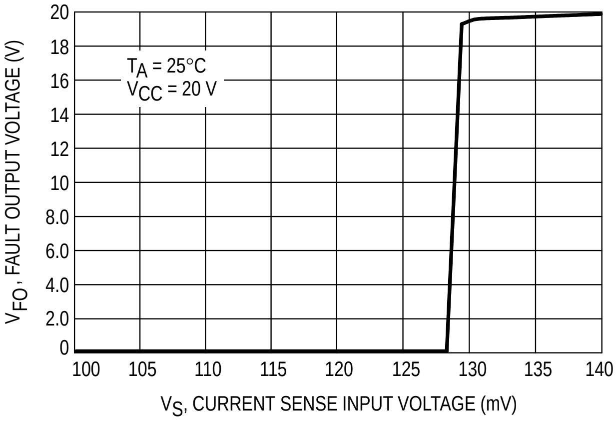


Figure 11. Overcurrent Threshold Voltage versus Temperature

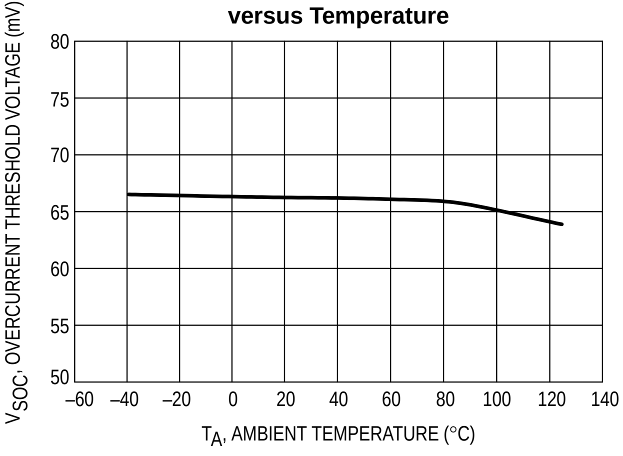


Figure 12. Short Circuit Threshold Voltage versus Temperature

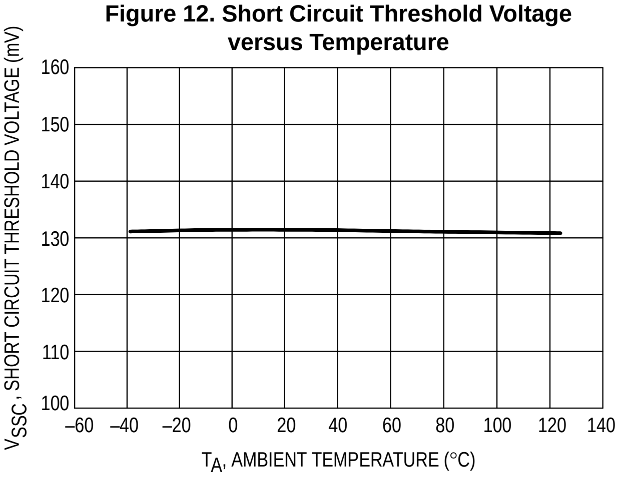


Figure 13. Sense Input Current versus Sense Voltage

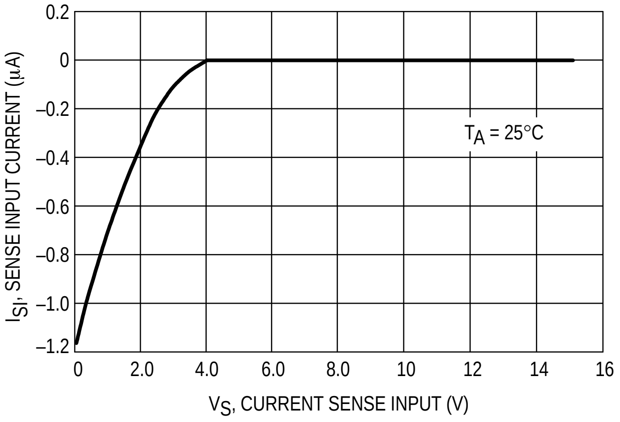
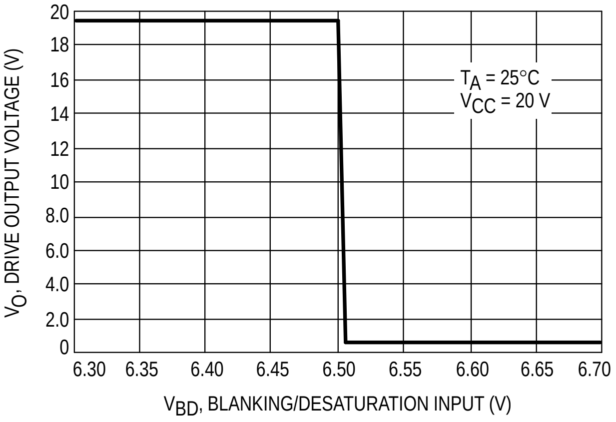


Figure 14. Output Voltage versus Blanking/Desaturation Voltage



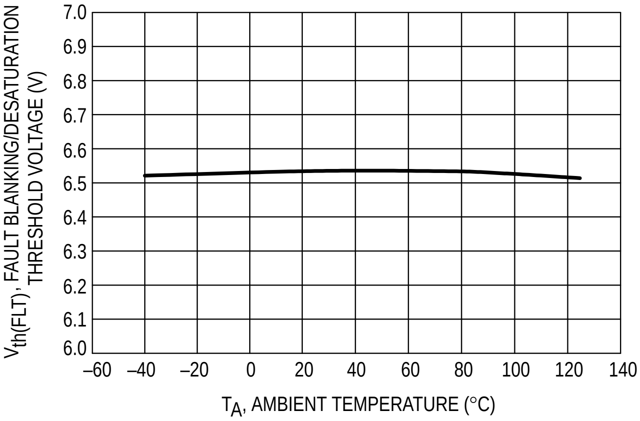


Figure 15. Desaturation Threshold versus Temperature

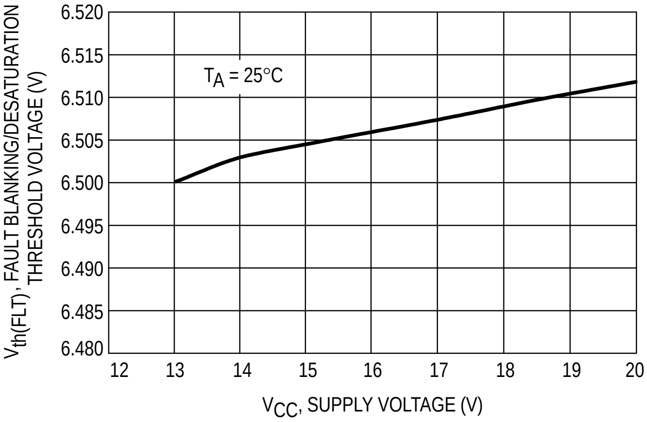


Figure 16. Blanking/Desaturation Threshold versus Supply Voltage

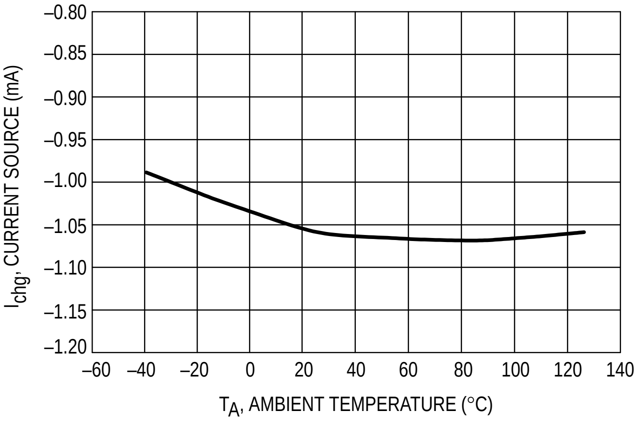


Figure 17. Blanking Current Source versus Temperature

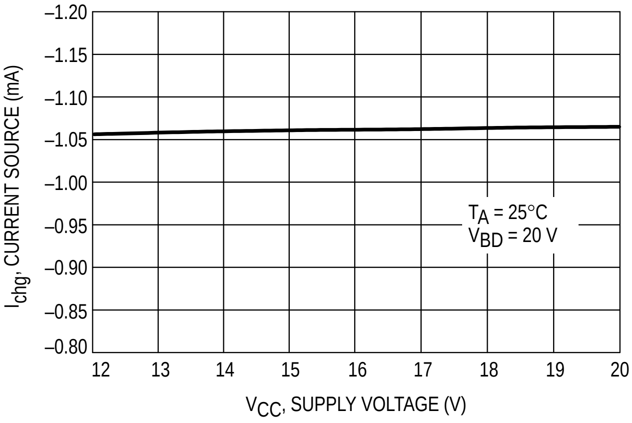


Figure 18. Blanking Current versus Supply Voltage

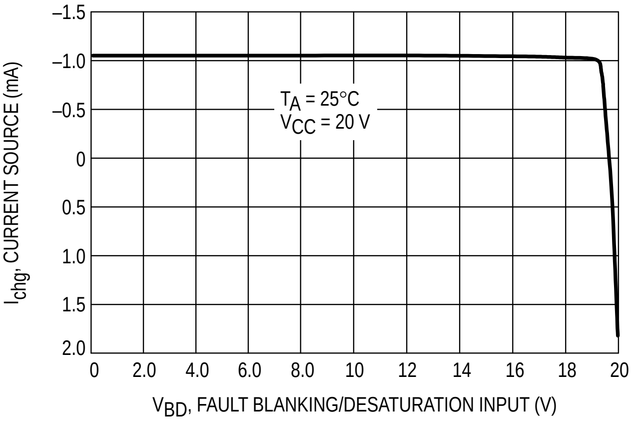


Figure 19. Blanking Current versus Blanking/Desaturation Voltage

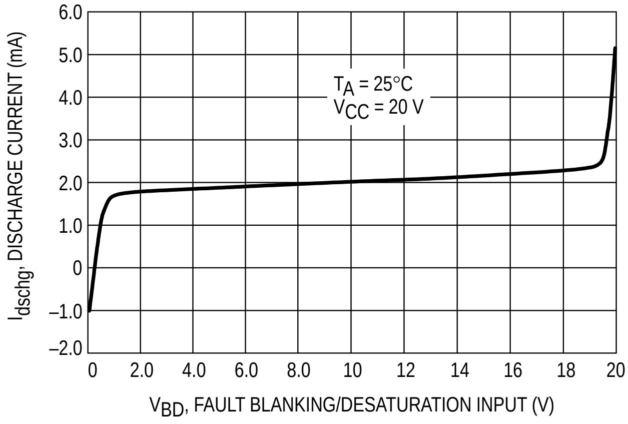


Figure 20. Blanking Discharge Current versus Blanking/Desaturation Voltage

Figure 21. Fault Output Voltage Low versus Fault Output Current

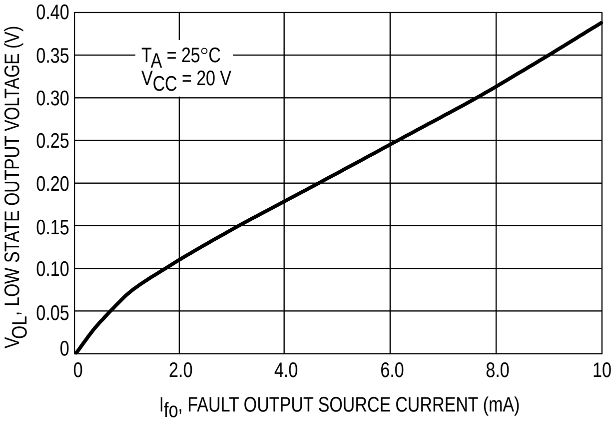


Figure 22. Fault Output Voltage High versus Fault Output Current

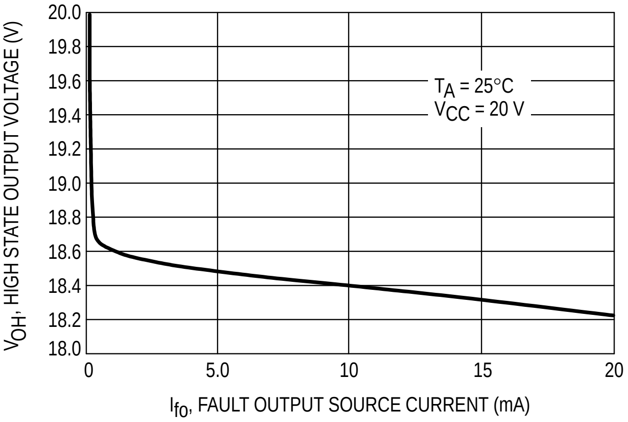


Figure 23. UVLO Start Threshold versus Temperature

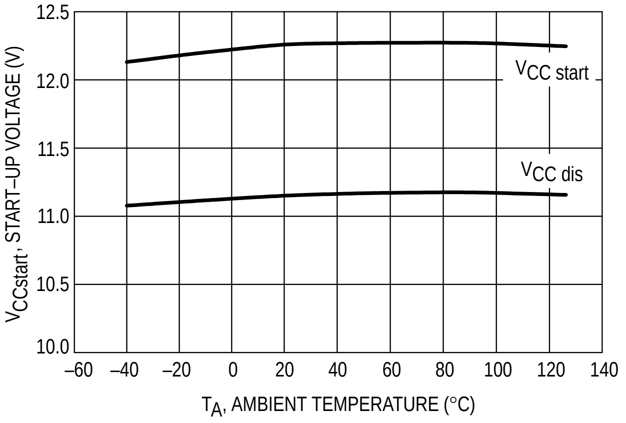


Figure 24. Standby Supply Current versus Supply Voltage

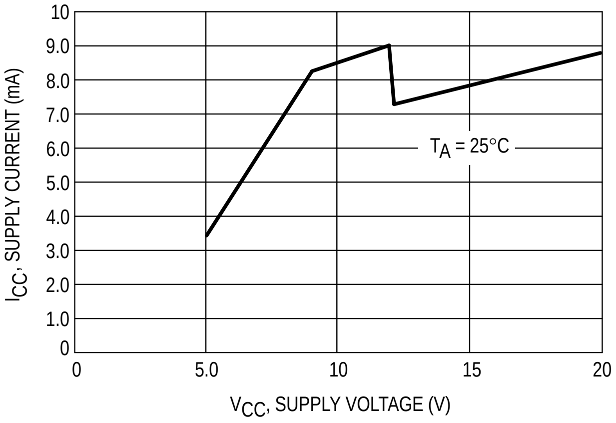
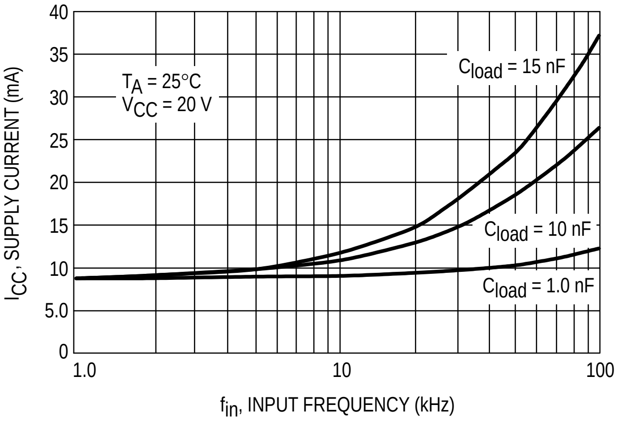


Figure 25. Supply Current versus Input Frequency



OPERATING DESCRIPTION

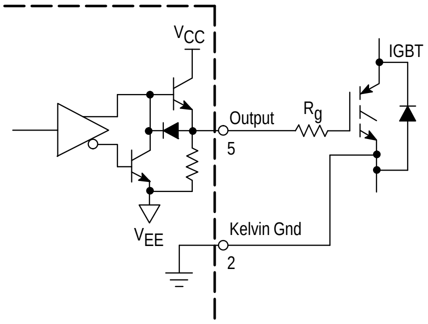
GATE DRIVE

Controlling Switching Times

The most important design aspect of an IGBT gate drive is optimization of the switching characteristics. Switching characteristics are especially important in motor control applications in which PWM transistors are used in a bridge configuration. In these applications, the gate drive circuit components should be selected to optimize turn–on, turn–off, and off–state impedance.

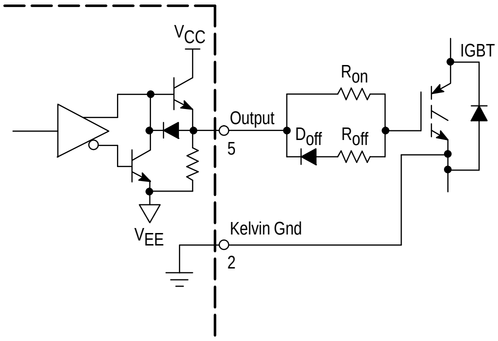
A single resistor may be used to control both turn–on and turn–off and shown in Figure 26. However, the resistor value selected must be a compromise in turn–on abruptness and turn–off losses. Using a single resistor is normally suitable only for very low frequency PWM.

Figure 26. Using a Single Gate Resistor



An optimized gate drive output stage is shown in Figure 27. This circuit allows turn–on and turn–off to be optimized separately.

Figure 27. Using Separate Resistors for Turn–On and Turn–Off



The turn–on resistor R_{on} provides control over the IGBT turn–on speed. In motor control circuits, the resistor sets the turn–on di/dt that controls how fast the free–wheel diode is cleared. The interaction of the IGBT and freewheeling diode determines the turn–on dv/dt.

Excessive turn–on dv/dt is a common problem in half–bridge circuits.

The turn–off resistor R_{off} controls the turn–off speed and ensures that the IGBT remains off under commutation stresses. Turn–off is critical to obtain low switching losses. While IGBTs exhibit a fixed minimum loss due to minority carrier recombination, a slow gate drive will dominate the turn–off losses. This is particularly true for fast IGBTs. It is also possible to turn–off an IGBT too fast. Excessive turn–off speed will result in large overshoot voltages. Normally the turn–off resistor is a small fraction of the turn–on resistor.

The MC33154 has a bipolar totem pole output. The output stage is capable of sourcing 4.0 amps and sinking 2.0 amps peak. The output stage also contains a pull down resistor to ensure that the IGBT is off when the gate drive power is not applied.

In a PWM inverter, IGBTs are used in a half–bridge configuration. Thus, at least one device is always off. While the IGBT is in the off–state it will be subjected to changes in voltage caused by the other devices. This is particularly a problem when the opposite transistor turns on.

When the lower device is turned on clearing the upper diode, the turn–on dv/dt of the lower device appears across the collector emitter of the upper device. To eliminate shoot–through currents it is necessary to provide a low sink impedance to the device in the off–state. Fortunately, the turn–off resistor can be made small enough to hold off the device under commutation without causing excessively fast turn–off speeds.

Sometimes a negative bias voltage is used in the off–state. This is a practice carried over from bipolar Darlington drives. A negative bias is generally not required for IGBTs. However, a negative bias will reduce the possibility of shoot–through. The MC33154 has separate pins for V_{EE} and Kelvin Gnd. This permits operation using a +15/–5 volt supply.

INTERFACING WITH OPTOISOLATORS

Isolated Input

The MC33154 may be used with an optically isolated input. The optoisolator can be used to provide level shifting and if desired, isolation from AC line voltages. An optoisolator with a very high dv/dt capability should be used, such as the Hewlett–Packard HCPL0453. The IGBT gate turn–on resistor should be set large enough to ensure that the opto's dv/dt capability is not exceeded. Like most optoisolators, the HCPL0453 has an active low open–collector output. Thus, when the LED is ON, the output will be low. The MC33154 has a non–inverting input pin to interface directly with an optoisolator using a pull up resistor.

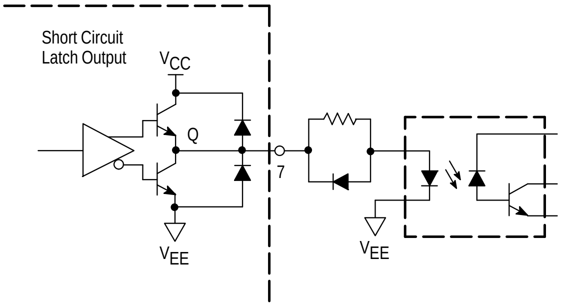
Optoisolator Output Fault

The MC33154 has an active high fault output. The fault output may be easily interfaced to an optoisolator. While it is important that all faults are properly reported, it is equally important that no false signals are propagated. Again a high dv/dt optoisolator should be used.

The LED drive provides a resistor programmable current of 10 to 20 mA when on and provides a low impedance path when off.

An active high output, resistor, and small signal diode provide an excellent LED driver. This circuit is shown in Figure 28.

Figure 28. Output Fault Optoisolator



UNDER VOLTAGE LOCK OUT

It is desirable to protect an IGBT from insufficient gate voltage. IGBTs require 15 V on the gate to guarantee device saturation. At gate voltages below 13 V, the “on” state voltage increases dramatically, especially at higher currents. At very lower gate voltages, below 10 V, the IGBT may operate in the linear region and quickly overheat. Many PWM motor drives use a bootstrap supply for the upper gate drive. The UVLO provides protection for the IGBT in case the bootstrap capacitor discharges.

The MC33154 will typically start up at about 12 V. The UVLO circuit has about 1.0 volt of hysteresis. The UVLO will disable the output if the supply voltage falls below about 11 V.

PROTECTION CIRCUITRY

Desaturation Protection

Bipolar Power circuits have commonly used what is known as “Desaturation Detection”. This involves monitoring the collector voltage and turning off the device if the collector voltage rises above a certain limit. A bipolar transistor will only conduct a certain amount of current for a given base drive. When the base is overdriven the device is in saturation. When the collector current rises above the knee, the device pulls out of saturation.

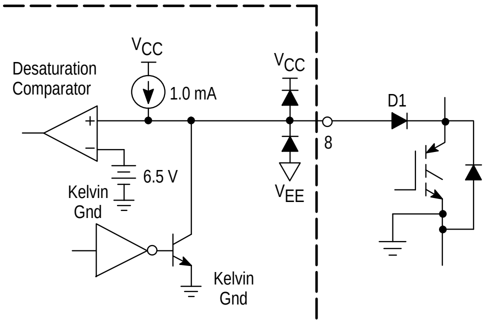
The maximum current the device will conduct in the linear region is a function of the base current and hfe of the transistor.

The output characteristics of an IGBT are similar to a Bipolar device. However the output current is a function of gate voltage, not current. The maximum current depends on the gate voltage and the device. IGBTs tend to have a very high transconductance and a much higher current density under a short circuit than a bipolar device.

Motor control IGBTs are designed for a lower current density under shorted conditions and a longer short circuit survival time.

The best method for detecting desaturation is the use of a high voltage clamp diode and a comparator. The MC33154 has a desaturation comparator which senses the collector voltage and provides an output indicating when the device is not full saturated. Diode D1 is an external high voltage diode with a rated voltage comparable to the power device. When the IGBT is ON and saturated, diode D1 will pull down the voltage on the desaturation input. When the IGBT is OFF or pulls out of saturation, the current source will pull up the voltage on the desaturation input. The voltage reference is set to about 6.5 V. This will allow a maximum ON–voltage of about 5.0 V.

Figure 29. Desaturation Detection Using a Diode



A fault exists when the gate input is high and V_{CE} of the IGBT is greater than the maximum allowable $V_{CE(sat)}$. The output of the desaturation comparator is ANDed with the gate input signal and fed into the Short Circuit (SC) latch. The SC latch will turn–off the IGBT for the remainder of the cycle when a fault is detected. When the input is toggled low, the latch will reset. The reference voltage is tied to the Kelvin Ground instead of the V_{EE} to make the threshold independent of negative gate bias.

The MC33154 also features a programmable turn–on blanking time. During turn–on the IGBT must clear the opposing free wheeling diode. The collector voltage will remain high until the diode is cleared. Once the diode has been cleared the voltage will come down quickly to the $V_{CE(sat)}$ of the device. Following turn–on there is normally considerable ringing on the collector due to the C_{OSS} of the IGBTs and the parasitic wiring inductance.

The error signal from the desaturation signal must be blanked out sufficiently to allow the diode to be cleared and the ringing to settle out.

The blanking function uses an NPN transistor to clamp the comparator input when the gate input is low. When the input is switched high, the clamp transistor will turn–off, and the current source will charge up the blanking capacitor. The time required for blanking capacitor to charge up from the on–voltage of the clamp FET to the trip voltage of the comparator is the blanking time.

If a short circuit occurs after the IGBT is turned on and saturated, the delay time will be the time required for the current source to charge up the blanking capacitor from the $V_{CE(sat)}$ to the trip voltage of the comparator.

Sense IGBT Protection

Another approach to protecting the IGBTs is to sense the emitter current using a current shunt or Sense IGBTs.

This method has the advantage of being able to use high gain IGBTs which do not have any inherent short circuit capability.

Current sense IGBTs work as well as current sense MOSFETs in most circumstances. However, the basic problem of working with very low sense voltages still exists. Sense IGBTs sense current through the channel and are therefore linear concerning collector current.

Because IGBTs have a very low incremental on–resistance, sense IGBTs behave much like low–on resistance current sense MOSFETs. The output voltage of a properly terminated sense IGBT is very low, normally less than 100 mV.

The sense IGBT approach requires a blanking time to prevent false tripping during turn–on. The sense IGBT also requires that the sense signal is ignored while the gate is low. This is because the mirror normally produces large transient voltages during both turn–on and turn–off due to the collector to mirror capacitance.

A low resistance current shunt may also be used to sense the emitter current. A very low resistance shunt (5.0 mΩ to 50 mΩ) must be used with high current IGBTs. The output voltage of a current shunt is also very low.

When the output is an actual short circuit the inductance will be very low. Since the blanking circuit provides a fixed minimum on–time the peak current under a short circuit may be very high. A short circuit discern function may be implemented using a second comparator with a higher trip voltage.

This circuit can distinguish between an overcurrent and a shorted output condition. Under an actual short circuit the die temperature may get very hot. When a short circuit is detected the transistor should be turned–off for several milliseconds to cool down before the device is turned back on.

The sense circuit is very similar to the Desaturation circuit. The MC33154 uses a combination circuit that provides protection for both Short Circuit capable IGBTs and Sense IGBTs.

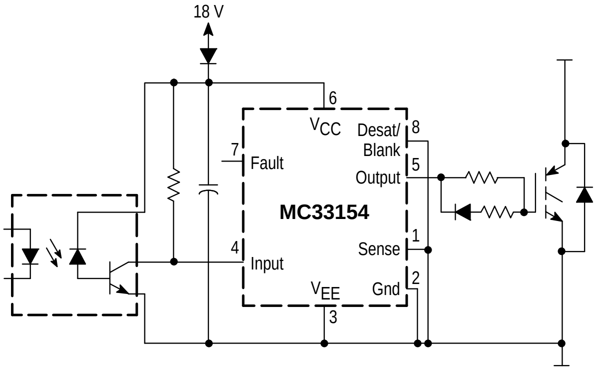
APPLICATION EXAMPLES

The simplest gate drive circuit using the MC33154 is shown in Figure 30. The optoisolator requires a pull up resistor. This resistor value should be set to bias the output transistor at the desired current. A decoupling capacitor should be placed close to the IC to minimize switching noise.

A bootstrap diode may be used to for a floating supply. If the protection features are not used, then both the desaturation input and the current sense input should be grounded.

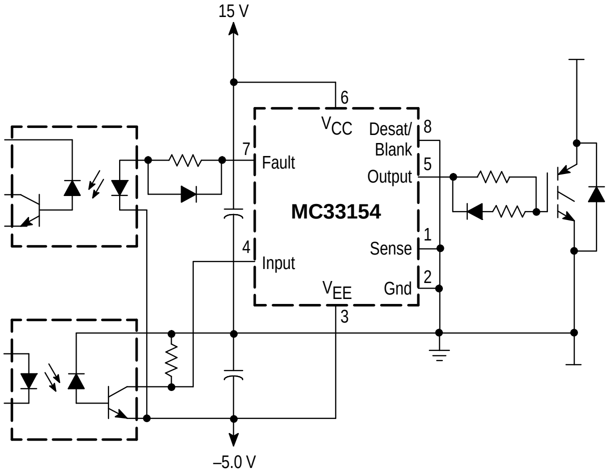
When used with a single supply the Kelvin Gnd and V_{EE} pins should be connected. Separate resistors are recommended for turn–on and turn–off.

Figure 30. Basic Application



When used with a dual supply as shown in Figure 31, the Gnd pin should be Kelvin connected to the emitter of the IGBT. If the protection features are not used, then both the desaturation input and the current sense input should be connected to Gnd. The input optoisolator, however, should be referenced to V_{EE}.

Figure 31. Dual Supply Application

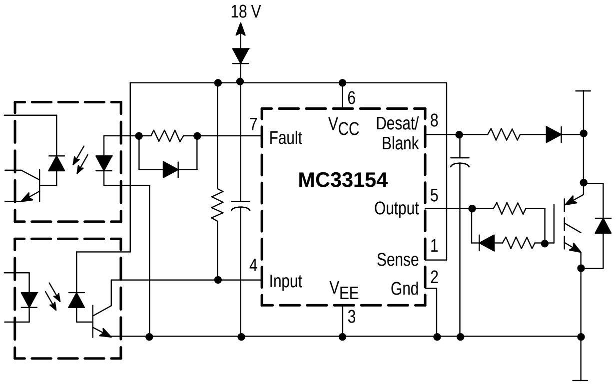


If Desaturation protection is desired as shown in Figure 32, a high voltage diode is connected to the Desaturation/Blanking pin. The blanking capacitor should be connected from the Desaturation pin to the V_{EE} pin. If a dual supply is used the blanking capacitor should be connected to the Kelvin Gnd.

Because desaturation protection is used in this example, the sense input should be tied high. The MC33154 design ANDs the output of the overcurrent comparators with the output of the desaturation comparator, allowing the circuit designer to choose either type of protection.

Although the reverse voltage on collector of the IGBT is clamped to the emitter by the free wheeling diode, there is normally considerable inductance within the package itself. A small resistor in series with the diode may be used to protect the IC from reverse voltage transients.

Figure 32. Desaturation Application

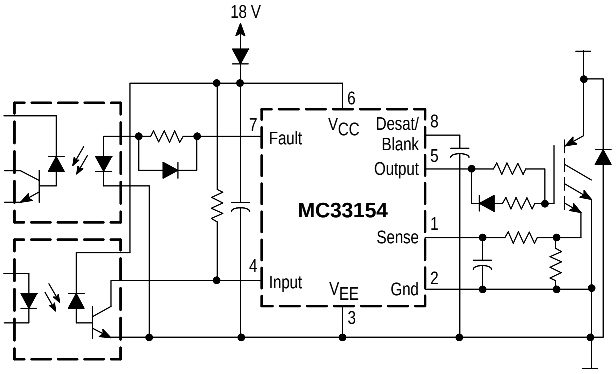


When using sense IGBTs or a sense resistor, as shown in Figure 33, the sense voltage is applied to the current sense input. The sense trip voltages are referenced to the Kelvin Gnd pin. The sense voltage is very small, typically about 65 mV, and sensitive to noise.

Therefore, the sense and ground return conductors should be routed as a differential pair. An RC filter is useful in filtering any high frequency noise. A blanking capacitor is connected from the blanking pin to V_{EE}. The stray capacitance on the blanking pin provides a very small level of blanking if left open.

The blanking pin should not be grounded when using current sensing. That would disable the overcurrent sense. The blanking pin should never be tied high. That would short out the internal IC clamp transistor.

Figure 33. Sense IGBT Application



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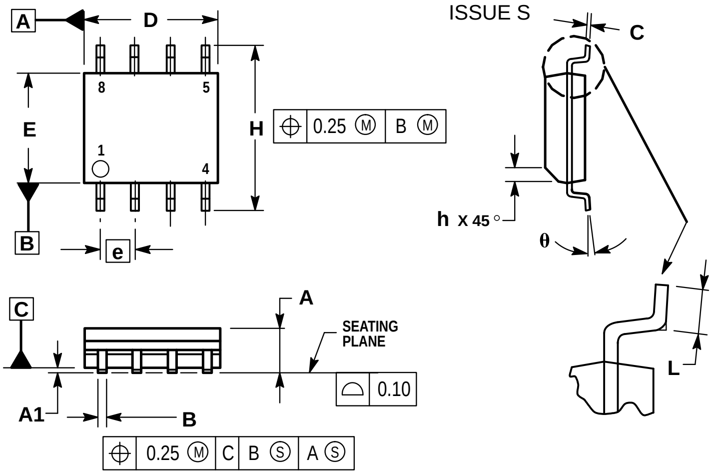
OUTLINE DIMENSIONS

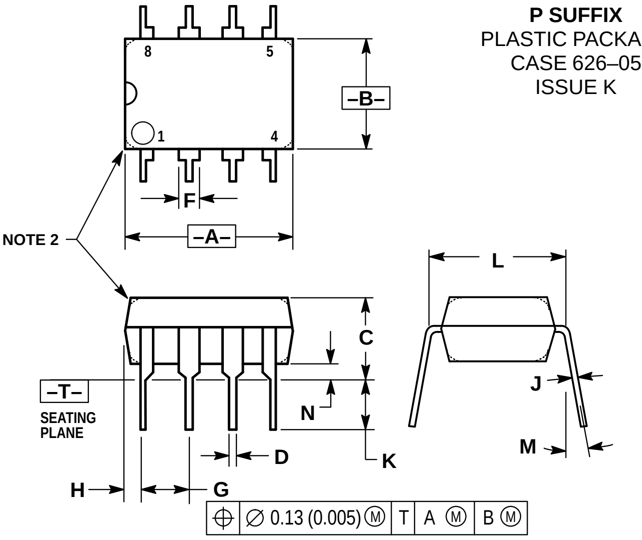
D SUFFIX
PLASTIC PACKAGE
CASE 751–05
ISSUE S



NOTES:
1. DIMENSIONING AND TOLERANCING PER ASME Y14.5M, 1994.
2. DIMENSIONS ARE IN MILLIMETERS.
3. DIMENSION D AND E DO NOT INCLUDE MOLD PROTRUSION.
4. MAXIMUM MOLD PROTRUSION 0.15 PER SIDE.
5. DIMENSION B DOES NOT INCLUDE MOLD PROTRUSION. ALLOWABLE DAMBAR PROTRUSION SHALL BE 0.127 TOTAL IN EXCESS OF THE B DIMENSION AT MAXIMUM MATERIAL CONDITION.

	MILLIMETERS	
DIM	**MIN**	**MAX**
A	1.35	1.75
A1	0.10	0.25
B	0.35	0.49
C	0.18	0.25
D	4.80	5.00
E	3.80	4.00
e	1.27 BSC	
H	5.80	6.20
h	0.25	0.50
L	0.40	1.25
θ	0°	7°

P SUFFIX
PLASTIC PACKAGE
CASE 626–05
ISSUE K



NOTES:
1. DIMENSION L TO CENTER OF LEAD WHEN FORMED PARALLEL.
2. PACKAGE CONTOUR OPTIONAL (ROUND OR SQUARE CORNERS).
3. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.

STYLE 1:
PIN 1. AC IN
2. DC + IN
3. DC – IN
4. AC IN
5. GROUND
6. OUTPUT
7. AUXILIARY
8. V_{CC}

	MILLIMETERS		INCHES	
DIM	**MIN**	**MAX**	**MIN**	**MAX**
A	9.40	10.16	0.370	0.400
B	6.10	6.60	0.240	0.260
C	3.94	4.45	0.155	0.175
D	0.38	0.51	0.015	0.020
F	1.02	1.78	0.040	0.070
G	2.54 BSC		0.100 BSC	
H	0.76	1.27	0.030	0.050
J	0.20	0.30	0.008	0.012
K	2.92	3.43	0.115	0.135
L	7.62 BSC		0.300 BSC	
M	——	10°	——	10°
N	0.76	1.01	0.030	0.040

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