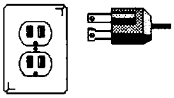
HARRIS
SEMICONDUCTOR

HIP5600

Thermally Protected High Voltage Linear Regulator

April 1994

Features



- **Operates from 50VDC to 400VDC**
- **Operates from 50VRMS to 280VRMS Line**
- **UL Recognized**
- **Variable DC Output Voltage 1.2VDC to V_{IN} - 50V**
- **Internal Thermal Shutdown Protection**
- **Internal Over Current Protection**
- **Up to 40mA Peak Output Current**
- **Surge Rated to ±650V; Meets IEEE/ANSI C62.41.1980 with Additional MOV**

Applications

- **Switch Mode Power Supply Start-Up**
- **Electronically Commutated Motor Housekeeping Supply**
- **Power Supply for Simple Industrial/Commercial/Consumer Equipment Controls**
- **Off-Line (Buck) Switch Mode Power Supply**

CAUTION: This product does not provide isolation from AC line.

Ordering Information

PART NUMBER	CASE TEMP. RANGE	PACKAGE
HIP5600IS	-40°C to +100°C	3 Lead Plastic SIP
HIP5600IB	-40°C to +100°C	8 Lead Plastic SOIC

Description

The HIP5600 is an adjustable 3-terminal positive linear voltage regulator capable of operating up to either 400VDC or 280VRMS. The output voltage is adjustable from 1.2VDC to within 50V of the peak input voltage with two external resistors. This high voltage linear regulator is capable of sourcing 1mA to 30mA with proper heat sinking. The HIP5600 can also provide 40mA peak (typical) for short periods of time.

Protection is provided by the on chip thermal shutdown and output current limiting circuitry. The HIP5600 has a unique advantage over other high voltage linear regulators due to its ability to withstand input to output voltages as high as 400V(peak), a condition that could exist under output short circuit conditions.

Common linear regulator configurations can be implemented as well as AC/DC conversion and start-up circuits for switch mode power supplies.

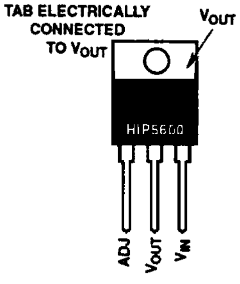
The HIP5600 requires a minimum output capacitor of 10µF for stability of the output and may require a 0.02µF input decoupling capacitor depending on the source impedance. It also requires a minimum load current of 1mA to maintain output voltage regulation.

All protection circuitry remains fully functional even if the adjustment terminal is disconnected. However, if this happens the output voltage will approach the input voltage.

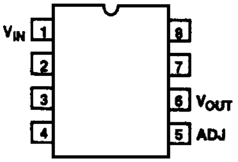
NOTE: Unless otherwise noted, information pertains to the TO-220 package.

Pinouts

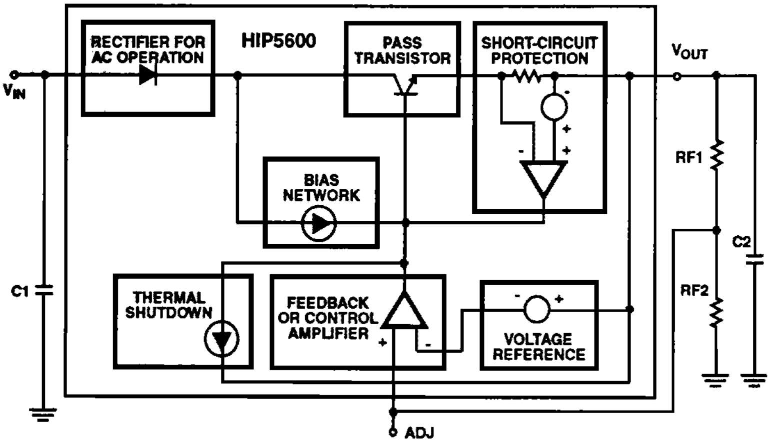
HIP5600 (SIP)
TOP VIEW



HIP5600 (SOIC)
TOP VIEW



Functional Block Diagram



Absolute Maximum Ratings

Input to Output Voltage, Continuous. . . . . +480V to -550V
Input to Output Voltage, Peak (Non Repetitive, 2ms). . . . . ±650V
Junction Temperature. . . . . +150°C
ADJ to Output, Voltage to ADJ. . . . . ±5V
Storage Temperature Range . . . . -65°C to +150°C

Thermal Information

Thermal Resistance	θ_{JA}	θ_{JC}
Plastic SIP Package	60°C/W	4°C/W
Plastic SOIC Package	170°C/W	-

Lead Temperature (Soldering 10s) . . . . +265°C

CAUTION: Stresses above those listed in "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress only rating and operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied.

Operating Conditions

Operating Voltage Range . . . . 80VRMS to 280VRMS or 50VDC to 400VDC

Operating Temperature Range . . . . -40°C to +100°C (Case)

Electrical Specifications

Conditions V_{IN} = 400VDC, I_L = 1mA, C_L = 10µF, V_{ADJ} = 3.79V, V_{OUT} = 5V (Unless Otherwise Specified)
Temperature = Case Temperature.

PARAMETER	CONDITION	TEMP	MIN	TYP	MAX	UNITS
INPUT						
Input Voltage	DC	Full	50	-	400	V
Max Peak Input Voltage	Non-Repetitive (2ms)	Full	-	-	±650	V
Input Frequency (Note 1)		Full	DC	-	1000	Hz
Bias Current (I_{BIAS} Note 2)		Full	0.4	0.5	0.6	mA
REFERENCE						
I_{ADJ}		+25°C	50	65	80	µA
$I_{ADJ}T_C$ (Note 1)	I_L = 1mA	Full	-	+0.15	-	µA/°C
$I_{ADJ\ LOAD\ REG}$ (Note 1)	I_L = 1mA to 10mA	+25°C	-	-215	-	nA/mA
V_{REF} (Note 3)		+25°C	1.07	1.18	1.30	V
V_{REF} T_C (Note 1)	I_L = 1mA	Full	-	-460	-	µV/°C
Line Regulation $V_{REF\ LINE\ REG}$	50VDC to 400VDC	+25°C	-	9	14.5	µV/V
		Full	-	9	29	µV/V
Load Regulation $V_{REF\ LOAD\ REG}$	I_{OUT} = 1mA to 10mA	+25°C	-	3	5	mV/mA
		Full	-	3	6	mV/mA
PROTECTION CIRCUITS						
Output Short Circuit Current Limit	V_{IN} = 50V	+25°C	35	-	45	mA
Thermal Shutdown T_{TS} (IC surface, not case temperature. Note 1)	V_{IN} = 400V	-	127	134	142	°C
Thermal Shutdown Hysteresis (Note 1)	V_{IN} = 400V	-	-	34	-	°C

NOTES:

1. Characterized not tested
2. Bias current ≡ input current with output pin floating.
3. $V_{REF} = V_{OUT} - V_{ADJ}$

Schematic Diagram

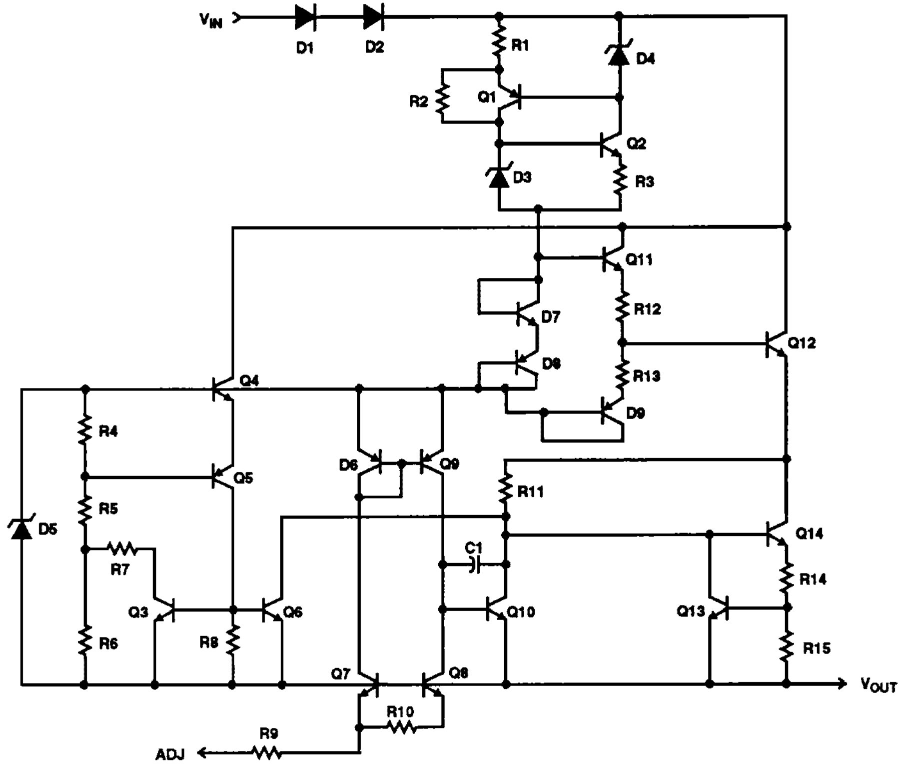


FIGURE 1.

Application Information

Introduction

In many electronic systems the components operate at 3V to 15V but the system obtains power from a high voltage source (AC or DC). When the current requirements are small, less than 10mA, a linear regulator may be the best supply provided that it is easy to design in, reliable, low cost and compact. The HIP5600 is similar to other 3 terminal regulators but operates from much higher voltages. It protects its load from surges +250V above its 400V operating input voltage and has short circuit current limiting and thermal shutdown self protection features.

Output Voltage

The HIP5600 provides a temperature independent 1.18V reference, V_{REF}, between the output and the adjustment terminal ($V_{REF} = V_{OUT} - V_{ADJ}$). This constant reference voltage is impressed across RF1 (see Figure 2) and results in a constant current (I_1) that flows through RF2 to ground. The voltage across RF2 is the product of its resistance and the sum of I_1 and I_{ADJ}. The output voltage is given in equations 1(A, B).

$$V_{OUT} = (V_{REF})\frac{RF1 + RF2}{RF1} + I_{ADJ}(RF2) \qquad \text{EQ 1(A)}$$

$$V_{OUT} = (1.18) \times \frac{RF1 + RF2}{RF1} + 65\mu A\,(RF2) \qquad \text{EQ 1(B)}$$

Error Budget

$$\Delta V_{OUT} = \Delta V^{T}_{REF}\left(\frac{RF1 + RF2}{RF1}\right) + \Delta I^{T}_{ADJ}RF2 + I_{ADJ}RF2\frac{\Delta RF2}{RF2} + V_{REF}\left(\frac{RF2}{RF1}\right)\left(\frac{\Delta RF2}{RF2} - \frac{\Delta RF1}{RF1}\right) \qquad \text{EQ 2(A)}$$

Where;

$$\Delta V^{T}_{REF} \equiv \Delta V_{REF} + V_{REF_{LOADREG}}(\Delta I_{OUT}) + V_{REF}TC(\Delta\ Temp) + V_{REF}TC(\theta_{SA})\Delta\ (I_{OUT} \cdot V_{IN}) + V_{REF_{LINEREG}} \qquad \text{EQ 2(B)}$$

$$\Delta I^{T}_{ADJ} \equiv \Delta I_{ADJ} + I_{ADJ_{LOADREG}}(\Delta I_{OUT}) + I_{ADJ}TC(\Delta\ Temp) + I_{ADJ}TC(\theta_{SA})\Delta\ (I_{OUT} \cdot V_{IN}) \qquad \text{EQ 2(C)}$$

Note:

$\frac{\Delta RFx}{RFx}$ = % tolerance of resistor x

Worst case θ_{SA} is calculated using the minimum T_{TS} of +127°C in Equation 6.

Example,

Given: V_{IN} = 400VDC V_{OUT} = 15V I_{LOAD} = 15mA
θ_{JC} = 4.8°C/W T_{TS} = +127°C I_{ADJ} = 80μA
T_A = +50°C RF1 = 1.1k
V_{REF} = 1.18V P = 6.2W = $(V_{IN} - V_{OUT})(I_{IN})$

$$I_{IN} = I_{ADJ} + \frac{V_{REF}}{RF1} + I_{LOAD}$$

Find: Proper heat sink to keep the junction temperature of the HIP5600 from exceeding T_{TS} (+127°C).

Solution: Use Equation 6,

$$\theta_{SA} = \frac{T_{TS} - T_A}{P} - \theta_{JC} \qquad \text{EQ (7)}$$

$$\theta_{SA} = \frac{127^\circ C - 50^\circ C}{6.2} - 4.8^\circ C = 7.62 \frac{^\circ C}{W} \qquad \text{EQ (8)}$$

The selection of a heat sink with θ_{SA} less than +7.62°C/W would ensure that the junction temperature would not exceed the thermal shut down temperature (T_{TS}) of +127°C. A Thermalloy P/N7023 at 6.2W power dissipation would meet this requirement with a θ_{SA} of +5.7°C/W.

Operation Without A Heatsink

The TO-220 package has a θ_{JA} of +60°C/W. This allows 0.7W power dissipation at +85°C in still air. Mounting the HIP5600 to a printed circuit board (see Figure 40 through Figure 42) decreases the thermal impedance sufficiently to allow about 1.6W of power dissipation at +85°C in still air.

Thermal Transient Operation (TO-220 Package)

For applications such as start-up, the HIP5600 in the TO-220 package can operate at several watts **-without a heat sink-** for a period of time before going into thermal shutdown.

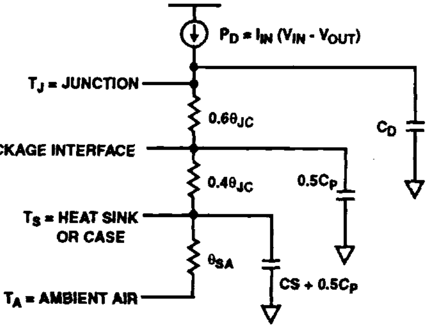


FIGURE 7. THERMAL CAPACITANCE MODEL OF HIP5600

Figure 7 shows the thermal capacitances of the TO-220 package, the integrated circuit and the heat sink, if used. When power is initially applied, the mass of the package absorbs heat which limits the rate of temperature rise of the junction. With no heat sink C_S equals zero and θ_{SA} equals the difference between θ_{JA} and θ_{JC}. The following equations predict the transient junction temperature and the time to thermal shutdown for ambient temperatures up to +85°C and power levels up to 8W. The output current limit temperature coefficient (Figure 39) precludes continuous operation above 8W.

$$T_J(t) = T_A + P\theta_{JC} + P\theta_{SA}\left(1 - e^{\frac{-t}{\tau}}\right) \qquad \text{EQ (9)}$$

Where:

$$\tau = \theta_{SA}(C_P + C_S)$$

$$t = -\tau \ln\left(\frac{P(\theta_{JC} + \theta_{SA}) + T_A - T_{TS}}{P\theta_{SA}}\right) \qquad \text{EQ (10)}$$

For the TO-220, C_P is 0.9Ws to 1.1Ws per degree compared to about 2.6mWs per degree for the integrated circuit and C_S is 0.9Ws per degree per gram for aluminum heat sinks.

Figure 8 shows the time to thermal shutdown versus power dissipation for a part in +22°C still air and at various elevated ambient temperatures with a θ_{SA} of +27°C/W from forced air flow.

For the shorter shutdown times, the θ_{SA} value is not important but the thermal capacitances are. A more accurate equation for the transient silicon surface temperature can be derived from the model shown in Figure 7. Due to the distributed nature of the package thermal capacitance, the second time constant is 1.7 times larger than expected.

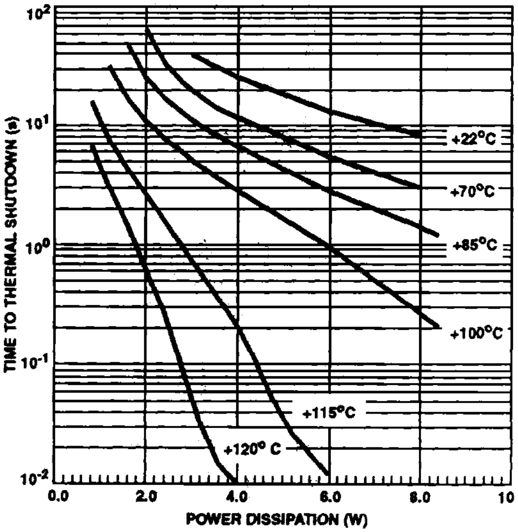


FIGURE 8. TIME TO THERMAL SHUTDOWN vs POWER DISSIPATION (TO-220 PACKAGE ONLY)

between the regulator and the load will have a load regulation due to line resistance of 0.05Ω x ΔI_L. If RF1 is connected near the load the effective load regulation will be 11.9 times worse (1+R2/R1, where R2 = 12k, R1 = 1.1k).

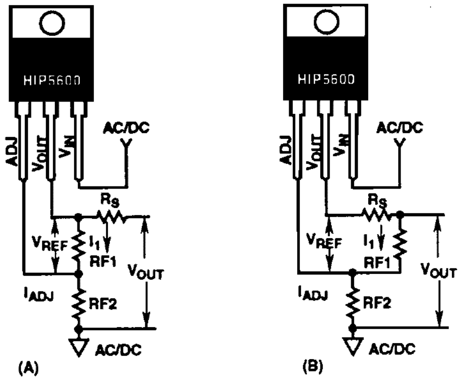
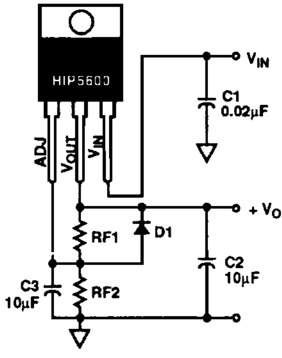


FIGURE 4.

Protection Diodes

The HIP5600, unlike other voltage regulators, is internally protected by input diodes in the event the input becomes shorted to ground. Therefore, **no** external protection diode is required between the input pin and the output pin to protect against the output capacitor (C2) discharging through the input to ground.

If the output is shorted in the absence of D1 (Figure 5), the bypass capacitor voltage (C3) could exceed the absolute maximum voltage rating of ±5V between V_{OUT} and V_{IN}. Note; No protection diode (D1) is needed for output voltages less than 6V or if C3 is not used.



D1 PROTECTS AGAINST C3 DISCHARGING WHEN THE OUTPUT IS SHORTED.

FIGURE 5. REGULATOR WITH PROTECTION DIODE

Selecting the Right Heat Sink

Linear power supplies can dissipate a lot of power. This power or heat must be safely dissipated to permit continuous operation. This section will discuss thermal resistance and show how to calculate heat sink requirements.

Electronic heat sinks are generally rated by their thermal resistance. Thermal resistance is defined as the temperature rise per unit of heat transfer or power dissipated, and is expressed in units of degrees centigrade per watt. For a particular application determine the thermal resistance (θ_{SA}) which the heat sink must have in order to maintain a junction temperature below the thermal shut down limit (T_{TS}).

A thermal network that describes the heat flow from the integrated circuit to the ambient air is shown in Figure 6. The basic relation for thermal resistance from the IC surface, historically called "junction", to ambient (θ_{JA}) is given in Equation 5. The thermal resistance of the heat sink (θ_{SA}) to maintain a desired junction temperature is calculated using Equation 6.

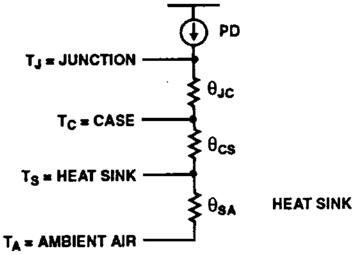


FIGURE 6.

$$\theta_{JA} = \frac{T_J - T_A}{P}\left(\frac{^\circ C}{W}\right) \qquad \text{EQ (5)}$$

Where:

$$\theta_{JA} = \theta_{JC} + \theta_{CS} + \theta_{SA} \quad \text{and} \quad T_J = T_{TS}$$

$$\therefore$$

$$\theta_{SA} + \theta_{CS} \approx \theta_{SA} = \frac{T_{TS} - T_A}{P} - \theta_{JC} \qquad \text{EQ (6)}$$

Where:

θ_{JA} = (Junction to Ambient Thermal Resistance) The sum of the thermal resistances of the heat flow path.
$\theta_{JA} = \theta_{JC} + \theta_{CS} + \theta_{SA}$

T_J = (Junction Temperature) The desired maximum junction temperature of the part. $T_J = T_{TS}$

T_{TS} = (Thermal Shutdown Temperature) The maximum junction temperature that is set by the thermal protection circuitry of the HIP5600
(min = +127°C, typ = +134°C and max = +142°C).

θ_{JC} = (Junction to Case Thermal Resistance) Describes the thermal resistance from the IC surface to its case.
θ_{JC} = 4.8°C/W

θ_{CS} = (Case to Mounting Surface Thermal Resistance) The resistance of the mounting interface between the transistor case and the heat sink.
For example, mica washer.

θ_{SA} = (Mounting Surface to Ambient Thermal Resistance) The resistance of the heat sink to the ambient air. Varies with air flow.

T_A = Ambient Temperature

P = The power dissipated by the HIP5600 in watts.
$P = (V_{IN} - V_{OUT})(I_{OUT})$

Worst case θ_{SA} is calculated using the minimum T_{TS} of +127°C in Equation 6.

Example,

Given: $V_{IN} = 400VDC$ $V_{OUT} = 15V$ $I_{LOAD} = 15mA$

$\theta_{JC} = 4.8°C/W$ $T_{TS} = +127°C$ $I_{ADJ} = 80\mu A$

$T_A = +50°C$ RF1 = 1.1k

$V_{REF} = 1.18V$ $P = 6.2W = (V_{IN} - V_{OUT})(I_{IN})$

$$I_{IN} \equiv I_{ADJ} + \frac{V_{REF}}{RF1} + I_{LOAD}$$

Find: Proper heat sink to keep the junction temperature of the HIP5600 from exceeding T_{TS} (+127°C).

Solution: Use Equation 6,

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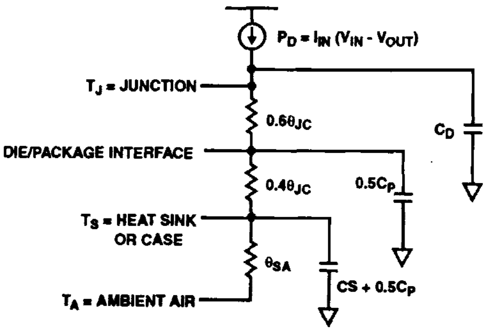

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Where:

$$\tau \equiv \theta_{SA}(C_P + C_S)$$

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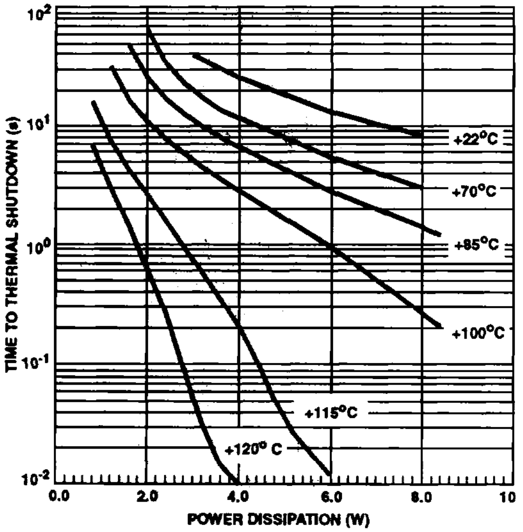


FIGURE 8. TIME TO THERMAL SHUTDOWN vs POWER DISSIPATION (TO-220 PACKAGE ONLY)

$$T_J(t) = T_A + T_1 + T_2 + T_3 \qquad \text{(EQ. 11A)}$$

$$T_1 \equiv P\theta_{SA}\left(1-e^{\frac{-t}{\tau 1}}\right)$$

Where: (EQ. 11B)

$$\tau 1 \equiv \theta_{SA}(C_P + C_S)$$

$$T_2 \equiv 0.4P\theta_{JC}\left(1-e^{\frac{-t}{\tau 2}}\right) \qquad \text{(EQ. 11C)}$$

Where:

$$\tau 2 \equiv 0.7\theta_{JC}\left(\frac{(0.5C_P + C_S)\,0.5C_P}{C_P + C_S}\right)$$

$$T_3 \equiv 0.6P\theta_{JC}\left(1-e^{\frac{-t}{\tau 3}}\right) \qquad \text{(EQ. 11D)}$$

Where:

$$\tau 3 \equiv 0.6\theta_{JC}C_D$$

Thermal Transient Operation (SOIC Package)

Equation (11A) can also be used for the SOIC package provided the following substitutions are made.

$$T_1 \equiv P\theta_1\left(1-e^{\frac{-t}{\tau 1}}\right) \qquad \text{(EQ. 11E)}$$

$$T_2 \equiv P\theta_2\left(1-e^{\frac{-t}{\tau 2}}\right) \qquad \text{(EQ. 11F)}$$

$$T_3 \equiv P\theta_3\left(1-e^{\frac{-t}{\tau 3}}\right) \qquad \text{(EQ. 11G)}$$

where

θ_1 = 160°C/W $\tau 1$ = 5.8s

θ_1 = 10°C/W $\tau 2$ = 86ms

θ_1 = 2.9°C/W $\tau 3$ = 7.5ms

For example, with the SOIC package mounted on a PC board at +85°C in still air, the HIP5600 could dissipate 4W for ~70ms before going into thermal shutdown.

For start-up applications a more useful parameter is the total charge delivered before thermal shutdown.

$$Q_L \approx \frac{(T_{TS} - T_A)}{V_{IN}} C_P \qquad \text{(EQ. 12)}$$

C_P is about 35mJ/°C for the SOIC package and about 1000mJ/°C for TO-220.

For example:

with T_{TS} = +127°C, T_A = +85°C

V_{IN} = 400V and C_P = 35mJ/°C

$Q_L \cong 3670\mu C$

which is enough to charge a 240µF capacitor to 15V.

Thermal Shutdown Hysteresis

Figure 9 shows the HIP5600 thermal hysteresis curve with V_{IN} = 100VDC, V_{OUT} = 5V and I_{OUT} = 10mA. Hysteresis is added to the thermal shutdown circuit to prevent oscillations as the junction temperature approaches the thermal shutdown limit. The thermal shutdown is reset when the input voltage is removed, goes negative (i.e. AC operation) or when the part cools down.

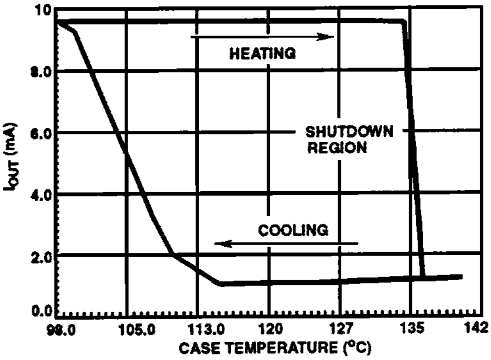


FIGURE 9. THERMAL HYSTERESIS CURVE

AC to DC Operation

Since the HIP5600 has internal high voltage diodes in series with its input, it can be connected directly to an AC power line. This is an improvement over typical low current supplies constructed from a high voltage diode and voltage dropping resistor to bias a low voltage zener. The HIP5600 provides better line and load regulation, better efficiency and heat transfer. The latter because the TO-220 package permits easy heat sinking.

The efficiency of either supply is approximately the DC output voltage divided by the RMS input voltage. The resistor value, in the typical low current supply, is chosen such that for maximum load at minimum line voltage there is some current flowing into the zener. This resistor value results in excess power dissipation for lighter loads or higher line voltages.

Using the circuit in Figure 3 with a 1000µF output capacitor the HIP5600 only takes as much current from the power line as the load requires. For light loads, the HIP5600 is even more efficient due to it's interaction with the output capacitor. Immediately after the AC line goes positive, the HIP5600 tries to replace all the charge drained by the load during the negative half cycle at a rate limited by the short circuit current limit (see "A1" and "B1" Figure 10). Since most of this charge is replaced before the input voltage reaches its RMS value, the power dissipation for this charge is lower than it would be if the charge were transferred at a uniform rate during the cycle. When the product of the input voltage and current is averaged over a cycle, the average power is less than if the input current were constant. Figure 11 shows the HIP5600 efficiency as a function of load current for 80VRMS and 132VRMS inputs for a 15.6V output.

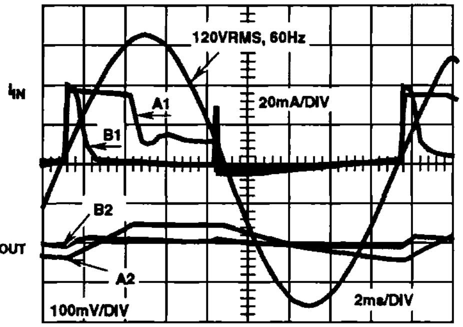


FIGURE 10. AC OPERATION

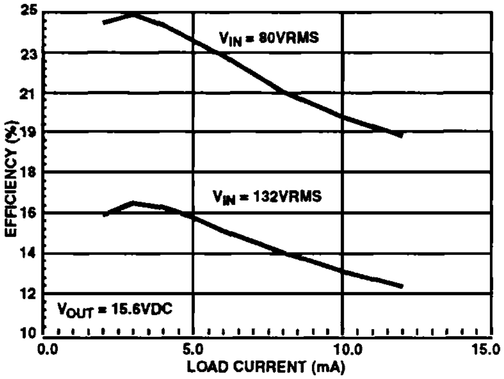


FIGURE 11. EFFICIENCY AS A FUNCTION OF LOAD CURRENT

Referring again to Figure 10, Curve "A1" shows the input current for a 10mA output load and curve "B1" with a 3mA output load. The input current spike just before the negative going zero crossing occurs while the input voltage is less than the minimum operating voltage but is so short it has no detrimental effect. The input current also includes the charging current for the 0.02µF input decoupling capacitor C1.

The maximum load current cannot be greater than 1/2 of the short circuit current because the HIP5600 only conducts over 1/2 of the line cycle. The short circuit current limit (Figure 39) depends on the case temperature, which is a function of the power dissipation. Figure 39 for a case temperature of +100°C (i.e. no heat sink) indicates for AC operation the maximum available output current is 10mA (1/2 x 20mA). Operation from full wave rectified input will increase the maximum output current to 20mA for the same +100°C case temperature.

As a reminder, since the HIP5600 is off during the negative half cycle, the output capacitor must be large enough to supply the maximum load current during this time with some acceptable level of droop. Figure 10 also shows the output ripple voltage, for both a 10mA and 3mA output loads "A2" and "B2", respectively.

Do's And Don'ts

DC Operation

1. Do not exceed the absolute maximum ratings.
2. The HIP5600 requires a minimum output current of 1mA. Minimum output current includes current through RF1. **Warning:** If there is less than 1mA load current, the output voltage will rise. If the possibility of no load exists, RF1 should be sized to sink 1mA under these conditions.

$$RF1_{MIN} = \frac{V_{REF}}{1mA} = \frac{1.07V}{1mA} = 1k\Omega$$

3. Do not "HOT" switch the input voltage without protecting the input voltage from exceeding ±650V. Note: inductance from supplies and wires along with the 0.02µF decoupling capacitor can form an under damped tank circuit that could result in voltages which exceed the maximum ±650V input voltage rating. Switch arcing can further aggravate the effects of the source inductance creating an over voltage condition.

   Recommendation: Adequate protection means (such as MOV, avalanche diode, surgector, etc.) may be needed to clamp transients to within the ±650V input limit of the HIP5600.
4. Do not operate the part with the input voltage below the minimum 50VDC recommended. **Low voltage operation:** For input voltages between 0VDC and +5VDC nothing happens ($I_{OUT} = 0$), for input voltages between +5VDC and +35VDC there is not enough voltage for the pass transistor to operate properly and therefore a high frequency (2MHz) oscillation occurs. For input voltages +35VDC to +50VDC proper operation can occur with some parts.
5. **Warning:** the output voltage will approach the input voltage if the adjust pin is disconnected, resulting in permanent damage to the low voltage output capacitor.

AC Operation

1. Do not exceed the absolute maximum ratings.
2. The HIP5600 requires a minimum output current of 0.5mA. Minimum output current includes current through RF1. **Warning:** If there is less than 0.5mA output current, the output voltage will rise. If the possibility of no load exists, RF1 should be sized to sink 0.5mA under these conditions.

$$RF1_{MIN} = \frac{V_{REF}}{0.5mA} = \frac{1.07V}{0.5mA} = 2k\Omega$$

3. If using a laboratory AC source (such as VARIACs or step-up transformers, etc.) be aware that they contain large inductances that can generate damaging high voltage transients when they are switched on or off.

   Recommendations

   (1) Preset VARIAC output voltage before applying power to part.

   (2) Adequate protection means (such as MOV, avalanche diode, surgector, etc.) may be needed to clamp transients to within the ±650V input limit of the HIP5600.

4. Do not operate the part with the input voltage below the minimum 50VRMS recommended. **Low voltage operation similar to DC operation** (reference step 4 under DC operation).
5. **Warning:** the output voltage will approach the input voltage if the adjust pin is disconnected, resulting in permanent damage to the low voltage output capacitor.

General Precautions

Instrumentation Effects

Background: Input to output parasitic impedances exist in most test equipment power supplies. The inter-winding capacitance of the transformer may result in substantial current flow (mA) from the equipment power lines to the DC ground of the HIP5600. This "ground loop" current can result in erroneous measurements of the circuits performance and in some cases lead to overstress of the HIP5600.

Recommendations for Evaluation of the HIP5600 in the Lab

a) The use of battery powered DVMs and scopes will eliminate ground loops.
b) When connecting test equipment, locate grounds as close to circuit ground as possible.
c) Input current measurements should be made with a non-contact current probe.

If AC powered test equipment is used, then the use of an isolated plug is recommended. The isolated plug eliminates any voltage difference between earth ground and AC ground. However, even though the earth ground is disconnected, ground loop currents can still flow through transformer of the test equipment. Ground loops can be **minimized** by connecting the test equipment ground as close to the circuit ground as possible.

CAUTION: Dangerous voltages may appear on exposed metal surfaces of AC powered test equipment.

Application Circuits

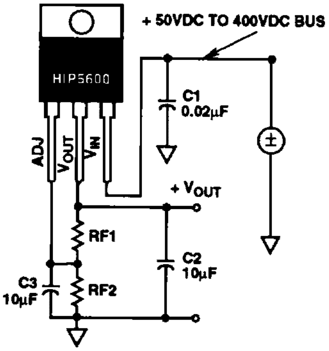


FIGURE 12. DC/DC CONVERTER

The HIP5600 can be configured in most common DC linear regulator applications circuits with an input voltage between 50VDC to 400VDC (above the output voltage) see Figure 12. A 10µF capacitor (C2) provides stabilization of the output stage. Heat sinking may be required depending upon the power dissipation. Normally, choose RF1 << V_{REF}/I_{ADJ}.

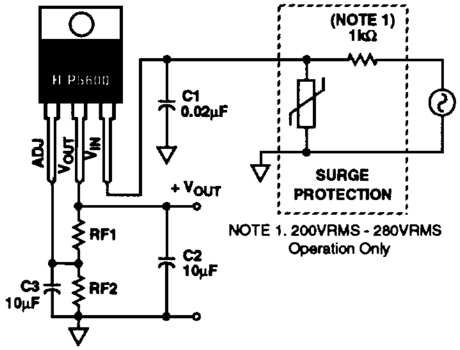


FIGURE 13. AC/DC CONVERTER

The HIP5600 can operate from an AC voltage between 50VRMS to 280VRMS, see Figure 13. The combination of a 1kΩ (2W) input resistor and a V275LA10B MOV provides input surge protection up to 6kV 1.2 x 50µs oscillating and pulse waveforms as defined in IEEE/ANSI C62.41.1980. When operating from 120VAC, a V130LA10B MOV provides protection **without** the 1kΩ resistor.

The output capacitor is larger for operation from AC than DC because the HIP5600 only conducts current during the positive half cycle of the AC line. The efficiency is approximately equal to V_{OUT}/V_{IN} (RMS), see Figure 11.

The HIP5600 provides an efficient and economical solution as a start-up supply for applications operating from either AC (50VRMS to 280VRMS) or DC (50VDC to 400VDC).

The HIP5600 has on chip thermal protection and output current limiting circuitry. These features eliminate the need for an in-line fuse and a large heat sink.

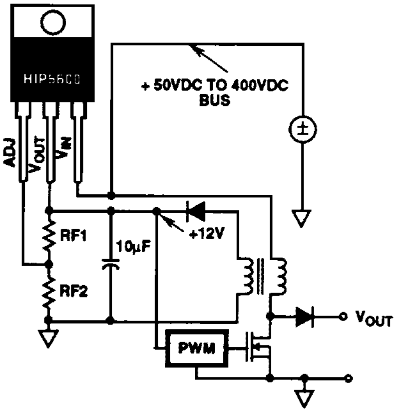


FIGURE 14. START UP CIRCUIT

The HIP5600 can provide up to 40mA for short periods of time to enable start up of a switch mode power supply's control circuit. The length of time that the HIP5600 will be on, prior to thermal shutdown, is a function of the power dissipation in the part, the amount of heat sinking (if any) and the ambient temperature. For example; at 400VDC with no heat sink, it will provide 20mA for about 8s, see Figure 8.

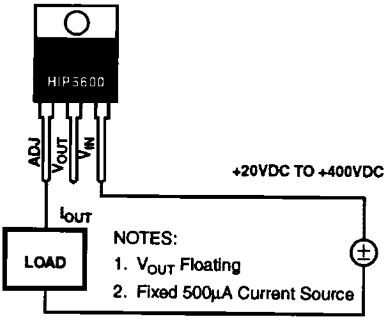
Power supply efficiency is improved by turning off the HIP5600 when the SMPS is up and running. In this application the output of the HIP5600 would be set via RF1 and RF2 to be about 9V. The tickler winding would be adjusted to about 12V to insure that the HIP5600 is kept off during normal operating conditions.The input current under these conditions is approximately equal to I_{BIAS}. (See Figure 28).

The HIP5600 can supply a 450µA (±20%) constant current. (See Figure 15). It makes use of the internal bias network. See Figure 28 for bias current versus input voltage.

With the addition of a potentiometer and a 10µF capacitor the HIP5600 will provide a constant current source. I_{OUT} is given by Equation 13 in Figure 16.

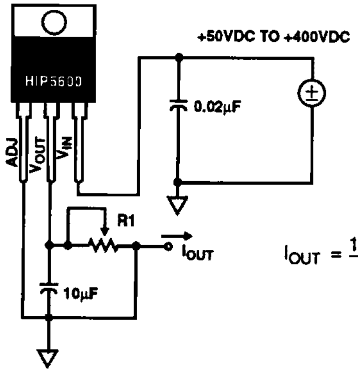
The HIP5600 can be operated as a self-oscillating buck regulator for increased output currents and circuit efficiencies approaching 75%. The circuit shown (Figure 17) is capable of operating from either DC (50VDC to 400VDC) or AC (90VRMS to 264VRMS) and is optimized for a 24V 150mA output. The output voltage is set by RF1 and RF2 resistor values and is slightly higher than the value predicted in Equation 1A. The frequency of operation for the circuit is around 16kHz.

The circuit shown (Figure 18) is optimized for a 24V 250mA output with a 90VRMS to 132VRMS input. Output short circuit protection is provided by adding a pnp transistor and a small 0.22Ω sense resistor. A snubber circuit was also added to reduce the power dissipation in the P-IGBT. The frequency of operation for the circuit is around 18kHz.



NOTES:
1. V_{OUT} Floating
2. Fixed 500µA Current Source

FIGURE 15. CONSTANT 450µA CURRENT SOURCE



$$I_{OUT} = \frac{1.21V}{R1} \quad \text{(EQ. 13)}$$

FIGURE 16. ADJUSTABLE CURRENT SOURCE

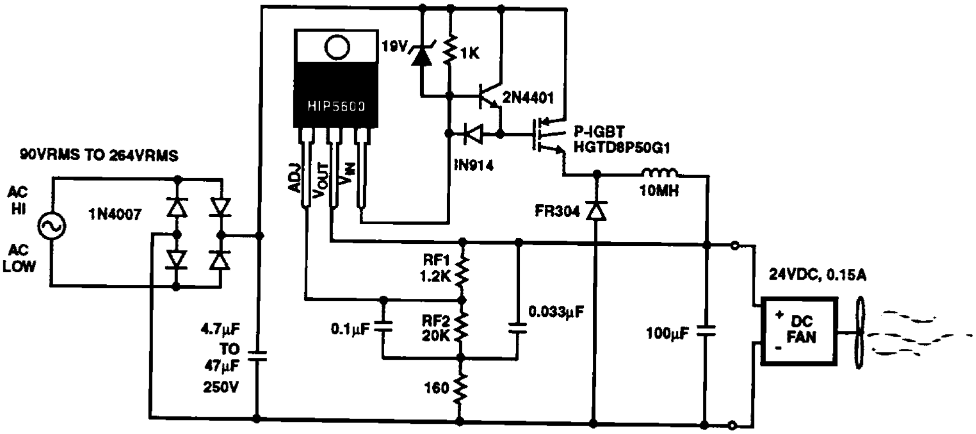


FIGURE 17. HIGH CURRENT "BUCK" REGULATOR

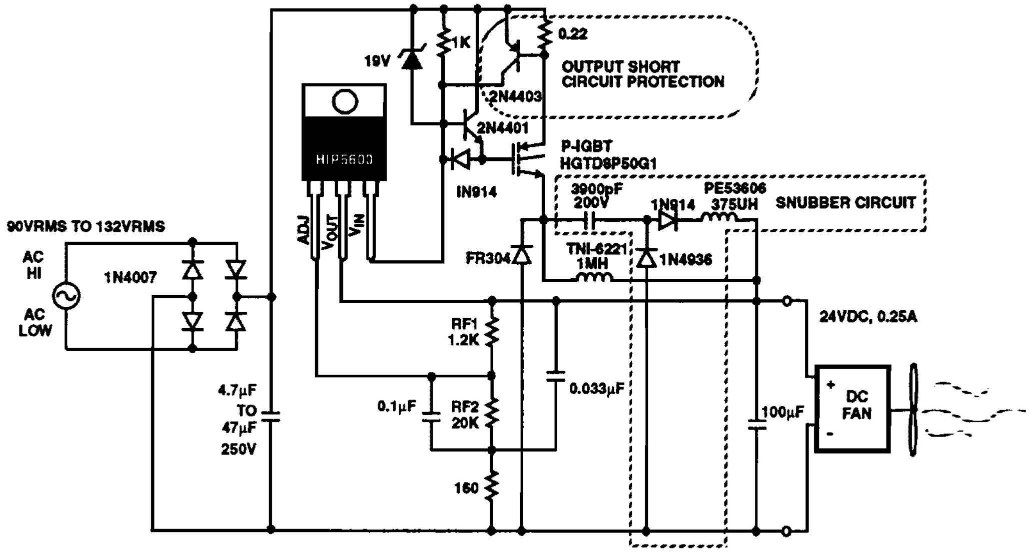


FIGURE 18. HIGH CURRENT "BUCK" REGULATOR WITH OUTPUT SHORT CIRCUIT PROTECTION AND SNUBBER

Typical Performance Curves

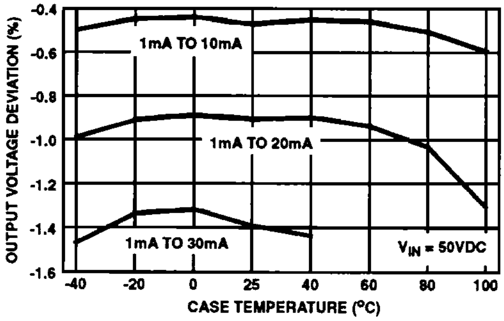


FIGURE 19. LOAD REGULATION vs TEMPERATURE

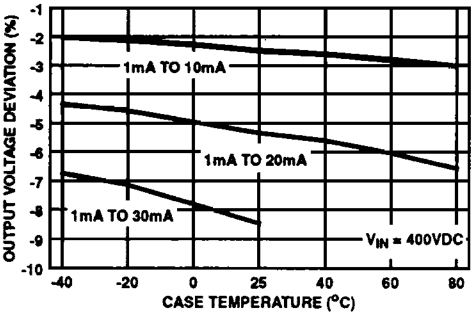


FIGURE 20. LOAD REGULATION VS. TEMPERATURE

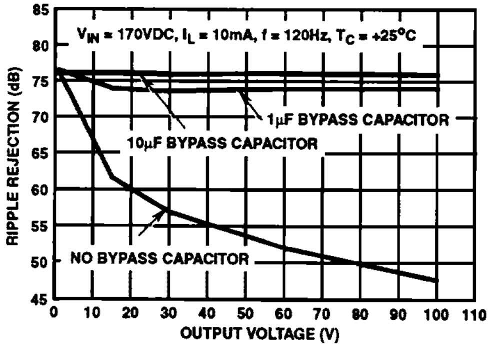


FIGURE 21. RIPPLE REJECTION RATIO (OUTPUT VOLTAGE)

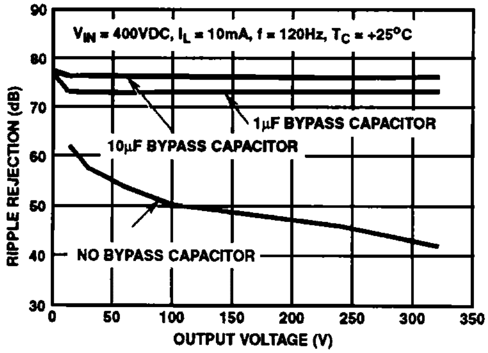


FIGURE 22. RIPPLE REJECTION RATIO (OUTPUT VOLTAGE)

Typical Performance Curves (Continued)

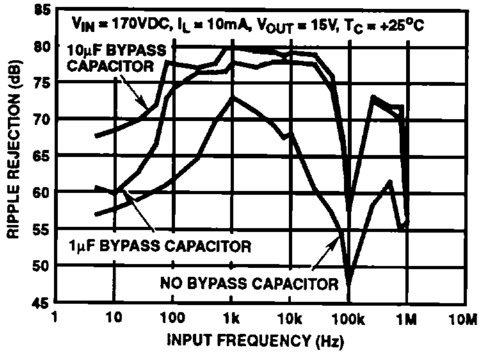


FIGURE 23. RIPPLE REJECTION RATIO (INPUT FREQUENCY)

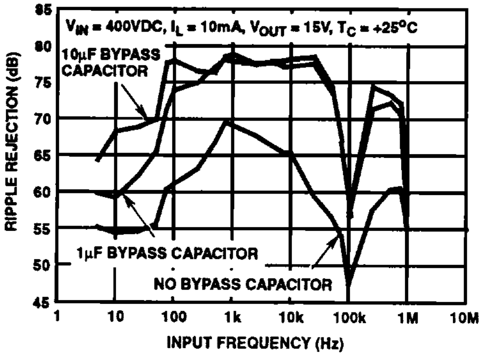


FIGURE 24. RIPPLE REJECTION RATIO (INPUT FREQUENCY)

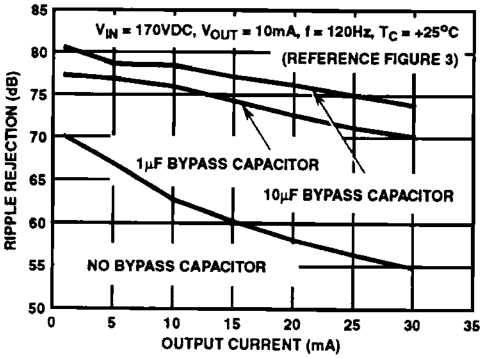


FIGURE 25. RIPPLE REJECTION RATIO (OUTPUT CURRENT)

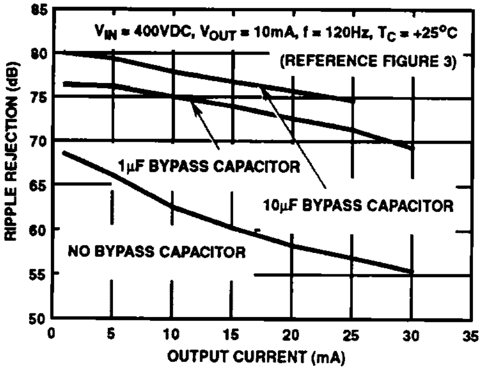


FIGURE 26. RIPPLE REJECTION RATIO (OUTPUT CURRENT)

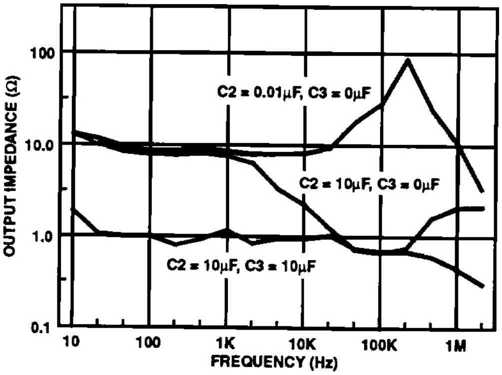


FIGURE 27. OUTPUT IMPEDANCE

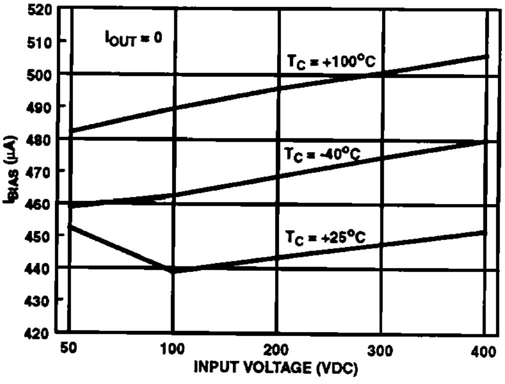


FIGURE 28. I_{BIAS} vs INPUT VOLTAGE

Typical Performance Curves (Continued)

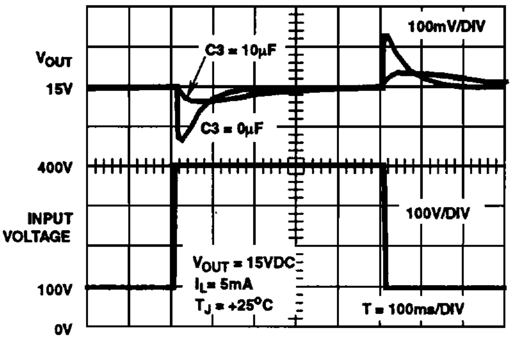


FIGURE 29. LINE TRANSIENT RESPONSE

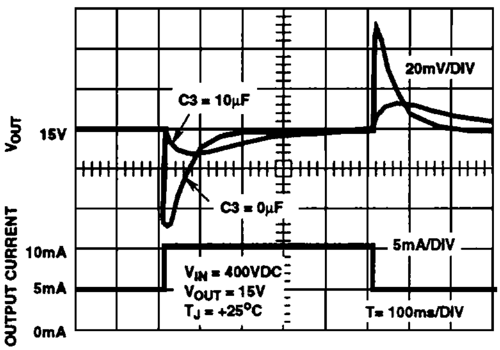


FIGURE 30. LOAD TRANSIENT RESPONSE

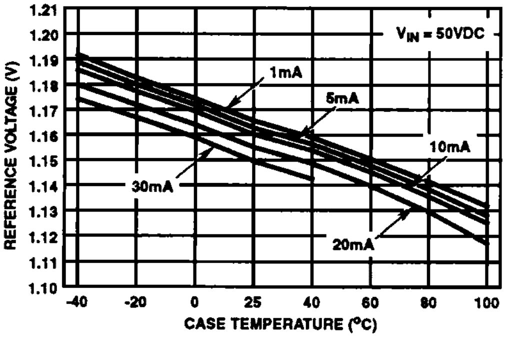


FIGURE 31. REFERENCE VOLTAGE vs TEMPERATURE

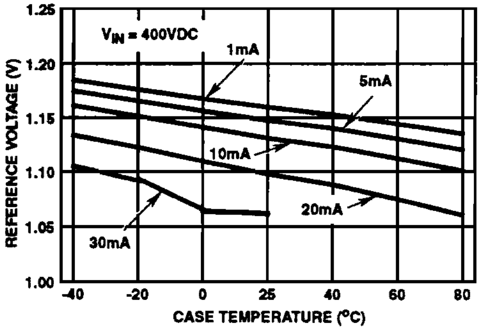


FIGURE 32. REFERENCE VOLTAGE vs TEMPERATURE

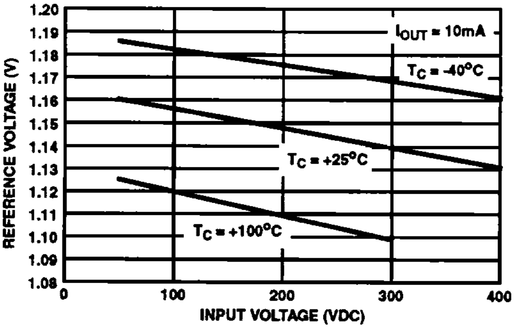


FIGURE 33. REFERENCE VOLTAGE vs INPUT VOLTAGE

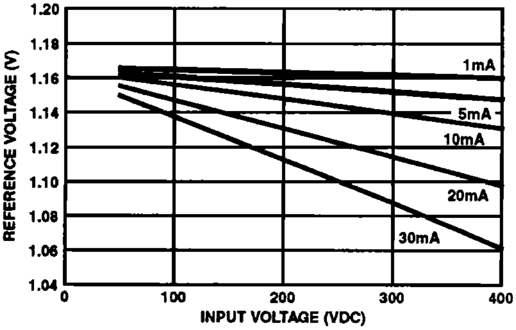


FIGURE 34. REFERENCE VOLTAGE vs V_{IN}; CASE TEMPERATURE OF +25°C

Typical Performance Curves (Continued)

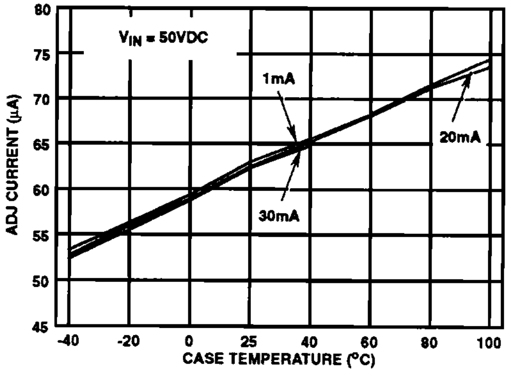


FIGURE 35. I_{ADJ} vs TEMPERATURE

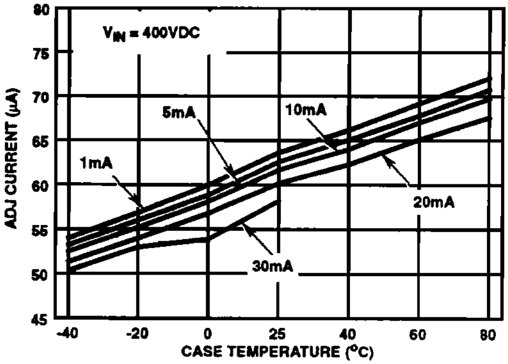


FIGURE 36. I_{ADJ} vs TEMPERATURE

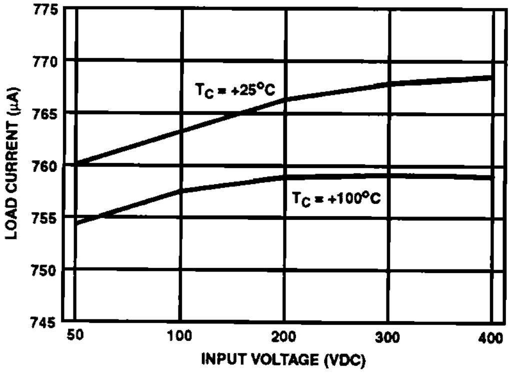


FIGURE 37. MINIMUM LOAD CURRENT vs V_{IN}

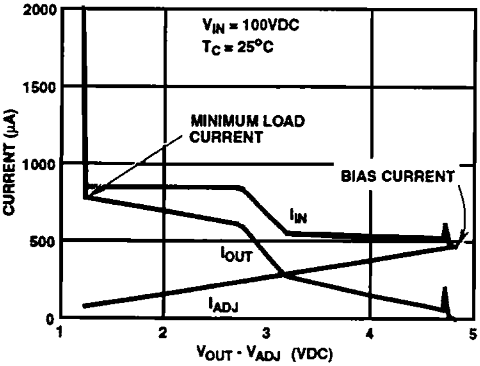


FIGURE 38. TERMINAL CURRENTS vs FORCED V_{REF}

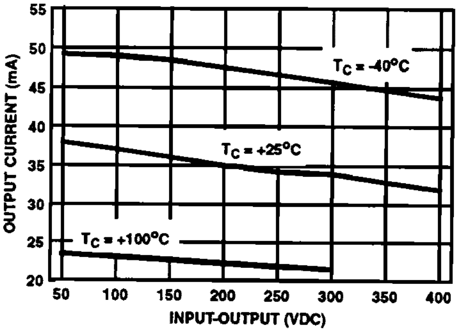


FIGURE 39. CURRENT LIMIT vs TEMPERATURE

Evaluation Boards

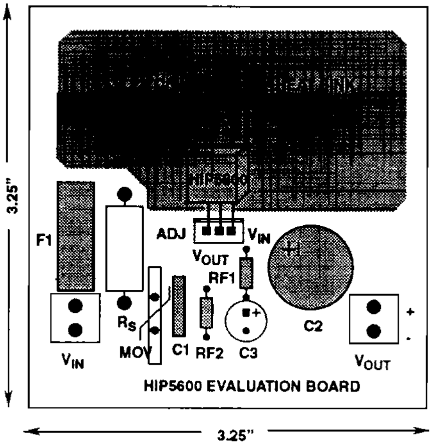


FIGURE 40. EVALUATION BOARD (TOP)

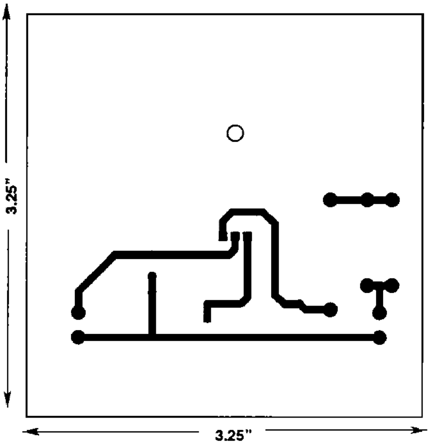


FIGURE 41. EVALUATION BOARD METAL MASK (BOTTOM)

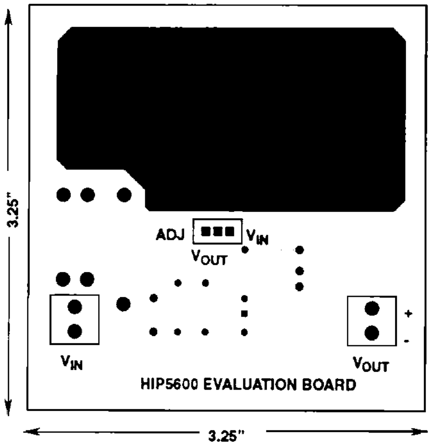


FIGURE 42. EVALUATION BOARD METAL MASK (TOP)