100kHz, 1.25A Switching Regulator with Catch Diode

FEATURES

- **Catch Diode Included in Package**
- Wide Input Voltage Range: 3V to 30V
- Low Quiescent Current: 6mA
- **Internal 1.25A Switch**
- Very Few External Parts Required
- Self-Protected Against Overloads
- **Operates in Nearly All Switching Topologies**
- Shutdown Mode Draws Only 50μA Typical Current
- Can Be Externally Synchronized

APPLICATIONS

- 3.3V-to-5V and 5V-to-12V Boost Converters
- Negative-to-Positive Converter
- SEPIC Converter (Input Can Be Greater or Less Than Output)
- Battery Charger

DESCRIPTION

The LT®1572 is a 1.25A 100kHz monolithic switching regulator with on-board switch and catch diode included in one package. It combines an LT1172 with a 1A Schottky catch diode. The LT1572 can be operated in all standard switching configurations, including boost, buck, SEPIC, flyback, forward, inverting and "Cuk". All necessary control, oscillator and protection circuitry is included on the die with the high efficiency switch. This makes the part extremely easy to use and provides "bustproof" operation similar to that obtained with 3-pin linear regulators.

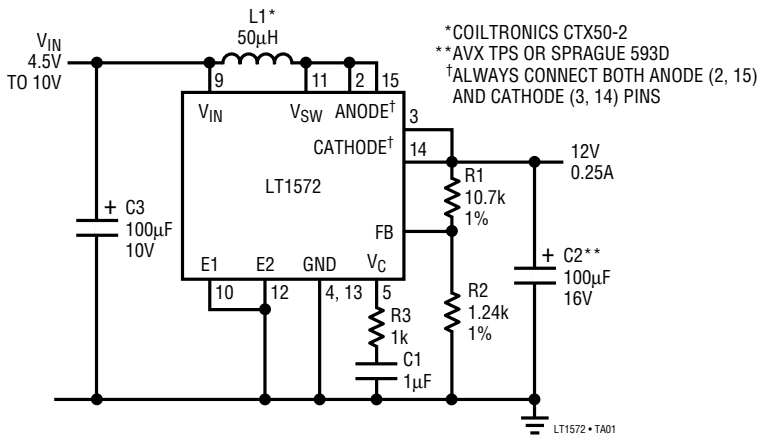
The LT1572 operates with supply voltages from 3V to 30V and draws only 6mA quiescent current. It can deliver load power up to 15W with no external power devices. By utilizing a current mode switching technique, the LT1572 achieves excellent response to load and line transients.

The LT1572 has many unique features not found on the more difficult to use control chips presently available. It uses adaptive anti-sat switch drive to allow very wide ranging load currents with no loss in efficiency. An externally activated shutdown mode reduces total supply current to 50μA typical for standby operation. External synchronizing of switching frequency is possible, with a range of 120kHz to 160kHz.

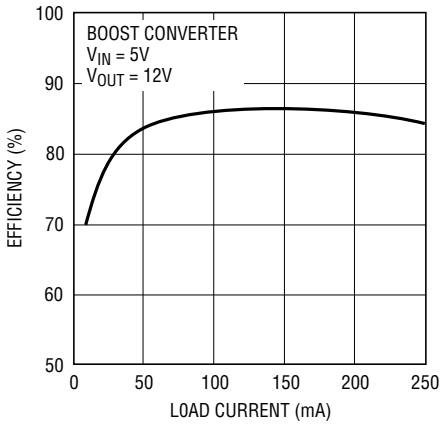
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TYPICAL APPLICATION

5V-to-12V Boost Converter



Boost Converter Efficiency



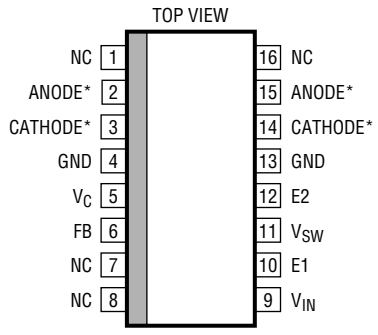
ABSOLUTE MAXIMUM RATINGS

Supply Voltage (Note 4) 40V
Switch Output Voltage (Note 4) 60V
Feedback Pin Voltage (Transient, 1ms) ..... ±15V
Operating Junction Temperature Range
  Operating ..... 0°C to 100°C
  Short Circuit ..... 0°C to 125°C
Storage Temperature Range ..... –65°C to 150°C
Lead Temperature (Soldering, 10 sec) ..... 300°C

DIODE

Average Forward Current 1A
Peak Repetitive Forward Current 2A
Peak Non-Repetitive Forward Current 3A
Peak Repetitive Reverse Voltage 20V
Continuous (Average) Reverse Voltage 15V
Operating Junction Temperature ..... 125°C

PACKAGE/ORDER INFORMATION



S PACKAGE
16-LEAD PLASTIC SO

*ALWAYS CONNECT BOTH ANODE AND BOTH CATHODE PINS

T_{JMAX} (REGULATOR) = 100°C
T_{JMAX} (DIODE) = 125°C
SEE THERMAL MANAGEMENT SECTION FOR θ_{JA}

ORDER PART NUMBER
LT1572CS

Consult factory for Industrial and Military grade parts.

Note 1: Minimum effective switch "on" time for the LT1572 (in current limit only) is ≈ 0.6µs. This limits the maximum safe input voltage during an output shorted condition. Buck mode and inverting mode input voltage during an output shorted condition is limited to:

V_{IN} (max, output shorted) = 15V + $\frac{R \times I_L + V_f}{t \times f}$
buck and inverting mode

R = Inductor DC resistance

I_L = 2.5A

V_f = Output catch diode forward voltage at I_L

t = 0.6µs, f = 100kHz switching frequency

Maximum input voltage can be increased by increasing R or V_f.

External current limiting such as that shown in AN19, Figure 39, will provide protection up to the full supply voltage rating. C1 in Figure 39 should be reduced to 200pF.

Transformer designs will tolerate much higher input voltages because leakage inductance limits rate of rise of current in the switch. These designs must be evaluated individually to assure that current limit is well controlled up to maximum input voltage.

Boost mode designs are never protected against output shorts because the external catch diode and inductor connect input to output.

ELECTRICAL CHARACTERISTICS

V_{IN} = 15V, V_C = 0.5V, V_{FB} = V_{REF}, output pin open, unless otherwise noted.

SYMBOL	PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
V_{REF}	Reference Voltage	Measured at Feedback Pin		1.224	1.244	1.264	V
		V_C = 0.8V	●	1.214	1.244	1.274	V
I_B	Feedback Input Current	V_{FB} = V_{REF}			350	750	nA
			●			1100	nA
g_m	Error Amplifier Transconductance	ΔI_C = ±25µA		3000	4400	6000	µmho
			●	2400		7000	µmho
	Error Amplifier Source or Sink Current	V_C = 1.5V		150	200	350	µA
			●	120		400	µA
	Error Amplifier Clamp Voltage	Hi Clamp, V_{FB} = 1V		1.80		2.30	V
		Lo Clamp, V_{FB} = 1.5V		0.25	0.38	0.52	V
	Reference Voltage Line Regulation	3V ≤ V_{IN} ≤ 40V	●			0.03	%/V
		V_C = 0.8V					
A_V	Error Amplifier Voltage Gain	0.9V ≤ V_C ≤ 1.4V		500	800		V/V
	Minimum Input Voltage (Note 3)		●		2.6	3.0	V
I_Q	Supply Current	3V ≤ V_{IN} ≤ 40V, V_C = 0.6V			6	9	mA

ELECTRICAL CHARACTERISTICS

V_{IN} = 15V, V_C = 0.5V, V_{FB} = V_{REF}, output pin open, unless otherwise noted.

SYMBOL	PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
	Control Pin Threshold	Duty Cycle = 0		0.8	0.9	1.08	V
			●	0.6		1.25	V
	Normal/Flyback Threshold on Feedback Pin			0.4	0.45	0.54	V
V_{FB}	Flyback Reference Voltage (Note 3)	I_{FB} = 50µA		15.0	16.3	17.6	V
			●	14.0		18.0	V
	Change in Flyback Reference Voltage	0.05 ≤ I_{FB} ≤ 1mA		4.5	6.8	9	V
	Flyback Reference Voltage Line Regulation (Note 3)	I_{FB} = 50µA 7V ≤ V_{IN} ≤ V_{MAX}			0.01	0.03	%/V
	Flyback Amplifier Transconductance (g_m)	ΔI_C = ±10µA		150	300	500	µmho
	Flyback Amplifier Source and Sink Current	V_C = 0.6V, Source	●	15	32	70	µA
		I_{FB} = 50µA, Sink	●	25	40	70	µA
BV	Output Switch Breakdown Voltage (Note 4)	3V ≤ V_{IN} ≤ 40V, I_{SW} = 1.5mA	●	60	80		V
V_{SAT}	Output Switch "On" Resistance (Note 1)		●		0.60	1.00	Ω
	Control Voltage to Switch Current Transconductance				2		A/V
I_{LIM}	Switch Current Limit	Duty Cycle = 50%, $T_J \geq 25°C$	●	1.25		3.0	A
		Duty Cycle = 50%, $T_J < 25°C$	●	1.25		3.5	A
		Duty Cycle = 80% (Note 2)	●	1.00		2.5	A
$\frac{\Delta I_{IN}}{\Delta I_{SW}}$	Supply Current Increase During Switch On-Time				25	35	mA/A
f	Switching Frequency			88	100	112	kHz
			●	85		115	kHz
DC_{MAX}	Maximum Switch Duty Cycle		●	80	90	95	%
	Shutdown Mode Supply Current	3V ≤ V_{IN} ≤ 40V V_C = 0.05V			100	250	µA
	Shutdown Mode Threshold Voltage	3V ≤ V_{IN} ≤ 40V		100	150	250	mV
			●	50		300	mV
	Flyback Sense Delay Time (Note 3)				1.5		µs

DIODE

PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
Forward Voltage (Note 5)	I_f = 200mA	●		0.45	0.57	V
	I_f = 500mA	●		0.52	0.65	V
	I_f = 1A	●		0.55	0.70	V
Reverse Leakage (Note 5)	V_R = 5V, T_J = 25°C			1	5	µA
	V_R = 5V, T_J = 75°C			25	100	µA
	V_R = 20V, T_J = 25°C			3	15	µA
	V_R = 20V, T_J = 75°C			70	300	µA
Diode Thermal Resistance	(Note 6)			90		°C/W

ELECTRICAL CHARACTERISTICS

V_{IN} = 15V, V_C = 0.5V, V_{FB} = V_{REF}, output pin open, unless otherwise noted.

The ● denotes the specifications which apply over the full operating temperature range, 0°C to 100°C for the regulator chip and 0°C to 125°C for the diode.

Note 1: Measured with V_C in hi clamp, V_{FB} = 0.8V. I_{SW} = 1A.

Note 2: For duty cycles (DC) between 50% and 80%, minimum guaranteed switch current is given by I_{LIM} = 0.833 (2 – DC).

Note 3: Minimum input voltage for isolated flyback mode is 7V.

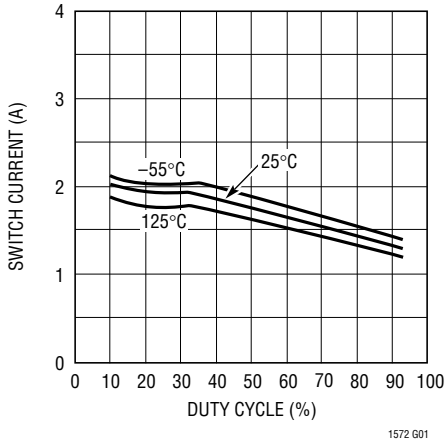
Note 4: Because the catch diode has a peak repetitive reverse voltage of 20V, diode breakdown may be the limiting factor on input voltage or switch voltage in many applications.

Note 5: See graphs for guaranteed forward voltage and reverse leakage current over temperature. Parameters are 100% tested at 25°C and guaranteed at other temperatures by design and QA sampling.

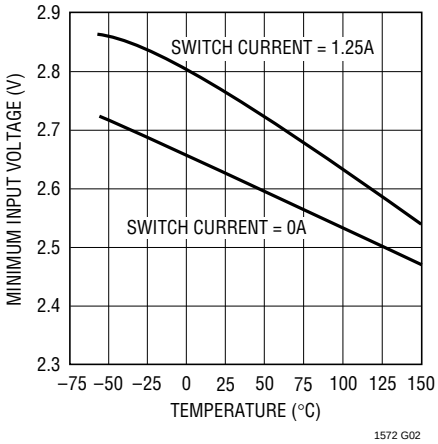
Note 6: Package soldered to FR4 board with ≥1oz copper and an internal or backside plane underneath the package to aid thermal transfer. Diode is partly thermally coupled to regulator section. See Application Information section for details on thermal calculations.

TYPICAL PERFORMANCE CHARACTERISTICS

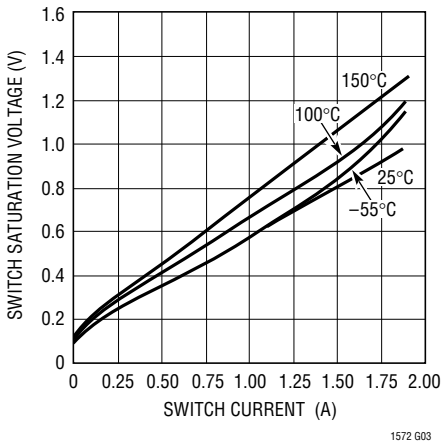
Switch Current Limit vs Duty Cycle



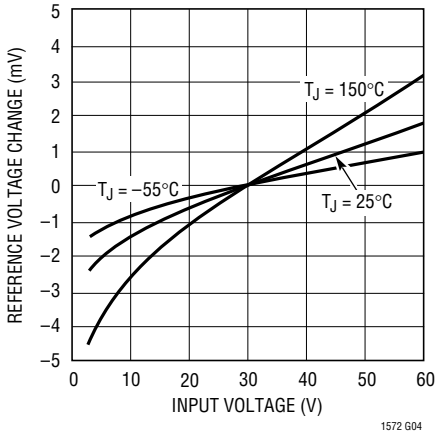
Minimum Input Voltage



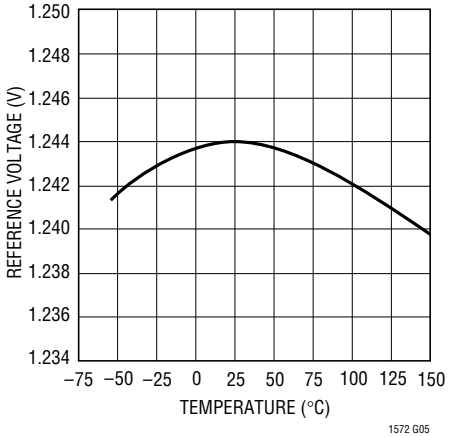
Switch Saturation Voltage



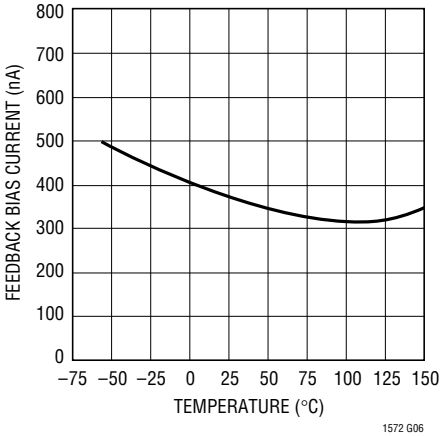
Line Regulation



Reference Voltage vs Temperature

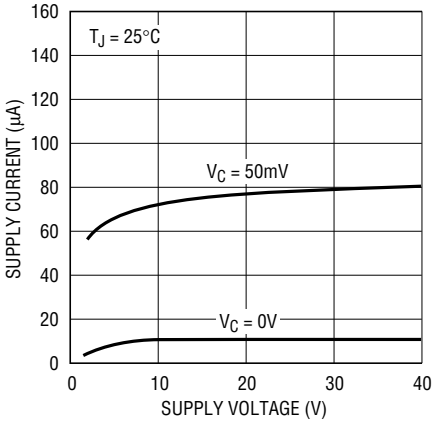


Feedback Bias Current vs Temperature

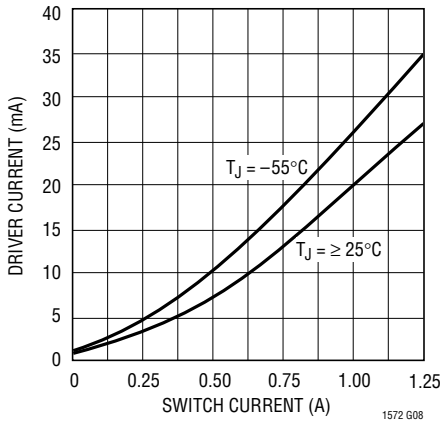


TYPICAL PERFORMANCE CHARACTERISTICS

Supply Current vs Supply Voltage (Shutdown Mode)

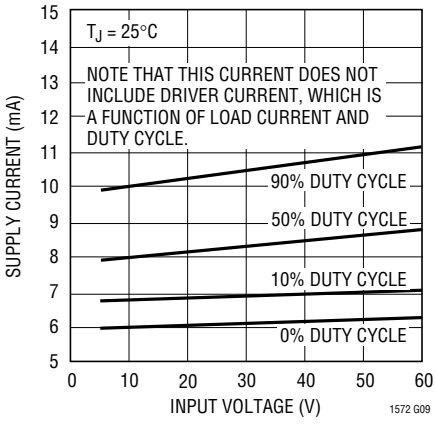


Driver Current* vs Switch Current



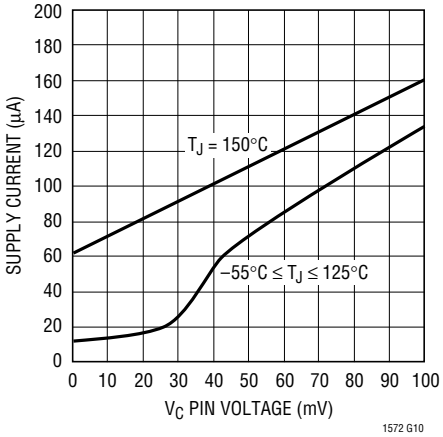
* AVERAGE POWER SUPPLY CURRENT IS FOUND BY MULTIPLYING DRIVER CURRENT BY DUTY CYCLE, THEN ADDING QUIESCENT CURRENT.

Supply Current vs Input Voltage*

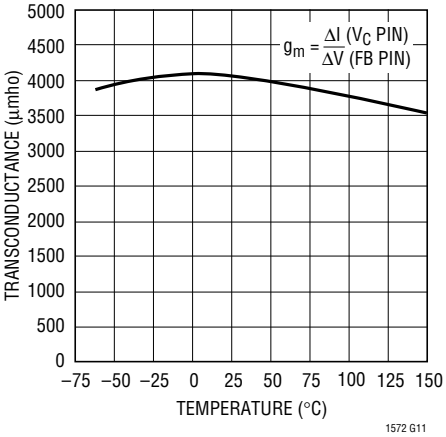


* UNDER VERY LOW OUTPUT CURRENT CONDITIONS, DUTY CYCLE FOR MOST CIRCUITS WILL APPROACH 10% OR LESS.

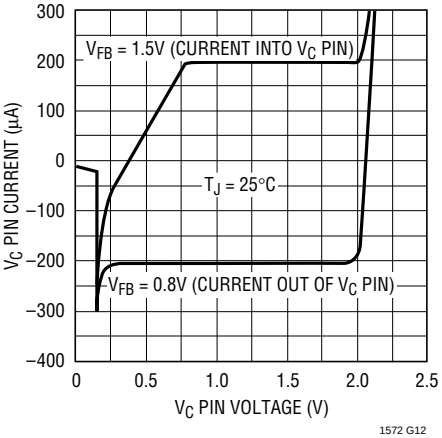
Shutdown Mode Supply Current



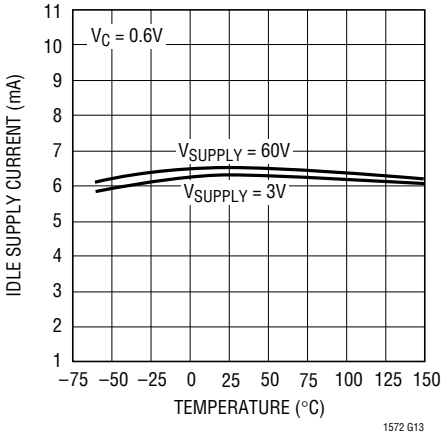
Error Amplifier Transconductance



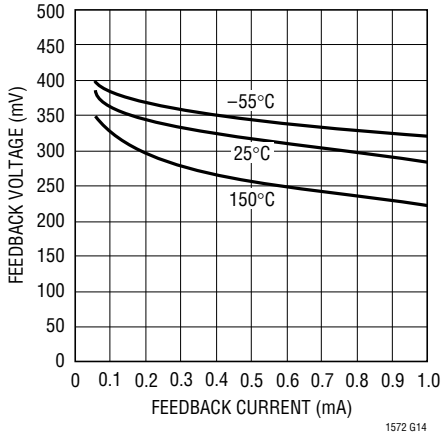
V_C Pin Characteristics



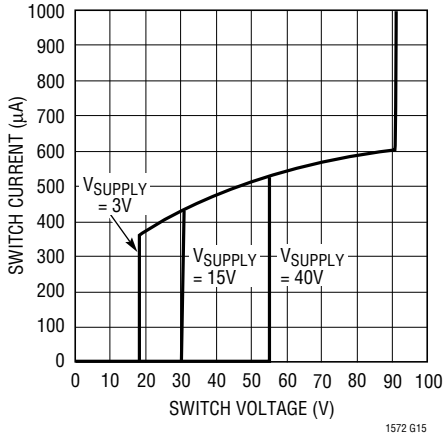
Idle Supply Current vs Temperature



Feedback Pin Clamp Voltage

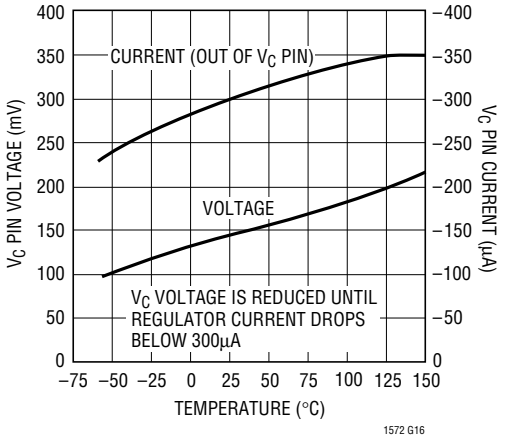


Switch "Off" Characteristics

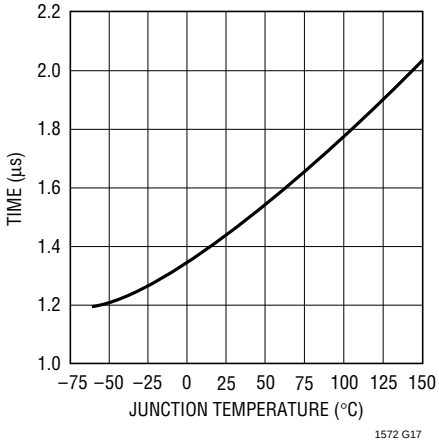


TYPICAL PERFORMANCE CHARACTERISTICS

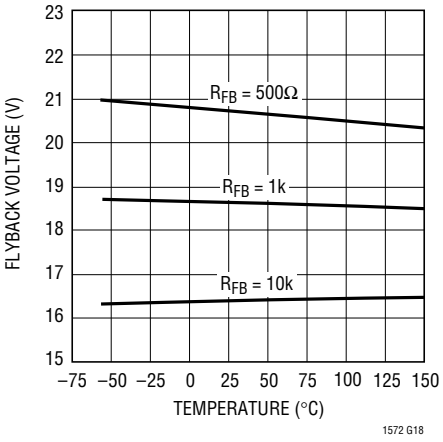
Shutdown Thresholds



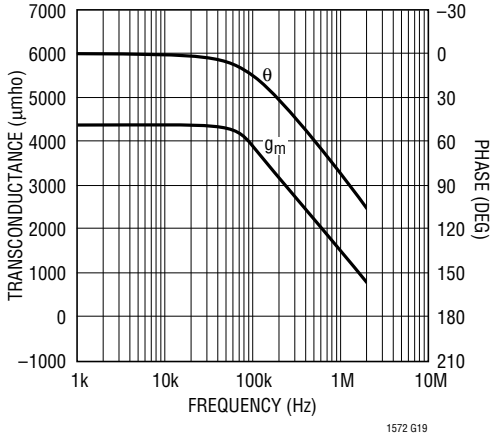
Flyback Blanking Time



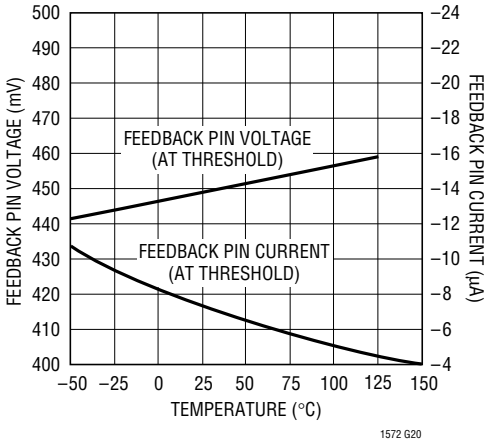
Isolated Mode Flyback Reference Voltage



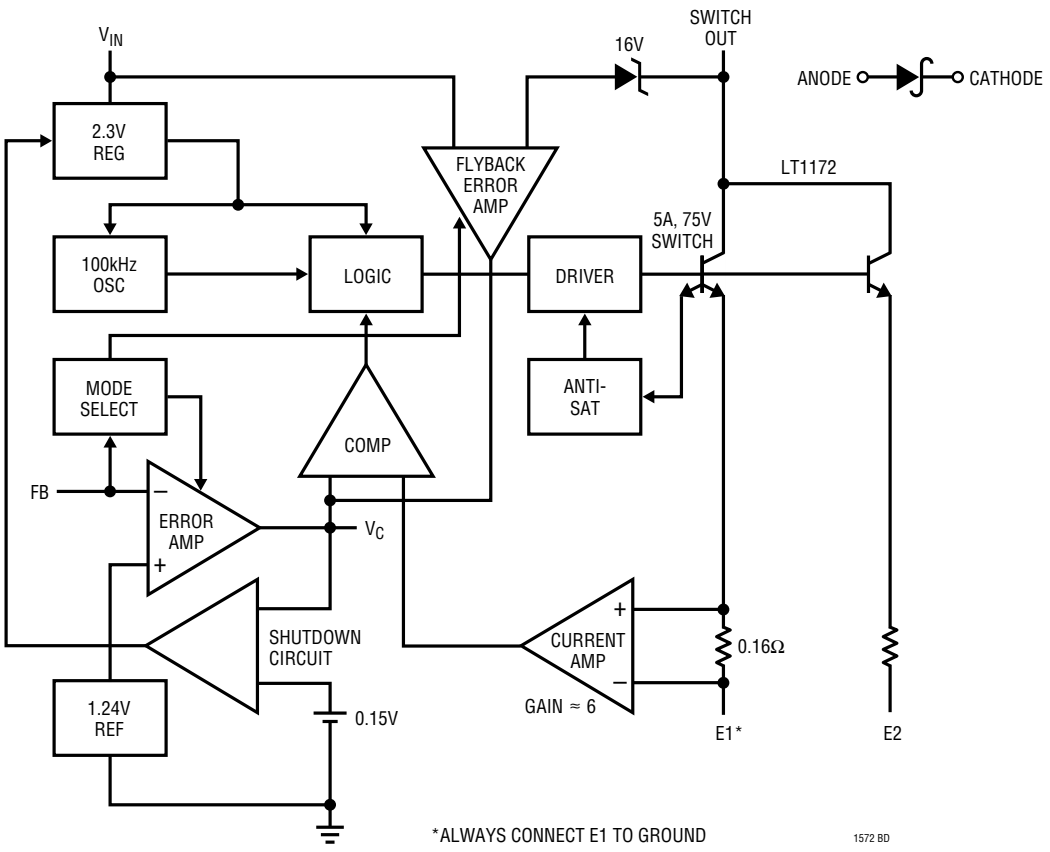
Transconductance of Error Amplifier



Normal/Flyback Mode Threshold on Feedback Pin



BLOCK DIAGRAM



OPERATION

The LT1572 is a current mode switcher. This means that switch duty cycle is directly controlled by switch current rather than by output voltage. Referring to the block diagram, the switch is turned "on" at the start of each oscillator cycle. It is turned "off" when switch current reaches a predetermined level. Control of output voltage is obtained by using the output of a voltage sensing error amplifier to set current trip level. This technique has several advantages. First, it has immediate response to input voltage variations, unlike ordinary switchers which have notoriously poor line transient response. Second, it reduces the 90° phase shift at mid-frequencies in the energy storage inductor. This greatly simplifies closed-loop frequency compensation under widely varying input voltage or output load conditions. Finally, it allows simple pulse-by-pulse current limiting to provide maximum switch protection under output overload or short conditions.

A low dropout internal regulator provides a 2.3V supply for all internal circuitry on the LT1572. This low dropout design allows input voltage to vary from 3V to 40V with virtually no change in device performance. A 100kHz oscillator is the basic clock for all internal timing. It turns "on" the output switch via the logic and driver circuitry. Special adaptive anti-sat circuitry detects onset of saturation in the power switch and adjusts driver current instantaneously to limit switch saturation. This minimizes driver dissipation and provides very rapid turn-off of the switch.

A 1.2V bandgap reference biases the positive input of the error amplifier. The negative input is brought out for output voltage sensing. This feedback pin has a second function; when pulled low with an external resistor, it programs the LT1572 to disconnect the main error amplifier output and connects the output of the flyback amplifier

OPERATION

to the comparator input. The LT1572 will then regulate the value of the flyback pulse with respect to the supply voltage.[1] This flyback pulse is directly proportional to output voltage in the traditional transformer coupled flyback topology regulator. By regulating the amplitude of the flyback pulse, the output voltage can be regulated with no direct connection between input and output. The output is fully floating up to the breakdown voltage of the transformer windings. Multiple floating outputs are easily obtained with additional windings. A special delay network inside the LT1572 ignores the leakage inductance spike at the leading edge of the flyback pulse to improve output regulation.

The error signal developed at the comparator input is brought out externally. This pin (V_C) has four different functions. It is used for frequency compensation, current limit adjustment, soft starting, and total regulator shutdown. During normal regulator operation this pin sits at a voltage between 0.9V (low output current) and 2.0V (high output current). The error amplifiers are current output (g_m) types, so this voltage can be externally clamped for adjusting current limit. Likewise, a capacitor coupled external clamp will provide soft start. Switch duty cycle goes to zero if the V_C pin is pulled to ground through a diode, placing the LT1572 in an idle mode. Pulling the V_C pin below 0.15V causes total regulator shutdown, with only 50μA supply current for shutdown circuitry biasing. See AN19 for full application details.

E1 and E2 Pins

The LT1572 has the emitters of the power transistor brought out separately from the ground pin. This eliminates errors due to ground pin voltage drops and allows the user to reduce switch current limit 2:1 by leaving the second emitter (E2) disconnected. The first emitter (E1) should always be connected to the ground pin. Note that switch "on" resistance doubles when E2 is left open, so efficiency will suffer somewhat when switch currents exceed 300mA. Also, note that chip dissipation will actually *increase* with E2 open during normal load operation, even though dissipation in current limit mode will *decrease*.

[1]See note under block diagram.

Other Application Help

More circuits and application help for the LT1572 can be found in the LT1172 data sheet, both in loose form and in the *1994 Linear Databook Volume III*. Extensive additional help is contained in Application Note 19. All application circuits using the LT1172 can also use the LT1572 as long as the 20V maximum reverse voltage of the diode is not exceeded. A CAD program called SwitcherCAD is also available. This program can be used with the LT1572 by simply treating the LT1572 as an LT1172 and ignoring the predicted die temperature results obtained from SwitcherCAD itself.

Thermal Management

Thermal management is particularly important with the LT1572 because both switch and diode power dissipation increase rapidly at low input voltage when using the popular boost topology. Regulator and diode die temperature must be calculated *separately* because they are not connected to an isothermal plane inside the package. Diode *plus* regulator thermal resistance is approximately 70°C/W when the LT1572 is soldered to 1oz copper traces over an internal or backside copper plane using FR4 board material. However, individual calculation of die temperature must take thermal coupling into account. To accomplish this, thermal resistance is broken into two sections, a common (coupled) section and a second uncoupled section. Die temperatures are calculated from:

$$T_{REG} = T_A + P_{REG}\,(90°C/W) + P_{DIODE}\,(45°C/W)$$

$$T_{DIODE} = T_A + P_{DIODE}\,(90°C/W) + P_{REG}\,(45°C/W)$$

T_A = ambient temperature
T_{REG} = regulator die temperature
T_{DIODE} = diode die temperature
P_{REG} = total regulator power dissipation
P_{DIODE} = diode power dissipation

The following formulas can be used as a rough guide to calculate LT1572 power dissipation. For more details, the reader is referred to Application Note 19 (AN19), "Efficiency Calculations" section.

OPERATION

Average supply current (including driver current) is:

$I_{IN} \approx 6mA + I_{SW}(0.004 + DC/40)$

I_{SW} = switch current
DC = switch duty cycle

Switch power dissipation is given by:

$P_{SW} = (I_{SW})^2 \times R_{SW} \times DC$

R_{SW} = LT1572 switch "on" resistance (1Ω maximum)

Total power dissipation is the sum of supply current times input voltage plus switch power:

$P_{REG} = I_{IN} \times V_{IN} + P_{SW}$

In a typical example, using a boost converter to generate 12V at 0.12A from a 5V input, duty cycle is approximately 60%, and switch current is about 0.65A, yielding:

$I_{IN} = 6mA + 0.65(0.004 + DC/40) = 18mA$

$P_{SW} = (0.65)^2 \times 1\Omega \times 0.6 = 0.25W$

$P_{REG} = 5V \times 0.018A + 0.25 = 0.34W$

Approximate diode power dissipation for boost and buck converters is shown below. For other topologies or more accurate results, see Application Note 19 or use SwitcherCAD.

Boost: $P_{DIODE} = I_{OUT} \times V_f$

Buck: $P_{DIODE} = I_{OUT} \times V_f \times (V_{IN} - V_{OUT})/V_{IN}$

V_f = diode forward voltage at a current equal to I_{OUT} for a buck converter and $I_{OUT} \times V_{OUT}/V_{IN}$ for a boost converter.

In most applications, full load current is used to calculate die temperature. However, if overload conditions must also be accounted for, three approaches are possible. First, if loss of regulated output is acceptable under overload conditions, the internal *thermal limit* of the LT1572 will protect the die in most applications by shutting off switch current. *Thermal limit is not a tested parameter*, however, and should be considered only for noncritical applications with temporary overloads.

The second approach for lower current applications is to leave the second switch emitter (E2) open. This increases switch "on" resistance by 2:1, but reduces switch current limit by 2:1 also, resulting in a net 2:1 reduction in I^2R switch dissipation under current limit conditions.

The third approach is to clamp the V_C pin to a voltage less than its internal clamp level of 2V. The LT1172 switch current limit is zero at approximately 1V on the V_C pin and 2A at 2V on the V_C pin. Peak switch current can be externally clamped between these two levels with a diode. See AN19 for details.

Diode Characteristics

The catch diode used in the LT1572 is a power Schottky diode with a very low storage time and low forward voltage. This gives good efficiency in switching regulator applications, but some thought must be given to maximum operating voltage and high temperature reverse leakage. *Peak repetitive reverse voltage rating on the diode is 20V*. In a boost converter, maximum diode reverse voltage is equal to regulated output voltage, so this limits maximum output voltage to 20V. In a negative-to-positive converter, maximum diode voltage will be equal to the sum of output voltage *plus* input voltage. Use the equations in Application Note 19 or SwitcherCAD or calculate maximum diode voltage for other topologies.

Diode reverse leakage increases rapidly with temperature. This leakage is not high enough to significantly impact efficiency or diode power dissipation, but it can be of concern in shutdown mode if the diode is connected in such a way that the leakage adds to regulator shutdown current. Use the graphs of diode leakage versus voltage and temperature to ensure proper high temperature system performance.

The LT1572 diode is internally bonded to more than two package pins to reduce internal bond wire currents. *All pins must be used to prevent excessive current in the individual internal bond wires*. This is important in low load current applications because the LT1572 will draw high surge currents during start-up (to charge the output capacitor) even with no output load current.

OPERATION

Synchronizing

The LT1572 can be externally synchronized in the frequency range of 120kHz to 160kHz. This is accomplished as shown in the accompanying figures. Synchronizing occurs when the V_C pin is pulled to ground with an external transistor. To avoid disturbing the DC characteristics of the internal error amplifier, the width of the synchronizing pulse should be under 0.3µs. C2 sets the pulse width at ≅ 0.2µs. The effect of a synchronizing pulse on the LT1572 amplifier offset can be calculated from:

$$\Delta V_{OS} = \frac{\left(\frac{KT}{q}\right)\left(t_S\right)\left(f_S\right)\left(I_C + \frac{V_C}{R3}\right)}{I_C}$$

$\frac{KT}{q}$ = 26mV at 25°C

t_S = pulse width

f_S = pulse frequency

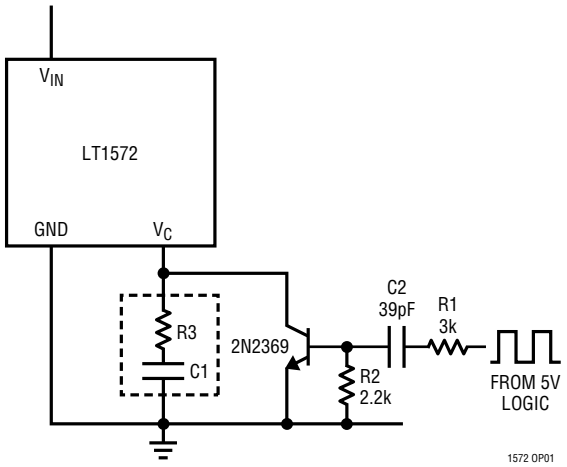
I_C = V_C source current (≈200µA)

V_C = operating V_C voltage (1V to 2V)

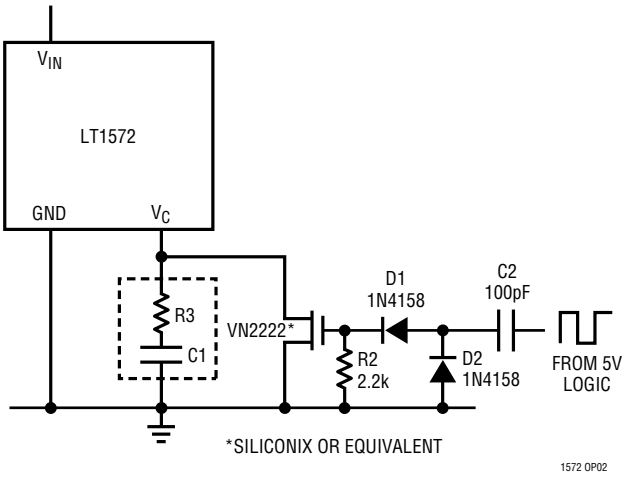
R3 = resistor used to set mid-frequency "zero" in frequency compensation network.

With t_S = 0.2µs, f_S = 150kHz, V_C = 1.5V, and R3 = 2k, offset voltage shift is ≈3.8mV. This is not particularly bothersome, but note that high offsets could result if R3 were reduced to a much lower value. Also, the synchronizing transistor must sink higher currents with low values of R3, so larger drives may have to be used. The transistor must be capable of pulling the V_C pin to within 200mV of ground to ensure synchronizing.

Synchronizing with Bipolar Transistor

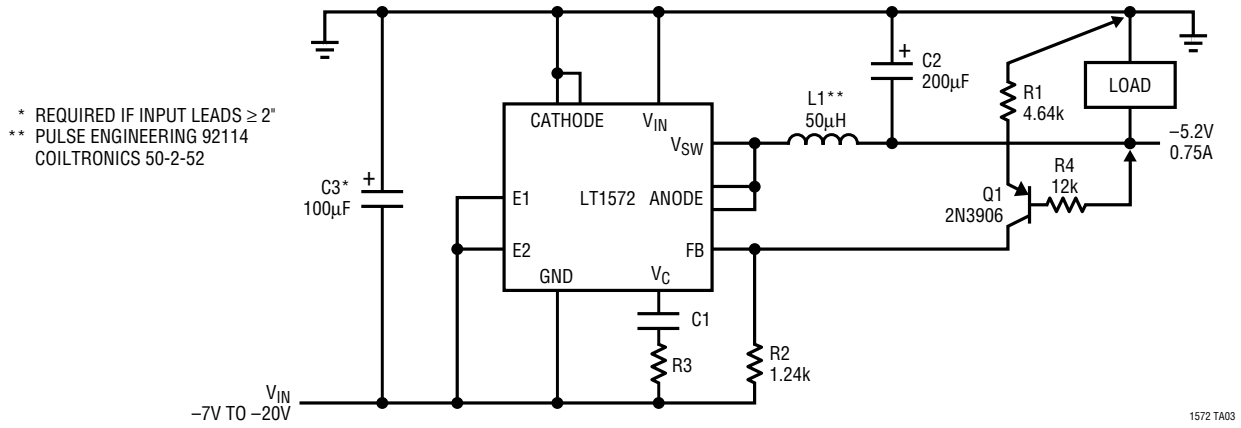


Synchronizing with MOS Transistor

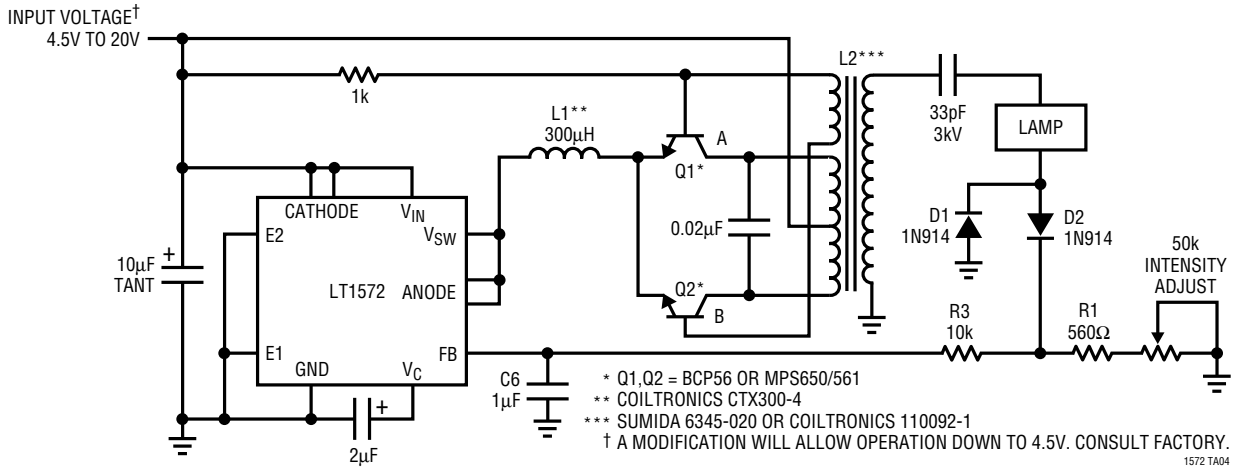


TYPICAL APPLICATIONS

Negative Buck Converter



Backlight CCFL Supply (see AN55 for details)

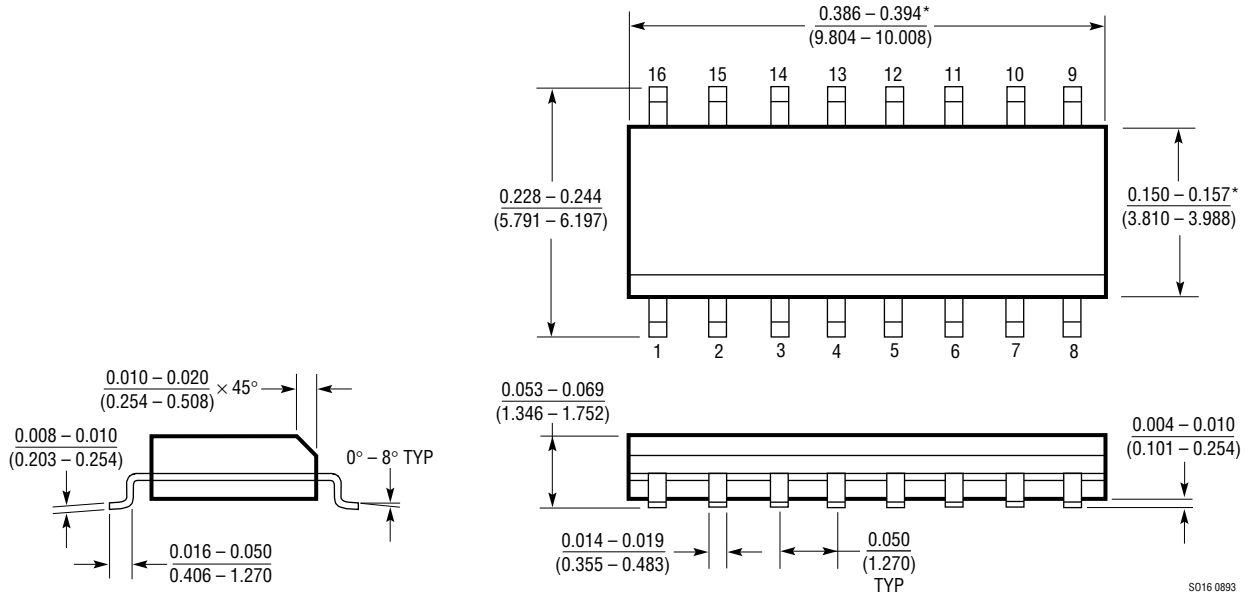


Information furnished by Linear Technology Corporation is believed to be accurate and reliable. However, no responsibility is assumed for its use. Linear Technology Corporation makes no representation that the interconnection of its circuits as described herein will not infringe on existing patent rights.

PACKAGE DESCRIPTION

Dimensions in inches (millimeters) unless otherwise noted.

S Package
16-Lead Plastic SOIC



*THESE DIMENSIONS DO NOT INCLUDE MOLD FLASH OR PROTRUSIONS.
MOLD FLASH OR PROTRUSIONS SHALL NOT EXCEED 0.006 INCH (0.15mm).

RELATED PARTS

PART NUMBER	DESCRIPTION	COMMENTS
LT1172	100kHz, 1.25A High Efficiency Switching Regulator	LT1572 Without Diode
LT1173	Micropower DC/DC Converter Adjustable and Fixed 5V, 12V	Operates Down to 2V Input
LT1372	500kHz High Efficiency 1.5A Step-Up Switching Regulator	Latest Technology, Uses Tiny Inductors
LTC1574	High Efficiency Step-Down DC/DC Converter with Internal Schottky Diode	LTC1174 with Diode

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