

# High Power Synchronous Switching Regulator Controller

November 1998

## FEATURES

- High Power Buck Converter from 5V or 3.3V Main Power
- Adjustable Current Limit in S0-8 with Topside FET  $R_{DS(ON)}$  Sensing
- No External Sense Resistor Required
- Hiccup Mode Current Limit Protection
- Adjustable, Fixed 1.9V, 2.5V, 2.8V and 3.3V Output
- All N-Channel MOSFET Synchronous Driver
- Excellent Output Regulation:  $\pm 2\%$  over Line, Load and Temperature Variations
- High Efficiency: Over 95% Possible
- Fast Transient Response
- Fixed 300kHz Frequency Operation
- Internal Soft Start Circuit
- Quiescent Current: 1mA, 45 $\mu$ A in Shutdown

## APPLICATIONS

- Power Supply for Pentium® II, AMD-K6®-2, SPARC, ALPHA and PA-RISC Microprocessors
- High Power 5V to 1.3V-3.5V Regulators

## DESCRIPTION

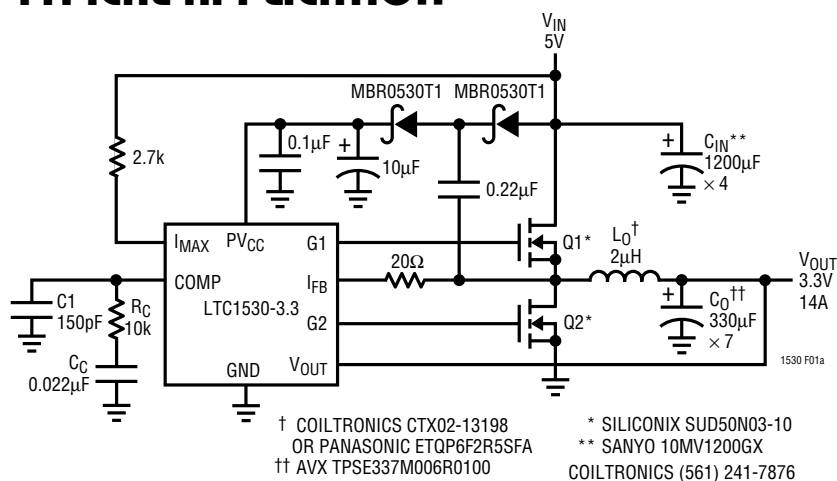
The LTC<sup>®</sup>1530 is a high power synchronous switching regulator controller optimized for 5V to 1.3V-3.5V output applications. Its synchronous switching architecture drives two external N-channel MOSFET devices to provide high efficiency. The LTC1530 contains a precision trimmed reference and feedback system that provides worst-case output voltage regulation of  $\pm 2\%$  over temperature, load current and line voltage shifts. Current limit circuitry senses the output current through the on-resistance of the topside N-channel MOSFET, providing an adjustable current limit without requiring an external low value sense resistor.

The LTC1530 includes a fixed frequency PWM oscillator that free runs at 300kHz, providing greater than 90% efficiency operation in converter designs from 1A to 20A of output current. Shutdown mode drops the LTC1530 supply current to 45 $\mu$ A.

The LTC1530 is specified for commercial and industrial temperature ranges and is available in the S0-8 package.

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 Pentium is a registered trademark of Intel Corp.  
 AMD-K6 is a registered trademark of Advanced Micro Devices, Inc.

## TYPICAL APPLICATION



Efficiency vs Load Current

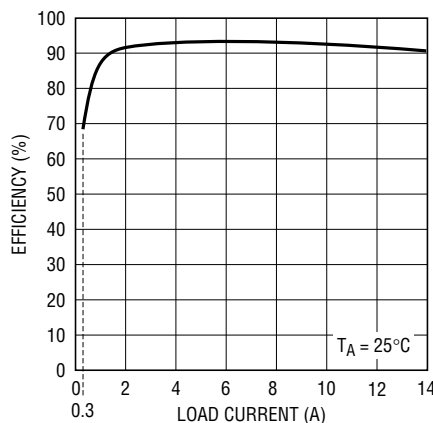


Figure 1. Single 5V to 3.3V Supply

## ABSOLUTE MAXIMUM RATINGS

(Note 1)

Supply Voltage

PV<sub>CC</sub> ..... 14V

Input Voltage

I<sub>FB</sub> (Note 2) ..... PV<sub>CC</sub> + 0.3VI<sub>MAX</sub> ..... -0.3V to 14VI<sub>FB</sub> Input Current (Notes 2,3) ..... -100mA

Operating Ambient Temperature Range

LTC1530C ..... 0°C to 70°C

LTC1530I ..... -40°C to 85°C

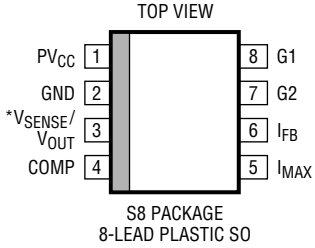
Maximum Junction Temperature

LTC1530C, LTC1530I ..... 125°C

Storage Temperature Range ..... -65°C to 150°C

Lead Temperature (Soldering, 10 sec) ..... 300°C

## PACKAGE/ORDER INFORMATION

TOP VIEW		ORDER PART NUMBER
 <p>S8 PACKAGE 8-LEAD PLASTIC SO</p> <p>*V<sub>OUT</sub> FOR FIXED VOLTAGE VERSIONS</p> <p>T<sub>JMAX</sub> = 125°C, θ<sub>JA</sub> = 130°C/W</p>		LTC1530CS8
		LTC1530CS8-1.9
		LTC1530CS8-2.5
		LTC1530CS8-2.8
		LTC1530CS8-3.3
		LTC1530IS8
		LTC1530IS8-1.9
		LTC1530IS8-2.5
		LTC1530IS8-2.8
		LTC1530IS8-3.3
S8 PART MARKING		
1530	153028	1530I
153019	153033	53019I
153025		53025I

Consult factory for Military grade parts.

ELECTRICAL CHARACTERISTICS PV<sub>CC</sub> = 12V, 0°C ≤ T<sub>A</sub> ≤ 70°C unless otherwise noted. (Note 3)

SYMBOL	PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
V <sub>SENSE</sub>	Internal Feedback Voltage	LTC1530CS8 (Note 4)	1.223	1.235	1.247	V
			1.216	1.235	1.254	V
V <sub>OUT</sub>	Output Voltage	LTC1530CS8-1.9 (Note 4)	1.881	1.9	1.919	V
			1.871	1.9	1.929	V
		LTC1530CS8-2.5 (Note 4)	2.475	2.5	2.525	V
			2.462	2.5	2.538	V
		LTC1530CS8-2.8 (Note 4)	2.772	2.8	2.828	V
			2.758	2.8	2.842	V
		LTC1530CS8-3.3 (Note 4)	3.267	3.3	3.333	V
			3.250	3.3	3.350	V
g <sub>mERR</sub>	Error Amplifier Transconductance	(Note 5)	1.6	2	2.6	millimho

PV<sub>CC</sub> = 12V, -40°C ≤ T<sub>A</sub> ≤ 85°C unless otherwise noted. (Note 3)

PV <sub>CC</sub>	Supply Voltage	(Note 6)	●	13.2			V
V <sub>UVLO</sub>	Undervoltage Lockout Voltage	(Note 7)		3.5	3.75		V
V <sub>SENSE</sub>	Internal Feedback Voltage	LTC1530IS8 (Note 4)	●	1.223	1.235	1.247	V
				1.210	1.235	1.260	V
V <sub>OUT</sub>	Output Voltage	LTC1530IS8-1.9 (Note 4)	●	1.881	1.9	1.919	V
				1.862	1.9	1.938	V
		LTC1530IS8-2.5 (Note 4)	●	2.475	2.5	2.525	V
				2.450	2.5	2.550	V

# ELECTRICAL CHARACTERISTICS

$PV_{CC} = 12V$ ,  $-40^{\circ}C \leq T_A \leq 85^{\circ}C$  unless otherwise noted. (Note 3)

SYMBOL	PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
$V_{OUT}$	Output Voltage	LTC1530IS8-2.8 (Note 4)		2.772	2.8	2.828	V
			●	2.744	2.8	2.856	V
		LTC1530IS8-3.3 (Note 4)		3.267	3.3	3.333	V
			●	3.234	3.3	3.366	V
$\Delta V_{OUT}$	Output Load Regulation	$I_{OUT} = 0$ to 14A			-5		mV
	Output Line Regulation	$V_{IN} = 4.75V$ to $5.25V$ , $I_{OUT} = 0$			$\pm 1$		mV
$I_{PVCC}$	Operating Supply Current	Figure 3, $V_{FB} = 0V$ (Note 8)			15		mA
	Quiescent Current	Figure 3, $COMP = 0.5V$ , $V_{FB} = 5V$	●		1.0	1.4	mA
	Shutdown Supply Current	Figure 3, $COMP = 0$ (Note 9)	●		45	80	$\mu A$
$f_{OSC}$	Internal Oscillator Frequency	Figure 4	●	250	300	350	kHz
	Oscillator Valley Voltage	$V_{COMP}$ at 0% Duty Cycle			2.5		V
	Oscillator Peak Voltage	$V_{COMP}$ at Max Duty Cycle			3.5		V
$G_{ERR}$	Error Amplifier Open-Loop DC Gain	(Note 5)	●	40	54		dB
$g_{mERR}$	Error Amplifier Transconductance	(Note 5)	●	1.6	2	2.8	millimho
$I_{MAX}$	$I_{MAX}$ Sink Current	$V_{IMAX} = 5V$		170	200	230	$\mu A$
		$V_{IMAX} = 5V$	●	120	200	300	$\mu A$
	$I_{MAX}$ Sink Current Tempco	$V_{IMAX} = 5V$			3300		ppm/ $^{\circ}C$
$V_{SHDN}$	Shutdown Threshold Voltage	Figure 4, Measured at COMP Pin (Note 9)	●	100	180		mV
$SR_{SS}$	Internal Soft Start Slew Rate	Figure 4, COMP Pulls High, $V_{FB} = 0V$ (Notes 9, 10)			0.4		V/ms
$t_{SS}$	Internal Soft Start Wake-Up Time	Figure 4, COMP Pulls High to G1 $\uparrow$ (Note 10)			3.5		ms
$t_r, t_f$	Driver Rise and Fall Time	Figure 4	●		90	140	ns
$t_{NOL}$	Driver Nonoverlap Time	Figure 4	●	30	100		ns
$DC_{MAX}$	Maximum G1 Duty Cycle	Figure 4	●	81	86		%

The ● denotes specifications that apply over the full operating temperature range.

**Note 1:** Absolute Maximum Ratings are those values beyond which the life of a device may be impaired.

**Note 2:** If  $I_{FB}$  is taken below GND, it is clamped by an internal diode. This pin handles input currents  $\leq 100mA$  below GND without latch-up. In the positive direction, it is not clamped to  $PV_{CC}$ .

**Note 3:** All currents into device pins are positive; all currents out of device pins are negative. All voltages are referenced to ground unless otherwise specified.

**Note 4:** The LTC1530 is tested in an op amp feedback loop which regulates  $V_{SENSE}$  or  $V_{OUT}$  based on  $V_{COMP} = 2V$  for the error amplifier.

**Note 5:** The Open-loop DC gain and transconductance from the  $V_{FB}$  pin to the COMP pin are  $G_{ERR}$  and  $g_{mERR}$  respectively. For fixed output voltage

versions, the actual open-loop DC gain and transconductance are  $G_{ERR}$  and  $g_{mERR}$  multiplied by the ratio  $1.235/V_{OUT}$ .

**Note 6:** The total voltage from the  $PV_{CC}$  pin to the GND pin must be  $\geq 8V$  for the current limit protection circuit to be active.

**Note 7:** G1 and G2 begin to switch once  $PV_{CC}$  is  $\geq$  the undervoltage lockout threshold voltage.

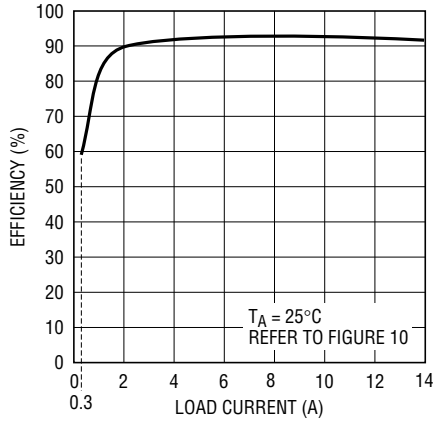
**Note 8:** Supply current in normal operation is dominated by the current needed to charge and discharge the external FET gates. This current varies with the LTC1530 operating frequency, supply voltage and the external FETs used.

**Note 9:** The LTC1530 enters shutdown if COMP is pulled low.

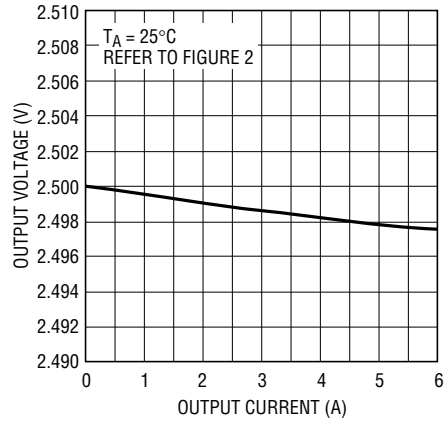
**Note 10:** Slew rate is measured at the COMP pin on the transition from shutdown to active mode.

## TYPICAL PERFORMANCE CHARACTERISTICS

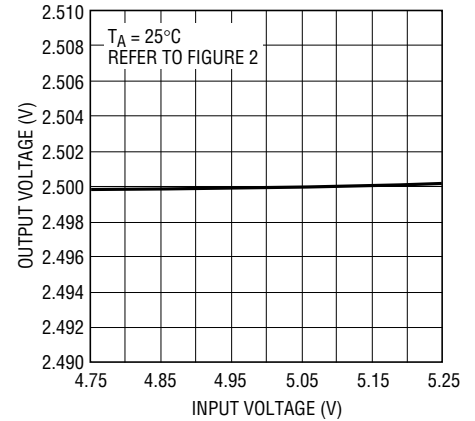
Efficiency vs Load Current



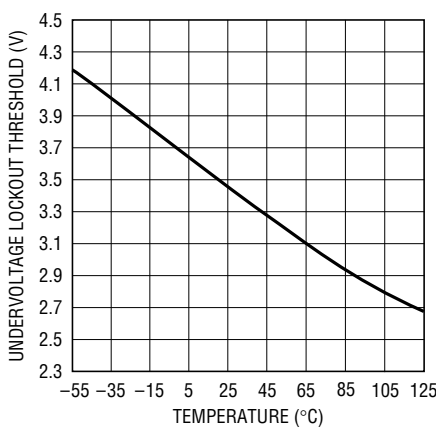
Load Regulation



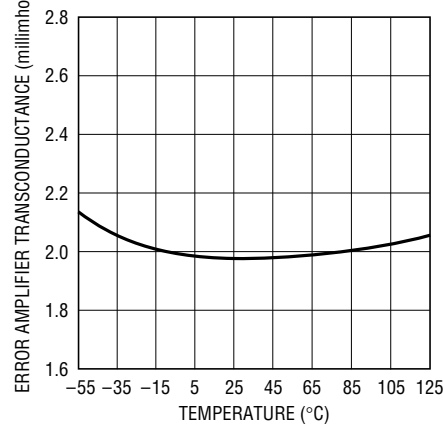
Line Regulation



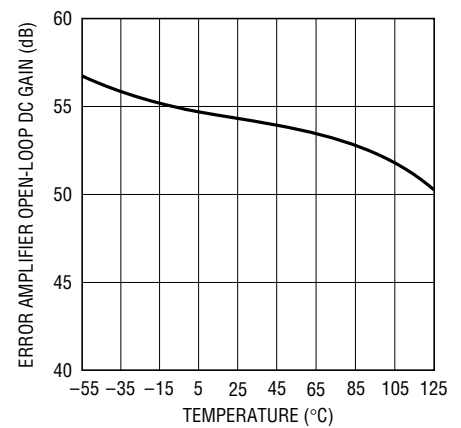
Undervoltage Lockout Threshold Voltage vs Temperature



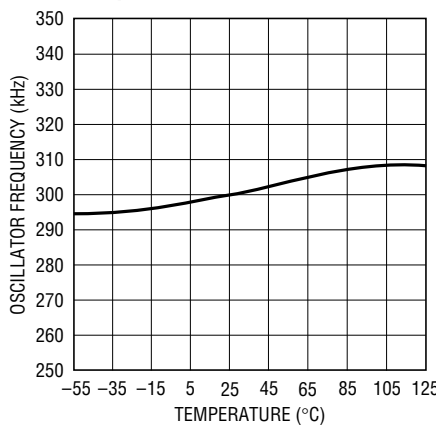
Error Amplifier Transconductance vs Temperature



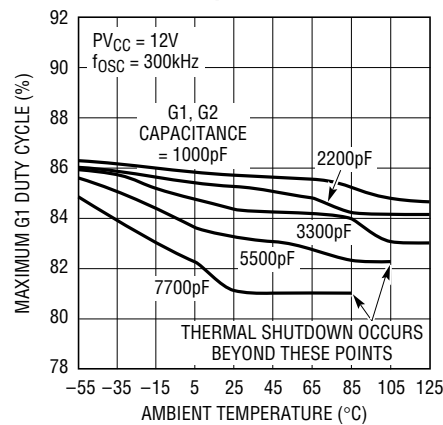
Error Amplifier Open-Loop Gain vs Temperature



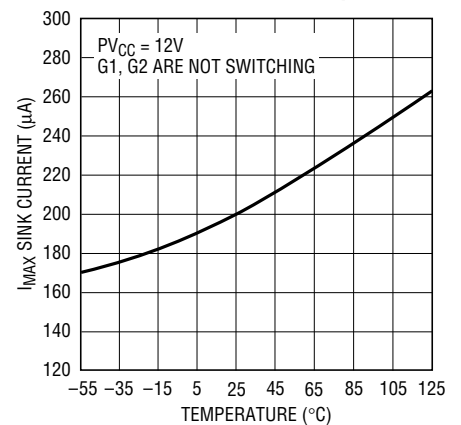
Oscillator Frequency vs Temperature



Maximum G1 Duty Cycle vs Ambient Temperature

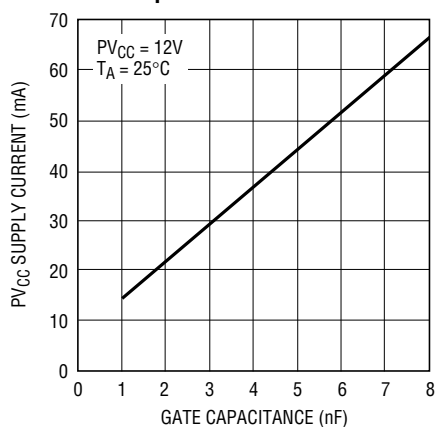


$I_{MAX}$  Sink Current vs Temperature



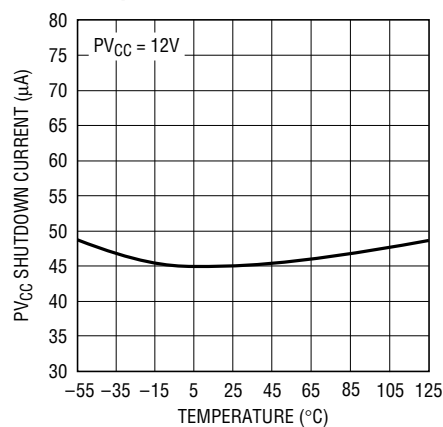
## TYPICAL PERFORMANCE CHARACTERISTICS

**PV<sub>CC</sub> Supply Current vs Gate Capacitance**



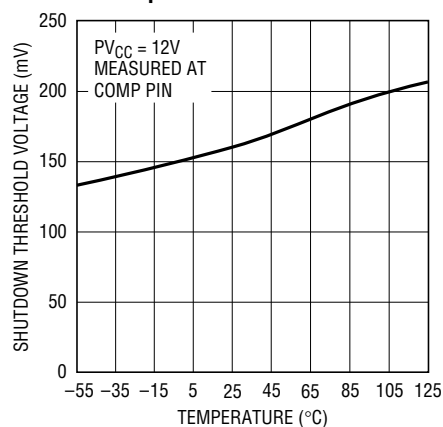
1530 G10

**PV<sub>CC</sub> Shutdown Supply Current vs Temperature**



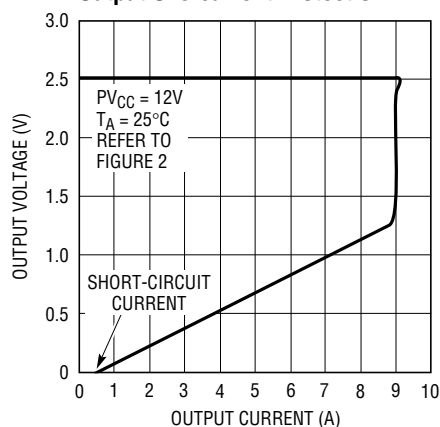
1530 G11

**Shutdown Threshold Voltage vs Temperature**



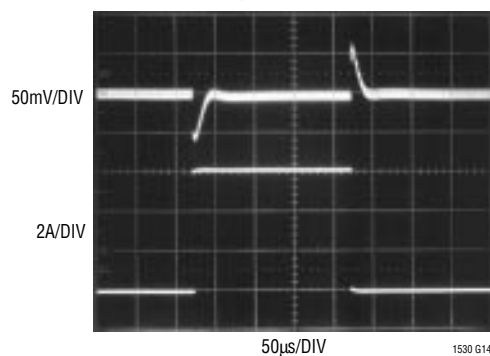
1530 G12

**Output Overcurrent Protection**



1530 G13

**Transient Response**



1530 G14

## PIN FUNCTIONS

**PV<sub>CC</sub> (Pin 1):** Power Supply for G1, G2 and Logic. PV<sub>CC</sub> must connect to a potential of at least  $V_{IN} + V_{GS(ON)Q1}$ . If  $V_{IN} = 5V$ , generate PV<sub>CC</sub> using a simple charge pump connected to the switching node between Q1 and Q2 (see Figure 1) or connect PV<sub>CC</sub> to a 12V supply. Bypass PV<sub>CC</sub> properly or erratic operation will result. A low ESR 10 $\mu$ F capacitor or larger bypass capacitor along with a 0.1 $\mu$ F surface mount ceramic capacitor in parallel is recommended from PV<sub>CC</sub> directly to GND to minimize switching ripple. Switching ripple should be  $\leq 100mV$  at the PV<sub>CC</sub> pin.

**GND (Pin 2):** Power and Logic Ground. GND is connected to the internal gate drive circuitry and the feedback circuitry. To obtain good output voltage regulation, use proper ground techniques between the LTC1530 GND and bottom-side FET source and the negative terminal of the output capacitor. See the Applications Information section for more details on PCB layout techniques.

**V<sub>SENSE</sub>/V<sub>OUT</sub> (Pin 3):** Feedback Voltage Pin. For the adjustable LTC1530, use an external resistor divider to set the required output voltage. Connect the tap point of the resistor divider network to V<sub>SENSE</sub> and the top of the divider network to the output voltage. For fixed output voltage versions of the LTC1530, the resistor divider is internal and the top of the resistor divider network is brought out to V<sub>OUT</sub>. Connect V<sub>OUT</sub> to the output voltage either at the output capacitors or at the actual point of load. V<sub>SENSE</sub>/V<sub>OUT</sub> is sensitive to switching noise injected into the pin. Isolate high current switching traces from this pin and its PCB trace.

**COMP (Pin 4):** External Compensation. The COMP pin is connected to the error amplifier output and the input of the PWM comparator. An RC + C network is typically used at COMP to compensate the feedback loop for optimum

transient response. To shut down the LTC1530, pull this pin below 0.1V with an open-collector or open-drain transistor. Supply current is typically reduced to 45 $\mu$ A in shutdown. An internal 4 $\mu$ A pullup ensures start-up.

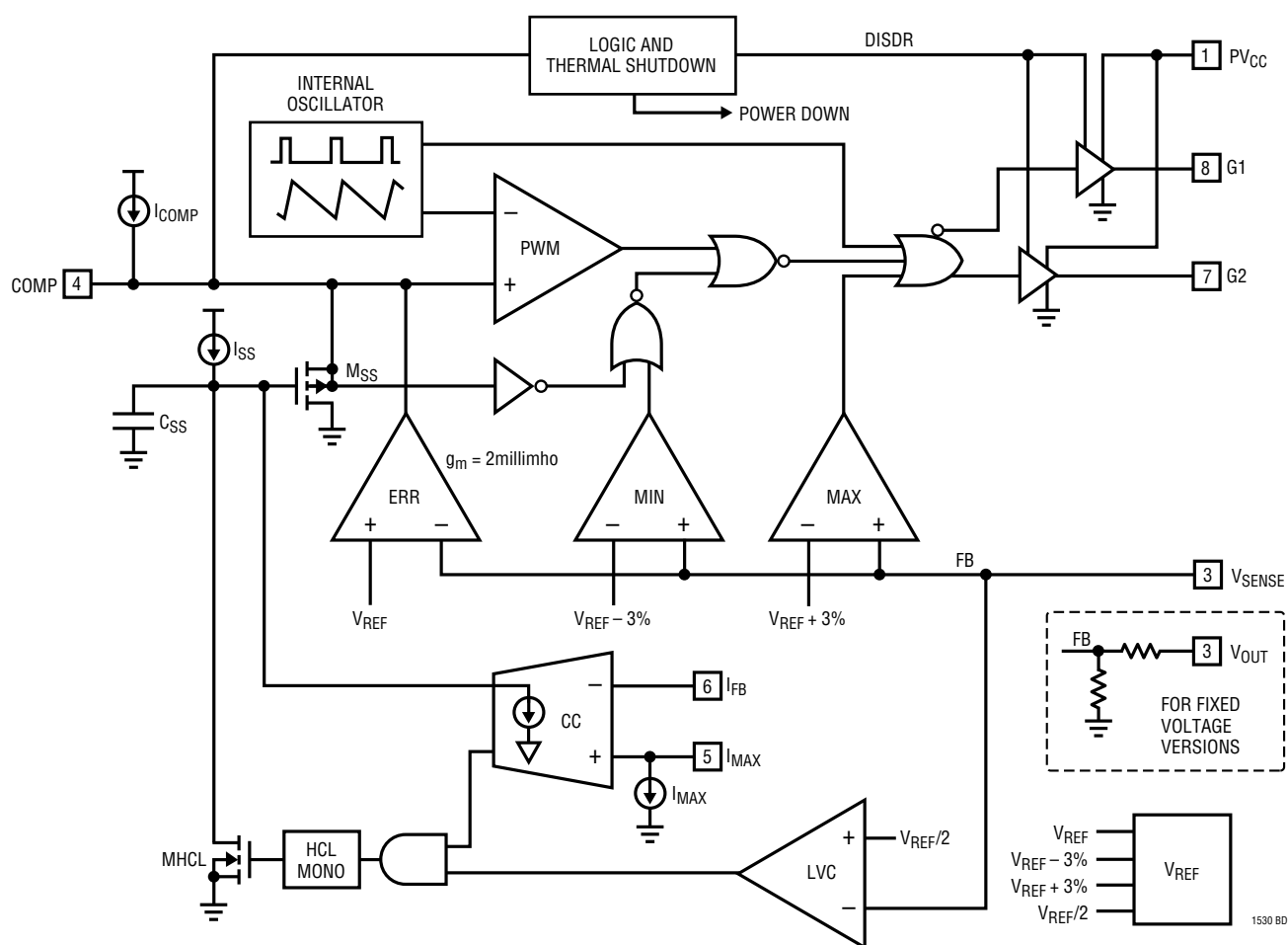
**I<sub>MAX</sub> (Pin 5):** Current Limit Threshold. Current limit is set by the voltage drop across an external resistor connected between the drain of Q1 and I<sub>MAX</sub>. This voltage is compared with the voltage across the R<sub>DS(ON)</sub> of the high side MOSFET. The LTC1530 contains a 200 $\mu$ A internal pull-down at I<sub>MAX</sub> to set current limit. This 200 $\mu$ A current source has a positive temperature coefficient to provide first order correction for the temperature coefficient of the external N-channel MOSFET's R<sub>DS(ON)</sub>.

**I<sub>FB</sub> (Pin 6):** Current Limit Sense Pin. Connect I<sub>FB</sub> to the switching node between Q1's source and Q2's drain. If I<sub>FB</sub> drops below I<sub>MAX</sub> with G1 on, the LTC1530 enters current limit. Under this condition, the internal soft start capacitor is discharged and COMP is pulled low slowly. Duty cycle is reduced and output power is limited. The current limit circuitry is only activated if PV<sub>CC</sub>  $\geq 8V$ . This action eases start-up considerations as PV<sub>CC</sub> is ramping up because the MOSFET's R<sub>DS(ON)</sub> can be significantly higher than what is measured under normal operating conditions. The current limit circuit is disabled by floating I<sub>MAX</sub> and shorting I<sub>FB</sub> to PV<sub>CC</sub>.

**G2 (Pin 7):** Gate Drive for the Low Side N-Channel MOSFET, Q2. This output swings from PV<sub>CC</sub> to GND. It is always low if G1 is high or if the output is disabled. To prevent undershoot during a soft start cycle, G2 is held low until G1 first transitions high.

**G1 (Pin 8):** Gate Drive for the Topside N-Channel MOSFET, Q1. This output swings from PV<sub>CC</sub> to GND. It is always low if G2 is high or if the output is disabled.

## BLOCK DIAGRAM



## TEST CIRCUITS

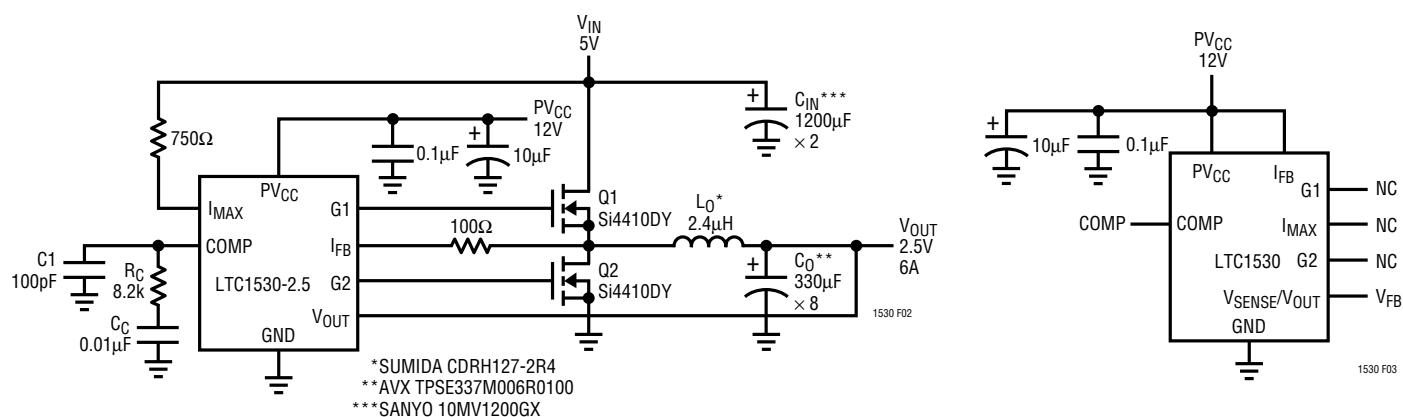


Figure 2

Figure 3

## TEST CIRCUITS

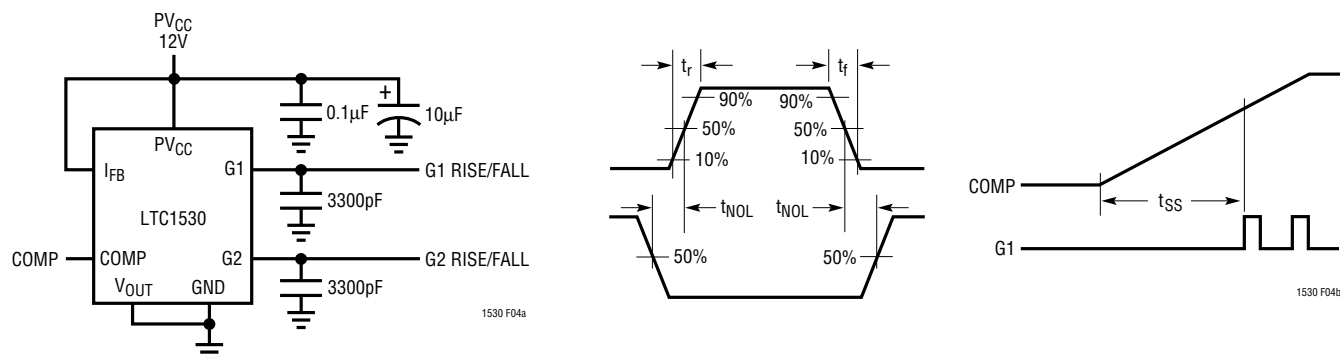


Figure 4

## APPLICATIONS INFORMATION

### OVERVIEW

The LTC1530 is a voltage feedback, synchronous switching regulator controller (see Block Diagram) designed for use in high power, low voltage step-down (buck) converters. It includes an on-chip soft start capacitor, a PWM generator, a precision reference trimmed to  $\pm 1\%$ , two high power MOSFET gate drivers and all the necessary feedback and control circuitry to form a complete switching regulator circuit running at 300kHz.

The LTC1530 includes a current limit sensing circuit that uses the topside external N-channel power MOSFET as a current sensing element, eliminating the need for an external sense resistor. If the current comparator, CC, detects an overcurrent condition, the duty cycle is reduced by discharging the internal soft start capacitor through a voltage-controlled current source. Under severe overloads or output short-circuit conditions, the soft start capacitor is pulled to ground and a start-up cycle is initiated. If the short circuit or overload persists, the chip repeats soft start cycles and prevents damage to external components.

### THEORY OF OPERATION

#### Primary Feedback Loop

The LTC1530 compares the output voltage with the internal reference at the error amplifier inputs. The error amplifier outputs an error signal to the PWM comparator. This signal is compared to the fixed frequency oscillator

sawtooth waveform to generate the PWM signal. The PWM signal drives the external MOSFETs at the G1 and G2 pins. The resulting chopped waveform is filtered by  $L_O$  and  $C_{OUT}$  which closes the loop. Loop frequency compensation is typically accomplished with an external RC + C network at the COMP pin, which is the output node of the transconductance error amplifier.

#### MIN, MAX Feedback Loops

Two additional comparators in the feedback loop provide high speed fault correction in situations where the error amplifier cannot respond quickly enough. MIN compares the feedback signal to a voltage 3% below the internal reference. If the signal is below the comparator threshold, the MIN comparator overrides the error amplifier and forces the loop to maximum duty cycle, typically 86%. Similarly, the MAX comparator forces the output to 0% duty cycle if the feedback signal is greater than 3% above the internal reference. To prevent these two comparators from triggering due to noise, the MIN and MAX comparators' response times are deliberately delayed by two to three microseconds. These comparators help prevent extreme output perturbations with fast output load current transients, while allowing the main feedback loop to be optimally compensated for stability.

#### Thermal Shutdown

The LTC1530 has a thermal protection circuit that disables both internal gate drivers if activated. G1 and G2 are held low and the LTC1530 supply current drops to about 1mA.



## APPLICATIONS INFORMATION

Typically, thermal shutdown is activated if the LTC1530's junction temperature exceeds 150°C. G1 and G2 resume switching when the junction temperature drops below 100°C.

### Soft Start and Current Limit

Unlike other PWM parts, the LTC1530 includes an on-chip soft start capacitor that is used during start-up and current limit operation. On power-up, an internal 4μA pull-up at COMP brings the LTC1530 out of shutdown mode. An internal current source then charges the internal C<sub>SS</sub> capacitor. The COMP pin is clamped to one V<sub>GS</sub> above the voltage on C<sub>SS</sub> during start-up. This prevents the error amplifier from forcing the loop to maximum duty cycle. The LTC1530 operates at low duty cycle as the COMP pin voltage increases above about 2.4V. The slew rate of the soft start capacitor is typically 0.4V/ms. As the voltage on C<sub>SS</sub> continues to increase, M<sub>SS</sub> eventually turns off and the error amplifier regulates the output. The MIN comparator is disabled if soft start is active to prevent an override of the soft start function.

The LTC1530 includes another feedback loop to control operation in current limit. Before each falling edge of G1, the current comparator, CC, samples and holds the voltage drop across external MOSFET Q1 with the LTC1530's I<sub>FB</sub> pin. CC compares the voltage at I<sub>FB</sub> to the voltage at the I<sub>MAX</sub> pin. As peak current rises, the voltage across the R<sub>DS(ON)</sub> of Q1 increases. If the voltage at I<sub>FB</sub> drops below I<sub>MAX</sub>, indicating that Q1's drain current has exceeded the maximum desired level, CC pulls current out of C<sub>SS</sub>. Duty cycle decreases and the output current is controlled. The CC comparator pulls current out of C<sub>SS</sub> in proportion to the voltage difference between I<sub>FB</sub> and I<sub>MAX</sub>. Under minor overload conditions, the voltage at C<sub>SS</sub> falls gradually, creating a time delay before current limit activates. Very short, mild overloads may not affect the output voltage at all. Significant overload conditions allow the voltage on C<sub>SS</sub> to reach a steady state and the output remains at a reduced voltage until the overload is removed. Serious overloads generate a large overdrive and allow CC to pull the C<sub>SS</sub> voltage down quickly, thus preventing damage to the external components.

By using the R<sub>DS(ON)</sub> of Q1 to measure output current, the current limit circuit eliminates the sense resistor that would otherwise be required. This minimizes the number of components in the high current power path. The current limit circuitry is not designed to be highly accurate. It is primarily meant to prevent damage to the power supply circuitry during fault conditions. The exact current level where current limiting takes effect will vary from unit to unit as the R<sub>DS(ON)</sub> of Q1 varies.

Figure 5a illustrates the basic connections for the current limit circuitry. For a given current limit level, the external resistor from I<sub>MAX</sub> to V<sub>IN</sub> is determined by:

$$R_{I_{MAX}} = \frac{(I_{L_{MAX}})R_{DS(ON)Q1}}{I_{I_{MAX}}}$$

where,

$$I_{L_{MAX}} = I_{LOAD} + \frac{I_{RIPPLE}}{2}$$

I<sub>LOAD</sub> = Maximum load current

I<sub>RIPPLE</sub> = Inductor ripple current

$$= \frac{(V_{IN} - V_{OUT})(V_{OUT})}{(f_{OSC})(L_O)(V_{IN})}$$

f<sub>OSC</sub> = LTC1530 oscillator frequency = 300kHz

L<sub>O</sub> = Inductor value

R<sub>DS(ON)Q1</sub> = On-resistance of Q1 at I<sub>LMAX</sub>

I<sub>I<sub>MAX</sub></sub> = 200μA sink current

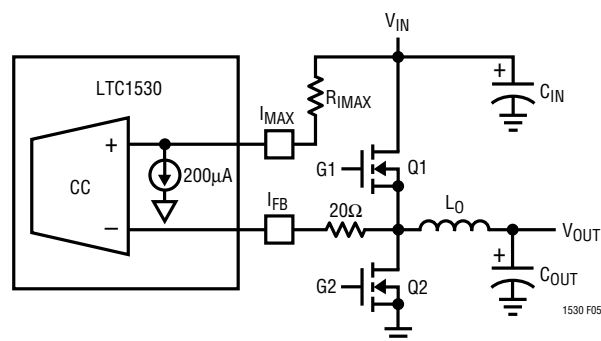


Figure 5a. Current Limit Setting (Use Kelvin-Sense Connections Directly at the Drain and Source of Q1)

## APPLICATIONS INFORMATION

Figure 5b is derived based on the condition that  $I_{LMAX} = I_{LOAD} + I_{RIPPLE}/2$ . Therefore, it only provides the minimum  $R_{IMAX}$  value. It must be understood that during the initial power-up phase ( $V_{OUT} = 0V$ ), the initial start-up  $I_{LMAX}$  can be much higher than the steady state condition  $I_{LMAX}$ . Therefore,  $R_{IMAX}$  must be selected with the start-up  $I_{LMAX}$  in mind. In general, high output capacitance combined with a low value inductor increases the start-up  $I_{LMAX}$ . Figures 6a and 6b plot the start-up  $I_{LMAX}$  vs output capacitance and inductance for unloaded and loaded conditions with the current limit circuit disabled. Figures 6a and 6b are provided as examples. Actual  $I_{LMAX}$  under start-up conditions must be measured for any application circuit so that  $R_{IMAX}$  can be properly chosen.

In order for the current limit circuit to operate properly and to obtain a reasonably accurate current limit threshold, the  $I_{MAX}$  and  $I_{FB}$  pins must be Kelvin sensed at Q1's drain and source pins. A  $0.1\mu F$  decoupling capacitor can also be connected across  $R_{IMAX}$  to filter switching noise. In addition, LTC recommends that the voltage drop across the  $R_{IMAX}$  resistor be set to  $\geq 100mV$ . Otherwise, noise spikes or ringing at Q1's source can cause the actual current limit to be greater than the desired current limit set point.

### MOSFET Gate Drive

The  $PV_{CC}$  supply must be greater than the input supply voltage,  $V_{IN}$ , by at least one power MOSFET  $V_{GS(ON)}$  for efficient operation. This higher voltage can be supplied with a separate supply, or it can be generated using a simple charge pump as shown in Figure 7. The 86% maximum duty cycle ensures sufficient off-time to refresh the charge pump during each cycle.

As  $PV_{CC}$  is powered up from 0V, the LTC1530 undervoltage lockout circuit prevents G1 and G2 from pulling high until  $PV_{CC}$  reaches about 3.5V. To prevent Q1's high  $R_{DS(ON)}$  from triggering the current limit comparator while  $PV_{CC}$  is slewing, the current limit circuit is disabled until  $PV_{CC}$  is  $\geq 8V$ . In addition, on start-up or recovery from thermal shutdown, the driver logic is designed to hold G2 low until G1 first goes high.

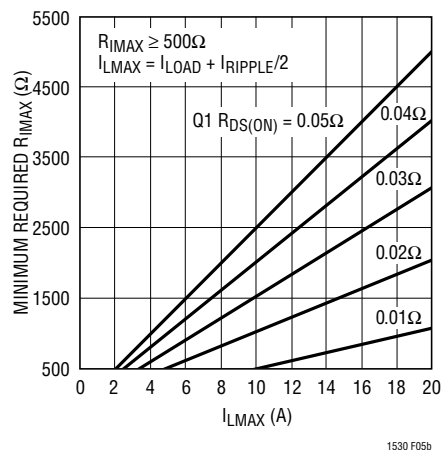


Figure 5b. Minimum Required  $R_{IMAX}$  vs  $I_{LMAX}$

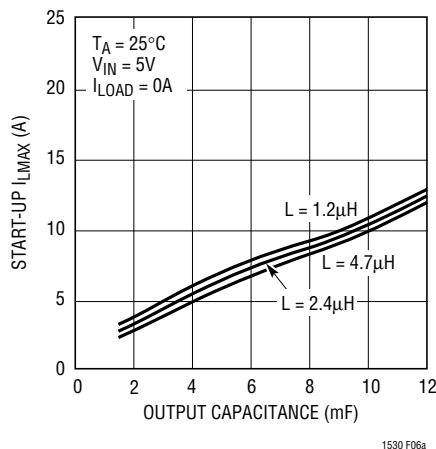


Figure 6a. Start-Up  $I_{LMAX}$  vs Output Capacitance

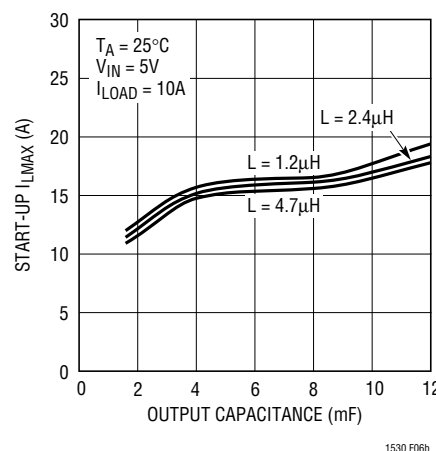


Figure 6b. Start-Up  $I_{LMAX}$  vs Output Capacitance

## APPLICATIONS INFORMATION

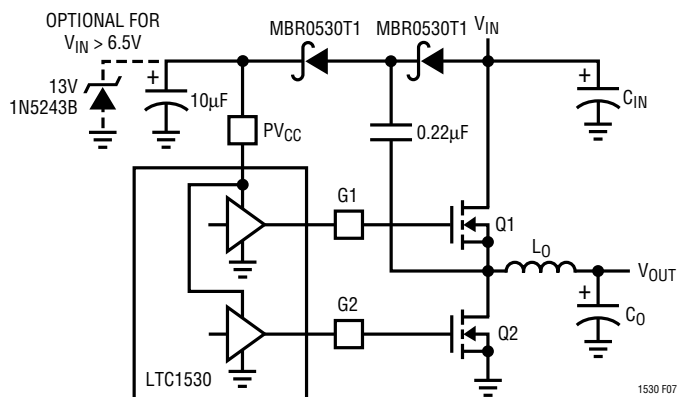


Figure 7. Doubling Charge Pump

## Power MOSFETs

Two N-channel power MOSFETs are required for synchronous LTC1530 circuits. They should be selected based primarily on threshold voltage and on-resistance considerations. Thermal dissipation is often a secondary concern in high efficiency designs. The required MOSFET threshold should be determined based on the available power supply voltages and/or the complexity of the gate drive charge pump scheme. In 5V input designs where a 12V supply is used to power  $PV_{CC}$ , standard MOSFETs with  $R_{DS(ON)}$  specified at  $V_{GS} = 5V$  or  $6V$  can be used with good results. The current drawn from the 12V supply varies with the MOSFETs used and the LTC1530's operating frequency, but is generally less than 50mA.

LTC1530 applications that use a 5V  $V_{IN}$  voltage and a doubling charge pump to generate  $PV_{CC}$  do not provide enough gate drive voltage to fully enhance standard power MOSFETs. Under this condition, the effective MOSFET  $R_{DS(ON)}$  may be quite high, raising the dissipation in the FETs and reducing efficiency. In addition, power supply start-up problems can occur with standard power MOSFETs. Logic level FETs are the recommended choice for 5V-only systems. Logic level FETs can be fully enhanced with a doubler charge pump and will operate at maximum efficiency. Note that doubler charge pump designs running from supplies higher than 6.5V should include a Zener diode clamp at  $PV_{CC}$  to prevent transients from exceeding the absolute maximum rating of the pin.

After the MOSFET threshold voltage is selected, choose the  $R_{DS(ON)}$  based on the input voltage, the output voltage, allowable power dissipation and maximum output current. In a typical LTC1530 buck converter circuit, operating in continuous mode, the average inductor current is equal to the output load current. This current flows through either Q1 or Q2 with the power dissipation split up according to the duty cycle:

$$DC(Q1) = \frac{V_{OUT}}{V_{IN}}$$

$$DC(Q2) = 1 - \frac{V_{OUT}}{V_{IN}} = \frac{(V_{IN} - V_{OUT})}{V_{IN}}$$

The  $R_{DS(ON)}$  required for a given conduction loss can now be calculated by rearranging the relation  $P = I^2R$ .

$$R_{DS(ON)Q1} = \frac{P_{MAX(Q1)}}{[DC(Q1)](I_{MAX}^2)} = \frac{(V_{IN})[P_{MAX(Q1)}]}{(V_{OUT})(I_{MAX}^2)}$$

$$R_{DS(ON)Q2} = \frac{P_{MAX(Q2)}}{[DC(Q2)](I_{MAX}^2)} = \frac{(V_{IN})[P_{MAX(Q2)}]}{(V_{IN} - V_{OUT})(I_{MAX}^2)}$$

$P_{MAX}$  should be calculated based primarily on required efficiency or allowable thermal dissipation. A high efficiency buck converter designed for the Pentium II with 5V input and a 2.8V, 11.2A output might allow no more than 4% efficiency loss at full load for each MOSFET. Assuming roughly 90% efficiency at this current level, this gives a  $P_{MAX}$  value of:

## APPLICATIONS INFORMATION

$(2.8)(11.2\text{A}/0.9)(0.04) = 1.39\text{W}$  per FET  
and a required  $R_{\text{DS(ON)}}$  of:

$$R_{\text{DS(ON)Q1}} = \frac{5\text{V}(1.39\text{W})}{2.8\text{V}(11.2\text{A}^2)} = 0.020\Omega$$

$$R_{\text{DS(ON)Q2}} = \frac{5\text{V}(1.39\text{W})}{(5\text{V} - 2.8\text{V})(11.2\text{A}^2)} = 0.025\Omega$$

Note that while the required  $R_{\text{DS(ON)}}$  values suggest large MOSFETs, the power dissipation numbers are only 1.39W per device or less—large TO-220 packages and heat sinks are not necessarily required in high efficiency applications. Siliconix Si4410DY or International Rectifier IRF7413 (both in SO-8) or Siliconix SUD50N03 or Motorola MTD20N03HDL (both in DPAK) are small footprint surface mount devices with  $R_{\text{DS(ON)}}$  values below  $0.03\Omega$  at 5V of  $V_{\text{GS}}$  that work well in LTC1530 circuits. With higher output voltages, the  $R_{\text{DS(ON)}}$  of Q1 may need to be significantly lower than that for Q2. These conditions can often be met by paralleling two MOSFETs for Q1 and using a

single device for Q2. Using a higher  $P_{\text{MAX}}$  value in the  $R_{\text{DS(ON)}}$  calculations generally decreases the MOSFET cost and the circuit efficiency and increases the MOSFET heat sink requirements.

In most LTC1530 applications,  $R_{\text{DS(ON)}}$  is used as the current sensing element. MOSFET  $R_{\text{DS(ON)}}$  has a positive temperature coefficient. Therefore, the LTC1530  $I_{\text{MAX}}$  sink current is designed with a positive 3300ppm/°C temperature coefficient. The positive tempco of  $I_{\text{MAX}}$  provides first order correction for current limit vs temperature. Therefore, current limit does not have to be set to an increased level at room temperature to guarantee a desired output current at elevated temperatures.

Table 1 highlights a variety of power MOSFETs that are suitable for use in LTC1530 applications.

### Inductor Selection

The inductor is often the largest component in an LTC1530 design and must be chosen carefully. Choose the inductor value and type based on output slew rate requirements and expected peak current. The required output slew rate primarily controls the inductor value. The maximum rate

**Table 1. Recommended MOSFETs for LTC1530 Applications**

MANUFACTURER	PART NO.	PACKAGE	$R_{\text{DS(ON)}}$ AT 25°C ( $\Omega$ )	RATED CURRENT (A)	TYPICAL INPUT CAPACITANCE $C_{\text{iss}}$ (pF)	$\theta_{\text{JC}}$ (°C/W)	$T_{\text{JMAX}}$ (°C)
Siliconix	SUD50N03-10	TO-252	0.019	15A at 25°C 10A at 100°C	3200	1.8	175
Siliconix	Si4410DY	SO-8	0.020	10A at 25°C 8A at 75°C	2700	—	150
Motorola	MTD20N03HDL	DPAK	0.035	20A at 25°C 16A at 100°C	880	1.67	150
SGS-Thomson	STD20N03L	DPAK	0.023	20A at 25°C 14A at 100°C	2300	2.5	175
Motorola	MTB75N03HDL	D <sup>2</sup> PAK	0.0075	75A at 25°C 59A at 100°C	4025	1.0	150
IRF	IRL3103S	D <sup>2</sup> PAK	0.014	56A at 25°C 40A at 100°C	1600	1.8	175
IRF	IRLZ44	TO-220	0.028	50A at 25°C 36A at 100°C	3300	1.0	175
Fuji	2SK1388	TO-220	0.037	35A at 25°C	1750	2.08	150

Note: Please refer to the manufacturer's data sheet for testing conditions and detailed information.

## APPLICATIONS INFORMATION

of rise of inductor current is set by the inductor's value, the input-to-output voltage differential and the LTC1530's maximum duty cycle. In a typical 5V input, 2.8V output application, the maximum rise time will be:

$$DC_{MAX} \left( \frac{V_{IN} - V_{OUT}}{L} \right) = \frac{1.85}{L} \frac{A}{\mu s}$$

where L is the inductor value in  $\mu H$ . With proper frequency compensation, the combination of the inductor and output capacitor values determine the transient recovery time. In general, a smaller value inductor improves transient response at the expense of ripple and inductor core saturation rating. A  $2\mu H$  inductor has a  $0.9A/\mu s$  rise time in this application, resulting in a  $5.5\mu s$  delay in responding to a 5A load current step. During this  $5.5\mu s$ , the difference between the inductor current and the output current is made up by the output capacitor. This action causes a temporary voltage droop at the output. To minimize this effect, the inductor value should usually be in the  $1\mu H$  to  $5\mu H$  range for most 5V input LTC1530 circuits. Different combinations of input and output voltages and expected loads may require different values.

Once the required inductor value is selected, choose the inductor core type based on peak current and efficiency requirements. Peak current in the inductor is equal to the maximum output load current plus half of the peak-to-peak inductor ripple current. Inductor ripple current is set by the inductor's value, the input voltage, the output voltage and the operating frequency. If the efficiency is high, ripple current is approximately equal to:

$$I_{RIPPLE} = \frac{(V_{IN} - V_{OUT})(V_{OUT})}{(f_{OSC})(L_O)(V_{IN})}$$

where

$f_{OSC}$  = LTC1530 oscillator frequency

$L_O$  = Inductor value

Solving this equation for a typical 5V to 2.8V application with a  $2\mu H$  inductor, ripple current is:

$$\frac{(2.2V)(0.56)}{(300kHz)(2\mu H)} = 2A_{P-P}$$

Peak inductor current at 11.2A load:

$$11.2A + \frac{2A}{2} = 12.2A$$

The ripple current should generally fall between 10% and 40% of the output current. The inductor must be able to withstand this peak current without saturating, and the copper resistance in the winding should be kept as low as possible to minimize resistive power loss. Note that in circuits not employing the current limit function, the current in the inductor may rise above this maximum under short circuit or fault conditions; the inductor should be sized accordingly to withstand this additional current. Inductors with gradual saturation characteristics (example: powdered iron) are often the best choice.

### Input and Output Capacitors

A typical LTC1530 design places significant demands on both the input and the output capacitors. During normal steady load operation, a buck converter like the LTC1530 draws square waves of current from the input supply at the switching frequency. The peak current value is equal to the output load current plus 1/2 the peak-to-peak ripple current. Most of this current is supplied by the input bypass capacitor. The resulting RMS current flow in the input capacitor heats it and causes premature capacitor failure in extreme cases. Maximum RMS current occurs with 50% PWM duty cycle, giving an RMS current value equal to  $I_{OUT}/2$ . A low ESR input capacitor with an adequate ripple current rating must be used to ensure reliable operation. Note that capacitor manufacturers' ripple current ratings are often based on only 2000 hours (3 months) lifetime at rated temperature. Further derating of the input capacitor ripple current beyond the manufacturer's specification is recommended to extend the useful life of the circuit. Lower operating temperature has the largest effect on capacitor longevity.

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The output capacitor in a buck converter under steady state conditions sees much less ripple current than the input capacitor. Peak-to-peak current is equal to inductor ripple current, usually 10% to 40% of the total load current. Output capacitor duty places a premium not on power dissipation but on ESR. During an output load transient, the output capacitor must supply all of the additional load current demanded by the load until the LTC1530 adjusts the inductor current to the new value. ESR in the output capacitor results in a step in the output voltage equal to the ESR value multiplied by the change in load current. An 11A load step with a 0.05Ω ESR output capacitor results in a 550mV output voltage shift; this is 19.6% of the output voltage for a 2.8V supply! Because of the strong relationship between output capacitor ESR and output load transient response, choose the output capacitor for ESR, not for capacitance value. A capacitor with suitable ESR will usually have a larger capacitance value than is needed to control steady-state output ripple.

Electrolytic capacitors rated for use in switching power supplies with specified ripple current ratings and ESR can be used effectively in LTC1530 applications. OS-CON electrolytic capacitors from Sanyo and other manufacturers give excellent performance and have a very high performance/size ratio for electrolytic capacitors. Surface mount applications can use either electrolytic or dry tantalum capacitors. Tantalum capacitors must be surge tested and specified for use in switching power supplies. Low cost, generic tantalums are known to have very short lives followed by explosive deaths in switching power supply applications. AVX TPS series surface mount devices are popular surge tested tantalum capacitors that work well in LTC1530 applications.

A common way to lower ESR and raise ripple current capability is to parallel several capacitors. A typical LTC1530 application might exhibit 5A input ripple current. Sanyo OS-CON capacitors, part number 10SA220M (220μF/10V), feature 2.3A allowable ripple current at 85°C; three in parallel at the input (to withstand the input ripple current) meet the above requirements. Similarly, AVX TPSE337M006R0100 (330μF/6V) capacitors have a rated maximum ESR of 0.1Ω; seven in parallel lower the net

output capacitor ESR to 0.014Ω. For low cost applications, the Sanyo MV-GX capacitor series can be used with acceptable performance.

### Feedback Loop Compensation

The LTC1530 voltage feedback loop is compensated at the COMP pin, which is the output node of the  $g_m$  error amplifier. The feedback loop is generally compensated with an RC + C network from COMP to GND as shown in Figure 8a.

Loop stability is affected by the values of the inductor, the output capacitor, the output capacitor ESR, the error amplifier transconductance and the error amplifier compensation network. The inductor and the output capacitor create a double pole at the frequency:

$$f_{LC} = \frac{1}{2\pi\sqrt{L_O(C_{OUT})}}$$

The ESR of the output capacitor and the output capacitor value form a zero at the frequency:

$$f_{ESR} = \frac{1}{(2\pi)(ESR)(C_{OUT})}$$

The compensation network used with the error amplifier must provide enough phase margin at the 0dB crossover frequency for the overall open-loop transfer function. The zero and pole from the compensation network are:

$$f_z = \frac{1}{(2\pi)(R_C)(C_C)} \quad \text{and} \quad f_p = \frac{1}{(2\pi)(R_C)(C_1)}$$

respectively. Figure 8b shows the Bode plot of the overall transfer function.

The compensation values used in this design are based on the following criteria,  $f_{SW} = 12f_{CO}$ ,  $f_z = f_{LC}$ ,  $f_p = 5f_{CO}$ . At the closed-loop frequency  $f_{CO}$ , the attenuation due to the LC filter and the input resistor divider is compensated by the gain of the PWM modulator and the gain of the error amplifier ( $g_{mERR})(R_C)$ .

## APPLICATIONS INFORMATION

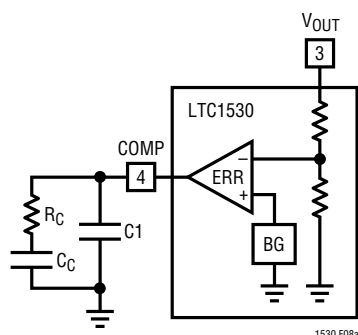
Although a mathematical approach to frequency compensation can be used, the added complication of input and/or output filters, unknown capacitor ESR, and gross operating point changes with input voltage, load current variations and frequency of operation all suggest a more practical empirical method. This can be done by injecting a transient current at the load and using an RC network box to iterate toward the final compensation values or by obtaining the optimum loop response using a network analyzer to find the actual loop poles and zeros.

Table 2 shows the suggested compensation components for 5V input applications based on the inductor and output capacitor values. The values were calculated using multiple paralleled 330 $\mu$ F AVX TPS series surface mount

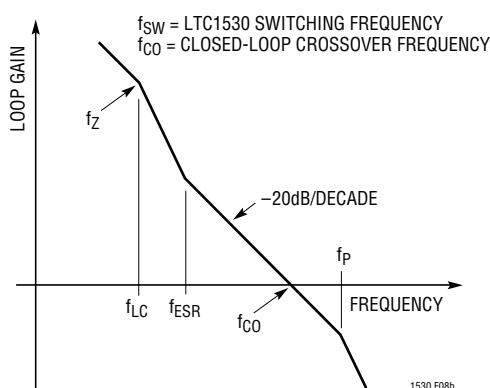
tantalum capacitors for the output capacitor. The optimum component values might deviate from the suggested values slightly because of board layout and operating condition differences.

**Table 2. Suggested Compensation Network for a 5V Input Application Using Multiple Paralleled 330 $\mu$ F AVX TPS Output Capacitors for 2.5V Output**

$L_O$ ( $\mu$ H)	$C_O$ ( $\mu$ F)	$R_C$ (k $\Omega$ )	$C_C$ ( $\mu$ F)	$C_1$ (pF)
1	990	1.3	0.022	1000
1	1980	2.7	0.022	470
1	4950	6.8	0.01	220
2.7	990	3.6	0.022	330
2.7	1980	7.5	0.01	220
2.7	4950	18	0.01	68
5.6	990	7.5	0.01	220
5.6	1980	15	0.01	100
5.6	4950	36	0.0047	47



**Figure 8a. Compensation Pin Hook-Up**



**Figure 8b. Bode Plot of the LTC1530 Overall Transfer Function**

An alternate output capacitor is the Sanyo MV-GX series. Using multiple paralleled 1500 $\mu$ F Sanyo MV-GX capacitors for the output capacitor, Table 3 shows the suggested compensation components for 5V input applications based on the inductor and output capacitor values.

**Table 3. Suggested Compensation Network for a 5V Input Application Using Multiple Paralleled 1500 $\mu$ F SANYO MV-GX Output Capacitors for 2.5V Output**

$L_O$ ( $\mu$ H)	$C_O$ ( $\mu$ F)	$R_C$ (k $\Omega$ )	$C_C$ ( $\mu$ F)	$C_1$ (pF)
1	4500	3	0.022	470
1	6000	4	0.022	330
1	9000	6	0.022	220
2.7	4500	8.2	0.022	150
2.7	6000	11	0.01	100
2.7	9000	16	0.01	100
5.6	4500	16	0.01	100
5.6	6000	22	0.01	68
5.6	9000	33	0.01	47

Note: For different values of  $V_{OUT}$ , multiply the  $R_C$  value by  $V_{OUT}/2.5$  and multiply the  $C_C$  and  $C_1$  values by  $2.5/V_{OUT}$ . This maintains the same crossover frequency for the closed-loop transfer function.

## APPLICATIONS INFORMATION

### Thermal Considerations

Limit the LTC1530's junction temperature to less than 125°C. The LTC1530's SO-8 package is rated at 130°C/W and care must be taken to ensure that the worst-case input voltage and gate drive load current requirements do not cause excessive die temperatures. Short-circuit or fault conditions may activate the internal thermal shutdown circuit.

### LAYOUT CONSIDERATIONS

When laying out the printed circuit board (PCB), the following checklist should be used to ensure proper operation of the LTC1530. These items are illustrated graphically in the layout diagram of Figure 9. The thicker lines show the high current power paths. Note that at 10A current levels or above, current density in the PCB itself is a serious concern. Traces carrying high current should be as wide as possible. For example, a PCB fabricated with 2oz copper requires a minimum trace width of 0.15" to carry 10A, and only if trace length is kept short.

1. In general, begin the layout with the location of the power devices. Orient the power circuitry so that a clean power flow path is achieved. Maximize conductor widths but minimize conductor lengths. Keep high current connections on one side of the PCB if possible. If not, minimize the use of vias and keep the current density in the vias to  $<1\text{A}/\text{via}$ , preferably  $<0.5\text{A}/\text{via}$ . After achieving a satisfactory power path layout, proceed with the control circuitry layout. It is much easier to find routes for the relatively small traces in the control circuits than it is to find circuitous routes for high current paths.
2. Tie the GND pin to the ground plane at a single point, preferably at a fairly quiet point in the circuit, such as the bottom of the output capacitors. However, this is not

always practical due to physical constraints. Connect the low side source to the input capacitor ground. Connect the input and output capacitor to the ground plane. Run a separate trace for the low side FET source to the input capacitors. Do not tie this single point ground in the trace run between the low side FET source and the input capacitor ground. This area of the ground plane is very noisy.

3. Locate the small signal resistor and capacitors used for frequency compensation close to the COMP pin. Use a separate ground trace for these components that ties directly to the GND pin of the LTC1530. Do not connect these components to the ground plane!
4. Place the  $\text{PV}_{\text{CC}}$  decoupling capacitor as close to the LTC1530 as possible. The  $10\mu\text{F}$  bypass capacitor shown at  $\text{PV}_{\text{CC}}$  helps provide optimum regulation performance by minimizing ripple at the  $\text{PV}_{\text{CC}}$  pin.
5. Connect the (+) plate of  $\text{C}_{\text{IN}}$  as close as possible to the drain of the upper MOSFET. LTC recommends an additional  $1\mu\text{F}$  low ESR ceramic capacitor between  $\text{V}_{\text{IN}}$  and power ground.
6. The  $\text{V}_{\text{SENSE}}/\text{V}_{\text{OUT}}$  pin is very sensitive to pickup from the switching node. Care must be taken to isolate this pin from capacitive coupling to the high current inductor switching signals. A  $0.1\mu\text{F}$  is recommended between the  $\text{V}_{\text{OUT}}$  pin and the GND pin directly at the LTC1530 for fixed voltage versions. For the adjustable voltage version, keep the resistor divider close to the LTC1530. The bottom resistor's ground connection should tie directly to the LTC1530's GND pin.
7. Kelvin sense  $\text{I}_{\text{MAX}}$  and  $\text{I}_{\text{FB}}$  at the drain and source pins of Q1.
8. Minimize the length of the gate lead connections.



## APPLICATIONS INFORMATION

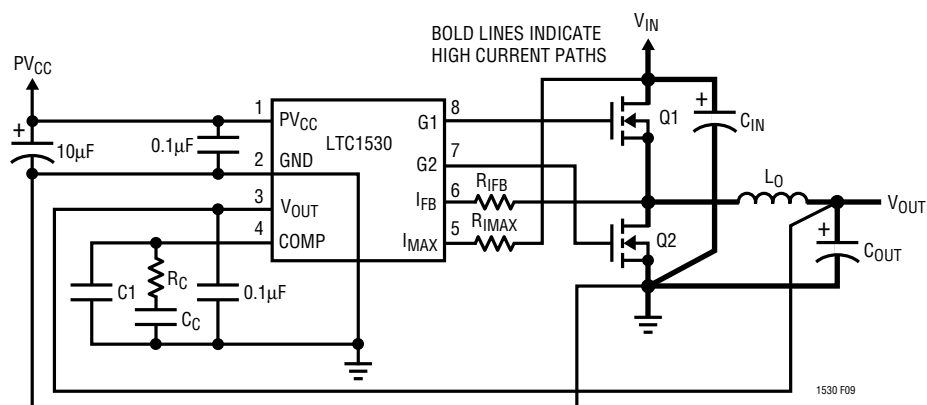
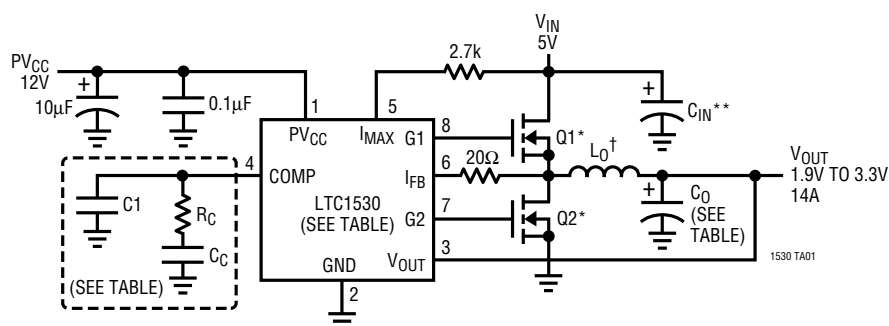


Figure 9. LTC1530 Layout Diagram



\* SILICONIX SUD50N03-10  
 \*\* 3 × SANYO 10MV1200GX OR  
 3 × SANYO OS-CON 6SH330K

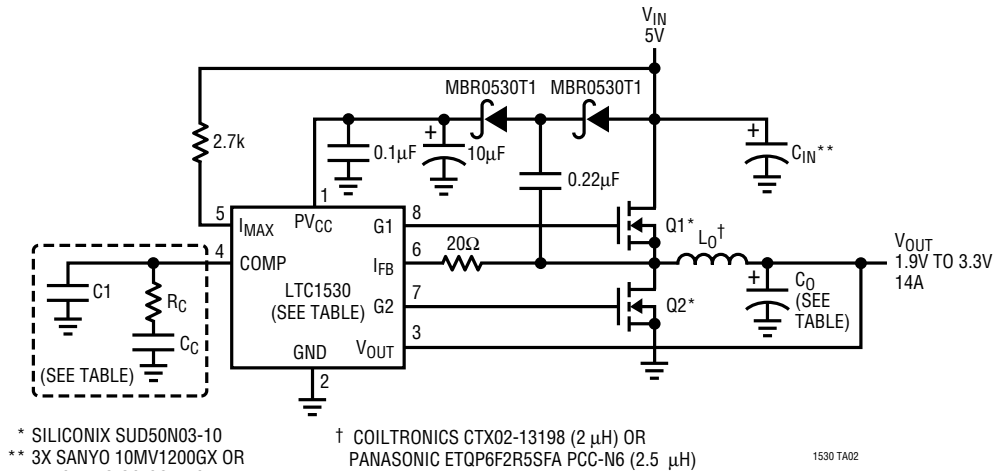
† COILTRONICS CTX02-13198 (2 µH) OR  
 PANASONIC ETQP6F2R5SFA PCC-N6 (2.5 µH)

DEVICE	OUTPUT CAPACITOR (C <sub>O</sub> )	R <sub>C</sub>	C <sub>C</sub>	C <sub>1</sub>
LTC1530-3.3	7 X330 µF AVX TPSE337M006R0100	10k	0.022 µF	150pF
LTC1530-3.3	4 X1500 µF SANYO 6MV1500GX	15k	0.022 µF	100pF
LTC1530-2.8	7 X330 µF AVX TPSE337M006R0100	8.6k	0.022 µF	150pF
LTC1530-2.8	4 X1500 µF SANYO 6MV1500GX	13k	0.022 µF	100pF
LTC1530-2.5	7 X330 µF AVX TPSE337M006R0100	7.5k	0.022 µF	220pF
LTC1530-2.5	4 X1500 µF SANYO 6MV1500GX	11k	0.022 µF	120pF
LTC1530-1.9	7 X330 µF AVX TPSE337M006R0100	5.6k	0.033 µF	220pF
LTC1530-1.9	4 X1500 µF SANYO 6MV1500GX	8.2k	0.022 µF	220pF

1530 TA TBL

Figure 10. 5V to 1.9V-3.3V Synchronous Buck Converter  
 PV<sub>CC</sub> Is Powered from 12V Supply

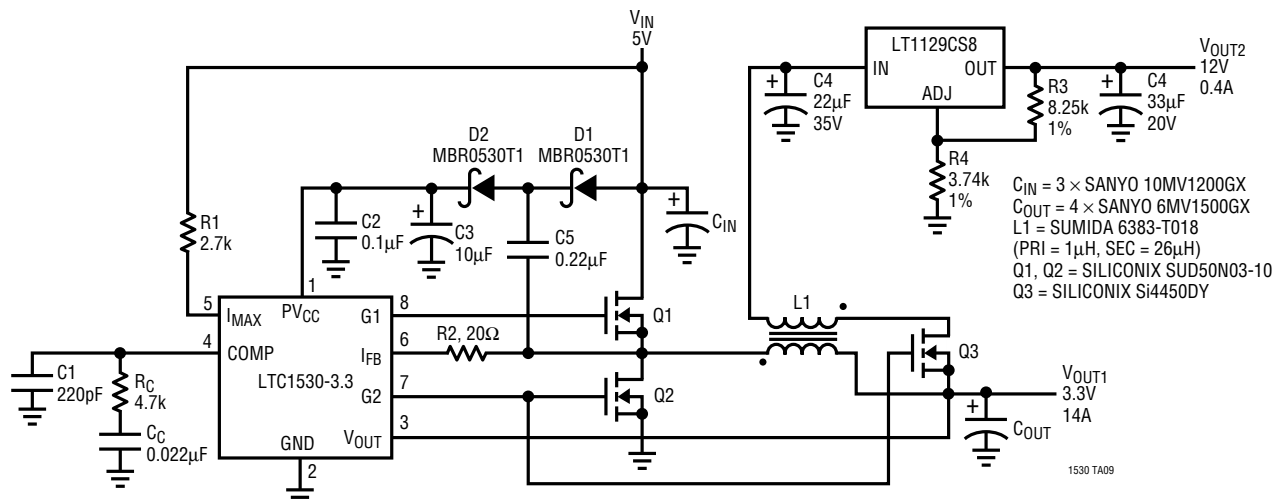
## TYPICAL APPLICATIONS

5V to 1.9V-3.3V Synchronous Buck Converter  
PV<sub>CC</sub> Is Generated from Charge Pump

DEVICE	OUTPUT CAPACITOR (C <sub>O</sub> )	R <sub>C</sub>	C <sub>C</sub>	C <sub>1</sub>
LTC1530-3.3	7 X330 μF AVX TPSE337M006R0100	10k	0.022 μF	150pF
LTC1530-3.3	4 X1500 μF SANYO 6MV1500GX	15k	0.022 μF	100pF
LTC1530-2.8	7 X330 μF AVX TPSE337M006R0100	8.6k	0.022 μF	150pF
LTC1530-2.8	4 X1500 μF SANYO 6MV1500GX	13k	0.022 μF	100pF
LTC1530-2.5	7 X330 μF AVX TPSE337M006R0100	7.5k	0.022 μF	220pF
LTC1530-2.5	4 X1500 μF SANYO 6MV1500GX	11k	0.022 μF	120pF
LTC1530-1.9	7 X330 μF AVX TPSE337M006R0100	5.6k	0.033 μF	220pF
LTC1530-1.9	4 X1500 μF SANYO 6MV1500GX	8.2k	0.022 μF	220pF

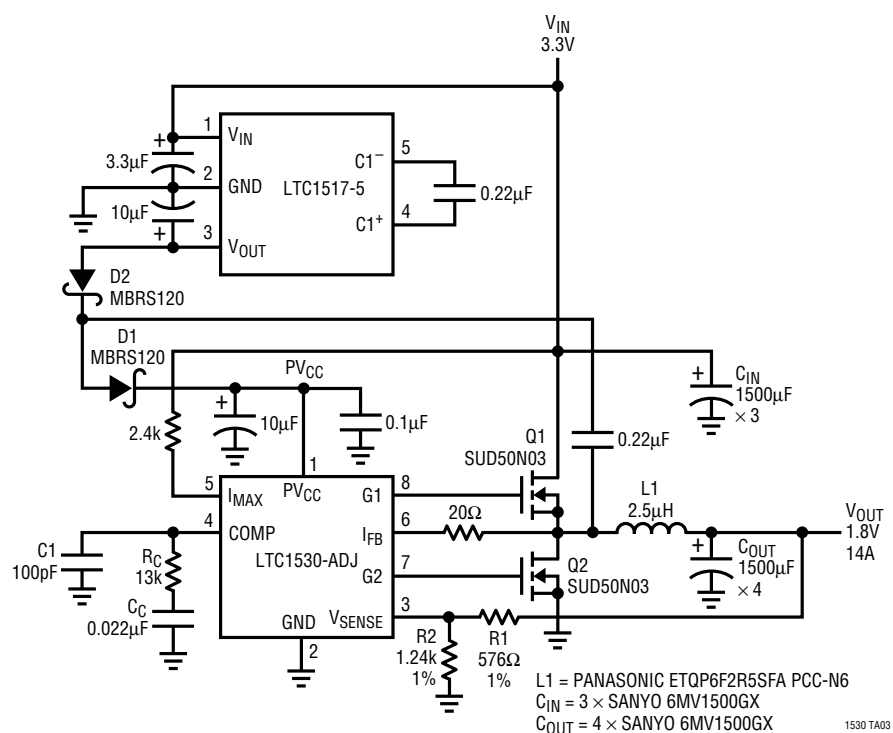
1530 TA TBL

## 5V to Dual Output (3.3V and 12V) Synchronous Buck converter

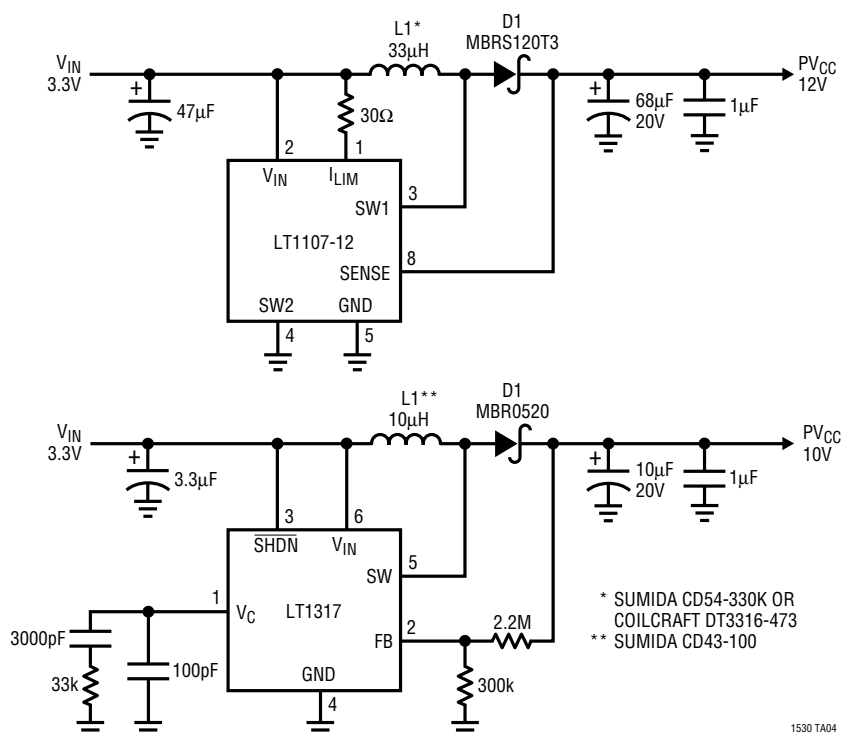


## TYPICAL APPLICATIONS

LTC1530 3.3V to 1.8V, 14A Application



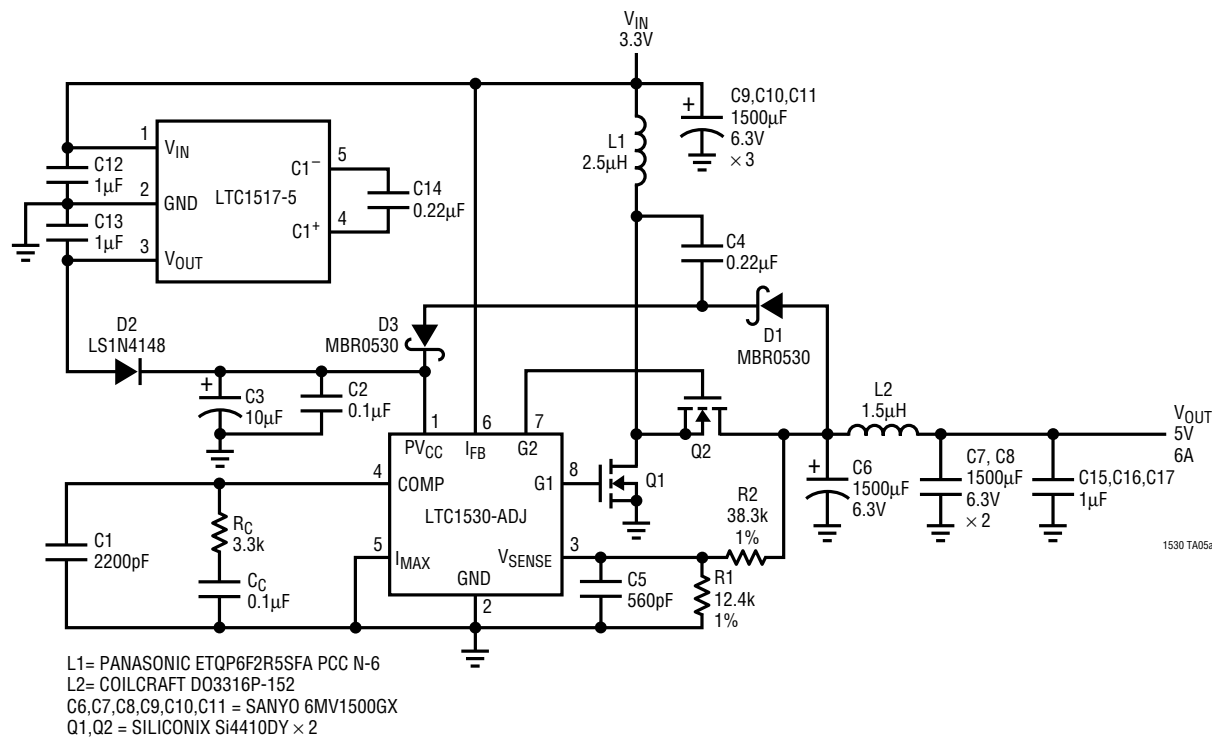
1530 TA03

Other Methods to Generate PV<sub>CC</sub> Supply from 3.3V Input

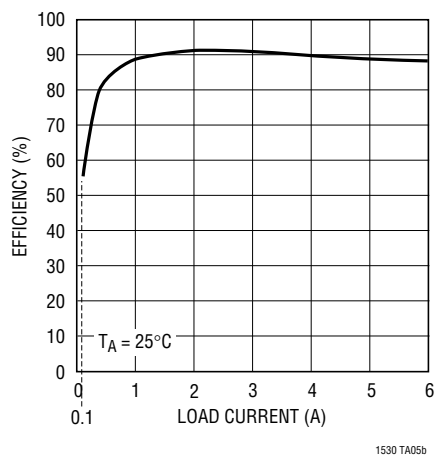
1530 TA04

TYPICAL APPLICATIONS

LTC1530 3.3V to 5V, 6A Boost Converter

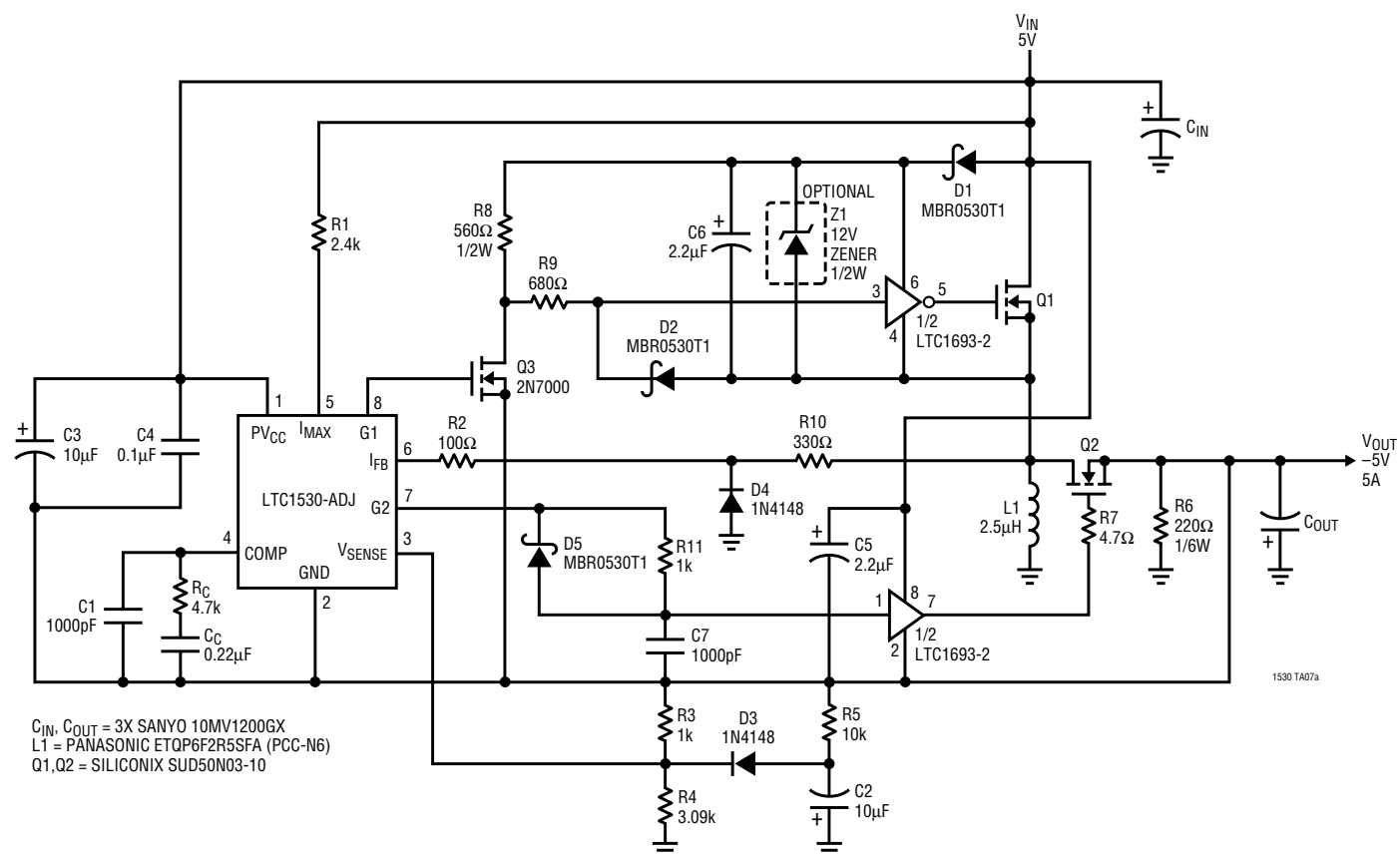


Efficiency vs Load Current

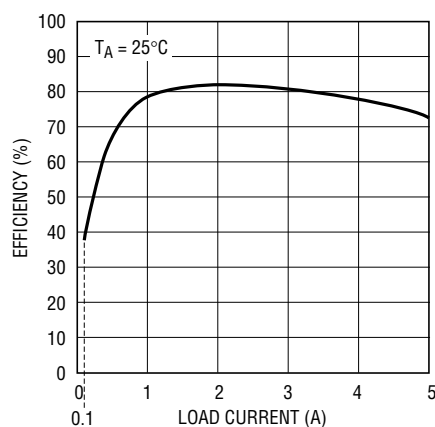


## TYPICAL APPLICATIONS

LTC1530 5V to -5V Synchronous Inverter

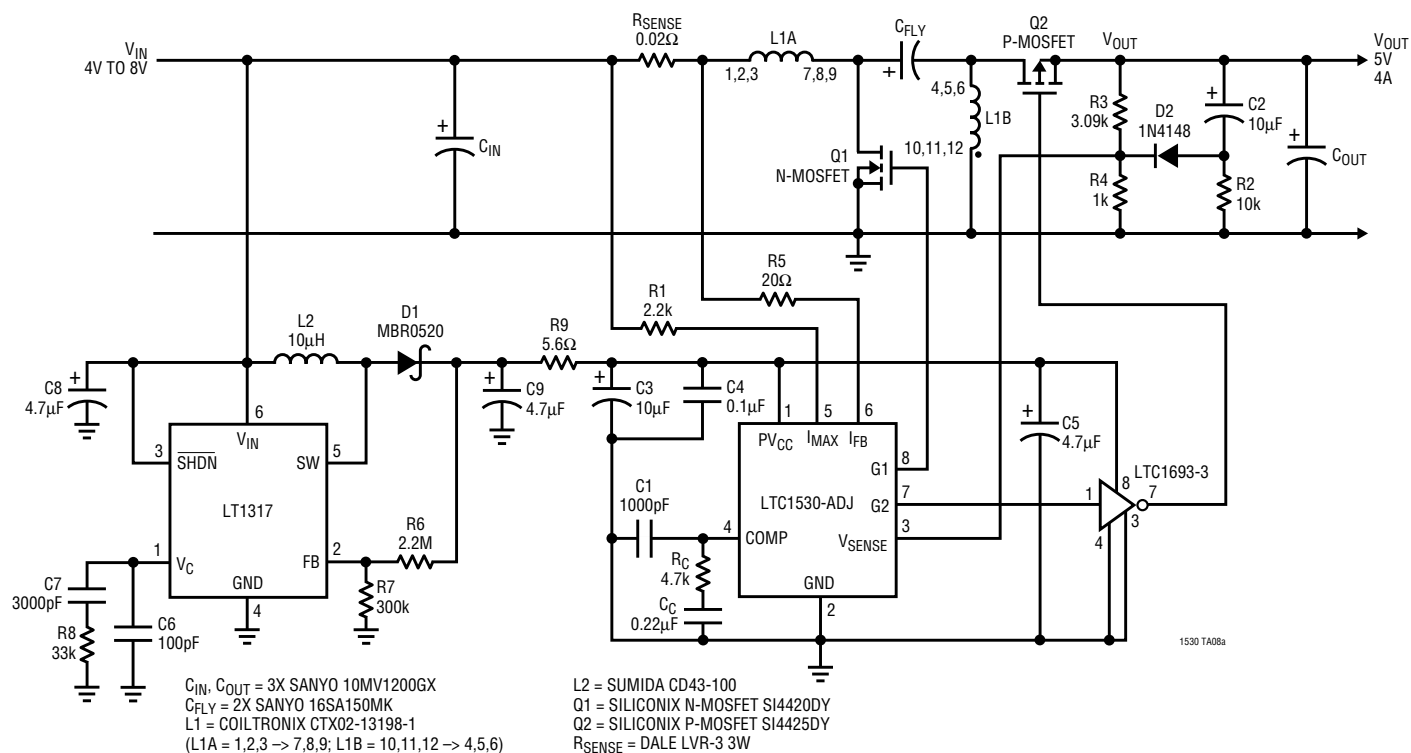


Efficiency vs Load Current

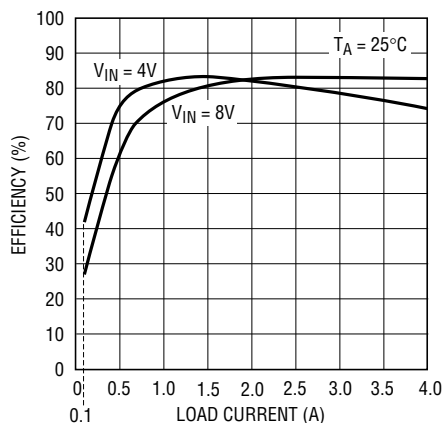


## TYPICAL APPLICATIONS

## LTC1530 Synchronous SEPIC Converter



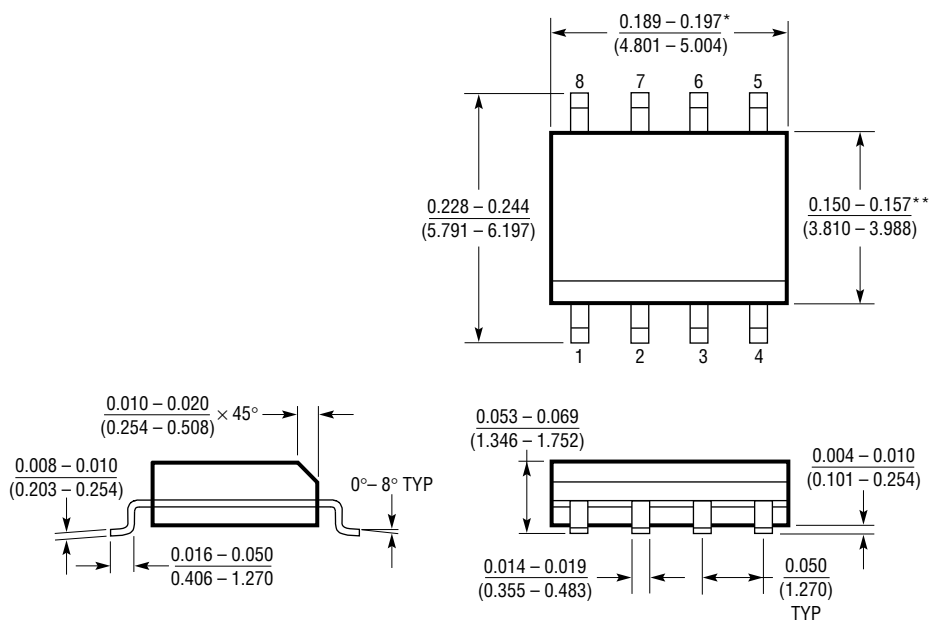
### Efficiency vs Load Current



**PACKAGE DESCRIPTION**

Dimensions in inches (millimeters) unless otherwise noted.

**S8 Package**  
**8-Lead Plastic Small Outline (Narrow 0.150)**  
 (LTC DWG # 05-08-1610)



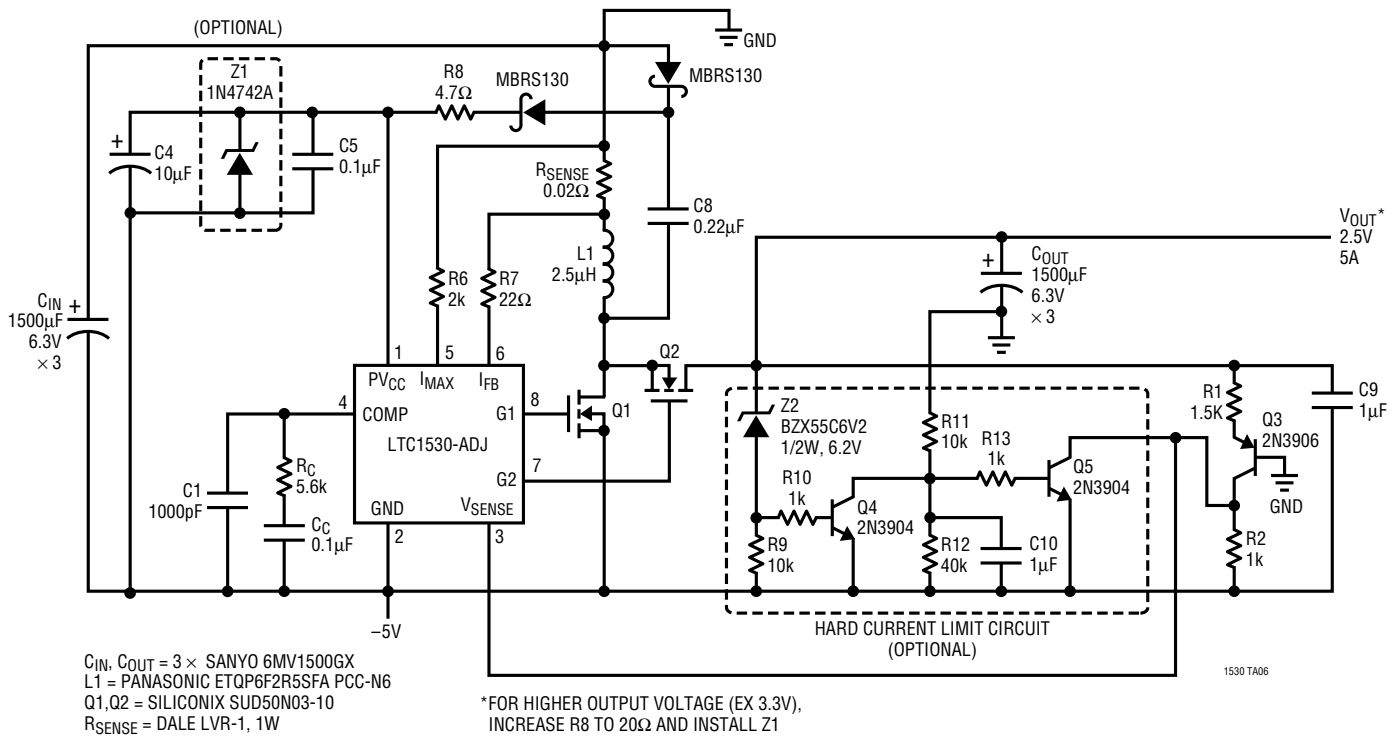
\*DIMENSION DOES NOT INCLUDE MOLD FLASH. MOLD FLASH SHALL NOT EXCEED 0.006" (0.152mm) PER SIDE

\*\*DIMENSION DOES NOT INCLUDE INTERLEAD FLASH. INTERLEAD FLASH SHALL NOT EXCEED 0.010" (0.254mm) PER SIDE

S08 0996

## TYPICAL APPLICATION

LTC1530 – 5V to 2.5V, 5A Inverting Polarity Converter



## RELATED PARTS

PART NUMBER	DESCRIPTION	COMMENTS
LTC1142	Current Mode Dual Step-Down Switching Regulator Controller	Dual Version of LTC1148
LTC1148	Current Mode Step-Down Switching Regulator Controller	Synchronous, $V_{IN} \leq 20V$
LTC1149	Current Mode Step-Down Switching Regulator Controller	Synchronous, $V_{IN} \leq 48V$ , For Standard Threshold FETs
LTC1159	Current Mode Step-Down Switching Regulator Controller	Synchronous, $V_{IN} \leq 40V$ , For Logic Threshold FETs
LTC1266	Current Mode Step-Up/Down Switching Regulator Controller	Synchronous N- or P-Channel FETs, Comparator/Low-Battery Detector
LTC1430A	High Power Step-Down Switching Regulator Controller	Synchronous N-Channel FETs, 3.3V to 2.5V Conversion
LTC1435	High Efficiency Low Noise Synchronous Step-Down Switching Regulator	Drive Synchronous N-Channel, $V_{IN} \leq 36V$
LTC1438	Dual High Efficiency Low Noise Synchronous Step-Down Switching Regulator	Dual LTC1435 with Power-On Reset
LTC1553	5-Bit Programmable Synchronous Switching Regulator Controller for Pentium II Processor	Synchronous N-Channel FETs, Voltage Mode $PV_{CC} \leq 20V$ , 1.8V to 3.5V Output
LTC1553L	5-Bit Programmable Synchronous Switching Regulator Controller for Pentium II Processor	Synchronous N-Channel FETs, Voltage Mode $PV_{CC} \leq 14V$ , 1.8V to 3.5V Output
LTC1753	5-Bit Programmable Synchronous Switching Regulator Controller for Pentium II Processor	Synchronous N-Channel FETs, Voltage Mode $PV_{CC} \leq 14V$ , 1.3V to 3.5V Output