LTC1627 Monolithic Synchronous Step-Down Regulator

DESCRIPTION

Demonstration circuit DC195 is a constant-frequency step-down converter using an LTC®1627 monolithic synchronous regulator. It provides low input voltage, high efficiency conversion for cell phones and other portable electronics operating from one or two Li-Ion cells or three to six NiCd cells. Constant 350kHz operation and up to 500mA output capability in an SO-8 package provide a low noise, space-efficient solution for wireless applications.

The circuit highlights the capability of the the LTC1627. Designed to work at low voltages, the input voltage (V_{IN}) can range from 2.65V to 8.5V. At input voltages lower than 4.5V, a charge pump bootstrapped to the SW node can be enabled via a jumper to produce a negative supply. This supply is used by the top driver to increase the gate overdrive of the top P-channel MOSFET, lowering its $R_{DS(ON)}$ and increasing efficiency. At V_{IN} < 2.5V, the LTC1627 shuts down and draws just a few microamperes, making it ideal for single lithium-ion battery applications. The output voltage is programmable from 1.8V to 3.3V via a second jumper.

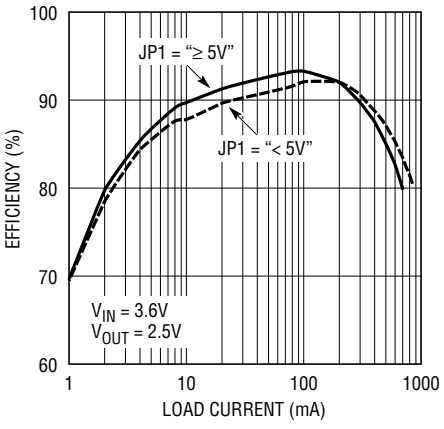
LT, LTC and LT are registered trademarks of Linear Technology Corporation.
Burst Mode is a trademark of Linear Technology Corporation.

PERFORMANCE SUMMARY

SYMBOL	PARAMETER	CONDITIONS	JUMPER POSITION	VALUE
V_{IN}	Input Voltage Range		JP1 = "≥ 5V" JP1 = "< 5V"	2.65V to 8.5V 2.65V to 4.5V
V_{OUT}	Output Voltage	See Figure 2	JP2 = "1.8V" JP2 = "2.5V" JP2 = "2.9V" JP2 = "3.3V" JP2 = "OPEN"	1.82V ± 0.043V 2.52V ± 0.06V 2.94V ± 0.07V 3.33V ± 0.079V Note 1
I_Q	Forced Continuous Supply Current Burst Mode™ Enabled Supply Current Shutdown Current	V_{IN} = 5V, SYNC/FCB = 0V, RUN/SS = 2V, I_{OUT} = 0mA V_{IN} = 5V, SYNC/FCB = 2V, RUN/SS = 2V, I_{OUT} = 0mA V_{IN} = 5V, RUN/SS = 0V, I_{OUT} = 0mA	JP1 = "≥ 5V," JP2 = "3.3V" JP1 = "≥ 5V," JP2 = "3.3V" JP1 = "≥ 5V," JP2 = "3.3V"	3.5mA 200µA 15µA

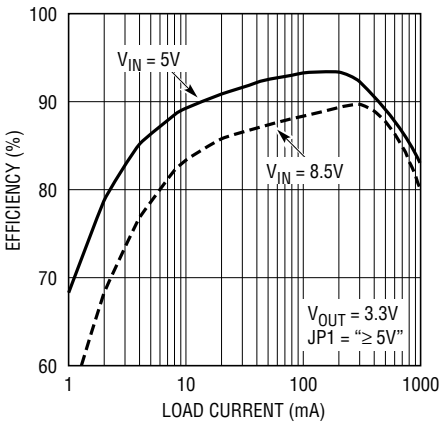
TYPICAL PERFORMANCE CHARACTERISTICS AND BOARD PHOTO

LTC1627 Efficiency Curve



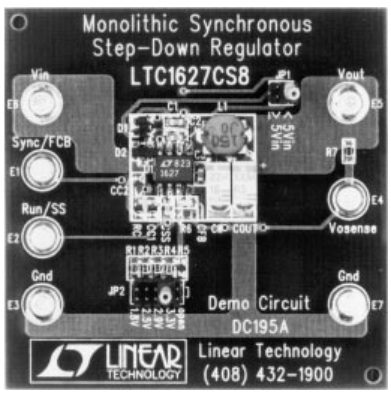
195 TPC01

LTC1627 Efficiency Curve



195 TPC02

Demo Board



DESCRIPTION

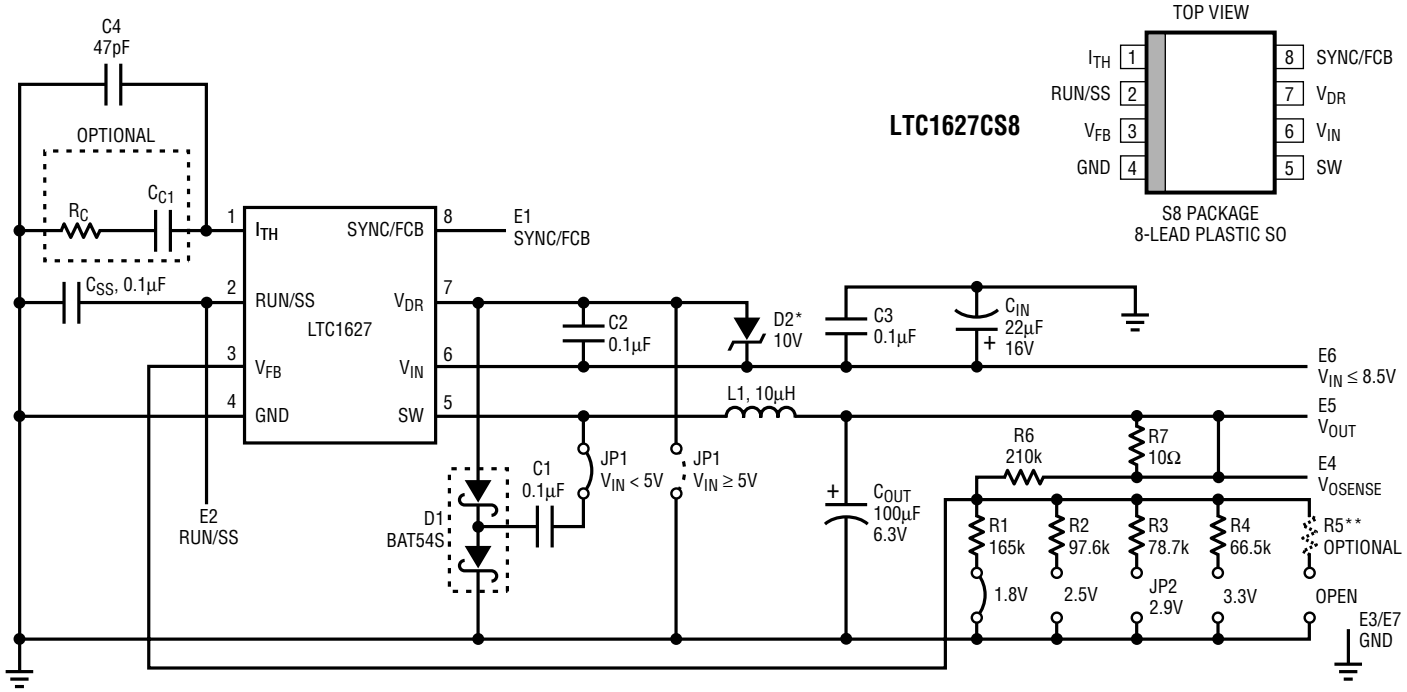
At low output currents, the LTC1627 automatically switches to Burst Mode operation to reduce switching losses and maintain high operating efficiencies. In switching-noise sensitive applications, Burst Mode operation can be inhibited by grounding the SYNC/FCB pin or synchronizing it with an external clock. **Gerber files for this circuit board are available. Call the LTC factory.**

PERFORMANCE SUMMARY

SYMBOL	PARAMETER	CONDITIONS	JUMPER POSITION	VALUE
I_{OUT}	Minimum Output Current	V_{IN} = 5V, V_{OUT} = 3.3V V_{IN} = 3V, V_{OUT} = 2.5V	JP1= "≥ 5V" JP1= "< 5V"	500mA 500mA
f_{OSC}	Operating Frequency	Unsynchronized Synchronized	All All	350kHz 385kHz to 525kHz
V_{RIPPLE}	Typical Output Ripple	I_{OUT} = 500mA, V_{IN} = 5V, V_{OUT} = 3.3V	JP1= "≥ 5V"	30mV_{P-P}
V_{OUT}	Typical Load Regulation	0mA < I_{OUT} < 0.5A, V_{IN} = 5V, V_{OUT} = 3.3V	JP1= "≥ 5V"	0.5%
V_{FCB}	Forced Continuous Threshold Voltage		All	0.8V
V_{SYNC}	Synchronize Threshold Voltage		All	1.2V
$V_{RUN/SS}$	Minimum Shutdown Threshold Voltage		All	0.4V

Note 1: Programmable via optional R5. V_{OUT} = 0.8V(1 + 210k/R5)

PACKAGE A ND SCHEMATIC DIAGRAMS



* D2 IS FOR PROTECTION AGAINST MISAPPLIED INPUT VOLTAGES WITH JP1 IN THE "< 5V" POSITION.
** SPACE IS PROVIDED FOR AN OPTIONAL RESISTOR TO PROGRAM A CUSTOM OUTPUT VOLTAGE. THE OUTPUT VOLTAGE MUST NOT EXCEED 3.3V.

DC195 • SCHEMATIC

Figure 1. LTC1627 Constant Frequency, High Efficiency Converter

PARTS LIST

REFERENCE DESIGNATOR	QUANTITY	PART NUMBER	DESCRIPTION	VENDOR	TELEPHONE
C_{IN}	1	TPSC226M016R0375	22µF 16V TPS Tantalum Capacitor	AVX	(803) 448-9411
C_{OUT}	1	TPSC107M006R0150	100µF 6V TPS Tantalum Capacitor	AVX	(803) 448-9411
C1, C2, C3, C_{SS}	4	0603YC104KAT	0.1µF 16V X7R Chip Capacitor	AVX	(803) 946-0362
C4	1	06035A470JAT	47pF 50V NPO Chip Capacitor	AVX	(803) 946-0362
C_{C1}			Optional		
D1	1	BAT54S	Dual Schottky Diode in SOT-23	Zetex	(516) 543-7100
E1 to E6	6	2501-2	Turret, Testpoint	Mill-Max	(516) 922-6000
JP1	1	3914-04-G2	0.05" Double Row Header	COMM CON	(818) 301-4200
JP2	1	3914-10-G2	0.05" Double Row Header	COMM CON	(818) 301-4200
JP1, JP2	2	50633-R	0.05" Center Shunt	COMM CON	(818) 301-4200
L1	1	CD54-150MC	15µH 20% Inductor	Sumida	(847) 956-0666
D2	1	MMBZ5240B	10V Zener Diode in SOT-23	Motorola	(602) 244-3576
R1	1	CR16-1653FM	165k 1% 1/16W Chip Resistor	TAD	(800) 508-1521
R2	1	CR16-9762FM	97.6k 1% 1/16W Chip Resistor	TAD	(800) 508-1521
R3	1	CR16-7872FM	78.7k 1% 1/16W Chip Resistor	TAD	(800) 508-1521
R4	1	CR16-6652FM	66.5k 1% 1/16W Chip Resistor	TAD	(800) 508-1521
R6	1	CR16-2103FM	210k 1% 1/16W Chip Resistor	TAD	(800) 508-1521
R7	1	CR16-100JM	10Ω 5% 1/16W Chip Resistor	TAD	(800) 508-1521
R5			Optional		
R_C			Optional		
U1	1	LTC1627CS8	Monolithic Synchronous Step-Down Regulator	LTC	(408) 432-1900

QUICK START GUIDE

This demonstration board is easily set up to evaluate the performance of the LTC1627 IC. Please follow the procedure outlined below for proper operation.

- Refer to Figure 6 for proper connection of monitoring equipment to ensure correct measurement.
- Connect the input power supply to the V_{IN} and GND terminals on the left-hand side of the board. Do not increase V_{IN} over 10V or the Zener, D2, will be damaged. Select the appropriate position of jumper JP1 for the V_{IN} voltage (position "V_{IN} <5V" for V_{IN} <4.5V only).
- Connect the load between the V_{OUT} and GND terminals on the right side of the board.
- The RUN/SS pin can be left unconnected. To shut down the LTC1627, tie this pin to GND.
- Set the desired output voltage with jumper JP2, as shown in Figure 2 and Table 1.

Table 1. Maximum Allowable Input Voltage vs Selected Output Voltage and JP1 Position

JP2 OUTPUT VOLTAGE	MAXIMUM V_{IN} FOR JP1 POSITION	
	"≥5V"	"< 5V" (Note 1)
1.8V	8.5V	4.5V
2.5V	8.5V	4.5V
2.9V	8.5V	4.5V
3.3V	8.5V	4.5V
N/A		

Note 1: The silkscreen label "<5V" on the demo board is a simplified notation. The actual voltage should be ≤4.25V.

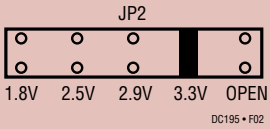


Figure 2. Output Voltage Selection (JP2) (3.3V Position Shown)

OPERATION

The circuit in Figure 1 highlights the capabilities of the LTC1627. The application circuit is set up for a variety of output voltages. Output voltages from 1.8V to 3.3V or user programmable voltages can be obtained by selecting the appropriate jumper position.

The LTC1627 is a monolithic synchronous step-down switching regulator using a fixed-frequency architecture. Burst Mode operation provides high efficiency at low load currents. Operating efficiencies typically exceed 90% over two decades of load current range. 100% duty cycle provides low dropout operation, which extends operating time in battery-operated systems.

Do not use small spring-clip leads when testing this circuit. Small spring-clip leads are very convenient for small-signal bench testing and voltage measurements, but should not be used with this circuit. Soldered wire connections are required to properly ascertain the performance of the PC board.

This demonstration board is intended for the evaluation of the LTC1627 switching regulator IC and was not designed for any other purpose.

The operating frequency of this demo circuit is 350kHz, the frequency of the LTC1627's internal oscillator. For higher frequencies, SYNC/FCB (E1) can be synchronized with an external clock. Burst Mode operation is automatically disabled when the SYNC/FCB pin is externally driven. Grounding SYNC/FCB also disables Burst Mode operation, potentially reducing noise and interference.

Soft start is provided by an external capacitor, C_{SS}, which can be used to properly sequence supplies. The maximum operating current level is 0.5A.

This demo board is optimized for 3.3V outputs and 5V input. Output voltages from 1.8V to 3.3V are available by selecting the appropriate jumper position of JP2. For other output voltages, select the OPEN (E) position and add an

OPERATION

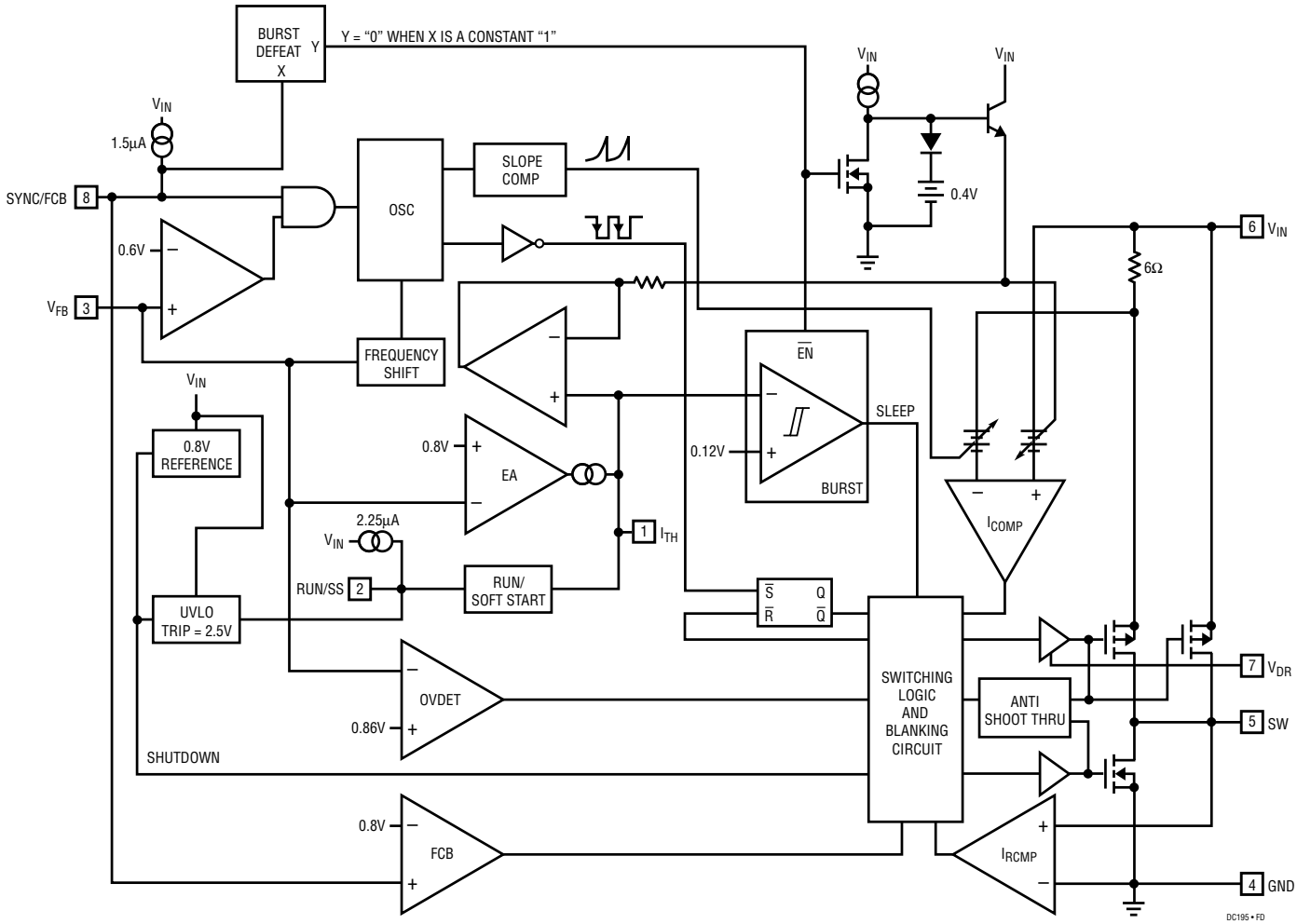


Figure 3. Functional Block Diagram

appropriate resistor value in the space provided. The output voltage must never exceed 3.3V because the output capacitor may be damaged. The input supply can range from 2.65V to 8.5V.

Main Control Loop (Refer to Functional Diagram)

The LTC1627 uses a constant-frequency, current mode step-down architecture. Both the main and synchronous switches, consisting of top P-channel and bottom N-channel power MOSFETs, are internal. During normal operation, the internal top power MOSFET is turned on during each cycle when the oscillator sets the RS latch, and turned off when the current comparator, I_{COMP}, resets the RS latch. The peak inductor current at which I_{COMP} resets the RS latch is controlled by the voltage on the I_{TH} pin, which is the output of error amplifier EA. The V_{FB} pin allows EA to receive an output feedback voltage from an external resistive divider. When the load current increases, it causes a slight decrease in the feedback voltage relative to the 0.8V reference, which, in turn, causes the I_{TH} voltage to increase until the average inductor current matches the new load current. While the top MOSFET is off, the bottom

OPERATION

MOSFET is turned on until either the inductor current starts to reverse, as indicated by the current reversal comparator I_{RCMP}, or the next cycle begins.

The main control loop is shut down by pulling the RUN/SS pin low. Releasing RUN/SS allows an internal 2.25µA current source to charge soft start capacitor C_{SS}. When C_{SS} reaches 0.7V, the main control loop is enabled with the I_{TH} voltage clamped at approximately 5% of its maximum value. As C_{SS} continues to charge, I_{TH} is gradually released, allowing normal operation to resume.

Comparator OVDET guards against transient overshoots > 7.5% by turning the main switch off and turning the synchronous switch on. With the synchronous switch turned on, the output is crowbarred. This may cause a large amount of current to flow from V_{IN} if the main switch is damaged, blowing the system fuse.

SYNC/FCB Pin Function (Frequency Synchronization and Burst Mode Disable)

The LTC1627 can be synchronized with an external TTL/CMOS-compatible clock signal driving the SYNC/FCB pin (E1). The frequency range of this signal must be from 385kHz to 525kHz. DO NOT attempt to synchronize the LTC1627 below 385kHz as this may cause abnormal operation and an undesired frequency spectrum. The top MOSFET turn-on follows the rising edge of the external source.

When the LTC1627 is clocked by an external source, Burst Mode operation is disabled; the LTC1627 then operates in PWM pulse-skipping mode. In this mode, when the output load is very low, current comparator I_{COMP} remains tripped for more than one cycle and forces the main switch to stay off for the same number of cycles. Increasing the output load slightly allows constant-frequency PWM operation to resume.

Frequency synchronization is inhibited when the feedback voltage, V_{FB}, is below 0.6V. This prevents the external clock from interfering with the frequency foldback for short-circuit protection.

The LTC1627 is capable of Burst Mode operation, in which the internal power MOSFETs operate intermittently based on load demand. To enable Burst Mode, simply allow the SYNC/FCB pin to float or connect it to a logic high. To disable Burst Mode operation and enable forced continuous mode (continuous switching even at no load), connect the SYNC/FCB pin to GND. The threshold voltage between Burst Mode and forced continuous mode is 0.8V. This provides a means to regulate a flyback winding output. See the LTC1627 data sheet for additional information.

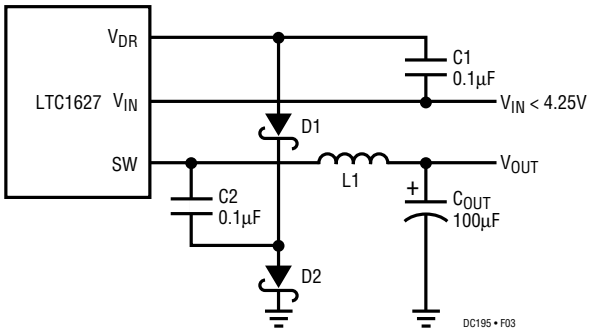


Figure 4. Using a Charge Pump to Bias V_{DR}

OPERATION

When the converter uses Burst Mode operation, the peak current of the inductor is set to approximately 200mA, even though the voltage at the I_{TH} pin indicates a lower value. The voltage at the I_{TH} pin drops when the inductor's average current is greater than the load requirement. As the I_{TH} voltage drops below 0.12V, the BURST comparator trips, causing the internal sleep line to go high and turn off both power MOSFETs.

In sleep mode, both power MOSFETs are held off and the internal circuitry is partially turned off, reducing the quiescent current to 200µA. The load current is now supplied from the output capacitor. When the output voltage drops, causing I_{TH} to rise above 0.22V, the top MOSFET is again turned on and this process repeats.

SHORT-CIRCUIT PROTECTION

When the output is shorted to ground, the frequency of the oscillator is reduced to about 35kHz, 1/10 of the nominal frequency. This frequency foldback ensures that the inductor current has more time to decay, thereby preventing runaway. The oscillator's frequency will gradually increase to 350kHz (or the synchronized frequency) when V_{FB} rises above 0.3V.

DROPOUT OPERATION

When the input supply voltage decreases toward the output voltage, the duty cycle increases toward the maximum on-time. Further reduction of the supply voltage forces the main switch to remain on for more than one cycle until it reaches 100% duty cycle. The output voltage will then be determined by the input voltage minus the voltage drop across the P-channel MOSFET and the inductor. In Burst Mode operation or pulse skipping mode operation (externally synchronized) with the outputs lightly loaded, the LTC1627 transistions through continuous mode as it enters dropout.

UNDERVOLTAGE LOCKOUT

A precision undervoltage lockout shuts down the LTC1627 when V_{IN} drops below 2.5V, making it ideal for single lithium-ion battery applications. In shutdown, the LTC1627 draws only several microamperes, which is low enough to prevent deep discharge and possible damage to a lithium-ion battery nearing its end of charge. A 150mV hysteresis ensures reliable operation with noisy supplies.

LOW SUPPLY OPERATION

The LTC1627 is designed to operate down to 2.65V supply voltage. At this voltage the converter is most likely to be running at high duty cycles or in dropout, where the main switch is on continuously. Hence, the I^2R loss is due mainly to the $R_{DS(ON)}$ of the P-channel MOSFET. See the LTC1627 data sheet for additional information.

When V_{IN} is low (< 4.5V), the $R_{DS(ON)}$ of the P-channel MOSFET can be lowered by driving its gate below ground. The top P-channel MOSFET driver makes use of a floating return pin, V_{DR}, to allow biasing below GND. A simple charge pump bootstrapped to the SW pin realizes a negative voltage at the V_{DR} pin, as shown in Figure 4. This charge pump can be enabled via jumper JP1 for $V_{IN} < 4.5V$. For $V_{IN} \geq 4.5V$, do not enable the charge pump to ensure that $V_{IN} - V_{DR}$ does not exceed its absolute maximum voltage. A 10V Zener clamp (Z3) prevents $V_{IN} - V_{DR}$ from exceeding 10V even if $V_{IN} \geq 5V$ is inadvertently applied.

When V_{IN} decreases to a voltage close to V_{OUT}, the loop may enter dropout and attempt to turn on the P-channel MOSFET continuously. When the V_{DR} charge pump is enabled, a dropout detector counts the number of oscillator cycles that the P-channel MOSFET remains on and periodically forces a brief off period to allow C1 to recharge. 100% duty cycle is allowed when V_{DR} is grounded.

SLOPE COMPENSATION AND PEAK INDUCTOR CURRENT

Slope compensation provides stability by preventing subharmonic oscillations. It works by internally adding a ramp to the inductor current signal at duty cycles in excess of 40%. As a result, the maximum inductor peak current is lower for $V_{OUT}/V_{IN} > 0.4$ than when $V_{OUT}/V_{IN} < 0.4$. See the maximum inductor peak current vs duty cycle graph in Figure 5.

OPERATION

The graph labeled "With External Clock" shows the worst-case peak current reduction obtained when the oscillator is synchronized at its minimum frequency, that is, to a clock just above the oscillator's free-running frequency.

HOW TO MEASURE VOLTAGE REGULATION

When trying to measure voltage regulation, remember that all measurements must be taken at the point of regulation. This point is where the LTC1627's control loop looks for the information to keep the output voltage constant. In this demonstration board, this information point occurs between Pin 4, the GND of the LTC1627, and the output side of R6. These points correspond to the GND (E7) and V_{OSENSE} (E4) terminals of the board. Output voltage test leads should be attached directly to these terminals. The load should be placed between V_{OUT} (E5) and GND (E7). Measurements *should not* be taken at the end of test leads at the load. Refer to Figure 6 for the proper monitoring equipment configuration.

This applies to line regulation (input-to-output voltage regulation) as well as load regulation tests. In doing the line regulation tests, always look at the input voltage across the input terminals.

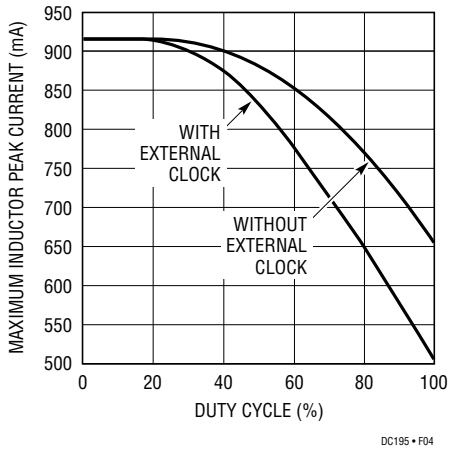


Figure 5. Maximum Inductor Peak Current Vs Duty Cycle

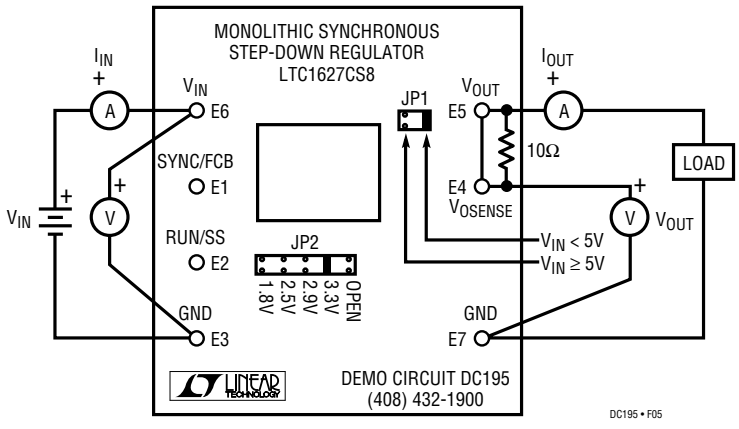


Figure 6. Proper Measurement Setup

OPERATION

For the purposes of these tests, the demonstration circuit should be powered from a regulated DC bench supply, so that variations on the DC input do not add errors to the regulation measurements.

REMOTE OUTPUT-VOLTAGE SENSING

Remote output-voltage sensing can be accomplished by modifying the PC board. A small PC trace connecting V_{OUT} to V_{OSENSE} must be cut, as shown in Figure 7. An external connection from V_{OSENSE} directly to the load must be made. To prevent uncertainty, there is a 10Ω resistor placed across the V_{OUT} and V_{OSENSE} terminals. Never, under any circumstance, allow V_{OSENSE} to float!

RUN/SOFT START FUNCTION

The RUN/SS pin (E2) is a dual-purpose pin that provides the soft start function and a means to shut down the LTC1627. Soft start reduces surge currents from V_{IN} by gradually increasing the internal current limit. Power supply sequencing can also be accomplished using this pin.

An internal 2.25µA current source charges an external capacitor, C_{SS}. When the voltage on RUN/SS reaches 0.7V, the LTC1627 begins operating. As the voltage on RUN/SS continues to increase from 0.7V to 1.8V, the internal current limit also increases at a proportional linear rate. The current limit begins at 25mA (at $V_{RUN/SS} \leq 0.7V$) and ends at the Figure 5 value ($V_{RUN/SS} \geq 1.8V$). The output current thus increases slowly, charging the output capacitor. If RUN/SS has been pulled all the way to ground, there is a delay before starting of approximately 310ms/µF, followed by an additional 490ms/µF to reach full current. C_{SS} = 0.1µF on this PC board.

Pulling the RUN/SS pin below 0.7V (0.4V min) puts the LTC1627 into a low quiescent current shutdown mode (I_Q < 15µA). See the LTC1627 data sheet for further information.

COMPONENT MANUFACTURERS

Table 2 is a partial list of manufacturers of components that can be used in LTC1627 applications. Using components other than the ones supplied on the demonstration board will require careful analysis to verify that all component specifications are not exceeded. Finally, recharacterizing the circuit for efficiency is necessary.

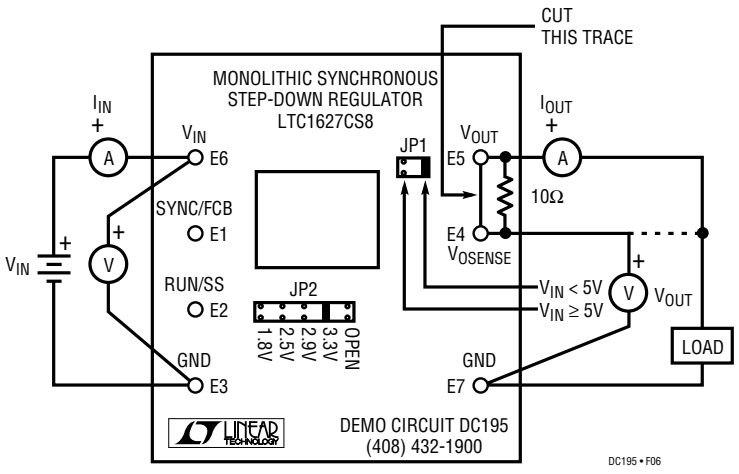


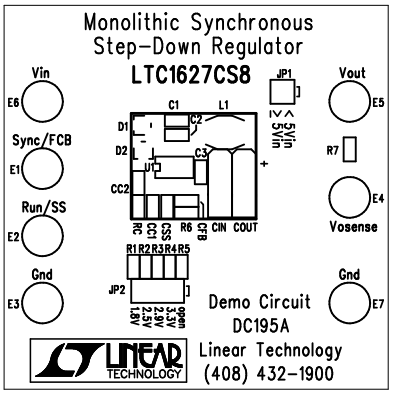
Figure 7. Remote Output Voltage Sense

OPERATION

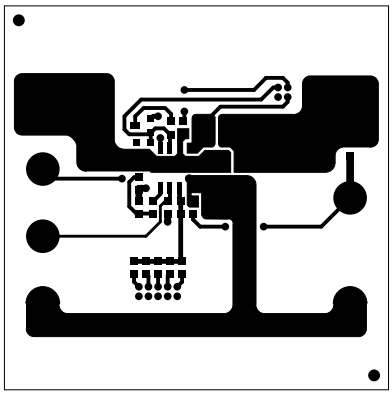
Table 2. List of Alternative Component Manufacturers

MANUFACTURER	DEVICE	PHONE	FAX
AVX	Capacitors	(803) 448-9411	(803) 448-1943
Central Semiconductor	Diodes	(516) 435-1110	(516) 435-1824
Coilcraft	Inductors	(847) 639-6400	(847) 639-1469
Coiltronics	Inductors	(561) 241-7876	(561) 241-9339
COMM CON	Connectors	(818) 301-4200	(818) 301-4212
Dale	Inductors	(605) 665-9301	(605) 665-0817
International Rectifier	Diodes	(310) 322-3331	(310) 322-3332
Motorola	Diodes	(602) 244-3576	(602) 244-4015
Murata-Erie	Capacitors	(814) 237-1431	(814) 238-0490
Sanyo	Capacitors	(619) 661-6835 (81) 0952-82-3959	(619) 661-1055 (81) 0952-82-4655
Sprague	Capacitors	(603) 224-1961	(603) 224-1430
Sumida	Inductors	(847) 956-0666 (81) 03-3607-5111	(847) 956-0702 (81) 03-3607-5114
TDK	Inductors	(847) 803-6100	(847) 803-6294
TAD	Resistors	(714) 255-9123	(714) 255-9291
Zetex	Diodes	(516) 543-7100	(516) 864-7630

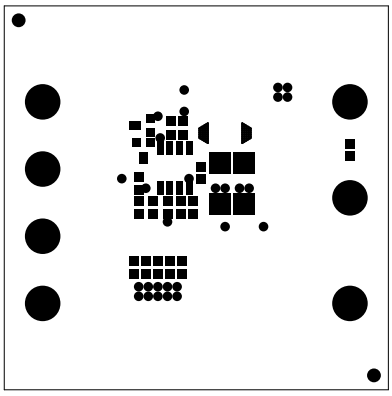
PCB LAYOUT AND FILM



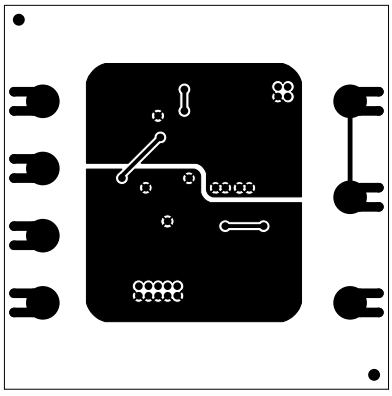
Component Side Silkscreen



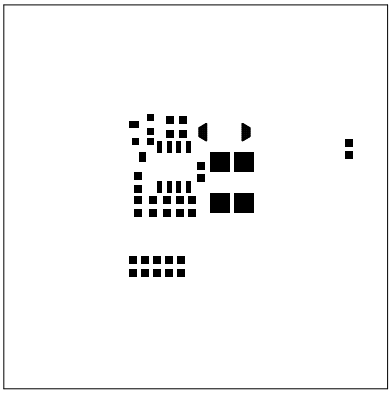
Component Side



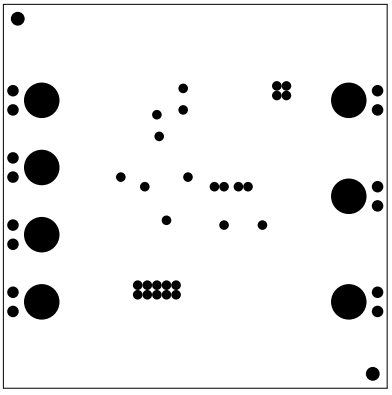
Component Side Solder Mask



Solder Side



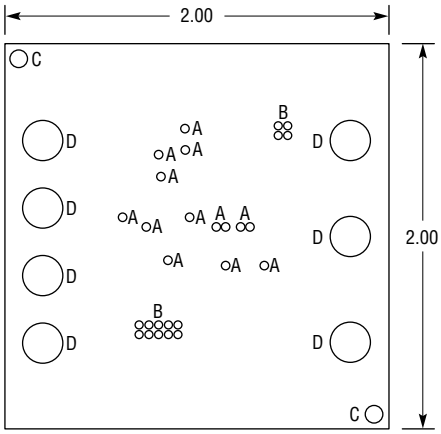
Pastemask



Solder Side Solder Mask

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.

PC FAB DRAWING



SYMBOL	DIAMETER	NUMBER OF HOLES
A	0.020	14
B	0.023	14
C	0.072	2
D	0.095	7

NOTES: UNLESS OTHERWISE SPECIFIED

1. MATERIAL: FR4 OR EQUIVALENT EPOXY, 2 OZ COPPER CLAD THICKNESS 0.062 ±0.006 TOTAL OF 2 LAYERS
2. FINISH: ALL PLATED HOLES 0.001 MIN/0.0015 MAX COPPER PLATE ELECTRODEPOSITED TIN-LEAD COMPOSITION BEFORE REFLOW, SOLDER MASK OVER BARE COPPER (SMOBC)
3. SOLDER MASK: BOTH SIDES USING SR1020 OR EQUIVALENT
4. SILKSCREEN: USING WHITE NONCONDUCTIVE EPOXY INK
5. ALL DIMENSIONS ARE IN INCHES

Linear Technology Corporation
1630 McCarthy Blvd., Milpitas, CA 95035-7417
(408)432-1900 • FAX: (408) 434-0507 • www.linear-tech.com
dc195f LT/TP 0898 500 • PRINTED IN USA
© LINEAR TECHNOLOGY CORPORATION 1998