LTC1771 Ultralow Supply Current, High Efficiency Step-Down Regulator

DESCRIPTION

Demo Board DC293 is a step-down (buck) regulator using the LTC®1771. Exclusive use of surface mount components and the LTC1771's tiny MS8 package results in a very efficient application in a small board space. Featuring outstanding light load efficiency and requiring as little as 10μA supply current to regulate the output at no load, it is ideal for cell phones and other portable electronics that have long standby times and need ultralow supply current to maximize battery life. DC293 is capable of providing 2A at various output voltages programmable from 1.8V to 5V via a jumper.

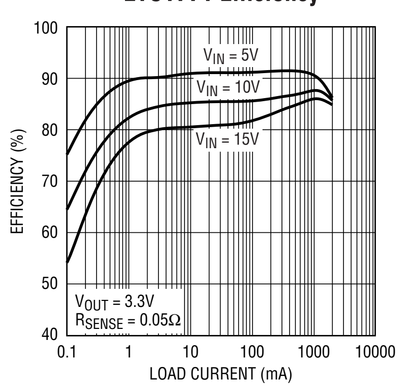
This demo board highlights the capabilities of the LTC1771, which uses a current mode, constant off-time architecture to control an external P-channel power MOSFET. This results in a high performance power supply that has low output voltage ripple and fast transient response. At low output currents, the LTC1771 automatically switches to Burst Mode™ operation to maintain high operating efficiencies and to minimize supply current. The part can be shut down to further reduce the supply current to 2μA. Its wide supply range allows operation from 2.8V to 18V. A MODE pin is provided to disable Burst Mode operation for noise-sensitive applications and soft-start is provided by an external capacitor that can also be used to properly sequence supplies. In dropout, the P-channel MOSFET is turned on continuously (100% duty cycle), providing low dropout operation with $V_{OUT} \cong V_{IN}$. **Gerber files for this circuit board are available. Call the LTC factory.**

PERFORMANCE SUMMARY

SYMBOL	PARAMETER	CONDITIONS (SEE NOTE)	BOARD SUFFIX	VALUE
V_{IN}	Input Voltage Range		A B	2.8V to 12V 4.5V to 18V
V_{OUT}	Output Voltage	I_{OUT} = 1A	A A, B A, B B	1.8V ±0.036V 2.5V ±0.050V 3.3V ±0.066V 5V ±0.10V
I_{OUT}	Maximum Output Current	R_{SENSE} = 0.05Ω	A, B	2A

TYPICAL PERFORMANCE CHARACTERISTICS AND BOARD PHOTO

LTC1771 Efficiency



PERFORMANCE SUMMARY

SYMBOL	PARAMETER	CONDITIONS	BOARD SUFFIX	VALUE
I_Q	Typical Supply Current	V_{IN} = 10V, I_{LOAD} = 0, V_{OUT} = 1.8V V_{IN} = 10V, V_{RUN} = 0	A A, B	10μA 2μA
V_{RIPPLE}	Typical Output Ripple	I_{OUT} = 1A I_{OUT} = 100mA, Burst Mode Operation Enabled I_{OUT} = 100mA, Burst Mode Operation Disabled	A, B A, B A, B	40mV 50mV 20mV
ΔV_{OUT}	Typical Line Regulation	2.8V < V_{IN} < 12V, I_{LOAD} = 1A 4.5V < V_{IN} < 18V, I_{LOAD} = 1A	A B	3mV 4mV
	Typical Load Regulation	0 < I_{LOAD} < 2A, V_{IN} = 10V 0 < I_{LOAD} < 2A, V_{IN} = 10V	A B	5mV 7mV

Note: V_{OUT} is voltage associated with the center position of JP3, unless otherwise specified.

PACKAGE AND SCHEMATIC DIAGRAMS

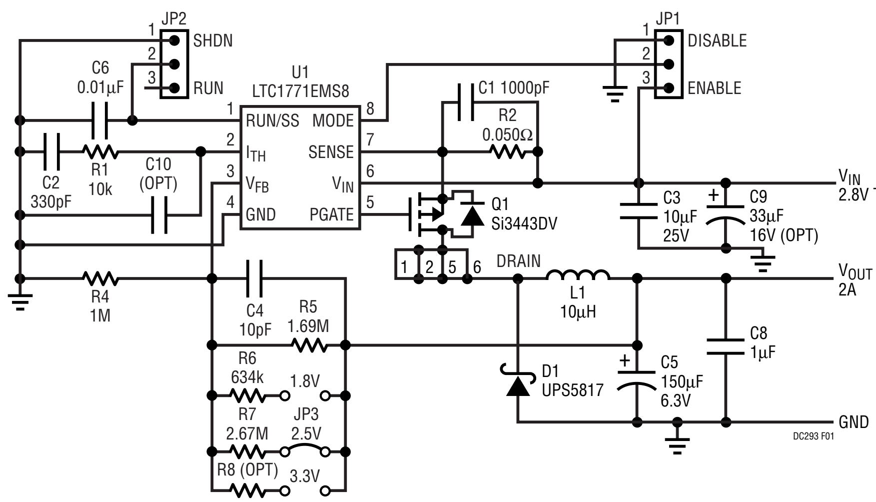
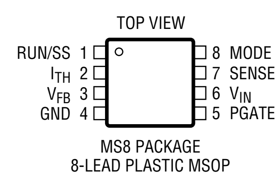


Figure 1. LTC1771 Demo Board Version A Schematic



LTC1771EMS8

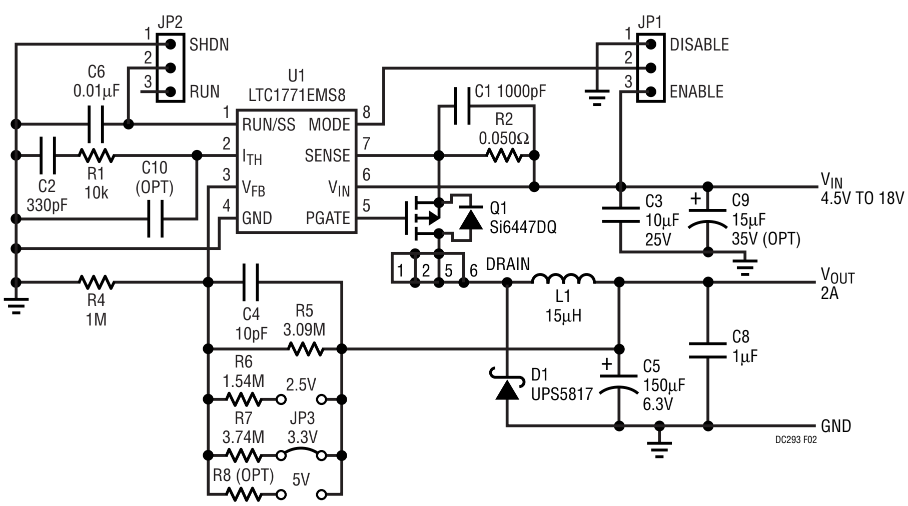


Figure 2. LTC1771 Demo Board Version B Schematic

PARTS LIST

REFERENCE DESIGNATOR	QUANTITY	PART NUMBER	DESCRIPTION	VENDOR	TELEPHONE
C1	1	06035C102KAT1A	1000pF 50V 10% X7R Capacitor	AVX	(843) 946-0362
C2	1	06035C331KAT1A	330pF 50V 10% X7R Capacitor	AVX	(843) 946-0362
C3	1	TMK432BJ106M	10µF 25V X5R Ceramic Capacitor	Taiyo Yuden	(800) 348-2496
C4	1	06033A100KAT2A	10pF 25V 10% NPO Capacitor	AVX	(843) 946-0362
C5	1	6TPB150M	150µF 6.3V 20% POSCAP Capacitor	Sanyo	(619) 661-6835
C6	1	06035C103KAT1A	0.01µF 50V 10% X7R Capacitor	AVX	(843) 946-0362
C8	1	0603ZG105KAT1A	1µF 10V 80% Y5V Capacitor	AVX	(843) 946-0362
C9	1	TPSC336M016R0300 TPSC156M035R0450	33µF 16V 20% Tantalum Capacitor, Board A 15µF 35V 20% Tantalum Capacitor, Board B	AVX	(207) 282-5111
D1	1	UPS5817	2A Schottky Diode	Microsemi	(617) 926-0404
TP1 to TP4	4	2502-02	Terminal Turret	Mill Max	(516) 922-6000
JP1, JP2	2	2802S-03-G2	2mm Pin Header	Comm Con	(626) 301-4200
JP3	1	2802S-02-G2	2mm Pin Jumper	Comm Con	(626) 301-4200
L1	1	CR75-100MC CR75-150MC	10µH Inductor, Board A 15µH Inductor, Board B	Sumida	(847) 956-0667
Q1	1	Si3443DV Si6447DQ	Sublogic Threshold 12V P-Ch MOSFET, Board A Logic Threshold 20V P-Ch MOSFET, Board B	Siliconix	(800) 554-5565
R1	1	CR16-103JM	10k 5% 0.1W 0603 Resistor	AAC	(800) 508-1521
R2	1	LR2010-01-050-F	0.05Ω 1% 0.5W 2010 Resistor	IRC	(361) 992-7900
R4	1	CR16-1004FM	1M 1% 0.1W 0603 Resistor	AAC	(800) 508-1521
R5	1	WCR0805-1694-F WCR0805-3094-F	1.69M 1% 1/16W 0805 Resistor, Board A 3.09M 1% 1/16W 0805 Resistor, Board B	AAC	(800) 508-1521
R6	1	WCR0805-6343-F WCR0805-1544-F	634k 1% 1/16W 0805 Resistor, Board A 1.54M 1% 1/16W 0805 Resistor, Board B	AAC	(714) 255-9186
R7	1	WCR0805-2674-F WCR0805-3744-F	2.67M 1% 1/16W 0805 Resistor, Board A 3.74M 1% 1/16W 0805 Resistor, Board B	AAC	(714) 255-9186
U1	1	LTC1771EMS8	Switching Regulator Controller IC	LTC	(408) 432-1900

QUICK START GUIDE

Demonstration Board DC293 is easy to set up for evaluation of the LTC1771. Please follow the procedure below for proper operation.

- Move jumper JP3 to the appropriate position for the required output voltage. For voltages other than the preset value, make sure you install the calculated resistor at the pads (see Output Voltage Setup).
- For Burst Mode operation at low load currents, move jumper JP1 to the Enable position. To disable Burst Mode operation, move the jumper to the Disable position.
- To shut down the circuit, move the jumper JP2 to the SHDN position. For normal operation, JP2 should be in the RUN position.
- Connect the input power supply to the V_{IN} and GND terminals.
- Connect the load between the V_{OUT} and GND terminals. Refer to Figure 4 for proper measurement equipment setup.

OPERATION

INTRODUCTION

The circuits shown in Figures 1 and 2 highlight the capabilities of the LTC1771. Two versions are available for two different input supply ranges due to the limited voltage ranges of the power MOSFETs. Version A is optimized for lower voltage operation (2.8V to 12V) and provides output voltages of 1.8V, 2.5V or 3.3V, selectable by the appropriate jumper position. Version B is optimized for higher voltage operation (4.5V to 18V) and provides output voltages of 2.5V, 3.3V or 5V.

The LTC1771 is a current mode switching regulator controller that drives an external P-channel power MOSFET using a constant off-time architecture. Burst Mode operation and ultralow quiescent current provide outstanding light-load efficiency, no-load supply current and enable high efficiencies for over four decades of load current range. 100% duty cycle provides low dropout operation, extending operating time in battery-operated systems.

The demonstration circuit is intended for the evaluation of the LTC1771 switching regulator IC and is not designed for any other purpose.

The LTC1771 uses the current mode, constant off-time architecture shown in Figure 3. Current mode operation provides the well known advantages of clean start-up and excellent line and load regulation. Constant off-time adds to this list simplicity (neither an oscillator nor ramp compensation are required) and inherent 100% duty cycle in dropout.

MAIN CONTROL LOOP

During normal operation, the P-channel MOSFET is turned on at the beginning of each cycle and turned off when the current comparator, C, triggers the one-shot timer. The external MOSFET switch stays off for the 3.5µs one-shot duration and then turns back on again to begin a new cycle.

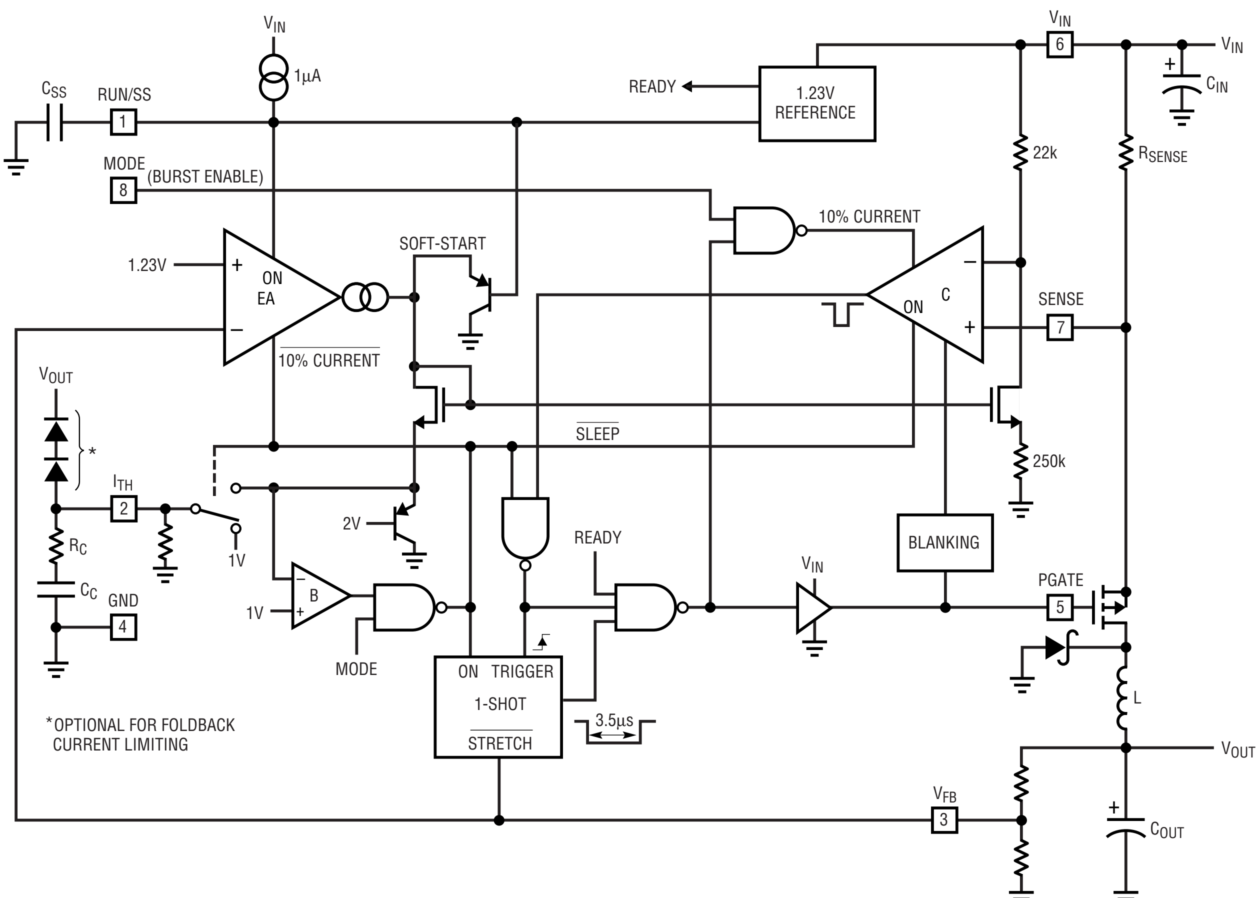


Figure 3. LTC1771 Block Diagram

OPERATION

The peak inductor current at which C triggers the one-shot is controlled by the voltage on Pin 2 (I_{TH}), the output of the error amplifier, EA. An external resistive divider connected between V_{OUT} and ground allows EA to receive an output feedback voltage, V_{FB}. When the load current increases, it causes a slight decrease in V_{FB} relative to the 1.23V reference, which, in turn, causes the I_{TH} voltage to increase until the average inductor current matches the new load current.

The main control loop is shut down by pulling Pin 1 (RUN/SS) low. Releasing RUN/SS allows an internal 1μA current source to charge the soft-start capacitor, C_{SS}. When C_{SS} reaches 1V, the main control loop is enabled with the I_{TH} voltage clamped at approximately 40% of its maximum value. As C_{SS} continues to charge, I_{TH} is gradually released, allowing normal operation to resume. C_{SS} can also be used for power supply sequencing by setting a turn-on delay equal to approximately $C_{SS}/I_{RUN/SS}$ seconds.

Burst Mode OPERATION

The LTC1771 provides outstanding low current efficiency and ultralow no-load supply current by using Burst Mode operation when Pin 8 (MODE) is pulled above 2V. Burst Mode operation commences when the load, detected by a comparator monitoring the I_{TH} voltage, falls below about 20% to 30% of the maximum load. During Burst Mode operation, short burst cycles of normal switching to charge the output capacitor are followed by a longer sleep period with the switch off and the load current supplied by the output capacitor. During this sleep period, only the minimum required circuitry—the reference voltage and the error amplifier—are left on. Supply current is further reduced with innovative new circuitry that allows the error amplifier to run on 10% of its normal operating current during sleep mode with no degradation in the transient response, reducing the total supply current to only 9μA. At light loads, the regulator spends most of the time in this low quiescent current sleep mode, thus minimizing the losses that would normally dominate (DC supply current losses and switching losses due to the MOSFET switch gate charge).

Burst Mode operation can be disabled by pulling the MODE pin to ground. Disabling Burst Mode operation allows the loads to decrease by another decade, to about 1% to 2% of the maximum load, before the regulator must skip cycles to maintain regulation. Although less efficient, disabling Burst Mode operation is useful for reducing both audio and RF interference by reducing voltage and current ripple and keeping frequency constant to lower output currents.

SHORT-CIRCUIT PROTECTION

When the output is shorted to ground, the off-time is increased in inverse proportion to V_{OUT}, to a maximum of 70μs at V_{OUT} = 0V. This increased off-time allows the inductor current to discharge, preventing runaway. Foldback current limiting can be implemented by adding two diodes in series between the output and the I_{TH} pin, as shown in Figure 3, to minimize heat dissipation in the catch diode during the short-circuit condition.

OUTPUT VOLTAGE SETUP

In this demonstration circuit, output voltages of 1.8V (version A only), 2.5V, 3.3V and 5V (version B only) can be obtained by moving the jumper JP3 to the appropriate position, as indicated on the demo board. If an output voltage other than those provided is desired, one of the feedback resistors R4, R5, R6, R7 or R8 can be removed and replaced with a new value to set the desired voltage according to the following equation:

$$V_{OUT} = 1.23(R4 + R5||RX)/R4$$

where RX is the resistor R6, R7 or R8 associated with the position of jumper JP3.

Note also that the output capacitor is rated at 6.3V; if the output voltage approaches this limit, the capacitor must be replaced with a capacitor with the proper rating (preferably twice the output voltage).

CHECKING TRANSIENT RESPONSE

Switching regulators take several cycles to respond to a step in DC (resistive) load current. When a load step occurs, V_{OUT} shifts by an amount equal to $(\Delta I_{LOAD})(ESR)$, where ESR is the effective series resistance of C_{OUT}. ΔI_{LOAD} also begins to charge or discharge C_{OUT} until the regulator loop adapts to the current change and returns V_{OUT} to its steady-state value. During this recovery time, V_{OUT} can be monitored for overshoot or ringing, which

OPERATION

would indicate a stability problem. The external components shown in Figure 1's circuit will prove adequate for most applications.

HOW TO MEASURE VOLTAGE REGULATION

When measuring voltage regulation, remember that all measurements must be taken at the point of regulation. This point is where the LTC1771's control loop looks for the information to keep the output voltage constant. On this demonstration board, it is located between Pin 5 of the LTC1771, the signal ground and the output side of R5. These points correspond to the output terminals of the demonstration board. Test leads should be attached to these terminals. Measurements **should not** be taken at the end of test leads at the load. This applies to line regulation (input-to-output voltage regulation) as well as load regulation tests. In doing line regulation tests, always look at the input voltage across the input terminals. Refer to Figure 4 for proper monitoring equipment configuration.

For the purposes of these tests, the demonstration circuit should be fed from a regulated DC bench supply so additional variation on the DC input does not add an error to the regulation measurements.

For measurement of no-load supply current and measurement of efficiency at loads below a milliamp, *the input impedance of the voltmeters may have a significant impact on these measurements*. For example, for voltmeters with 10MΩ input impedance connected to the input and output, the no-load supply current at V_{IN} = 15V will increase from 10μA with no voltmeters connected, to 11.5μA with them connected. Likewise, with V_{IN} = 15V and I_{LOAD} = 100μA,

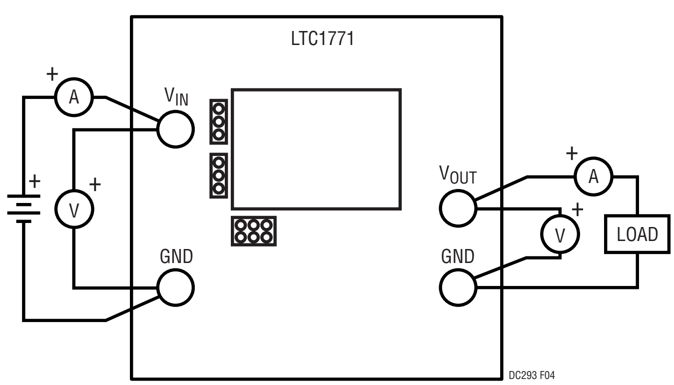


Figure 4. Correct Measurement Setup

the efficiency decreases from 55% to 53% when the voltmeters are connected. Therefore, for the most accurate measurements at light loads, first record the voltmeter readings, then disconnect the voltmeters before making the input supply current measurement.

COMPONENT CONSIDERATIONS

This demo board is designed for easy modification. It can accommodate a variety of different MOSFET footprints: TSOP-6, TSSOP-8, SO-8 (on bottom) and SOT-23, a larger catch diode and extra input/output capacitors. Component selection can be very critical in power supply applications. Be sure to refer to the LTC1771 data sheet for guidelines in selecting the external components surrounding the IC. This section highlights a few of the effects to consider when changing components to optimize or change the specifications of the demo board.

Optimizing the Inductor

When the optimal inductance value for L1 is used, the regulator has the highest efficiency and the smoothest transition between Burst Mode operation and continuous mode. The optimal inductor value is, however, dependent upon output voltage. Since the demo boards provide a selection of three output voltages, the inductor provided can only be optimized for one of the three, which is the output voltage with the jumper in the center position, i.e., 2.5V for version A and 3.3V for version B. The optimal inductance for the other output voltages can be calculated with the following equation:

$$L_{OPT} = 75\mu H(V_{OUT} + V_D)R_{SENSE}$$

Setting the Maximum Load

The demo board is equipped with a 0.05Ω resistor to set the maximum current to 2A according to the equation:

$$I_{MAX} = 0.1/R_{SENSE}$$

This resistor can be increased or decreased as necessary to program the regulator for the desired current. If the current is increased, make sure that the increased current does not exceed the ratings of the input capacitor (ripple current), the power MOSFET, Schottky diode or the inductor.

OPERATION

Minimizing No-Load Supply Current

The no-load supply current of the regulator originates from three sources: the LTC1771's 9μA sleep mode quiescent current, Schottky diode reverse leakage and feedback resistor leakage. The LTC1771's I_Q is drawn directly from the supply, whereas the Schottky and feedback resistor leakage are drawn from the output; thus their effect on the supply varies with duty ratio: from about 10μA at low duty ratios to about 15μA at higher duty ratios.

The feedback resistor leakage can be minimized by simply using large valued resistors in the megaohm range. Unfortunately, 1% resistors above 1M are currently not available in sizes smaller than 0805.

Selecting Schottky diodes with low reverse leakage current is critical, since the leakage can often approach the magnitude of the LTC1771 supply current. Selecting a low leakage Schottky diode, however, is complicated by the fact that diodes with lower reverse leakage tend to have higher forward drops. Low forward drop is critical for high current efficiency, since loss is proportional to forward drop. Thus a trade-off must be made between low no-load supply current and high efficiency. The UPS5817 used on the demo board provides a good trade-off for a 2A application.

Optional Input Capacitor

The demo board is equipped with an extra input capacitor, C9, that may not be needed in the final application but is provided for evaluating the demo board over the full input supply range. The 10μF ceramic capacitor C3 is usually sufficient for duty ratios less than about 80% but above this ratio the optional capacitor C9 is recommended. Also, when evaluating the demo board connected to a lab bench supply with typical long leads, disconnecting and reconnecting the supply may cause transients, due to the resonance of the high lead inductance with the high Q ceramic input capacitor, which may exceed the absolute maximum supply voltage of the LTC1771. The lower Q tantalum capacitor in parallel with the ceramic greatly reduces the amplitude of this resonance, eliminating this potential problem.

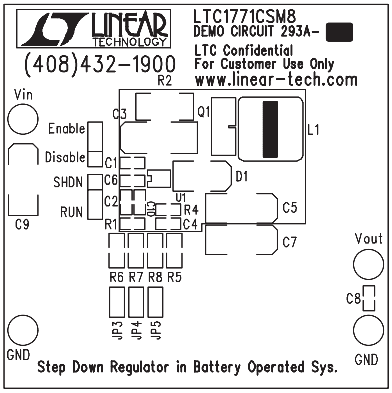
Component Manufacturers

Besides those components that are used on the demonstration board, other components may also be used. Table 1 is a partial list of the manufacturers whose components you can use for the switching regulator. Using components other than the ones on the demo board requires recharacterizing the circuit for efficiency.

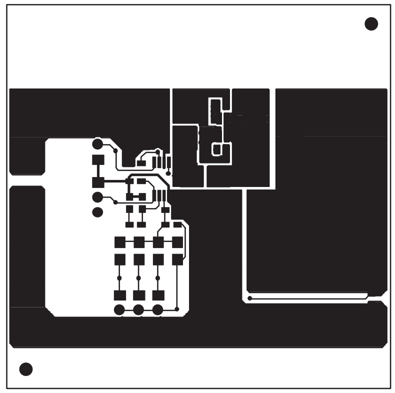
Table 1

MANUFACTURER	DEVICE	TELEPHONE	FAX
AVX	Capacitors	(843) 448-9411	(843) 448-1943
AVX	Resistors	(843) 946-0524	(843) 448-6042
Central Semiconductor	Diodes	(631) 435-1110	(631) 453-1824
Coilcraft	Inductors	(847) 639-6400	(847) 639-1469
Cooper Electronic Technology	Inductors	(561) 752-5000	(561) 742-0134
International Rectifier	MOSFETs, Diodes	(310) 322-3331	(310) 322-3332
Microsemi	Diodes	(617) 926-0404	(617) 924-1235
ON Semiconductor	MOSFETs, Diodes	(602) 244-6600	(602) 244-3345
Murata-Erie	Capacitors	(770) 436-1300	(814) 238-0490
Sanyo	Capacitors	(619) 661-6835	(619) 661-1055
Vishay	Inductors	(605) 665-9301	(605) 665-0817
Vishay Siliconix	MOSFETs	(408) 988-8000	(408) 567-8977
Sprague	Capacitors	(207) 324-4140	(207) 324-7223
Sumida	Inductors	(847) 956-0667	(847) 956-0702
TDK	Inductors	(847) 803-6100	(847) 803-6294
Zetex	Diodes	(631) 543-7100	(631) 864-7630

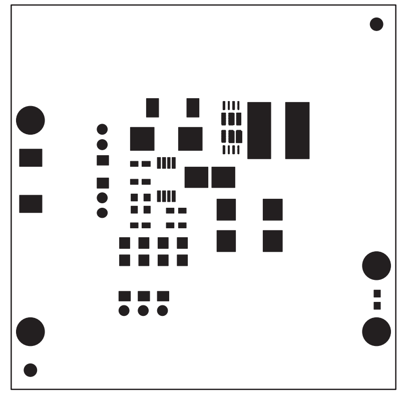
PCB LAYOUT AND FILM



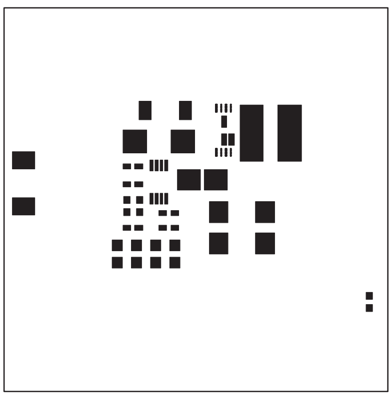
Component Side Silkscreen



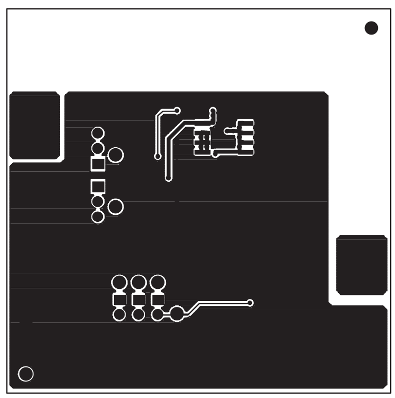
Component Side



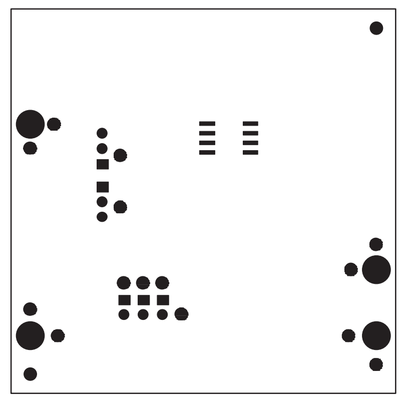
Component Side Solder Mask



Component Side Paste Mask

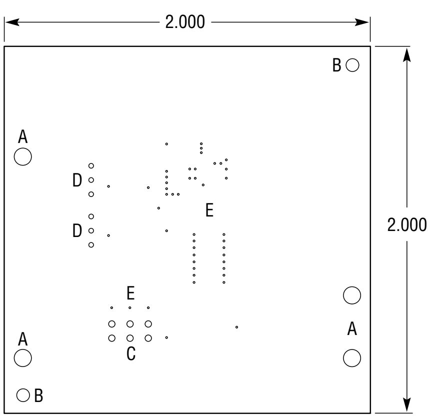


Solder Side



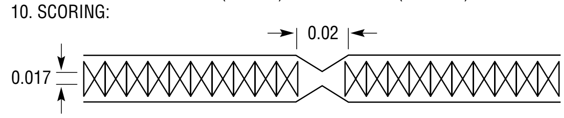
Solder Side Solder Mask

PC FAB DRAWING



SYMBOL	DIAMETER	NUMBER OF HOLES	PLTD
A	0.094	4	PLTD
B	0.070	2	NPLTD
C	0.035	6	PLTD
D	0.026	6	PLTD
E	0.010	47	PLTD
	TOTAL HOLES	65	

NOTES: UNLESS OTHERWISE SPECIFIED
1. MATERIAL: 2 LAYERS, 0.062" THK. FR-4 GLASS EPOXY 2 OZ COPPER CLAD
2. ALL HOLES SHALL BE PLATED THRU
3. PLATE THRU HOLES WITH COPPER 0.0014 MIN. THICKNESS ALL HOLE SIZES IN HOLE TABLE ARE AFTER PLATING
4. SILKSCREEN: WITH WHITE NONCONDUCTIVE EPOXY INK
5. NO SILKSCREEN ALLOWED ON PAD LANDS
6. SOLDERMASK: LPI, GREEN
7. NO BLOCK SOLDERMASKING OF PAD ROWS
8. DO NOT MAKE CHANGES ON SILKSCREEN, SUCH AS COMPANY LOGO, QC STAMPS
9. DO NOT PLATE TOOLING (3 PLCS) AND SCORING (26 PLCS) HOLES
10. SCORING:



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dc293 LT/TP 0900 500 • PRINTED IN USA