

# LTC1435 Constant Frequency Synchronous DC/DC Converter

## DESCRIPTION

Demonstration Circuit 094 is a constant frequency step-down (buck) regulator implemented entirely in surface mount using the LTC<sup>®</sup>1435 switching regulator controller. The output voltage is programmable from 1.8V to 5V via a jumper. The input voltage can range from 4.5V to 28V (limited by the external MOSFETs). The circuit highlights the capabilities of the LTC1435 which uses a current mode, constant frequency architecture to switch a pair of N-channel power MOSFETs while providing 99% maximum duty cycle. Operating efficiencies exceeding 90% are obtained.

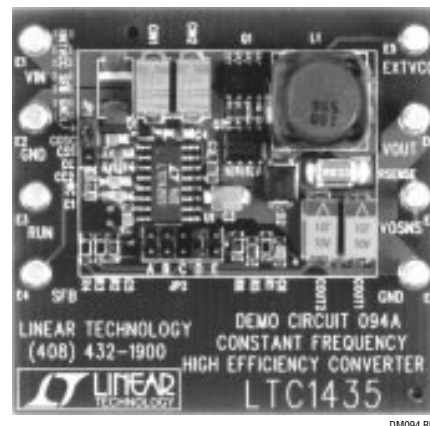
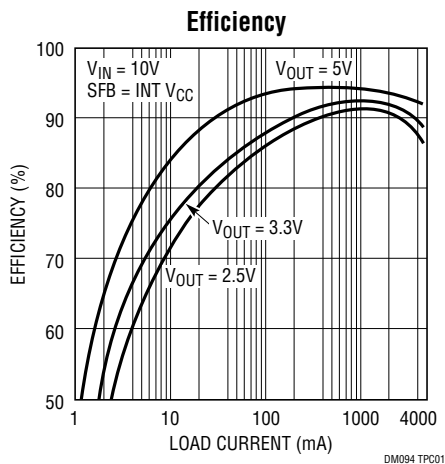
This results in a power supply that has very high efficiency, low ripple and fast transient response. At low output currents the LTC1435 automatically switches to Burst Mode<sup>™</sup> operation to reduce switching losses and maintain high operating efficiencies. Additionally, the supply current can be shut down to less than 20 $\mu$ A with an input voltage of 10V. This feature is an absolute necessity to maximize battery life in portable applications. **Gerber files for this circuit board are available. Call the LTC factory.**

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

## PERFORMANCE SUMMARY Operating Temperature Range 0°C to 50°C

Input Voltage Range	Maximum Input Voltage (Limited by External MOSFET and Input Capacitor)	4.5V to 28V
Output	Output Voltage (Jumper Selectable)	1.8V, 2.5V, 2.9V, 3.3V, 5V
	Maximum Output Current (Continuous)	3A
	Maximum Output Current (Peak)	3.5A
	Typical Output Ripple at 10MHz Bandwidth (Burst Mode Operation) $I_O = 100\text{mA}$	50mV <sub>p-p</sub>
	Typical Output Ripple at 10MHz Bandwidth (Continuous) $I_O = 1\text{A}$	35mV <sub>p-p</sub>
$V_{IN}$	Line Regulation, 6V to 20V	0.002%/V
$I_{OUT}$	Load Regulation, No Load to Full Rated Output	-1%
$I_Q$	Supply Current with No Load at 10V Input (Typical), SFB = INT $V_{CC}$ , EXT $V_{CC} = 5\text{V}$	50 $\mu$ A
	Supply Current in Shutdown (Typical), $V_{IN} = 10\text{V}$	15 $\mu$ A
$I_{EXTVCC}$	EXT $V_{CC}$ Pin Current, $V_{EXTVCC} = 5\text{V}$ , $V_{IN} = 10\text{V}$ , No Load	650 $\mu$ A
$V_{RUN}$	Run Pin Threshold (Typical)	1.3V
Frequency	Operating Frequency (Typical), $C_{OSC} = 68\text{pF}$	170kHz

## TYPICAL PERFORMANCE CHARACTERISTICS AND BOARD PHOTO



## PACKAGE A ID SCHEMATIC DIAGRAMS

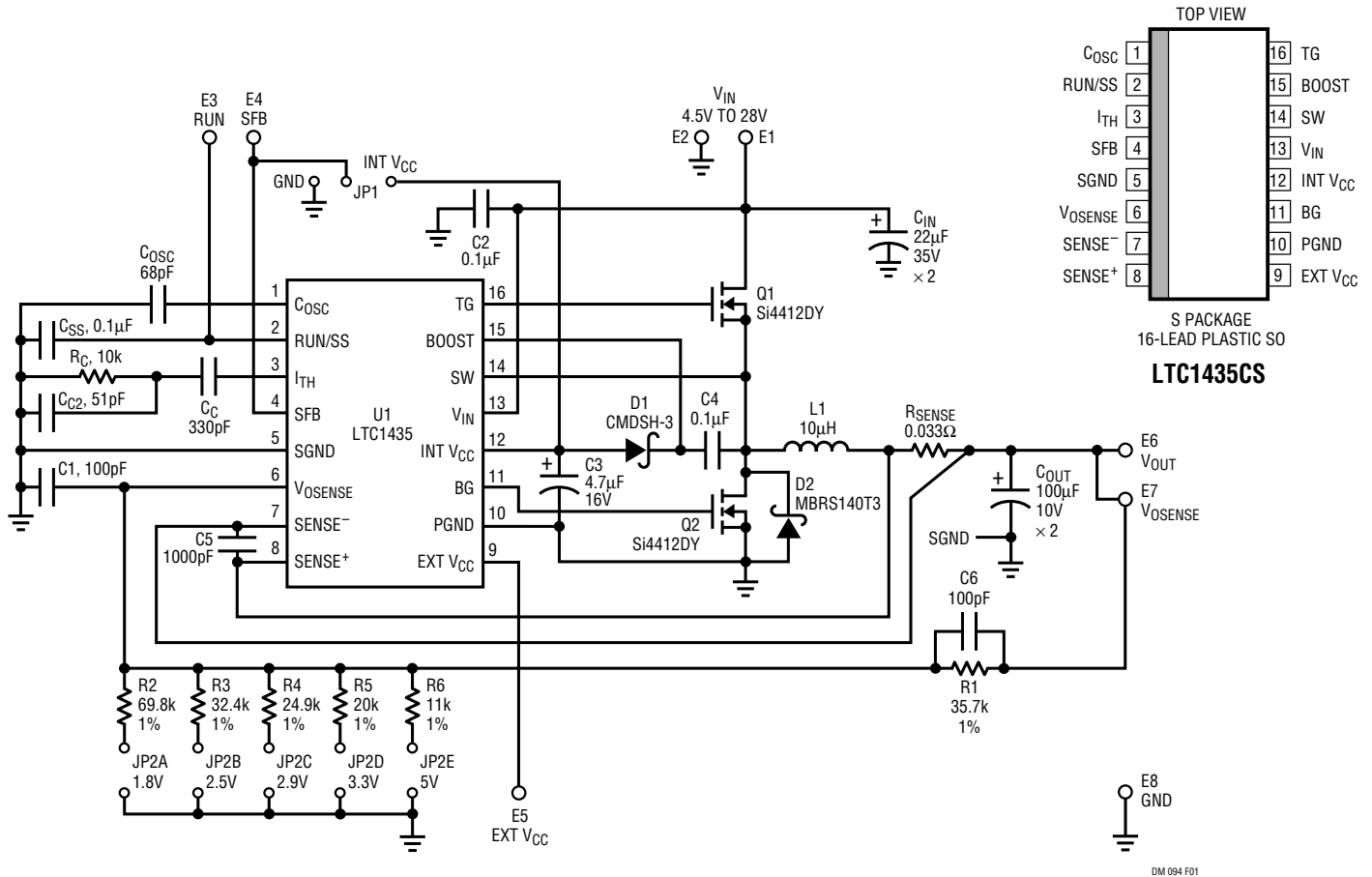


Figure 1. LTC1435 Constant Frequency, High Efficiency Converter

## PARTS LIST

REFERENCE DESIGNATOR	QUANTITY	PART NUMBER	DESCRIPTION	VENDOR	TELEPHONE
C <sub>C</sub>	1	08055A331KAT1A	330pF 50V 10% NPO Chip Capacitor	AVX	(803) 448-9411
C <sub>C2</sub>	1	08055A510KAT1A	51pF 50V 10% NPO Chip Capacitor	AVX	(803) 448-9411
C <sub>IN1</sub> , C <sub>IN2</sub>	2	TPSE226M035	22μF 35V 20% Tantalum Capacitor	AVX	(803) 448-9411
C <sub>OSC</sub>	1	08055A680JAT1A	68pF 50V 5% NPO Chip Capacitor	AVX	(803) 448-9411
C <sub>OUT1</sub> , C <sub>OUT2</sub>	2	TPSD107M010R0080	100μF 10V 20% Tantalum Capacitor	AVX	(803) 448-9411
C1, C6	2	08055A101KAT1A	100pF 50V 10% NPO Chip Capacitor	AVX	(803) 448-9411
C2, C4, C <sub>SS</sub>	3	08055G104KAT1A	0.1μF 50V 10% Y5V Chip Capacitor	AVX	(803) 448-9411
C3	1	TAJB475M016	4.7μF 16V 20% Tantalum Capacitor	AVX	(803) 448-9411
C5	1	08055C102KAT1A	1000pF 50V 10% X7R Chip Capacitor	AVX	(803) 448-9411
D1	1	CMDSH-3	BVR = 30V Schottky Diode	Central	(516) 435-1110
D2	1	MBRS140T3	BVR = 40V Schottky Diode	Motorola	(602) 244-3576
E1 to E8	8	1502-2	Turret Terminal	Keystone	(718) 956-8900

## PARTS LIST

REFERENCE DESIGNATOR	QUANTITY	PART NUMBER	DESCRIPTION	VENDOR	TELEPHONE
JP1	1	2802S-03-G2	2mm Pin Header	Comm Con	(818) 301-4200
JP2	1	2802S-10-G2	2mm Pin Header	Comm Con	(818) 301-4200
L1	1	CDRH125-10 CDRH127-10	10 $\mu$ H Inductor 10 $\mu$ H Inductor (Alternate)	Sumida Sumida	(708) 956-0666
Q1, Q2	2	Si4412DY	N-Channel MOSFET	Siliconix	(800) 554-5565
R1	1	CR21-3572F-T	35.7k 1/10W 1% Chip Resistor	AVX	(803) 448-9411
R2	1	CR21-6982F-T	69.8k 1/10W 1% Chip Resistor	AVX	(803) 448-9411
R3	1	CR21-3242F-T	32.4k 1/10W 1% Chip Resistor	AVX	(803) 448-9411
R4	1	CR21-2492F-T	24.9k 1/10W 1% Chip Resistor	AVX	(803) 448-9411
R5	1	CR21-2002F-T	20k 1/10W 1% Chip Resistor	AVX	(803) 448-9411
R6	1	CR21-1102F-T	11k 1/10W 1% Chip Resistor	AVX	(803) 448-9411
R <sub>C</sub>	1	CR21-103J-T	10k 1/10W 5% Chip Resistor	AVX	(803) 448-9411
R <sub>SENSE</sub>	1	LR2010-01-R033-F	0.033 $\Omega$ 1/2W 1% Resistor	IRC	(512) 992-7900
U1	1	LTC1435CS	16-Lead Narrow Small Outline IC	LTC	(408) 432-1900
	2	CCIJ2mm-138-G	Jumper	Comm Con	(818) 301-4200

## QUICK START GUIDE

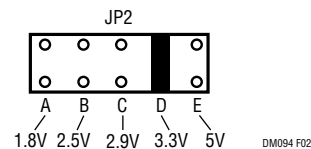
This demonstration board is easy to set up to evaluate the performance of the LTC1435. Please follow the procedure outlined below for proper operation.

1. Refer to Figure 3 for proper arrangement of monitoring equipment for correct measurement equipment setup.
2. Connect the input power supply to the V<sub>IN</sub> and GND terminals on the left-hand side of the board. Do not increase V<sub>IN</sub> over 28V or the MOSFET(s) *will be damaged*. At lower output voltages (V<sub>OUT</sub>  $\leq$  2.5V) the maximum input voltage must be decreased. See Table 1.
3. Connect the load between the V<sub>OUT</sub> and GND terminals on the right side of the board.
4. The RUN pin can be left unconnected. To shut down the LTC1435 tie this pin to ground.
5. When the 5V output voltage option is selected externally connect EXT V<sub>CC</sub> to V<sub>OUT</sub>.
6. Set the jumper JP1 so that SFB is connected to INT V<sub>CC</sub>.

7. Set the desired output voltage with jumper JP2 shown in Figure 2 and Table 1.

**Table 1. Maximum Allowable Input Voltage vs Selected Output Voltage**

POSITION	OUTPUT VOLTAGE	MAXIMUM INPUT VOLTAGE
A	1.8V	18V
B	2.5V	24V
C	2.9V	28V
D	3.3V	28V
E	5V	28V



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

## INTRODUCTION

The circuit in Figure 1 highlights the capabilities of the LTC1435. The application circuit is set up for a variety of output voltages. Output voltages from 1.8V to 5V are available by selecting the appropriate jumper position.

The LTC1435 is a synchronous step-down switching regulator controller which drives external N-channel power MOSFETs using a fixed frequency architecture. Burst Mode operation provides high efficiency at low load currents. Operating efficiencies typically exceed 90% over three decades of load current range. A maximum high duty

cycle limit of 99% provides low dropout operation which extends operating time in battery-operated systems.

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

This demonstration unit is intended for the evaluation of the LTC1435 switching regulator IC and was not designed for any other purpose.

---

## OPERATION

The operating frequency is set by an external capacitor  $C_{OSC}$ , allowing maximum flexibility in optimizing efficiency. In this application the frequency is set to 170kHz. A secondary winding feedback control pin SFB inhibits Burst Mode which reduces noise and RF interference.

Soft start is provided by an external capacitor  $C_{SS}$  which can be used to properly sequence supplies. The operating current level is user-programmable via an external current sense resistor and is set to 3A. Short-circuit current limit is set approximately to 4A.

This demo board is optimized for 3.3V outputs. A wide input supply range allows operation from 4.5V to 28V for  $V_{OUT}$  voltages of 3.3V and 5V. Because this board allows for a wide output voltage range (1.8V to 5V) and the operating frequency remains constant at 170kHz, there is a duty cycle induced limit on the maximum input voltage when low output voltages are selected ( $V_{OUT} < 2.9V$ ). This is necessary for an adequate turn-on time for the top MOSFET with the required duty cycle at a given frequency. If a higher input supply voltage is required together with low output voltage, the operating frequency can be decreased by increasing  $C_{OSC}$ .

### Main Control Loop

The LTC1435 uses a constant frequency, current mode step-down architecture. Current mode operation was judged to be mandatory for its well-known advantages of

clean start-up, accurate current limit and excellent line and load regulation.

During normal operation, the top MOSFET is turned on each cycle when the oscillator sets a latch and turned off when the main current comparator resets the latch. The peak inductor current is controlled by the voltage on the  $I_{TH}$  pin, which is the output of error amplifier EA.

The  $V_{OSENSE}$  pin allows EA to receive an output feedback voltage  $V_{FB}$  from an external resistive divider. When the load current increases, it causes a slight decrease in  $V_{FB}$  relative to the 1.19V 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 MOSFET is turned on until either the inductor current starts to reverse or the beginning of the next cycle.

The top MOSFET driver is biased from floating bootstrap capacitor C4, which normally is recharged during each off cycle. However, when  $V_{IN}$  decreases to a voltage close to  $V_{OUT}$ , the loop may enter dropout and attempt to turn on the top MOSFET continuously. The dropout detector counts the number of oscillator cycles that the top MOSFET remains on and periodically forces a brief off period to allow C4 to recharge.

A built-in comparator guards against transient overshoots  $> 7.5\%$  by turning off the top MOSFET and keeping it off until the fault is removed.

## OPERATION

### Low Current Operation

The LTC1435 is capable of Burst Mode operation in which the external MOSFETs operate intermittently based on load demand. If the voltage across  $R_{SENSE}$  does not exceed approximately 20mV for one full cycle, then on following cycles the top and bottom drives are disabled. This continues until the  $I_{TH}$  voltage exceeds 0.6V, which causes drive to be returned to the top MOSFET on the next cycle.

Two conditions can force continuous synchronous operation, even when the load current would otherwise dictate low current operation. One is when the common mode voltage of the Sense+ and Sense- pins is below 1.4V, and the other is when the SFB pin is below 1.19V. See the SFB pin function description.

### INT $V_{CC}$ /EXT $V_{CC}$ Power

Power for the top and bottom MOSFET drivers and most of the other LTC1435 circuitry is derived from INT  $V_{CC}$  pin. When the EXT  $V_{CC}$  pin is left open, an internal 5V low dropout regulator supplies INT  $V_{CC}$  power. If EXT  $V_{CC}$  is taken above 4.7V, the 5V regulator is turned off and an internal switch is turned on to connect EXT  $V_{CC}$  to INT  $V_{CC}$ . This allows the INT  $V_{CC}$  power to be derived from a high efficiency external source such as the output of the regulator itself or a secondary winding, as described in the LTC1435 data sheet.

When the 5V output voltage option is selected (JP2E installed) the EXT  $V_{CC}$  pin should be externally connected to  $V_{OUT}$ .

### 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 LTC1435's control loop looks for the information to keep the output voltage constant. In this demonstration board this information point occurs between Pin 5 of the LTC1435, the signal ground, and the output side of R1. These points correspond to the  $V_{OSENSE}$  (E7) terminal of the board. Output voltage test leads should be attached directly to this

terminal. The load should be placed across  $V_{OUT}$  (E6) to GND (E8). Measurements *should not* be taken at the end of test leads at the load. Refer to Figure 3 for the proper monitoring equipment configuration.

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.

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.

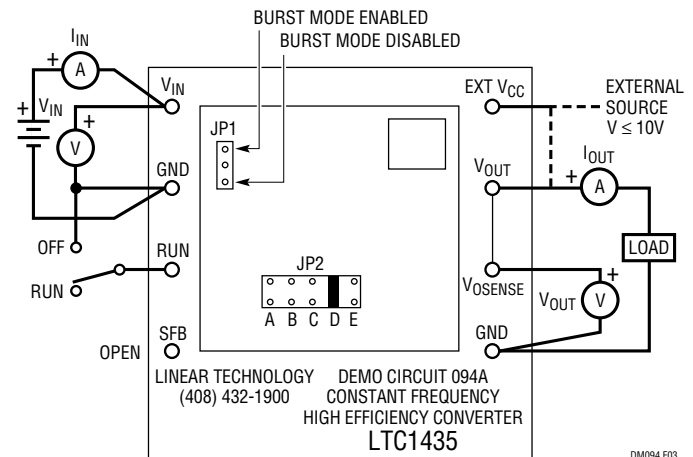


Figure 3. Proper Measurement Setup

### 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 4. An external connection from  $V_{OSENSE}$  directly across the load must be made. To prevent uncertainty, solder a 10 $\Omega$  resistor across the  $V_{OUT}$  and  $V_{OSENSE}$  terminals. Never, under any circumstance, allow  $V_{OSENSE}$  to float!

## OPERATION

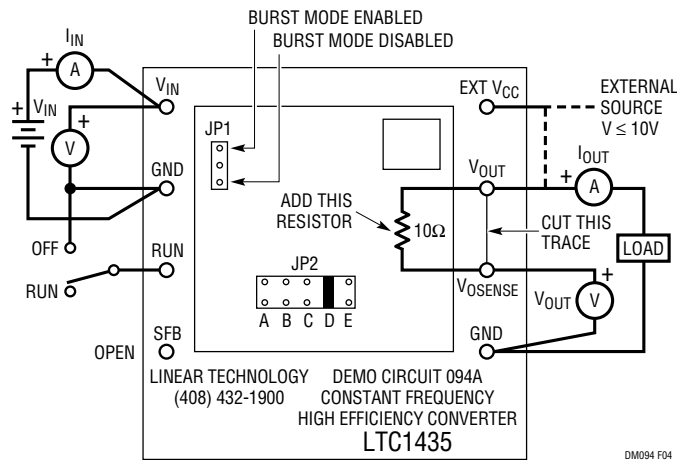


Figure 4. Remote Output Voltage Sense

### INT V<sub>CC</sub> Regulator

An internal P-channel low dropout regulator produces the 5V supply which powers the drivers and internal circuitry within the LTC1435. The INT V<sub>CC</sub> pin can supply up to 15mA (this includes the gate drive currents). External loading of the INT V<sub>CC</sub> pin may be up to 10mA. At high input voltages the maximum junction temperature rating for the LTC1435 may be exceeded if too large an external load is placed on INT V<sub>CC</sub>. See the LTC1435 data sheet for further details.

### EXT V<sub>CC</sub> Connection

The LTC1435 contains an internal P-channel MOSFET switch connected between the EXT V<sub>CC</sub> and INT V<sub>CC</sub> pins. The switch closes and supplies the INT V<sub>CC</sub> power whenever the EXT V<sub>CC</sub> pin is above 4.7V and remains closed until EXT V<sub>CC</sub> drops below 4.5V. This allows the MOSFET driver and control power to be derived from the output during normal operation ( $4.7V < V_{OUT} \leq 9V$ ) and from the internal regulator when the output is out of regulation (start-up, short circuit). Do not apply greater than 10V to the EXT V<sub>CC</sub> pin and ensure that  $EXT V_{CC} \leq V_{IN}$ .

Significant efficiency gains can be realized by powering INT V<sub>CC</sub> from the output, since the V<sub>IN</sub> current resulting from the driver and control currents will be scaled by a factor of (Duty Cycle)/(Efficiency). For 5V regulators this simply means connecting the EXT V<sub>CC</sub> pin directly to V<sub>OUT</sub>.

However, for 3.3V and other lower voltage regulators, additional circuitry is required to derive INT V<sub>CC</sub> power from the output.

The following list summarizes the four possible connections for EXT V<sub>CC</sub>:

1. EXT V<sub>CC</sub> Left Open (or Grounded). This will cause INT V<sub>CC</sub> to be powered from the internal 5V regulator resulting in an efficiency penalty of up to 10% at high input voltages.
2. EXT V<sub>CC</sub> Connected Directly to V<sub>OUT</sub>. This is the normal connection for a 5V regulator and provides the highest efficiency.
3. EXT V<sub>CC</sub> Connected to an Output-Derived Boost Network. For 3.3V and other low voltage regulators, efficiency gains can still be realized by connecting EXT V<sub>CC</sub> to an output-derived voltage which has been boosted to greater than 4.7V. See the LTC1435 data sheet for further details.
4. EXT V<sub>CC</sub> Connected to an External Supply. If an external supply is available in the 5V to 10V range ( $EXT V_{CC} \leq V_{IN}$ ), it may be used to power EXT V<sub>CC</sub> providing an efficiency boost.

### SFB Pin Function (Burst Mode Disable)

When the SFB (E4) pin drops below its ground-referenced 1.19V threshold, continuous mode operation is forced (Burst Mode is inhibited). In continuous mode the N-channel main and synchronous switches are continuously switched irrelevant of the load on the main output. This reduces noise and interference but impacts efficiency. Jumper JP1 sets the voltage on SFB and is set as follows:

SFB	Condition
GND	Burst Mode Inhibited
INT V <sub>CC</sub>	Burst Mode Enabled

In addition to providing a logic input to force continuous synchronous operation, the SFB pin provides a means to regulate a flyback winding output. See the LTC1435 data sheet for additional information.

## OPERATION

When the SFB pin is left floating (no jumper installed at J1) Burst Mode is enabled. *Do not apply an external voltage to SFB (E4) when the jumper JP1 is installed!*

### Run/Soft Start Function

The Run/SS pin (E3) is a dual purpose pin which provides the soft start function and a means to shut down the LTC1435. 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  $3\mu\text{A}$  current source charges up an external capacitor  $C_{SS}$ . When the voltage on Run/SS reaches 1.3V the LTC1435 begins operating. As the voltage on Run/SS continues to ramp from 1.3V to 2.4V, the internal current limit is also ramped at a proportional linear rate. The current limit begins at approximately  $50\text{mV}/R_{SENSE}$  (at  $V_{RUN/SS} = 1.3\text{V}$ ) and ends at  $150\text{mV}/R_{SENSE}$  ( $V_{RUN/SS} \leq$

2.7V). The output current thus ramps up slowly, charging the output capacitor. If Run/SS has been pulled all the way to ground there is a delay before starting of approximately  $500\text{ms}/\mu\text{F}$ , followed by an additional  $500\text{ms}/\mu\text{F}$  to reach full current.  $C_{SS} = 0.1\mu\text{F}$  on this PC board.

Pulling the Run/SS pin below 1.3V puts the LTC1435 into a low quiescent current shutdown ( $I_Q < 20\mu\text{A}$ ). The Run/SS pin has an internal 6V Zener clamp (see the data sheet for further information).

### Component Manufacturers

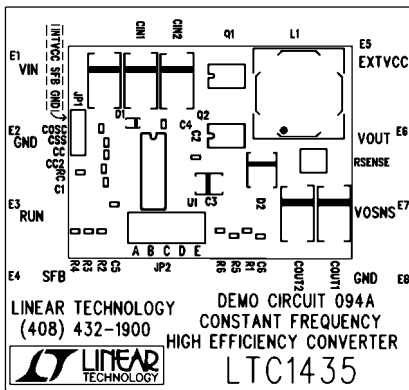
Following is a partial list of component manufacturers which can be used in LTC1435 applications. Using components other than the ones supplied on the demonstration board will require careful analysis to verify that all component specifications are not exceeded. Finally, re-characterizing the circuit for efficiency is necessary.

MANUFACTURER	DEVICE	TELEPHONE	FAX
AVX	Capacitors	(803) 448-9411	(803) 448-1943
Central Semiconductor	Diodes	(516) 435-1110	(516) 435-1824
Coilcraft	Inductors	(708) 639-6400	(708) 639-1469
Coiltronics	Inductors	(407) 241-7876	(407) 241-9339
Comm Con	Connectors	(818) 301-4200	(818) 301-4212
Dale	Inductors/Sense Resistors	(605) 665-9301	(605) 665-0817
International Rectifiers	MOSFETs/Diodes	(310) 322-3331	(310) 322-3332
IRC	Sense Resistors	(512) 992-7900	(512) 992-3377
KRL	Sense Resistors	(603) 668-3210	(603) 624-0634
Motorola	MOSFETs/Diodes	(602) 244-3576	(602) 244-4015
Murata-Erie	Capacitors	(770) 436-1300	(770) 436-3030
Sanyo	Capacitors/MOSFETs	(619) 661-6835 [81] 0952-82-3959	(619) 661-1055 [81] 0952-82-4655
Siliconix	MOSFETs	(800) 554-5565	(408) 970-3979
Sprague	Capacitors	(603) 224-1961	(603) 224-1430
Sumida	Inductors	(708) 956-0666 [81] 03-3607-5111	(708) 956-0702 [81] 03-3607-5144
TDK	Inductors	(708) 803-6100	[81] 03-3278-5358

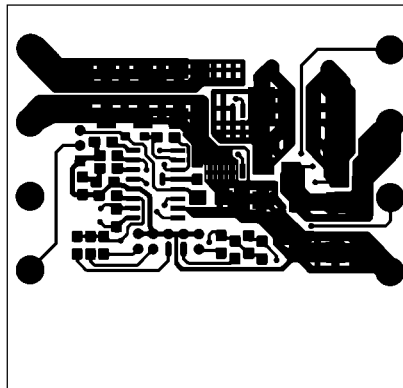
# DEMO MANUAL DC094

## DESIGN READY SWITCHER

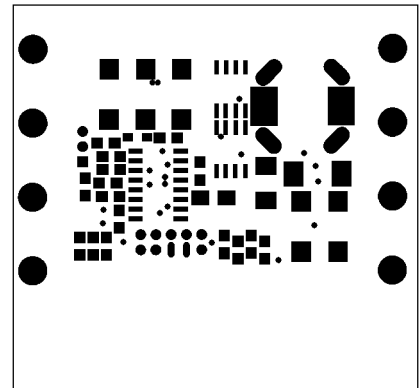
### PCB LAYOUT AND FILM



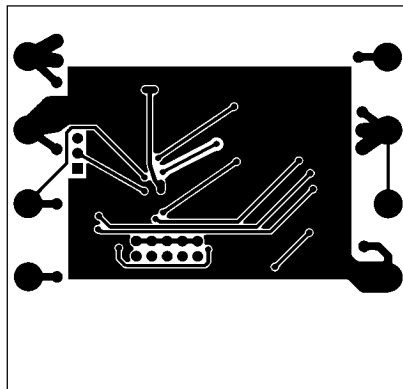
Component Side Silkscreen



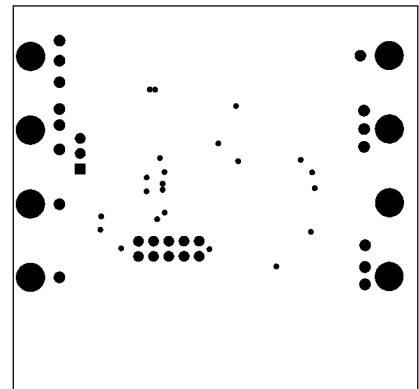
Component Side



Component Side Solder Mask

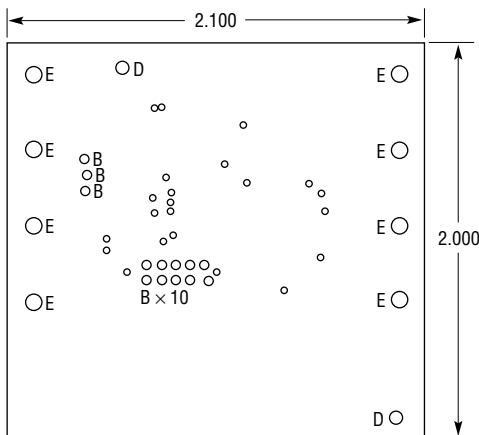


Solder Side



Solder Side Solder Mask

### PC FAB DRAWING



#### HOLE CHART

SYMBOL	DIAMETER	# OF HOLES	PLATED
A	0.125	3	NO
B	0.030	260	YES
C	0.094	22	NO
D	0.070	40	NO
E	0.094	160	YES
UNMARKED	0.018	440	YES
TOTAL HOLES		945	

#### NOTES:

1. MATERIAL IS FR4, 0.062" WITH 2 OZ COPPER
2. PCB WILL BE DOUBLE SIDED WITH PLATED THROUGH HOLES
3. HOLE SIZES ARE AFTER PLATING. PLATED THROUGH HOLE WALL THICKNESS MIN 0.0014" (1 OZ)
4. USE PADMASTER PROCESS
5. SOLDER MASK BOTH SIDES WITH PC401 USING FILM PROVIDED
6. SILKSCREEN COMPONENT SIDE USING FILM PROVIDED. USE WHITE, NONCONDUCTIVE INK
7. ALL DIMENSIONS ARE IN INCHES  $\pm 0.005$
8. ALL PANELS IN ORDER MUST BE THE SAME DIMENSIONS  $\pm 0.030$ "
9. DO NOT PLATE TOOLING HOLES - 0.125
10. DO NOT PLATE SCORING HOLES (22 HOLES 0.094 AT PANEL EDGE) DO NOT PLATE ALIGNMENT HOLES - 40 HOLES 0.070"
11. SCORE BOTH SIDES LEAVING 0.017 - 0.002 + 0.000 THICKNESS
12. ALL HOLE SIZES AFTER PLATING + 0.003/- 0.