

# LT1317/LT1317B

## Micropower, 600kHz PWM DC/DC Converters

### DESCRIPTION

Demonstration Circuit DC194 is a micropower boost regulator that converts an input as low as 1.5V to an output of 3.3V or 5.0V. DC194 version A uses the LT<sup>®</sup>1317CMS8; version B uses the LT1317BCMS8. This circuit provides regulated power for battery-powered devices, such as laptop and palmtop computers, cellular phones, pagers, LCD panels and other portable devices. It is also useful for local conversion of logic supplies, such as 3.3V to 5V conversion in PC card devices.

The LT1317 and LT1317B are 600kHz PWM DC/DC converters. Their high operating frequency and small package

result in small, cost effective solutions. The micropower LT1317 shifts automatically to low power Burst Mode<sup>™</sup> operation at light loads, whereas the LT1317B operates at a fixed frequency at all loads. Both parts feature a low-battery detector that remains active while the part is shut down. The wide voltage ratings (12V input and 30V switch) make the LT1317 and LT1317B versatile parts, suitable for implementing boost, flyback and SEPIC topologies.

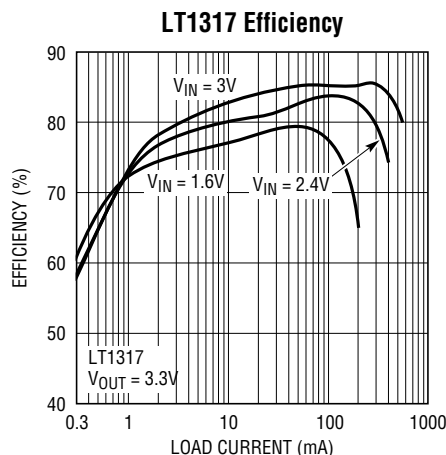
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Burst Mode is a trademark of Linear Technology Corporation.

### PERFORMANCE SUMMARY

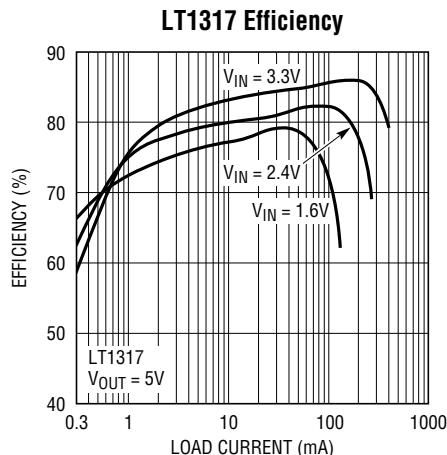
PARAMETER	CONDITIONS	VALUE
Input Voltage (Note 1)	$V_{OUT} = 3.3V$ $V_{OUT} = 5V$	1.5V to 3.6V 1.5V to 5.3V
Maximum Load Current, Min	$V_{OUT} = 3.3V, V_{IN} = 1.6V$ $V_{OUT} = 3.3V, V_{IN} = 2.4V$ $V_{OUT} = 5V, V_{IN} = 2V$ $V_{OUT} = 5V, V_{IN} = 3.3V$	175mA 320mA 140mA 290mA
Shutdown Current, Typ	$V_{IN} = 2.5V, \overline{SHDN} = 0V$	25 $\mu A$
No Load Quiescent Current, Typ	$V_{OUT} = 3.3V, V_{IN} = 2.4V$ , LT1317 $V_{OUT} = 3.3V, V_{IN} = 2.4V$ , LT1317B	125 $\mu A$ 4.8mA

**Note 1:** This limit is based on the DC194 circuit. The LT1317 can operate from high supply voltages.

### TYPICAL PERFORMANCE CHARACTERISTICS AND BOARD PHOTO

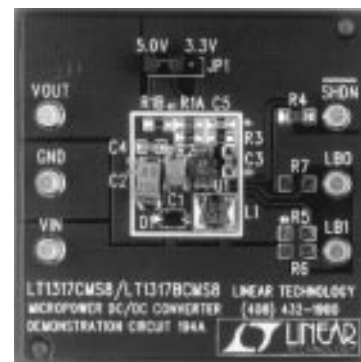


DC194 G04



DC194 G03

**Board Photo**



DC194 BP



### PARTS LIST

REFERENCE DESIGNATOR	QUANTITY	PART NUMBER	DESCRIPTION	VENDOR	TELEPHONE
C1	1	TPSB226M010R0700	22 $\mu$ F 10V 20% Tantalum Capacitor	AVX	(207) 282-5111
C2	1	TPSC107M006R0150	100 $\mu$ F 6.3V 20% Tantalum Capacitor	AVX	(207) 282-5111
C3	1	0805YG332KAT2	3300pF 16V Y5V 0805 Capacitor	AVX	(843) 946-0362
C4	1	08053G104KAT2	0.1 $\mu$ F 25V Y5V 0805 Capacitor	AVX	(843) 946-0362
C5	1	0805YG101KAT2	100pF 16V Y5V 0805 Capacitor	AVX	(843) 946-0362
D1	1	MBR0520LT1	20V 0.5A SOD123 Schottky Diode	Motorola	(800) 441-2447
L1	1	CD43-100MC	10 $\mu$ H CD43 Inductor	Sumida	(847) 956-0666
R1A	1	CR10-6043F-T	604k 1/10W 1% 0805 Resistor	TAD	(800) 508-1521
R1B	1	CR10-3323F-T	332k 1/10W 1% 0805 Resistor	TAD	(800) 508-1521
R2	1	CR10-1004F-T	1M 1/10W 1% 0805 Resistor	TAD	(800) 508-1521
R3	1	CR10-333J-T	33k 1/8W 5% 0805 Resistor	TAD	(800) 508-1521
R4 (Optional)	1	CR18-104J-T	100k 1/8W 5% 1206 Resistor	TAD	(714) 255-9123
R5 to R7 (Optional)	3	CR18-XXXJ-T	XXX 1/8W 5% 1206 Resistor	TAD	(714) 255-9123
JP1	1	3801S-03-G1	3-Pin Header, 0.1" Center	Comm	(626) 301-4200
	1	CCIJ230-G	SHUNT FOR JP1	Comm	(626) 301-4200
U1	1	LT1317CMS8, MSOP LT1317BCMS8, MSOP	LTHA DC/DC Converter Version A LTHB DC/DC Converter Version B	LTC	(408) 432-1900

### QUICK START GUIDE

DC194 can regulate a 3.3V output from an input of 1.5V to 3.6V; it can regulate a 5V output from an input of 1.5V to 5.3V. Select the desired output voltage by moving jumper JP1 to the appropriate position. Apply the DC input voltage between the  $V_{IN}$  and GND terminals of the DC194. Do not apply more than 5.5V to the input of this circuit.

With the input supply present, the LT1317/LT1317B will regulate the output to 3.3V or 5V. Attach a suitable load between  $V_{OUT}$  and GND.

The LT1317/LT1317B can be placed in shutdown mode by tying the SHDN terminal to the GND terminal. For normal operation, the SHDN terminal can be left floating or pulled high (above 1.4V and up to  $V_{IN}$ ).

Note that, as with any boost regulator, there is a direct DC path between the input and output; a shorted output will draw large currents, possibly damaging the DC194.

# DEMO MANUAL DC194

## MICROPOWER BOOST REGULATOR

## OPERATION

### INTRODUCTION

The LT1317 and LT1317B are 600kHz PWM step-up DC/DC converters. With a wide input voltage range (1.5V to 12V) and high switch voltage (30V), these parts are suitable for a wide variety of switching regulator circuits. DC194 demonstrates their application in a simple boost regulator with an output of either 3.3V or 5V.

DC194 is available in two versions. Version A uses the LT1317CMS8. At light loads, this part switches automatically into power-saving Burst Mode operation, resulting in high efficiency over a broad range of load currents. Version B uses the LT1317BCMS8, which operates at a fixed frequency, regardless of load, eliminating low frequency ripple on the output at the expense of light load efficiency. You can confirm which version of the board you have by checking the code on the IC; the LT1317 is marked with the code LTHA, whereas the LT1317B is marked with LTHB. In the comments below, “LT1317” will refer to both parts. In cases where their characteristics result in different behavior, the LT1317B will be mentioned explicitly.

This manual describes the operation of this demonstration circuit, its performance and variations on the basic circuit. For a thorough discussion of the LT1317 and its application, please consult the part’s data sheet.

### Hookup and Initial Tests

DC194 is a fairly simple low power switching regulator. However, some precautions are necessary in order to test the circuit safely. Proper hookup and accurate measurements are necessary for meaningful evaluation of efficiency and line and load regulation. Refer to Figure 2 for proper connections.

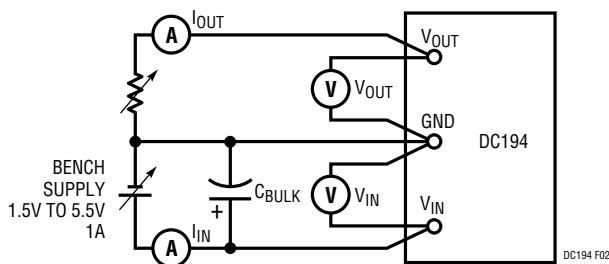


Figure 2. Recommended Hookup for Proper Evaluation of Efficiency and Regulation (See Text)

Select the desired output voltage by moving jumper JP1. The input can safely accept a voltage up to 5.5V. A good starting point is to apply 2.5V between the  $V_{IN}$  and GND terminals of the DC194, using a bench-top supply with a 1A current limit. Because the  $\overline{SHDN}$  pin of the LT1317 has been left floating, the LT1317 will begin operating as soon as  $V_{IN}$  is above 1.5V.

A load can be applied between the  $V_{OUT}$  and GND terminals, using either a fixed resistor, a decade resistor box (provided that it is rated for the power) or an active load. A simple initial load might be a 1/2W 100 $\Omega$  resistor. **Warning:** Because the basic boost circuit contains a DC path between the input and output (through inductor L1 and diode D1), the circuit is not protected against a shorted output. It is recommended that preliminary testing of the circuit be performed using a current-limited supply on the input.

With power applied to the DC194, the LT1317 should be switching and regulating the output. Figure 3 shows some of the circuit’s operating waveforms. The scope photos show the output voltage, the current through inductor L1 and the voltage on the SW pin of the LT1317. The LT1317 is in Burst Mode operation in the first photo. The second photo shows operation at a higher load current, where the LT1317 is operating at a fixed frequency. LT1317B circuits will operate in this mode at all load currents.

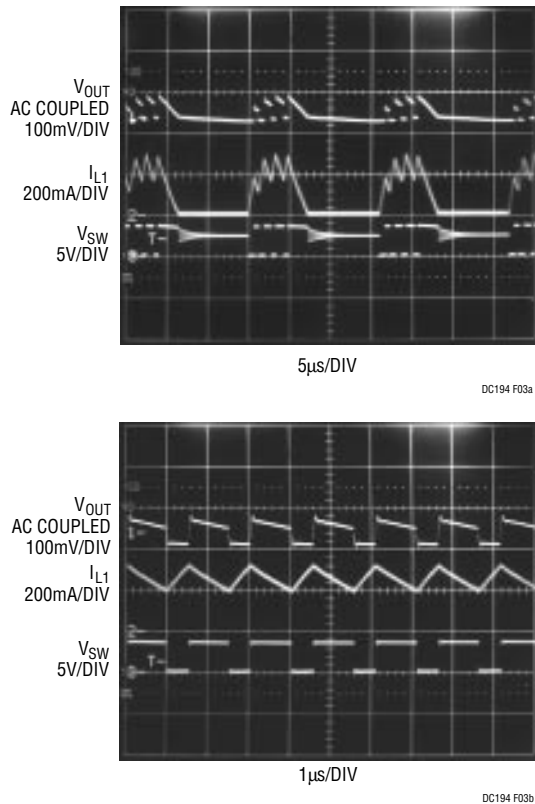
### PERFORMANCE

#### Input Range and Power Capability

The LT1317 will operate from inputs above 1.5V. The maximum allowable input voltage to this circuit is 5.5V, which is based on the voltage ratings of the input and output capacitors C1 and C2. The boost circuit will allow the LT1317 to regulate the output only when the input voltage is less than the desired output voltage plus one diode drop. This means that the practical input range is 1.5V to 3.6V for a 3.3V output and 1.5V to 5.3V for a 5V output.

The power capability of the DC194 is determined primarily by the input voltage and the current limit of the LT1317’s internal power switch and, to a lesser extent, by the value of inductor L1. Therefore, the maximum load current that this circuit can supply depends on the input voltage. A

### OPERATION



**Figure 3. DC194's Operating Waveforms.** In the Upper Photo, the LT1317 is in Burst Mode, Delivering 50mA to the Load. In the Lower Photo, the Load Current is 160mA and the LT1317 is Switching at 600kHz.  $V_{IN} = 2.5V$ ,  $V_{OUT} = 3.3V$

graph of maximum load appears in the Typical Performance section of this manual. The lower curve shows the guaranteed load capability based on the minimum current limit specification in the LT1317 data sheet. The upper curve shows the load capability of a typical DC194. As load current is increased beyond this level, the output voltage will sag as the LT1317 reaches its current limit. Again, be aware that L1 and D1 provide a direct path between the input and output and that this circuit does not limit the output current. As an increasing load drags the output voltage below the input, a larger current will flow, limited only by the impedance of the power source, inductor L1 and diode D1.

#### Shutdown Mode

The  $\overline{SHDN}$  pin of the LT1317 is tied directly to the  $\overline{SHDN}$  terminal of the DC194 and has been left floating. An internal current source will pull up on this pin and the

LT1317 will run in this condition. The LT1317 will also operate if this pin is pulled above 1.4V by an external signal. The  $\overline{SHDN}$  pin can be pulled as high as  $V_{IN} + 0.3V$ .

The LT1317 is placed in shutdown mode by pulling this pin below 0.4V; you can do this by tying the  $\overline{SHDN}$  terminal of the DC194 to the GND terminal. The current consumption of the LT1317 in shutdown mode is typically 25μA. However, the load can draw additional current through the inductor and catch diode, raising the power consumption in shutdown. The LT1317's low-battery detector remains active in shutdown. Applications of the low-battery detector are discussed below.

#### Efficiency

The efficiency of the DC194 is plotted in the Typical Performance section of this manual. Efficiency measurements should be made with care, as there is plenty of opportunity for errors to creep in.

The efficiency is defined as the power delivered to the load divided by the power drawn from the input supply. Normally, the average input voltage, input current, output voltage and output current are measured under steady-state conditions and the efficiency is calculated from these values. Each should be measured with the highest accuracy and precision possible.

Figure 2 shows connections for the proper measurement of efficiency and output regulation. The input and output voltages are measured at the DC194 in order to avoid including voltage drops across ammeters and terminal connections. It is best to take all of these measurements at one time. Be aware that most digital multimeters drop significant voltage when they are used as ammeters, so you must measure the input voltage while the ammeter is in the circuit—the input voltage will be lower than the voltage at the output of your bench-top supply. Another difficulty occurs at low power when the LT1317 is in Burst Mode operation. Here, the part will be drawing a few hundred milliamperes while switching, but only a few hundred microamperes average. An ammeter set to a sensitive scale will have too much resistance to allow these pulses of current to pass without large voltage drops. The result is that the power delivered to the LT1317 is not equal to the average current times the average



## OPERATION

voltage. Normally, the high resistance of the ammeter will not be present, so its negative effect on efficiency measurements is misleading. This measurement problem can be avoided by adding a large (1000 $\mu$ F to 10,000 $\mu$ F) bypass capacitor across  $V_{IN}$  between the ammeter and the DC194.

### Comments on Layout

The layout used for this demonstration circuit may be transferred to your circuit board (Gerber files are available). Also, the data sheet includes layout guidelines.

A boost regulator contains a high frequency current loop that includes the power switch (between the SW and GND pins of the LT1317), the diode (D1) and the output capacitor (C2). This loop should be kept small and an unbroken ground plane should be placed below it. Connect this local ground plane to the LT1317 near its ground pin and to the system ground at just one point. The feedback resistors and the components on the  $V_C$  pin should be as close as possible to the LT1317 and should be returned to the LT1317's ground pin.

### Testing in Your System

You may want to paste this circuit into your system to test compatibility. This should be done with care, since long hookup wires and ground loops can introduce noise sources and regulation problems that would not be present if the LT1317 DC/DC converter was properly designed into your PCB.

Treat the DC194 as a 3-terminal device with  $V_{IN}$ ,  $V_{OUT}$  and GND terminals. Wire the DC194 to your circuit board with wires as short as practical, to points on the circuit board that are close to each other. Also, add high frequency bypass capacitors (0.1 $\mu$ F ceramics) from  $V_{IN}$  and  $V_{OUT}$  to ground on your circuit board.

If you are bringing power directly to the DC194, use two wires from the input source to the  $V_{IN}$  and GND terminals of the DC194. The output power should be applied to your system as described above, and either the input supply or your circuit should be floating in order to avoid ground loops.

## DESIGN ALTERNATIVES

### Component Selection

The components used for the DC194 represent a compromise in cost, performance and size. They are well matched for the power capabilities of the LT1317 but there are many options for the designer to optimize the circuit for his or her application.

Diode D1 (Motorola MBR0520LT1) is a 0.5A, 20V Schottky diode. It is a good choice for nearly any LT1317 application, unless the output voltage or the circuit topology requires a diode rated for higher reverse voltages. Motorola also offers 30V and 40V versions. Most 0.5A and 1A Schottky diodes are suitable and they are available from many manufacturers. If you use a silicon diode, it must be an ultrafast recovery type. Efficiency will be lower due to the silicon diode's higher forward voltage drop.

L1 is a 10 $\mu$ H inductor rated for 1A of operating current. The value of the inductor should be matched to the power requirements and operating voltages of your application. In most cases a value of 10 $\mu$ H is suitable. The inductor should be rated for ~0.75A peak without excessive saturation—the current limit of the LT1317 internal power switch allows the part to tolerate moderate inductance loss. The Sumida CD43-100 used on the DC194 has a relatively small footprint with low losses. The DO1608 series from Coilcraft offers a similar inductor. A smaller, less expensive choice is the Murata LQH3C100K24, which fits in a tiny 1210 footprint. Efficiency will be slightly lower at higher operating currents. Finally, Coiltronics' CTX10-1 is a surface mount toroidal inductor with good performance; it will generate lower stray magnetic fields than the drum-type inductors listed above.

### Lower Ripple

The quality of the output capacitor is the greatest determinant of the boost converter's output voltage ripple. The output capacitor performs two major functions. It must have enough capacitance to satisfy the load under transient conditions, and it must shunt the AC component of the current coming through the diode from the inductor. The ripple on the output results when this AC current

### OPERATION

passes through the finite impedance of the output capacitor. The capacitor should have low impedance at the 600kHz switching frequency of the LT1317. The impedance at this frequency is usually dominated by the capacitor's equivalent series resistance (ESR). Choosing a capacitor with lower ESR will result in lower output ripple. Note also that the AC current contains fast edges, so that you need low impedance at the switching regulator's harmonics. This can be obtained by adding a small ceramic capacitor in parallel with the main output capacitor.

The DC194 uses a surface mount tantalum capacitor from AVX. Other companies, including Kemet and Sprague, make similar products. Some tantalum capacitor manufacturers recommend doubling the voltage rating for power supply applications; for highest reliability in 5V applications, the output capacitor of the DC194 should be replaced with a 10V version. The ESR of tantalum capacitors designed for DC/DC converters is specified by the manufacturers and you have some choice in trading ripple performance for cost and size.

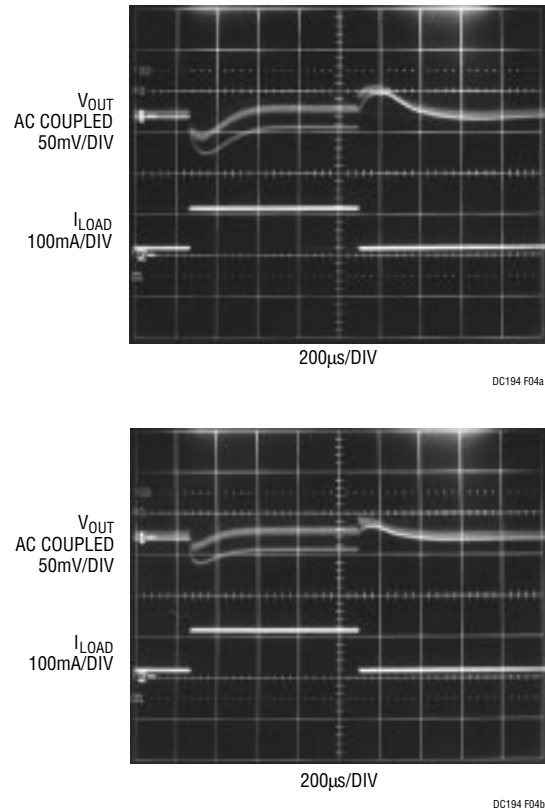
Newer technologies also offer low ESR capacitors. Panasonic's SP series and Sanyo's POSCAP series of surface mount capacitors use an organic electrolyte to achieve a lower ESR than tantalum capacitors of the same size.

### Loop Compensation Components

The components connected to the  $V_C$  pin of the LT1317 ( $C_3$ ,  $R_3$  and  $C_5$ ) compensate the control loop of the DC194. The values chosen here are conservative and provide stable operation for a wide range of input voltage, output voltage and output capacitor types. However, the loop response can be optimized further once the power components have been chosen. Figure 4 shows the transient response of the DC194; the upper trace in each photo is the output voltage and the lower trace is the load current. The lower photo shows the improvement in dynamic response after changing the compensation components.

### All Ceramic, Low Profile Design

Large value ceramic capacitors are now available that are suitable for use as the main output capacitor of an LT1317 boost regulator. These capacitors have very low ESR and



**Figure 4. The Dynamic Response of the Circuit Can Be Improved by Optimizing the Compensation Network. The Upper Photo Shows the Response to a Load Current Step from 20mA to 120mA. With  $R_3 = 68k$  and  $C_3 = 1.5nF$ , the Circuit Responds Faster to Changing Loads (Lower Photo). When the Load Current Is High, the 25mV<sub>p-p</sub> Output Ripple Makes the  $V_{OUT}$  Trace Appear as Two Traces.  $V_{IN} = 2.5V$ ,  $V_{OUT} = 3.3V$ , LT1317B**

therefore offer very low output ripple in a small package. However you should approach their use with some caution.

Ceramic capacitors are manufactured using a number of dielectrics, each with different behavior across temperature and applied voltage. Y5V is a common dielectric used for high value capacitors, but you can lose more than 80% of the original capacitance with applied voltage and extreme temperatures. The transient behavior and loop stability of the switching regulator depend on the value of the output capacitor, so you may not be able to afford this loss. Other dielectrics (X7R and X5R) result in more stable characteristics and are suitable for use as the output

# DEMO MANUAL DC194

## MICROPOWER BOOST REGULATOR

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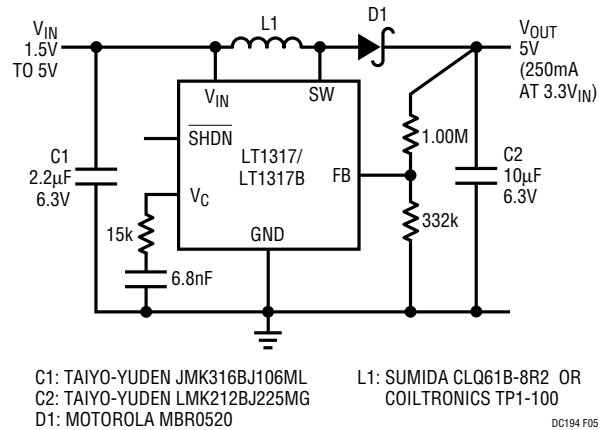
capacitor. The X7R type has better stability across temperature, while the X5R is less expensive and is available in higher values.

The second concern in using ceramic capacitors is that many switching regulators benefit from the ESR of the output capacitor because it introduces a zero in the regulator's loop gain. This zero may not be effective because the ceramic capacitor's ESR is very low. Most current mode switching regulators (including the LT1317) can be easily compensated without this zero. Any design should be tested for stability at the extreme operating temperatures; this is particularly true of circuits that use ceramic output capacitors.

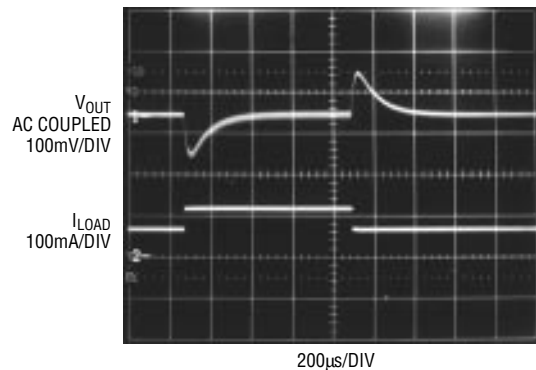
Figure 5 shows a design that uses ceramic capacitors at both input and output. It is intended to convert 3.3V to 5V at 250mA and is a good circuit for use in PCMCIA cards. The ceramic capacitors result in both low output ripple and low height. The inductors listed result in a circuit height under 1.8mm. The Sumida inductor requires a hole in the circuit board for mounting; however, it requires less board area than the Coiltronics part. Figure 6 shows the ripple and transient response. Note that transient response generally suffers with reduced output capacitance. This is especially true with the LT1317 in Burst Mode operation, when the load changes from a very low current (<100 $\mu$ A) to a higher current.

#### Low-Battery Detector

The LT1317's low-battery detector is a comparator whose open collector output appears at the LBO pin of the LT1317. The inverting input is internally tied to a 200mV reference and the noninverting input appears at the LBI pin. The LBI and LBO pins appear at the edge of the DC194. There are also pads to add a resistor divider (R5 and R6) from  $V_{IN}$  to the LBI pin and a pull-up resistor (R4) from the LBO to  $V_{IN}$ . Figure 7 shows two applications of the low-battery detector. The first shows its intended use, as an input voltage monitor; the second shows how to use it as an undervoltage lockout.

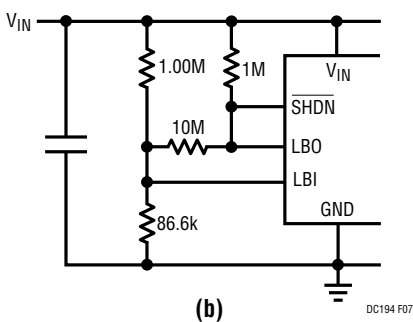


**Figure 5. Ceramic Capacitors Result in Low Output Ripple and Minimum Circuit Size in This Low Profile Design**

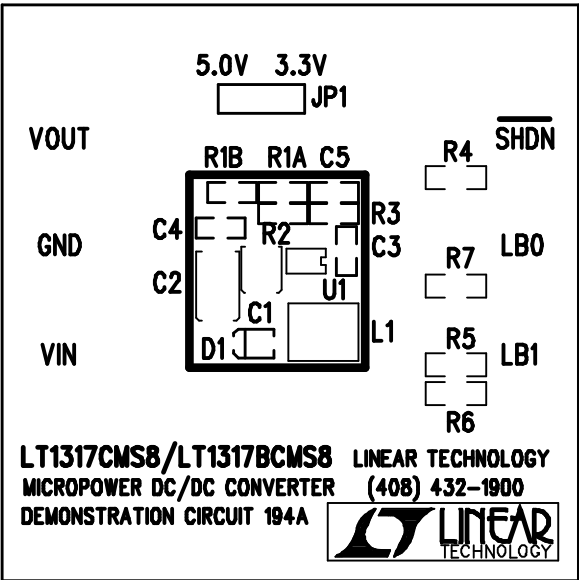


**Figure 6. Above Is the Transient Response of the All-Ceramic Design to a 50mA Load Step. The Low Impedance of the Ceramic Output Capacitor Results in Low Output Ripple.  $V_{IN} = 3.3V$ ,  $V_{OUT} = 5V$**



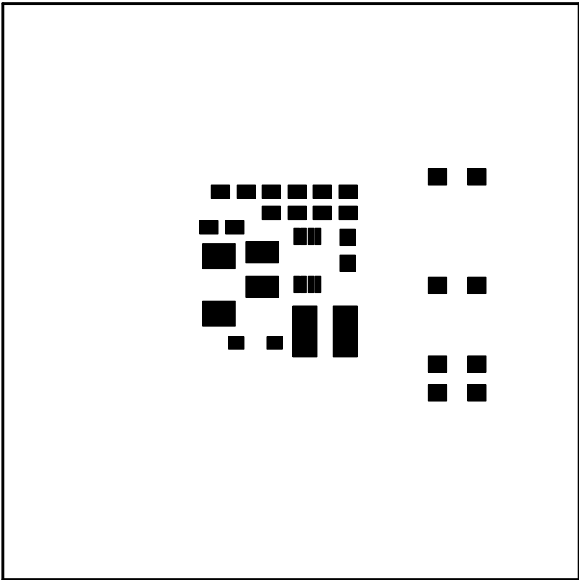


PCB LAYOUT AND FILM



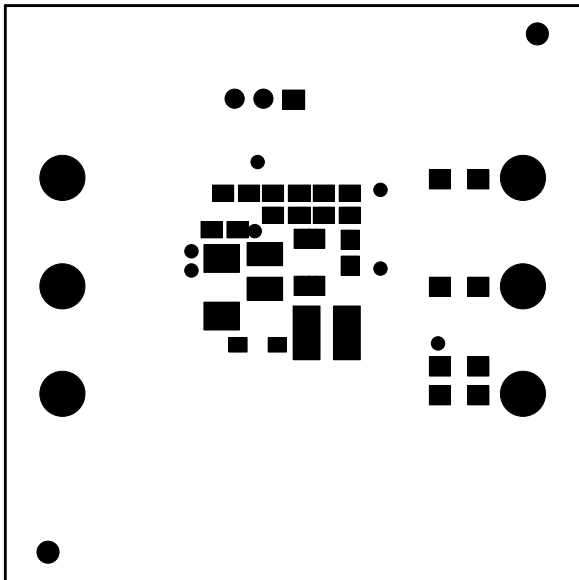
DC194 TSLK

Silkscreen Top



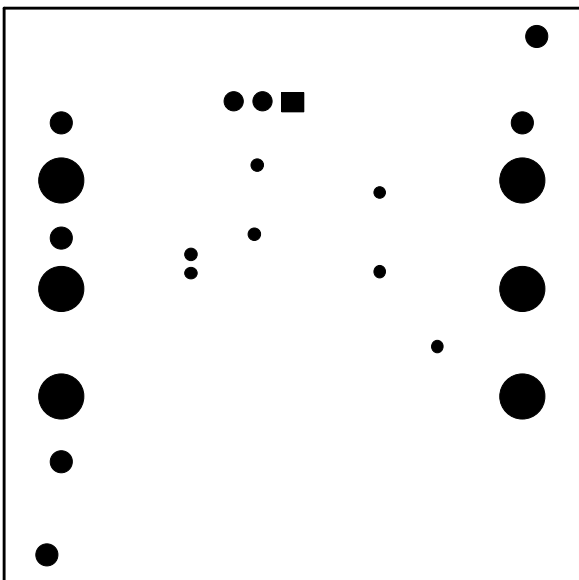
DC194 TSP

Solder Paste Top



DC194 TSM

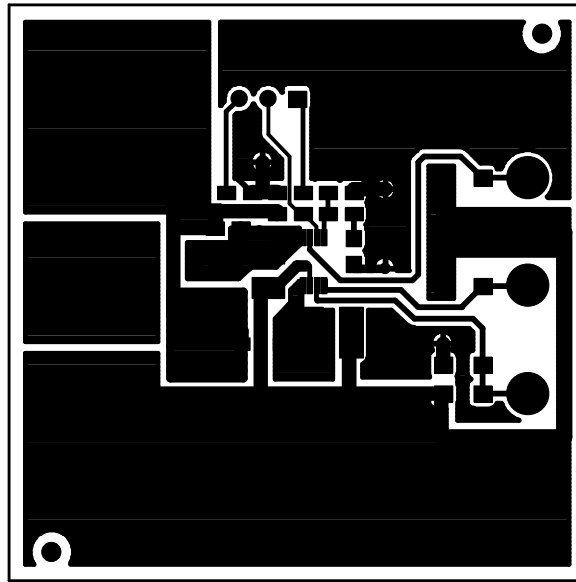
Solder Mask Top



DC194 BSM

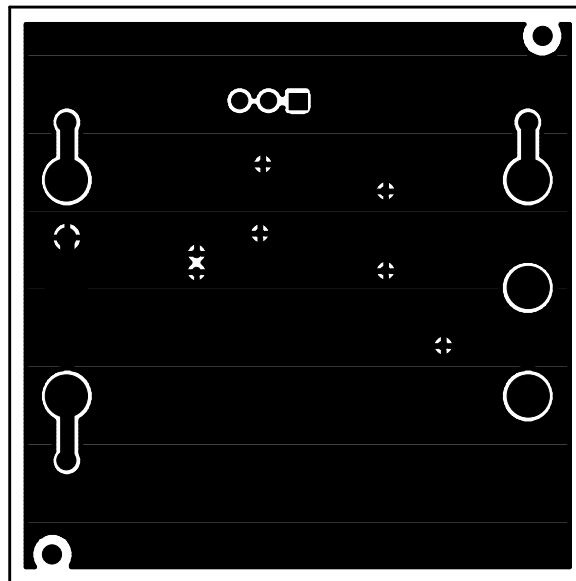
Solder Mask Bottom

## PCB LAYOUT AND FILM



DC194 TL

Top Layer



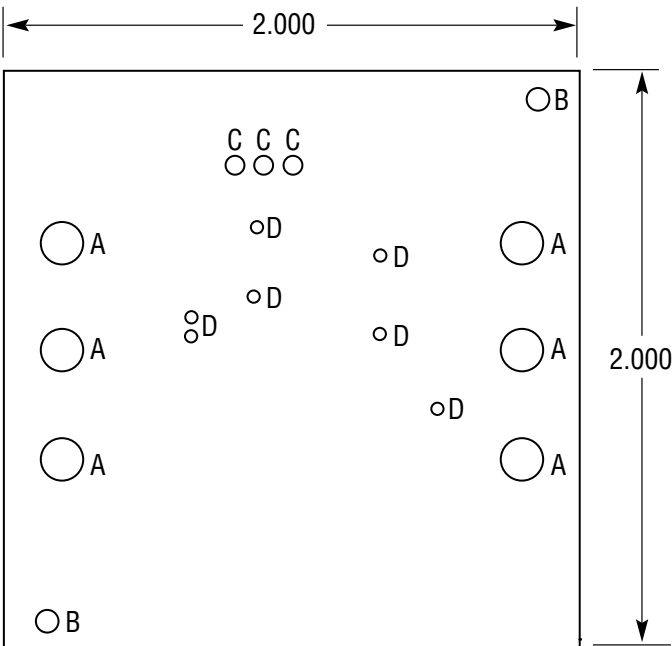
DC194 BL

Bottom Layer

# DEMO MANUAL DC194

## MICROPOWER BOOST REGULATOR

### PC FAB DRAWING



DC194 FAB

SYMBOL	DIAMETER	NUMBER OF HOLES	PLATED
A	0.094	6	YES
B	0.07	2	NO
C	0.035	3	YES
D	0.02	7	YES

- 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 LPI OR EQUIVALENT
  - 4. SILKSCREEN: USING WHITE NONCONDUCTIVE EPOXY INK
  - 5. UNUSED SMD COMPONENTS SHOULD BE FREE OF SOLDER
  - 6. FILL UP ALL VIAS WITH SOLDER
  - 7. ALL DIMENSIONS ARE IN INCHES