LT1512 SEPIC Constant-Current/Constant-Voltage Lithium-Ion Battery Charger

DESCRIPTION

Demonstration Board DC099 is a complete Lithium-Ion constant-current/constant-voltage battery charger designed for 1- or 2-cell applications. The LT®1512 is used in the SEPIC (single-ended primary inductance converter) current mode topology, which allows the input voltage to the charger to be less than, equal to or greater than the battery-charging voltage. The 500kHz switching frequency allows small surface mount components to be used, minimizing board space and height. The printed circuit area required for the complete charger is less than $0.7in^2$, making it ideal for base stations and portable handheld devices such as palmtops and cellular phones.

The SEPIC topology allows the current sense circuit to be completely separated from the battery, simplifying battery switching and system grounding problems. It also eliminates the DC current path from the battery to the input when the charger is off.

In addition to the 1% constant-voltage accuracy, the LT1512 also contains circuitry to provide a constant-current charge with a 5% accuracy. The IC includes a 1.5A switch that can provide up to 1A charging current for some conditions. The maximum charge current is dependent upon the input voltage and whether the converter is stepping the input voltage up or down.

Located on the demo board is a jumper to select the correct charging voltage for either 1- or 2-cell applications (4.2V or 8.4V), although up to five cells can be charged by changing resistor values. On this board, the charging current is set at 0.4A by resistor R3.

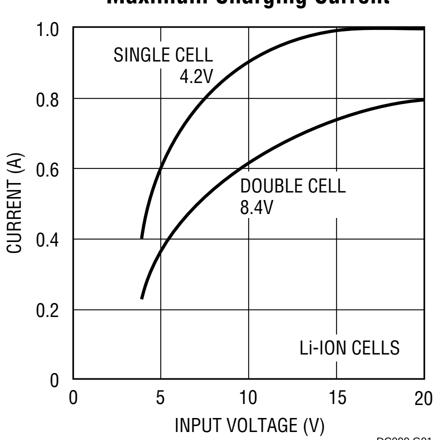
A dual function pin (SYNC and/or SHUTDOWN) can be used to synchronize the switching frequency to a higher external clock frequency and can also be used for a low quiescent current shutdown (12µA).

PERFORMANCE SUMMARY

PARAMETER	CONDITIONS	LIMITS
Input voltage (V_{IN})		$2.7V \le V_{IN} \le 15V$
Battery Float Voltage (V_{BAT})	$V_{IN} = 5V$, $I_{BAT} = 100mA$	4.2V ±0.85% or 8.4V ±0.85%
Constant Battery Charging Current	$V_{IN} = 5V$	400mA ±5%

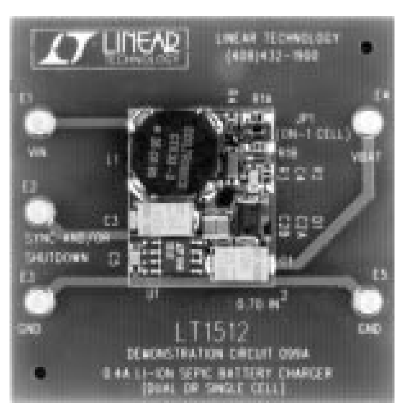
TYPICAL PERFORMANCE CHARACTERISTICS AND BOARD PHOTO

Maximum Charging Current



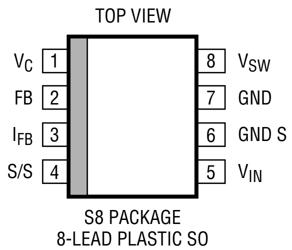
DC099 G01

Component Side



DC099 BP

PACKAGE AND SCHEMATIC DIAGRAMS



LT1512CS8

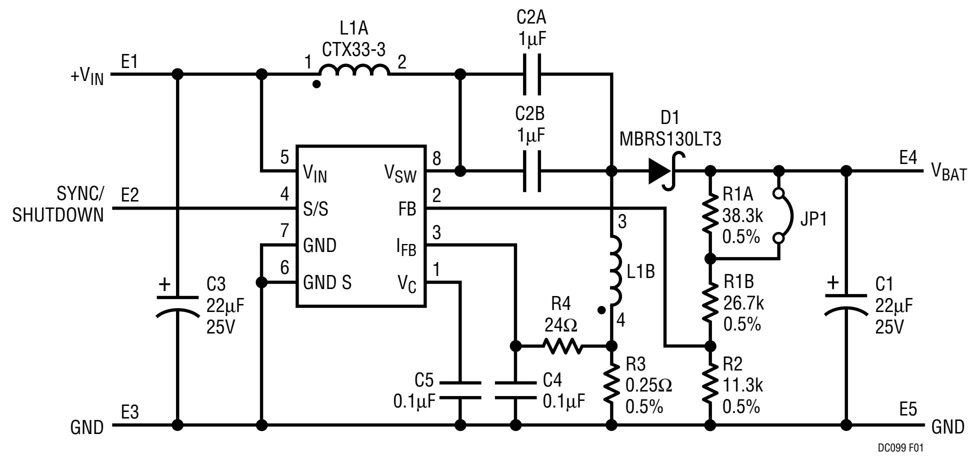


Figure 1. SEPIC Constant-Current/Constant-Voltage Lithium-Ion Battery Charger

PARTS LIST

REFERENCE DESIGNATOR	QUANTITY	PART NUMBER	DESCRIPTION	VENDOR	TELEPHONE
C1, C3	2	TPSD226M025	22µF, 25V, 20%, Tantalum Capacitor	AVX	(803) 946-0238
C2A, C2B	2	1206YZ105MAT1A	1µF, 16V, 20% X7S Ceramic Capacitor	AVX	(803) 946-0362
C4, C5	2	0805YC104KAT1A	0.1µF, 16V, 10% X7R Ceramic Capacitor	AVX	(803) 946-0362
D1	1	MBRS130LT3	1A, 30V Schottky Diode	Motorola	(602) 244-3576
E1 to E5	5	1502-2	Test Point Turret	Keystone	(718) 956-8900
JP1	1	TSW-102-07-G-S	2-Pin Jumper	Comm Con	(818) 301-4200
(JP1)	1	CCIJ2MM-138-G	2mm Removable Shunt	Comm Con	(818) 301-4200
L1	1	CTX33-3	33µH, SMT Inductor (2 Windings: A , B)	Coiltronics	(561) 241-7876
R1A	1	RR1220R3832D	38.3k, 0.1W, 0.5%, 0805 Chip Resistor	Thin Film Tech	(507) 625-8445
R1B	1	RR1220R2672D	26.7k, 0.1W, 0.5%, 0805 Chip Resistor	Thin Film Tech	(507) 625-8445
R2	1	RR1220R1132D	11.3k, 0.1W, 0.5%, 0805 Chip Resistor	Thin Film Tech	(507) 625-8445
R3	1	LR120601R250F	0.25Ω, 0.25W, 1%,1206 Chip Resistor	IRC	(512) 992-7900
R4	1	CR21-240J-T	24Ω, 0.1W, 5%, 0805 Chip Resistor	AVX	(803) 946-0524
U1	1	LT1512CS8	SO-8, Battery Charger IC	Linear Technology	(408) 432-1900

OPERATION

The DC099 demonstration board is intended for evaluating the LT1512 switch mode battery charger IC. This board contains a complete charger for either one or two lithium-Ion cells (selected by a jumper) in a current limited, constant-voltage regimen. The charge voltages are 4.2V or 8.4V ± 1% with a constant-current limit of 400mA ± 5%. Other voltages and currents can be obtained by selecting appropriate resistor values, allowing charging of other battery voltages or battery types. The input voltage can range from 2.7V to 15V or higher, depending on the output voltage.

The SEPIC topology (see Figure 1), combined with unique output current sense circuitry, is ideal for charging batteries. The input voltage can be less than, equal to or greater than the battery voltage, virtually eliminating dropout voltage problems associated with buck switchers. The constant-current control circuitry is completely separated from the battery, simplifying battery switching and system ground problems. The SEPIC design eliminates the DC current path from the battery to the input when the charger is off and also eliminates snubber losses inherent in flyback designs.

Only surface mount components are used on this board, with the circuitry occupying approximately $0.7in^2$ of printed circuit board area.

Inductor

The SEPIC topology requires two inductors. Normally, two identical windings on one core are used, although two separate inductors of the same value can also be used. Torroids with low loss cores, such as Kool Mµ®, Molypermalloy or Metglas, are recommended, although ferrite pot or E cores also work well, but may be more expensive. Because of the large external magnetic fields associated with open-core types of inductors, they are not recommended. To minimize DC losses, the DC wire resistance should be low, typically less than 0.1Ω.

The Coiltronics OCTA-PAC™ inductor used on this demo board consists of two windings on a Kool Mu torroid core with a current rating of 680mA and DC resistance of 0.07Ω.

Kook Mu is a registered trademark of Magnetics, Inc.
OCTA-PAC is a trademark of Coiltronics, Inc.

Coupling Capacitor

A SEPIC converter also requires a coupling capacitor (C2). The DC voltage applied to this capacitor is equal to the input voltage; hence, the capacitor voltage rating required for a reliable design is approximately 125% of the maximum input voltage. The RMS ripple current present in this capacitor can be as high as 750mA and is calculated using the following formula:

$$I_{C2(RMS)} = \frac{I_{CHRG}\left(V_{IN} + V_{BAT}\right)\left(1.1\right)}{2\left(V_{IN}\right)}$$

Multilayer ceramic capacitors are recommended because of their low ESR, high ripple current ratings and small size. Solid tantalum capacitors can also be used, but higher capacitor values are needed to satisfy the ripple current requirements. In this demo board, two 1µF, 16V multilayer ceramic capacitors are used in parallel, although a single 2µF capacitor could also be used. To accommodate higher input voltages, up to 30V, replace coupling and input capacitors with a higher voltage rating.

Input Capacitor

Either a low ESR 22µF solid tantalum or a 2.2µF multilayer ceramic capacitor can be used in this location (C3). The RMS current rating required is typically 100mA to 200mA RMS, depending on the inductor value. Lower inductor values result in higher ripple currents. This capacitor must be located as close to the V_{IN} and ground pins as possible.

Solid tantalum capacitors are also appropriate because of their high capacitance, small size, low ESR, relatively high ripple current capability and good high frequency characteristics. But a small percentage of tantalum capacitors can be destroyed (shorted) when subjected to very high surge currents. These high currents can occur if a low impedance power source is "hot switched" to a charger input. To minimize failures of this type, capacitor manufacturers recommend derating the capacitor operating voltage by at least 50% or more and selecting a capacitor that has been surge current tested. Capacitors manufactured by AVX (TPS series) and Sprague (593 series) are 100% surge current tested.

OPERATION

Multilayer ceramic capacitors can also be used for input bypassing of switching regulator applications. Their features include small size, very low ESR, high ripple current capability and good high frequency characteristics; further, they do not have the surge current problem associated with tantalum capacitors. Disadvantages include relatively low capacitance values, poor capacitance vs. temperature performance and poor capacitance vs. applied voltage performance. Since multilayer ceramic capacitors do not have an input surge current limitation, they are recommended for situations where high surge currents may occur.

Output Capacitor

Recommended capacitors for C1 include solid tantalum, aluminum polymer, OS-CON and multilayer ceramic. Here again, the ripple current rating of the capacitor is important and must be sized accordingly. For a reliable design, the manufacturer's data sheet must be consulted to ensure adequate ripple current ratings. Although a portion of the ripple current will flow into the battery, it can be assumed as a worst-case condition that all the switching output ripple current could flow in the output capacitor. For this demo board, the maximum RMS output ripple current is approximately 400mA.

See the previous section on input capacitors for details on problems associated with solid tantalum capacitors and high surge currents if the battery may be "hot switched" to the output of the charger.

Diode

For minimum losses, a Schottky diode is recommended for D1. Maximum reverse voltage seen by this diode is equal to the input voltage plus the battery or output voltage, whereas the average diode current is equal to the charging current. For most applications, a 1A diode is recommended.

Since Schottky diodes can have relatively high reverse leakage currents, some care must be exercised when selecting a diode. When the input power is removed, any diode leakage current will be a drain on the battery. If the battery is left connected to the charger for an extended period of time, it could discharge the battery. Check diode leakage current specifications before selecting a Schottky diode.

If very low battery drain is needed, an ultrafast recovery diode (25ns) can be used if the slightly increased power dissipation is not a problem. These diodes have very low reverse leakage current, thus minimizing battery drain current due to diode leakage.

Programming Battery Voltage

The battery charge voltage is programmed by a resistor voltage divider across the output. The divider resistor values are selected to provide 1.25V at the V_{REF} pin when the output is at the desired value. Selecting 100μA divider current minimizes output voltage errors due to input bias current variations. The equation for calculating the feedback resistor (R1) is:

With R2 = 11.3k, V_{REF} = 1.245V and Ib = 0.3μA:

$$R1 = \frac{R2\left(V_{BAT} - 1.245\right)}{1.245 + R2\left(0.3\mu A\right)}$$

The 100μA divider current represents a drain on the battery when the input power is removed. Lowering the divider current (by increasing the divider resistance) minimizes this drain current at the expense of output voltage accuracy.

To completely eliminate the battery drain current due to the output resistor divider, a small MOS transistor can be added to disconnect the voltage divider when the input power is removed. Disconnecting the divider resistors

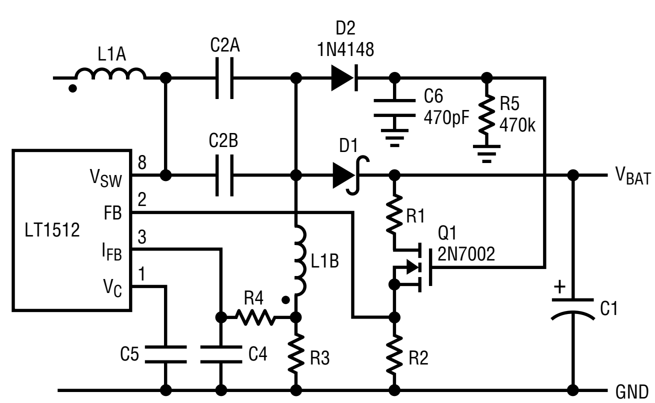


Figure 2. Output Voltage Divider Disconnect Circuitry

OPERATION

leaves only the diode leakage as a battery drain (see Figure 2). To ensure adequate gate drive when the input voltage is at its lowest operating point of 2.7V, the gate is driven with a peak-detected and filtered voltage via D2, R5 and C6. Do not substitute for Q1 unless the new device has adequate V_{GS} maximum rating, because the gate drive voltage is equal to battery voltage plus input voltage. The 2N7002 MOSFET used on this board has a maximum V_{GS} rating of ±40V.

Programming Charging Current

The SEPIC topology allows ground-referenced sensing of the battery charge current that is separate from the battery circuit. The average current flowing in the second inductor (L1B) and current sense resistor (R3) is equal to the battery-charging current. A current sense voltage is generated across R3, filtered by R4 and C4 and drives the I_{FB} pin to complete the constant-current feedback loop. R4 is purposely kept low to minimize current errors due to the 4k input resistance of the I_{FB} pin. When the charger is providing a constant current, the voltage required at the I_{FB} pin is –100mV. The equation for the current sense resistor is:

$$R3 = 100mV/I_{CHRG}$$

Although the demo board is programmed for a constant current of 400mA, other charge currents can be obtained by changing resistor R3. The maximum charge current is dependent on the output voltage required and the input voltage available. See the curve on the front page. Additional information can be found in the LT1512 data sheet.

Figure 3 shows a simple change to the demo board that allows the constant charge current to be easily programmed over a 5:1 range by using a DC control signal. The current sense resistor R3 is selected to have a 100mV drop across it at the lowest current level. Applying a positive DC voltage to R5 programs a higher charge current. Do not exceed the power dissipation rating of R3.

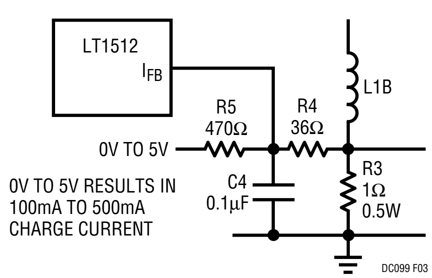


Figure 3. Programming Charge Current (100mA to 500mA) Using a DC Control Signal (1V to 5V)

Shutdown/Synchronization

This dual function pin provides a low (12µA) quiescent current shutdown and can also be used for synchronizing the switching frequency to a higher clock frequency. For normal operation it can be left open or pulled high (up to 30V). A logic low activates shutdown.

To synchronize the switching frequency to a clock, apply logic-level pulses between 600kHz and 800kHz to the Shutdown/Synchronization pin.

Maximum Input Voltage

The LT1512 has a maximum voltage rating of 30V for the V_{IN} pin and 40V for the V_{SW} pin. The maximum input voltage that can be applied to the LT1512 charger circuit is partially determined by the output (battery) voltage. A SEPIC converter requires a maximum switch voltage rating equal to input voltage plus output voltage. This limits the maximum input voltage to 30V or (40V – V_{BAT}), whichever is less.

The maximum input voltage for this demo board is 15V. If higher input voltages are anticipated, replace the coupling capacitor and possibly the input capacitor with capacitors of higher voltage ratings.

PC Board Layout Considerations

Surface mount components rely primarily on the PC board copper to conduct the heat to the surrounding air. For the LT1512, the majority of the heat generated by the IC is conducted through the copper leads to the PC board. It is important to provide as much PC board copper around the package leads as is practical. Backside copper and internal copper layers interconnected by feedthrough vias all contribute to the overall effectiveness of the PC board as a heat sink. Other heat-producing surface mount components, such as the Schottky diode and the inductor, also rely on the PC board copper to conduct the heat away from the components. Remember, the PC board is the heat sink.

OPERATION

Although SEPIC efficiencies are typically in the high 70s, a PC board layout using good thermal practices will allow operation up to an ambient temperature of 85°C.

Besides good thermal layout techniques, the 500kHz switching frequency requires good PC board layout techniques. Copper traces must be kept short and input and output capacitors and diode connections must be located close to the LT1512. Because of the fast switching voltage present on the switch pin, the printed circuit copper surrounding this pin should be minimized for minimum EMI radiation.

Demo Board Setup

Select the correct charge voltage for either one or two cells by using the jumper (JP1) located in the upper right portion of the demo board. Install the shunt for one cell (4.2V); remove the shunt for two cells (8.4V).

Five terminals are included for easy hookup to a power supply and battery. The terminals include input voltage, input ground, battery voltage, battery ground and synchronization/shutdown.

Attach a suitable load, such as a battery, resistor or battery simulator, between the V_{BAT} and GND terminals, E4 and E5 (see the Battery Simulator section). Insert an ammeter or a low value current sensing resistor (0.1Ω or less) in series with the load to measure charge current. If the battery simulator is used, the charge current can be measured by measuring the voltage across R_{INT}.

Clip or solder wires to the demo board input terminals E1 and E3. With the output of a 1.5A bench power supply set for approximately 5V, connect the input wires to the power supply. If your bench supply has adjustable current limit, make sure the current is set sufficiently high to allow the LT1512 to start up without exceeding the bench supply current limit. When the input power is applied and a discharged battery or a battery simulator (set for a discharged battery voltage) is connected, the charger will begin sourcing a constant current of 400mA ±5%. As the battery accepts charge, its voltage increases. When the rising battery voltage approaches the charger's programmed voltage (4.2V or 8.4V), the charge current begins decreasing and the constant-voltage charge begins. As the constant-voltage charge continues, the battery approaches a fully charged condition and the charge current continues to decrease. When the battery voltage is equal (or very close) to the programmed charge voltage, the charge current drops to near zero. This natural drop in charge current as the battery nears full charge occurs with most batteries being charged with a constant voltage.

Terminating Charge

Most manufacturers of Li-Ion cells recommend a current limited (1**C** rate), constant-voltage (4.1V or 4.2V/cell) charge cycle for approximately 2.5 hours, after which the charge is terminated. Another method used is very similar, except that the charge current is monitored and, when the current decreases to approximately 10% of the maximum charge current, a 30-minute to 90-minute timer is started, after which the charge is terminated.

To stop all charging current, force the Shutdown/Synchronization pin low (low quiescent current mode); forcing the V_C pin low also stops the charging current, but does not put the part into a low quiescent current mode.

In addition, many manufacturers recommend removing the charge voltage after the charge cycle is complete. Maintaining a float voltage for extended periods of time may reduce the battery cycle life.

Consult the manufacturer of the cells being used for their recommendations on charging and termination methods.

Battery Simulator

A battery simulator is the best and easiest method of evaluating a battery charger circuit. A simple simulator consists of an adjustable DC power supply that can both source and sink current. Most DC power supplies can only source current but they can be made to sink current by adding a load resistor across the output. Current through this resistor should be approximately 110% of the programmed constant current of the charger that is under evaluation. This allows the power supply (with the resistive load attached) to source and sink current like a battery. Any battery condition, from fully discharged to fully charged, can be simulated by changing the power supply voltage. See Figure 4 for the battery voltage curve.

OPERATION

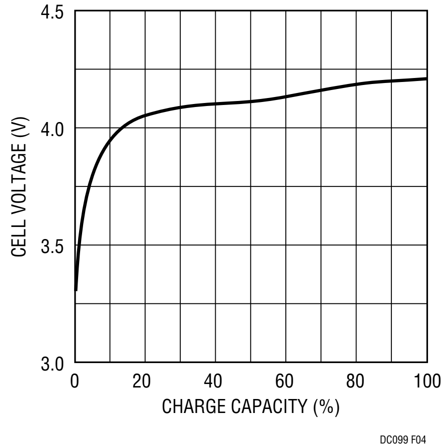


Figure 4. Single Lithium-Ion Cell Charging Voltage

Select the load resistor value using Ohm's law, using the minimum (discharged) battery voltage and approximately 110% of the maximum charge current. The battery's internal impedance is represented by a low value resistor (R_{INT}). Typical values for Li-Ion cells will range from 0.04Ω/cell to 0.15Ω/cell. The power supply used should be well-regulated and must have good output voltage adjustability (with at least 10mV resolution) consisting of either a multiturn or a coarse and fine voltage adjust control. An accurate DVM is also required to monitor the simulator voltage, because even a 10mV change can result in relatively large changes in current when the charger is in the constant-voltage mode. The DVM can also be used to measure the voltage across R_{INT} (see Figure 5) to determine charge current.

For example, in the case of two lithium-ion cells charging at a constant current of 400mA: V_{BAT} discharged = 3V • 2 = 6V, R = 6V/0.45A = 13.3Ω; nearest resistor value = 12Ω. The resistor power rating should be greater than 6W (P = 8.4V • 0.7A = 5.88W); R_{INT} = 0.075 • 2 = 0.15Ω. Adjust the battery simulator power supply voltage to approximately 7V to simulate a discharged 2-cell Li-Ion battery pack. Remove jumper JP1 from the demo board to program the charger for two cells, and apply input power (5V to 10V) to the charger demo board. Connect the battery simulator to the charger output (V_{BAT} and GND terminals). A constant charge current of 400mA will begin flowing into the simulator. Slowly increasing the power supply voltage will simulate a battery accepting charge. When the voltage approaches 8.35V, the charging current begins dropping as the charger begins constant-voltage operation. At 8.4V (the fully charged battery voltage), the charge current will drop to very low levels.

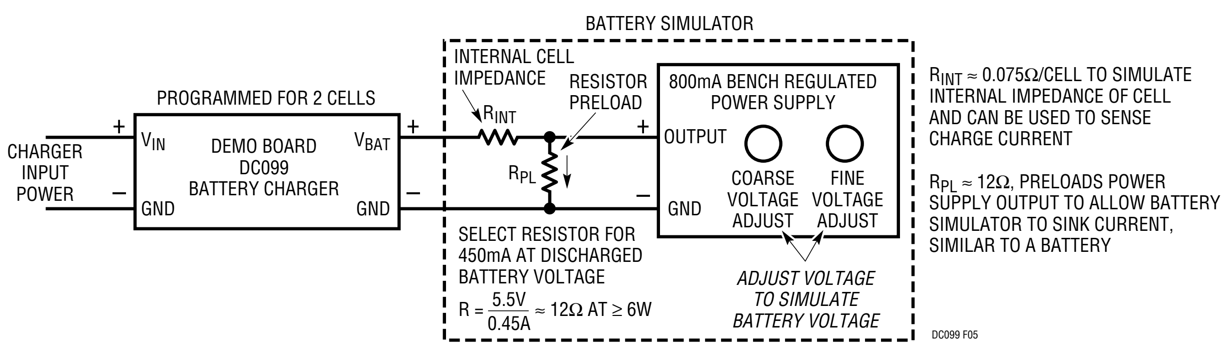
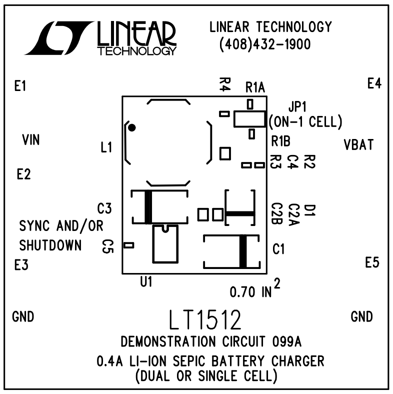
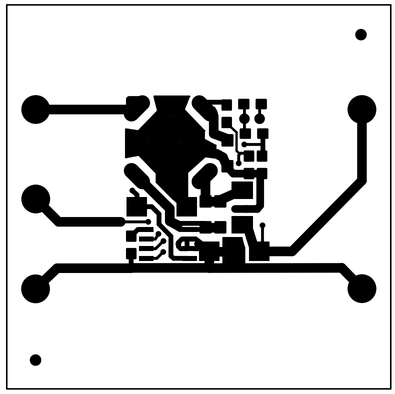


Figure 5. Block Diagram of Battery Simulator

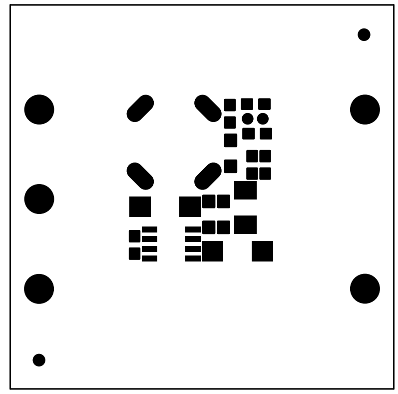
PCB LAYOUT AND FILM



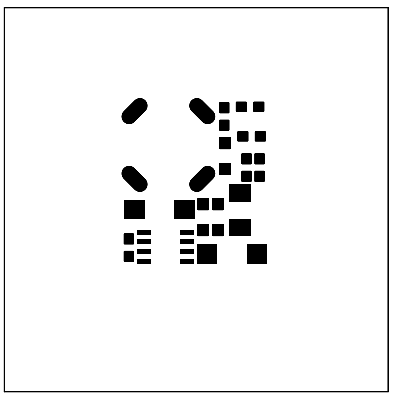
Component Side Silkscreen



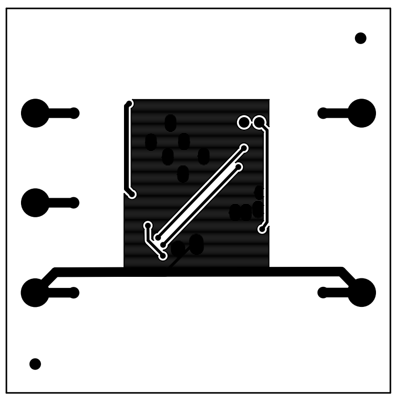
Component Side



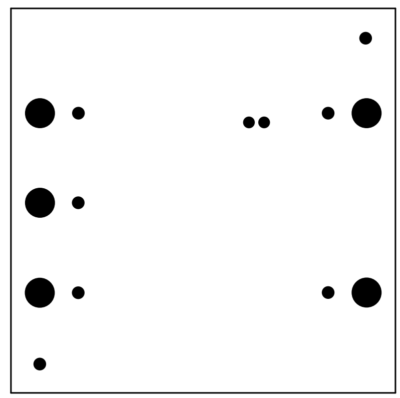
Component Side Solder Mask



Paste Mask Top

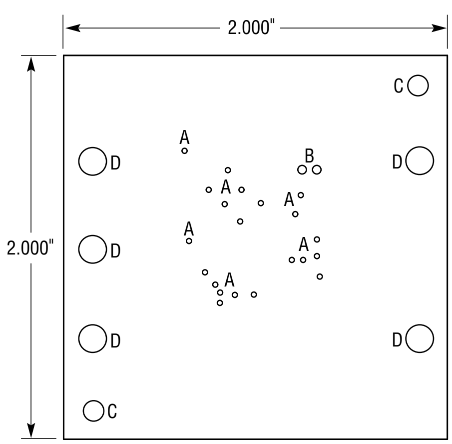


Solder Side



Solder Side Solder Mask

PC FAB DRAWING



NOTES:

1. BOARD MATERIAL IS FR-4, 0.062" THICK, 2 OZ COPPER
2. PCB WILL BE DOUBLE-SIDED WITH PLATED THROUGH HOLES
3. SOLDER MASK BOTH SIDES WITH PC401 SILKSCREEN COMPONENT SIDE. USE WHITE NONCONDUCTIVE INK
4. ALL DIMENSIONS ARE IN INCHES ±0.005"

SIZE	QTY	SYMBOL	PLATED
0.018	21	A	YES
0.030	2	B	YES
0.070	2	C	NO
0.094	5	D	YES

Linear Technology Corporation
1630 McCarthy Blvd., Milpitas, CA 95035-7417
(408)432-1900 • FAX: (408) 434-0507 • www.linear-tech.com

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