

## LTC4000 Battery Charger Controller and PowerPath Manager

### DESCRIPTION

Demonstration circuit 1830B is a battery charger controller and PowerPath™ manager featuring the **LTC®4000**. This board should be connected to a front end DC/DC power supply for a complete charger solution.

The DC1830B is customizable to handle a wide variety of applications with output voltages from 3V to 30V and output currents up to 6.5A with the PFETs supplied, and up to 60V and/or 13A with higher voltage rating and/or added PFETs. The reference design provided with DC1830A is targeted at 4-cell LiFePO<sub>4</sub> (14.6V/5A) applications.

The DC1830B loop compensation values were proven with the LTC3845A buck-boost power converter shown and are typical for other applications. The output of this demo board was specifically tailored for a Tenergy 10A-hour battery, P/N 30207. Other voltages can be set by changing R<sub>OFB2</sub> and R<sub>BFB2</sub>. The desired nominal voltage can be accurately trimmed by using trim resistors R<sub>OFBX</sub> and R<sub>BFBX</sub>. For example, for 14.4V battery float voltage, change R<sub>OFB2</sub> and R<sub>BFB2</sub> to 86.6k, and add 7.5M at R<sub>OFBX</sub> and R<sub>BFBX</sub> for greater set point accuracy. Other parameters can be adjusted to suit specific applications with guidance provided in the LTC4000 data sheet. Table 2 provides a summary of parameter adjustments.

This circuit was designed to demonstrate the high levels of performance and small solution size attainable using

this part to control a switch mode power converter to form a battery charger, intelligent PowerPath manager, and power supply system. It produces a regulated 5A/14.6V battery charger output as well as a system output of up to 5.5A: suitable for a wide variety of portable applications including instruments, industrial equipment, power tools, and computers.

The DC1830B-A provides a solution complete with both battery charger control and PowerPath management. It includes a second PFET (Q2) between V<sub>OUT-SYS</sub> and BAT to provide instant-on functionality which keeps V<sub>OUT-SYS</sub> within a narrow range regardless of battery voltage, and disconnects the battery when it is fully charged and power is available from the front end DC/DC converter. Thermal regulation circuitry is also provided to limit the temperature of both PFETs. The DC1830B-B provides a simple battery-charger-controller only solution without the PowerPath manager. It deletes the second PFET and thermal regulation circuitry. In this case, the battery is always online and V<sub>OUT-SYS</sub> tracks BAT voltage.

**Design files for this circuit board are available at <http://www.analog.com/DC1830B-A>**

All registered trademarks and trademarks are the property of their respective owners.

### PERFORMANCE SUMMARY Specifications are at T<sub>A</sub> = 25°C

SYMBOL	PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
V <sub>IN</sub>	Input Supply Range	This is the Input Voltage of the Front End DC/DC Supply	20		60	V
I <sub>IN</sub>	Input Current Limit	This is the Input Current Limit Set by the LTC4000		3		A
V <sub>FLOAT</sub>	Battery Float Voltage		14.4	14.6	14.8	V
	Output Regulation	Line and Load (20V to 60V, 0A to 4.5A)		±0.005		%
I <sub>BAT</sub>	Battery Charge Current			5		A
	Battery Charge Current – Trickle			0.6		A
t <sub>T</sub>	Charge Termination Time	V <sub>BAT</sub> = V <sub>FLOAT</sub>		2.9		hours
V <sub>OUT-SYS</sub>	System Output Voltage		12.3	14.6	15.5	V
I <sub>OUT-SYS</sub>	System Output Current Range	*Input Current Limited Below 35V <sub>IN</sub>	0		5.5*	A

Rev. A

### QUICK START PROCEDURE

Demonstration circuit 1830 is offered for use in combination with a front end DC/DC converter, and will need to be customized to suit the intended application. It has been supplied with components for a design as outlined in the performance summary, and tested in conjunction with the LTC3845A buck converter that it was tailored to. A separate demonstration board is available for the LTC4000/LTC3789 buck-boost combination, the DC1721A. The LTC4000 data sheet should be used for guidance in determining circuit values for the application at hand. You may follow the design example on page 26 of the data sheet. Table 1 provides a summary of parameter adjustments.

NOTE: The PFETs supplied on this board are rated at 30V.

Once the circuit has been customized to suit the application at hand, it is easy to set up to evaluate the performance of the LTC4000 when combined with a suitable switching power converter, such as the LTC3845A. Voltages and currents cited in this procedure are for the design as delivered; if the design has been customized, substitute the appropriate values. Refer to Figure 1 for proper measurement equipment setup and follow the procedure below:

**WARNING: BATTERIES ARE POTENTIALLY DANGEROUS HIGH ENERGY SOURCES. IMPROPER CONNECTION, OVERCHARGE, OR RAPID DISCHARGE COULD RESULT IN EXPLOSION AND/OR FIRE.**

1. Set an input power supply that is capable of 60V and 3A, to 24V. Then turn off the supply.
2. With power off, connect the supply to the input terminals VIN and GND.

NOTE:

- a. Input voltages lower than 20V can keep the converter from turning on due to the undervoltage lockout feature of the LTC4000.
- b. If efficiency measurements are desired, refer to Figure 1 for the test setup.

3. Set CHARGE jumper to ENABLE.

4. Turn on the power at the input.

NOTE: Make sure that the input voltage never exceeds 60V.

5. Check for the proper BAT output voltage of 14.6V. Turn off the power at the input.

6. Now that the proper output voltage is established, connect a variable load capable of sinking 6A at 16V to the output terminals BAT and GND. Set the current for 0A.

7. Turn on the power at the input.

NOTE: If there is no output, temporarily disconnect the load to make sure that the load is not set too high.

8. Once the proper BAT output voltage is again established, adjust the load and/or source within the operating range and observe the battery float voltage regulation, charge current, and other desired parameters.

9. Set the load to constant voltage mode to more easily observe charge current and trickle charge current.

NOTE: The following applies to the DC1830B-A.

NOTE: Operation in the instant-on region ( $V_{OUT} < 12.5V$ ) may engage thermal limit circuit to protect Q2 in the linear region.

NOTE: The optional thermal limit circuit for Q1 (Q5, RNTC3, R8 to 12, and U2) is included to protect Q1 in case of an extended short-circuit on VOUT-SYS under adverse thermal conditions ( $T_A > 40^\circ C$ ). It may not be needed in applications with less severe thermal conditions, lower current available to VOUT-SYS, or where continuous short-circuit protection on VOUT-SYS is not required.

## QUICK START PROCEDURE

10. Turn off the power at the input.
11. Connect the output load and meters to the VOUT-SYS output.
12. Set CHARGE jumper to DISABLE.
13. Turn on the power at the input.
14. Once the proper VOUT-SYS is again established, adjust the load and/or source within the operating range and observe the output voltage regulation, ripple voltage, efficiency, input and output current limit, and other desired parameters.

**Table 1. LTC4000 Charger Setup Parameters and Reference Values**

REFERENCE	DESCRIPTION	NOMINAL VALUE (V)*	MIN/MAX	CONDITIONS
I <sub>IL</sub>	Input Current Regulation/Limit	$(50\mu\text{A} \cdot R_{IL})/20$	45/55	50mV max
I <sub>CL</sub>	Charge Current Regulation/Limit	$(50\mu\text{A} \cdot R_{CL})/20$	45/55	50mV max
I <sub>CL</sub>	Trickle Charge Current Regulation/Limit	$(5\mu\text{A} \cdot R_{CL})/20$	4.5/5.5	
V <sub>BAT-FLOAT</sub>	Battery Float Voltage	1.136V	1.125/1.147	
V <sub>OUT</sub>	System Voltage	1.193V	1.181/1.204	Charger Off
		(Follows V <sub>BAT</sub> )		Charger Float
		(Follows V <sub>BAT</sub> )		Charging at I <sub>CL</sub> , $0.86V_{\text{BAT-FLOAT}} < V_{\text{BAT}} < V_{\text{BAT-FLOAT}}$
		$0.86 \cdot 1.136\text{V}$	0.82/0.90	Instant-On, $0.68V_{\text{BAT-FLOAT}} < V_{\text{BAT}} < 0.86V_{\text{BAT-FLOAT}}$
		$0.86 \cdot 1.136\text{V}$	0.82/0.90	Instant-On, Trickle, $V_{\text{BAT}} < 0.68V_{\text{BAT-FLOAT}}$
VM	Input Voltage Monitor/UVLO	1.193V	1.181/1.204	Falling, (40mV Hysteresis)
CX	C/X Monitor/Charge Termination	$(5\mu\text{A} \cdot R_{CX} - 10\text{mV})/20$	4.5/5.5	Short TMR to BIAS for C/X Termination
TMR	Charge Termination Timer	104S/nF	83/126	

\*Normalized to sense point

# DEMO MANUAL

## DC1830B-A/DC1830B-B

### QUICK START PROCEDURE

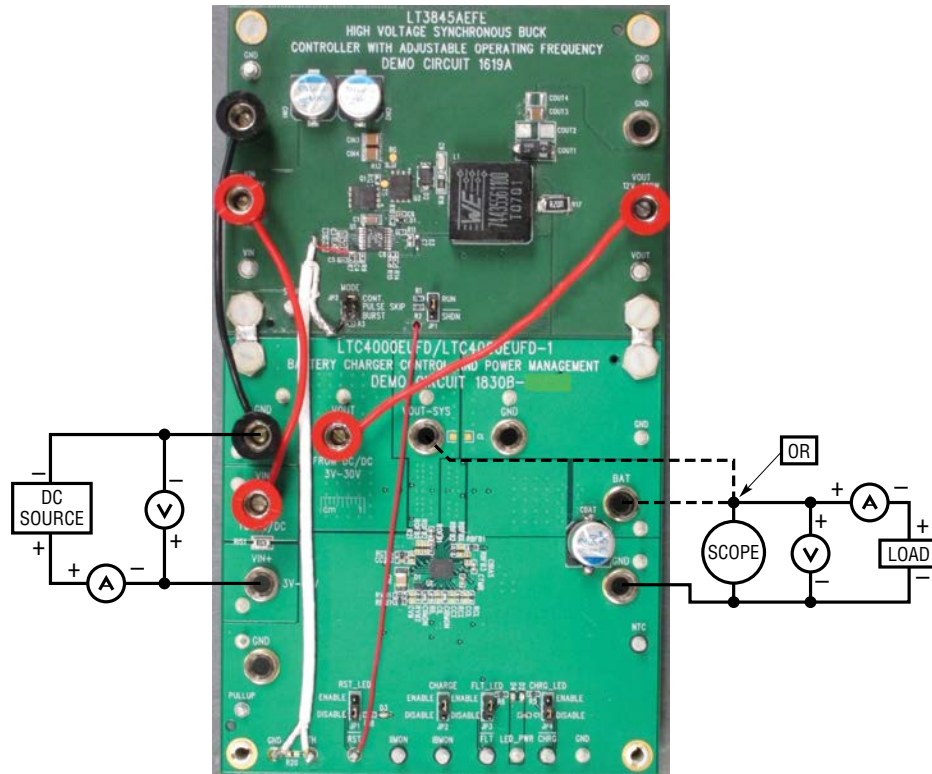


Figure 1. Fixture Connections and Measurement Equipment Setup

## QUICK START PROCEDURE

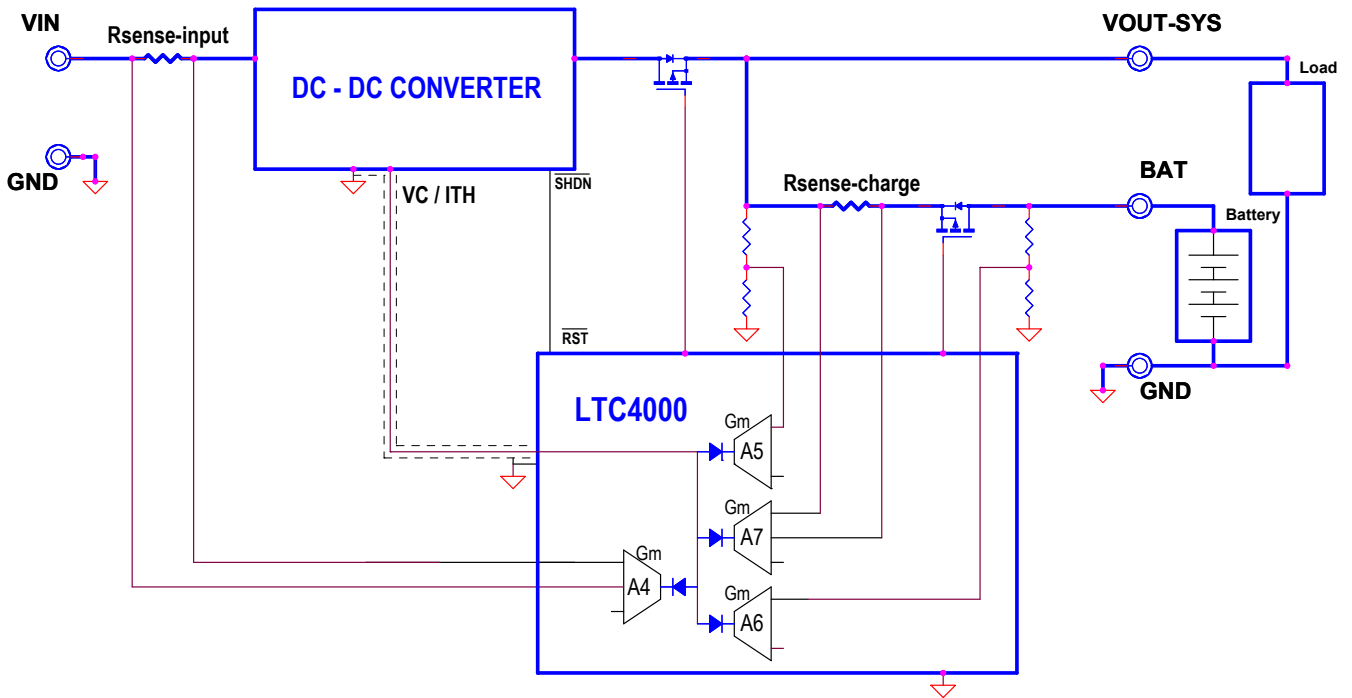


Figure 2. Block Diagram with Typical DC/DC Converter

# DEMO MANUAL

## DC1830B-A/DC1830B-B

### PARTS LIST

ITEM	QTY	REFERENCE	PART DESCRIPTION	MANUFACTURER/PART NUMBER
<b>DC1830B-A Required Circuit Components</b>				
1	1	C1	CAP., X5R, 4.7µF, 10V, 20% 0603	AVX, 0603ZD475MAT2A
2	1	CBAT	CAP., SMT ALUMINUM, 150µF, 35V	SUNCON, 35HVP150M
3	1	CBIAS	CAP., X7R, 1µF, 16V, 10% 0603	AVX, 0603YC105KAT2A
4	1	CBGATE	CAP., X7R, 10nF, 50V, 5% 0603	MURATA, GRM188R71H103JA01D
5	2	CC2, CTMR	CAP., X7R, 0.1µF, 50V, 10% 0603	AVX, 06035C104KAT2A
6	2	CIIMON, CIBMON	CAP., C0G, 1000pF, 25V, 5% 0603	AVX, 06033A102JAT2A
7	1	CIN	CAP., X7R, 1µF, 50V, 10% 1210	AVX, 12105C105KAT2A
8	2	COU1, CL	CAP., X7R, 2.2µF, 50V, 10% 1206	MURATA, GRM31CR71H225KA88L
9	1	D1	DIODE ZENER 3.0V 200MW SOD-323	DIODE INC., BZT52C3V0S-7-F
10	1	D2	LED, GREEN, SMT, 0603	LITE-ON, LTST-C190KGKT
11	2	D3, D4	LED 660NM SUPER RED DIFF 0603 SMD	LUMEX, SML-LX0603SRW-TR
12	1	F2	FUSE 12A 32V T-LAG 1206 SMD	COOPER BUSSMAN, 3216TD12-R
13	2	Q1, Q2	MOSFET P-CHAN., 30V, POWERPAK-8	VISHAY, SI7135DP-T1-GE3
14	2	Q5, Q6	SMALL SIGNAL MOSFET	ON SEMI., 2N7002LT1G
15	2	RBFB2, ROFB2	RES., CHIP, 84.5k, 0.1W, 1% 0603	VISHAY, CRCW060384K5FKEA
16	4	RBFB1, ROFB1, R12, R17	RES., CHIP, 1M, 0.1W, 1% 0603	VISHAY, CRCW06031M00FKEA
17	1	RC1	RES., CHIP 4.22k 1/10W 1% 0603	YAGEO, RT0603FRE074K22L
18	1	RCL	RES., CHIP, 24.3k, 0.1W, 1% 0603	VISHAY, CRCW060324K3FKEA
19	1	RCS	SENSOR RES., 0.01Ω 1W 2% 1508 SMD	SUSUMU, RL3720WT-R010-G
20	3	RCX, R8, R13	RES., CHIP, 10k, 0.1W, 1% 0603	YAGEO, RC0603FR-0710KL
21	1	RIS1	SENSOR RES 0.015Ω 1W 2% 1508 SMD	SUSUMU, RL3720WT-R015-G
22	1	RIL	RES., CHIP, 18.2k, 0.1W, 1% 0603	VISHAY, CRCW060318K2FKEA
23	2	RNTC2, RNTC3,	THERMISTOR NTC 10k 5% 0603	VISHAY, NTHS0603N02N1002J
24	1	RVM1	RES., CHIP 35.7k 1/10W 1% 0603	VISHAY, CRCW060335K7FKEA
25	1	RVM2	RES., CHIP 2.49k 1/10W 1% 0603	YAGEO, RC0603FR-072K49L
26	1	R5	RES., CHIP, 2.2k, 0.1W, 5% 0603	VISHAY, CRCW06032K2JKEA
27	3	R4, R7, R19	RES., CHIP, 100k, 0.1W, 5% 0603	VISHAY, CRCW0603100KJKEA
28	2	R6, R18	RES., CHIP, 4.7k, 0.1W, 5% 0603	VISHAY, CRCW06034K7JKEA
29	1	R9	RES., CHIP, 46.4k, 0.1W, 1% 0603	VISHAY, CRCW060346K4FKEA
30	2	R10, R15	RES., CHIP, 20k, 0.1W, 1% 0603	VISHAY, CRCW060320K0FKEA
31	2	R11, R16	RES., CHIP, 38.3k, 0.1W, 1% 0603	VISHAY, CRCW060338K3FKEA
32	1	R14	RES., CHIP, 78.7k, 0.1W, 1% 0603	VISHAY, CRCW060378K7FKEA
33	1	U1	I.C. LTC4000EUF, 28PIN QFN	ANALOG DEVICES, LTC4000EUFD#PBF
34	2	U2, U3	NANOPWR COMPARATOR, MSOP8	ANALOG DEVICES, LTC1540CMS8#PBF

## PARTS LIST

ITEM	QTY	REFERENCE	PART DESCRIPTION	MANUFACTURER/PART NUMBER
<b>Additional Demo Board Circuit Components</b>				
1	0	CC1, CIGATE, CNTC, CCX, CCL, CIL, CVM	CAP., 0603 OPT	
2	0	CL1, CL2, CL3, CL4, CL5	CAP, 1206, 50V OPT	
3	0	F1, F3	FUSE 12A 32V T-LAG 1206 SMD OPT	
4	0	Q3, Q4	MOSFET P-CHAN., 30V, POWERPAK-8 OPT	
5	0	R1, R2, R3, R20, R21, RIG, RBG, RIFB1, RBFBX, RBFB3, ROFBX	RES., 0603 OPT	
<b>Hardware: For Demo Board Only</b>				
1	16	E1 - E6, E9 - E14, E18, E19, E20, E21	TESTPOINT, TURRET, 0.061" pbf	MILL-MAX, 2308-2-00-80-00-00-07-0
2	5	E7, E8, E15, E16, E17	TESTPOINT, TURRET, 0.094" pbf	MILL-MAX, 2501-2-00-80-00-00-07-0
3	4	JP1, JP2, JP3, JP4	HEADER, 3 PIN 0.079 SINGLE ROW	SAMTEC, TMM-103-02-L-S
4	4	XJP1, XJP2, XJP3, XJP4	SHUNT, 0.079" CENTER	SAMTEC, 2SN-BK-G
5	9	J1, J2, J3, J4, J5, J6, J7, J8, J9	CONNECTOR, BANANA JACK	KEYSTONE, 575-4
6	4	MTG1, MTG2, MTG3, MTG4	STAND-OFF, NYLON (SNAP ON), 0.50" TALL	KEYSTONE, 8833(SNAP ON)

# DEMO MANUAL

## DC1830B-A/DC1830B-B

### PARTS LIST

ITEM	QTY	REFERENCE	PART DESCRIPTION	MANUFACTURER/PART NUMBER
<b>DC1830B-B Required Circuit Components</b>				
1	1	C1	CAP., X5R, 4.7 $\mu$ F, 10V, 20% 0603	AVX, 0603ZD475MAT2A
2	1	CBAT	CAP., SMT ALUMINUM, 150 $\mu$ F, 35V	SUNCON, 35HVP150M
3	1	CBIAS	CAP., X7R, 1 $\mu$ F, 16V, 10% 0603	AVX, 0603YC105KAT2A
4	2	CC2, CTMR	CAP., X7R, 0.1 $\mu$ F, 50V, 10% 0603	AVX, 06035C104KAT2A
5	2	CIIMON, CIBMON	CAP., COG, 1000pF, 25V, 5% 0603	AVX, 06033A102JAT2A
6	1	COUT	CAP., X7R, 2.2 $\mu$ F, 50V, 10% 1206	MURATA, GRM31CR71H225KA88L
7	1	CIN	CAP., X7R, 1 $\mu$ F, 50V, 10% 1210	AVX, 12105C105KAT2A
8	1	D1	DIODE ZENER 3.0V 200MW SOD-323	DIODE INC., BZT52C3V0S-7-F
9	2	D2, D3	LED 660NM SUPER RED DIFF 0603 SMD	LUMEX, SML-LX0603SRW-TR
10	1	D4	LED, GREEN, SMT, 0603	LITE-ON, LTST-C190KGKT
11	1	F2	FUSE 12A 32V T-LAG 1206 SMD	COOPER BUSSMAN, 3216TD12-R
12	1	Q1	MOSFET P-CHAN., 30V, POWERPAK-8	VISHAY, SI7135DP-T1-GE3
13	2	RBFB1, ROFB1	RES., CHIP, 1M, 0.1W, 1% 0603	VISHAY, CRCW06031M00FKEA
14	1	RBFB2	RES., CHIP, 84.5k, 0.1W, 1% 0603	VISHAY, CRCW060384K5FKEA
15	1	RC1	RES., CHIP 4.22k 1/10W 1% 0603	YAGEO, RT0603FRE074K22L
16	1	RCL	RES., CHIP, 24.3k, 0.1W, 1% 0603	VISHAY, CRCW060324K3FKEA
17	1	RCS	SENSOR RES., 0.01 $\Omega$ 1W 2% 1508 SMD	SUSUMU, RL3720WT-R010-G
18	2	RCX, R21	RES., CHIP, 0.0 $\Omega$ , 0.1W, 0603	VISHAY, CRCW06030000Z0EA
19	1	RIL	RES., CHIP, 18.2k, 0.1W, 1% 0603	VISHAY, CRCW060318K2FKEA
20	1	RIS1	Sensor RES 0.015 $\Omega$ 1W 2% 1508 SMD	SUSUMU, RL3720WT-R015-G
21	1	RVM1	RES., CHIP 35.7k 1/10W 1% 0603	VISHAY, CRCW060335K7FKEA
22	1	RVM2	RES., CHIP 2.49k 1/10W 1% 0603	YAGEO, RC0603FR-072K49L
23	3	R4, R7, R19	RES., CHIP, 100k, 0.1W, 5% 0603	VISHAY, CRCW0603100KJKEA
24	1	R5	RES., CHIP, 2.2k, 0.1W, 5%, 0603	VISHAY, CRCW06032K2JKEA
25	2	R6, R18	RES., CHIP, 4.7k, 0.1W, 5% 0603	VISHAY, CRCW06034K7JKEA
26	1	R22	0 $\Omega$ THICK FILM JUMPER CHIP, 2010	IRC., LRC-LRZ-2010LF-R000
27	1	U1	I.C. LTC4000EUF, 28PIN QFN	ANALOG DEVICES, LTC4000EUF#PBF



# DEMO MANUAL

## DC1830B-A/DC1830B-B

### PARTS LIST

ITEM	QTY	REFERENCE	PART DESCRIPTION	MANUFACTURER/PART NUMBER
<b>Additional Demo Board Circuit Components</b>				
1	0	CC1, CBGATE, CIGATE, CNTC, CCX, CCL, CIL, CVM	CAP., 0603 OPT	
2	0	CL, CL1, CL2, CL3, CL4, CL5	CAP., 1206, 50V OPT	
3	0	F1, F3	FUSE 12A 32V T-LAG 1206 SMD OPT	
4	0	RNTC2, RNTC3	THERMISTOR NTC 10k 5% 0603 OPT	VISHAY, NTHS0603N02N1002J
5	0	R1, R2, R3, R20, RIG, RBG, RIFB1, RBFBX, RBFB3, ROFBX, ROFB2	RES., 0603 OPT	
6	0	R8, R13	RES., CHIP, 10k, 0.1W, 1% 0603 OPT	YAGEO, RC0603FR-0710KL
7	0	R9	RES., CHIP, 46.4k, 0.1W, 1% 0603 OPT	VISHAY, CRCW060346K4FKEA
8	0	R10, R15	RES., CHIP, 20k, 0.1W, 1% 0603 OPT	VISHAY, CRCW060320K0FKEA
9	0	R11, R16	RES., CHIP, 38.3k, 0.1W, 1% 0603 OPT	VISHAY, CRCW060338K3FKEA
10	0	R12, R17	RES., CHIP, 1M, 0.1W, 1% 0603 OPT	VISHAY, CRCW06031M00FKEA
11	0	R14	RES., CHIP, 78.7k, 0.1W, 1% 0603 OPT	VISHAY, CRCW060378K7FKEA
12	0	Q3, Q4	MOSFET P-CHAN., 30V, POWERPAK-8 OPT	
13	0	Q5, Q6	SMALL SIGNAL MOSFET OPT	ON SEMI., 2N7002LT1G
14	0	U2, U3	NANOPWR COMPARATOR, MSOP8 OPT	ANALOG DEVICES, LTC1540CMS8#PBF
<b>Hardware: For Demo Board Only</b>				
1	16	E1 - E6, E9 - E14, E18, E19, E20, E21	TESTPOINT, TURRET, 0.061" pbf	MILL-MAX, 2308-2-00-80-00-00-07-0
2	5	E7, E8, E15, E16, E17	TESTPOINT, TURRET, 0.094" pbf	MILL-MAX, 2501-2-00-80-00-00-07-0
3	4	JP1, JP2, JP3, JP4	HEADER, 3 PIN 0.079 SINGLE ROW	SAMTEC, TMM-103-02-L-S
4	4	XJP1, XJP2, XJP3, XJP4	SHUNT, 0.079" CENTER	SAMTEC, 2SN-BK-G
5	9	J1, J2, J3, J4, J5, J6, J7, J8, J9	CONNECTOR, BANANA JACK	KEYSTONE, 575-4
6	4	MTG1, MTG2, MTG3, MTG4	STAND-OFF, NYLON (SNAP ON), 0.50" TALL	KEYSTONE, 8833(SNAP ON)

# DEMO MANUAL

## DC1830B-A/DC1830B-B

### SCHEMATIC DIAGRAM

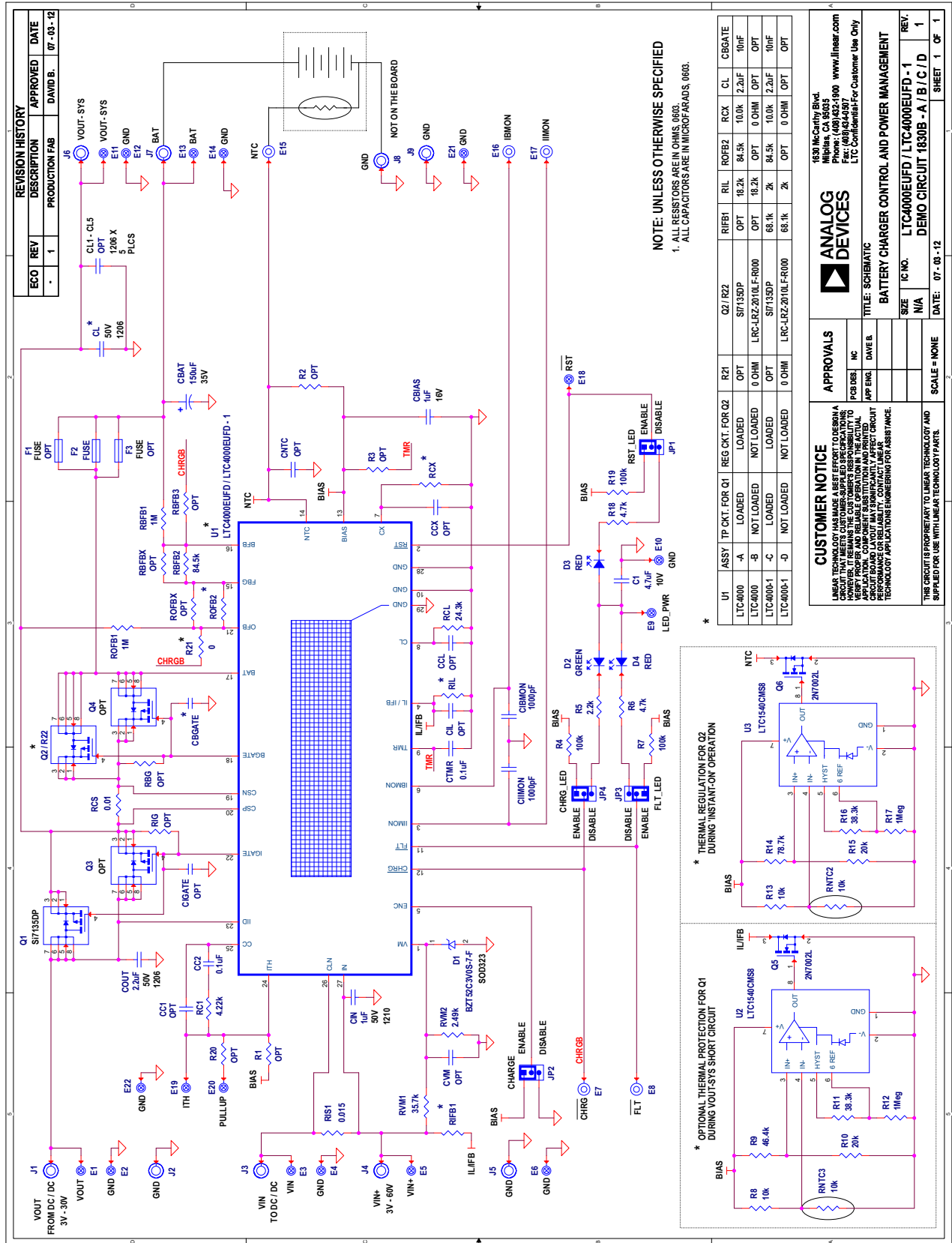


Figure 3. Schematic, DC1830A

## SCHEMATIC DIAGRAM

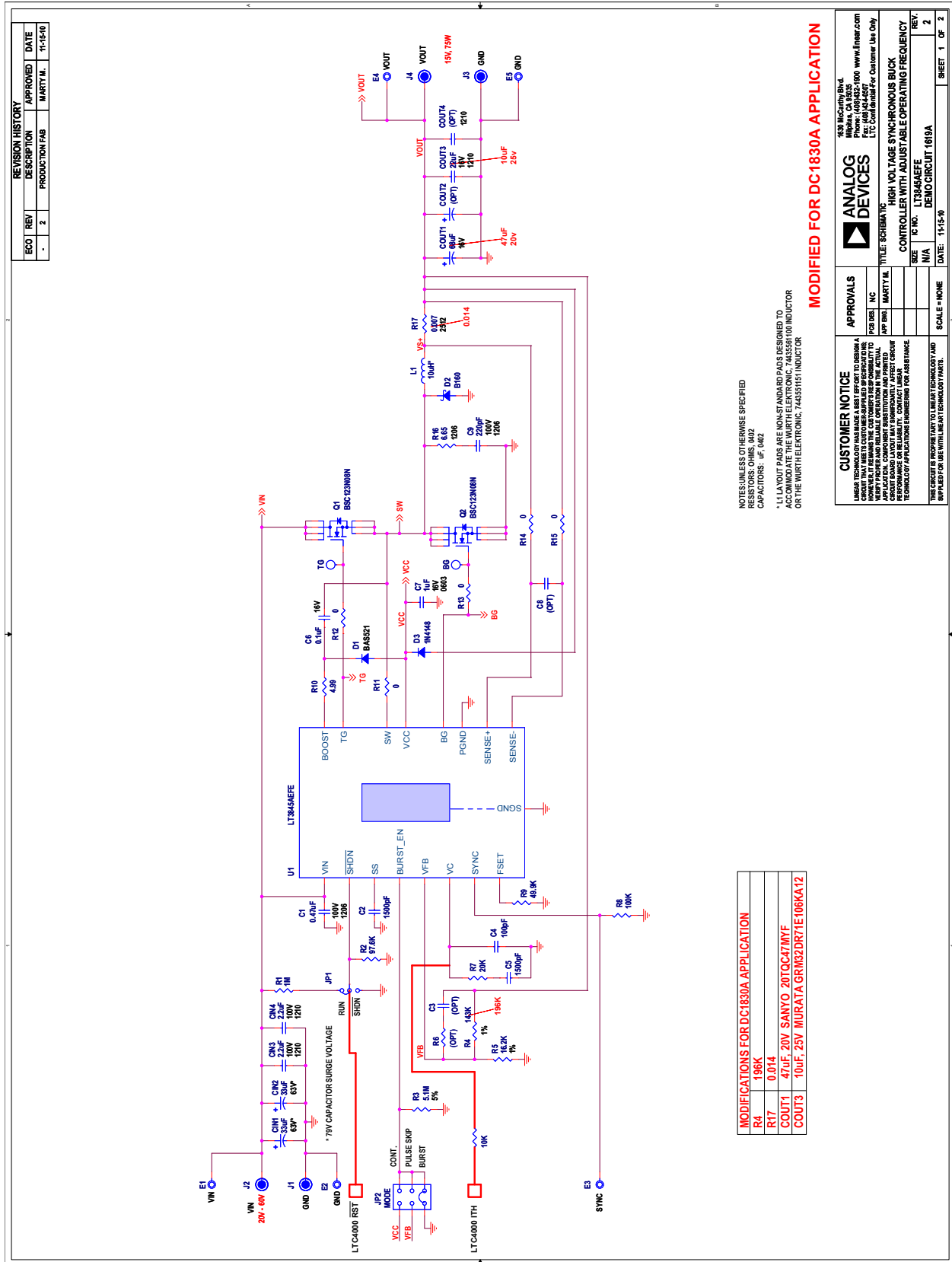


Figure 4. Schematic, Modified DC1619A as Used with DC1830A

# DEMO MANUAL

## DC1830B-A/DC1830B-B

---



### ESD Caution

**ESD (electrostatic discharge) sensitive device.** Charged devices and circuit boards can discharge without detection. Although this product features patented or proprietary protection circuitry, damage may occur on devices subjected to high energy ESD. Therefore, proper ESD precautions should be taken to avoid performance degradation or loss of functionality.

### Legal Terms and Conditions

By using the evaluation board discussed herein (together with any tools, components documentation or support materials, the "Evaluation Board"), you are agreeing to be bound by the terms and conditions set forth below ("Agreement") unless you have purchased the Evaluation Board, in which case the Analog Devices Standard Terms and Conditions of Sale shall govern. Do not use the Evaluation Board until you have read and agreed to the Agreement. Your use of the Evaluation Board shall signify your acceptance of the Agreement. This Agreement is made by and between you ("Customer") and Analog Devices, Inc. ("ADI"), with its principal place of business at One Technology Way, Norwood, MA 02062, USA. Subject to the terms and conditions of the Agreement, ADI hereby grants to Customer a free, limited, personal, temporary, non-exclusive, non-sublicensable, non-transferable license to use the Evaluation Board FOR EVALUATION PURPOSES ONLY. Customer understands and agrees that the Evaluation Board is provided for the sole and exclusive purpose referenced above, and agrees not to use the Evaluation Board for any other purpose. Furthermore, the license granted is expressly made subject to the following additional limitations: Customer shall not (i) rent, lease, display, sell, transfer, assign, sublicense, or distribute the Evaluation Board; and (ii) permit any Third Party to access the Evaluation Board. As used herein, the term "Third Party" includes any entity other than ADI, Customer, their employees, affiliates and in-house consultants. The Evaluation Board is NOT sold to Customer; all rights not expressly granted herein, including ownership of the Evaluation Board, are reserved by ADI. CONFIDENTIALITY. This Agreement and the Evaluation Board shall all be considered the confidential and proprietary information of ADI. Customer may not disclose or transfer any portion of the Evaluation Board to any other party for any reason. Upon discontinuation of use of the Evaluation Board or termination of this Agreement, Customer agrees to promptly return the Evaluation Board to ADI. ADDITIONAL RESTRICTIONS. Customer may not disassemble, decompile or reverse engineer chips on the Evaluation Board. Customer shall inform ADI of any occurred damages or any modifications or alterations it makes to the Evaluation Board, including but not limited to soldering or any other activity that affects the material content of the Evaluation Board. Modifications to the Evaluation Board must comply with applicable law, including but not limited to the RoHS Directive. TERMINATION. ADI may terminate this Agreement at any time upon giving written notice to Customer. Customer agrees to return to ADI the Evaluation Board at that time. LIMITATION OF LIABILITY. THE EVALUATION BOARD PROVIDED HEREUNDER IS PROVIDED "AS IS" AND ADI MAKES NO WARRANTIES OR REPRESENTATIONS OF ANY KIND WITH RESPECT TO IT. ADI SPECIFICALLY DISCLAIMS ANY REPRESENTATIONS, ENDORSEMENTS, GUARANTEES, OR WARRANTIES, EXPRESS OR IMPLIED, RELATED TO THE EVALUATION BOARD INCLUDING, BUT NOT LIMITED TO, THE IMPLIED WARRANTY OF MERCHANTABILITY, TITLE, FITNESS FOR A PARTICULAR PURPOSE OR NON-INFRINGEMENT OF INTELLECTUAL PROPERTY RIGHTS. IN NO EVENT WILL ADI AND ITS LICENSORS BE LIABLE FOR ANY INCIDENTAL, SPECIAL, INDIRECT, OR CONSEQUENTIAL DAMAGES RESULTING FROM CUSTOMER'S POSSESSION OR USE OF THE EVALUATION BOARD, INCLUDING BUT NOT LIMITED TO LOST PROFITS, DELAY COSTS, LABOR COSTS OR LOSS OF GOODWILL. ADI'S TOTAL LIABILITY FROM ANY AND ALL CAUSES SHALL BE LIMITED TO THE AMOUNT OF ONE HUNDRED US DOLLARS (\$100.00). EXPORT. Customer agrees that it will not directly or indirectly export the Evaluation Board to another country, and that it will comply with all applicable United States federal laws and regulations relating to exports. GOVERNING LAW. This Agreement shall be governed by and construed in accordance with the substantive laws of the Commonwealth of Massachusetts (excluding conflict of law rules). Any legal action regarding this Agreement will be heard in the state or federal courts having jurisdiction in Suffolk County, Massachusetts, and Customer hereby submits to the personal jurisdiction and venue of such courts. The United Nations Convention on Contracts for the International Sale of Goods shall not apply to this Agreement and is expressly disclaimed.