

## LTC3305EFE Lead Acid Battery Balancer

### DESCRIPTION

Demonstration circuit 2043B is a lead-acid battery balancer featuring the [LTC®3305](#). The LTC3305 balances up to four lead-acid batteries connected in series and incorporates all voltage monitoring, gate drive and fault detection circuitry. The LTC3305 employs an auxiliary battery or an alternative storage means to transfer charge to or from each individual battery within the stack. There are two operating modes, TIMER mode and CONTINUOUS mode, selected by the MODE pin. In TIMER mode, once the balancing operation is complete, the LTC3305 goes to a low power state for a programmed time and then periodically rebalances the

batteries. In CONTINUOUS mode, the balancing operation continues even after the batteries are balanced to their programmed termination voltage.

The LTC3305EFE is available in a 7mm × 7mm 38-lead TSSOP surface mount package with exposed pad.

**Design files for this circuit board are available at <http://www.linear.com/demo/DC2043B>**

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### BOARD PHOTO

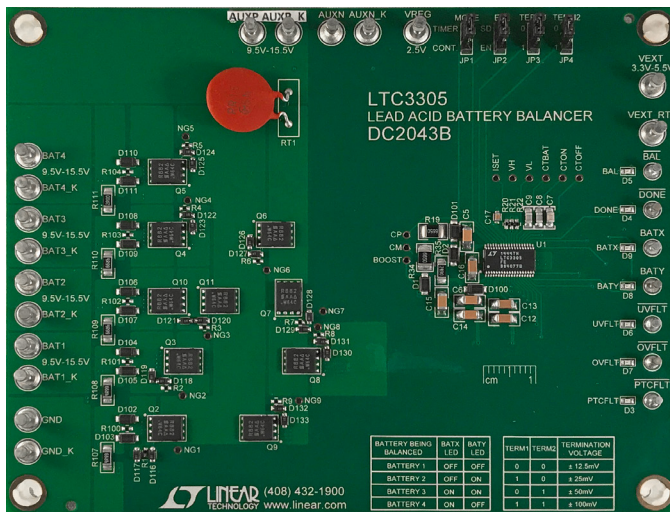


Figure 1. DC2043B Demo Board

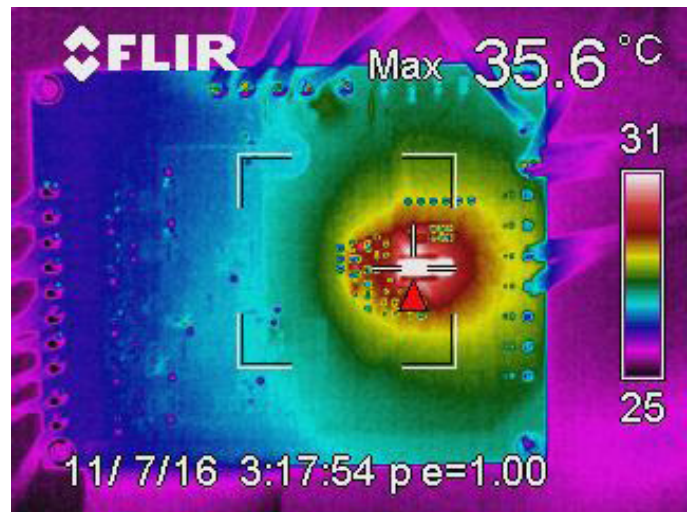


Figure 2. Thermal Image of DC2043B

## PERFORMANCE SUMMARY Specifications are at $T_A = 25^\circ\text{C}$

SYMBOL	PARAMETER	CONDITIONS	MIN	MAX	UNITS
$V_{BAT}$	Battery Voltage Range		4.0	to 16.0	V
$V_{TERMINATE}$	Termination Voltage Range	TERM2 = 0, TERM1 = 0	±5	to ±20	mV
$V_{TERMINATE}$	Termination Voltage Range	TERM2 = 0, TERM1 = 1	±17.5	to ±32.5	mV
$V_{TERMINATE}$	Termination Voltage Range	TERM2 = 1, TERM1 = 0	±42.5	to ±57.5	mV
$V_{TERMINATE}$	Termination Voltage Range	TERM2 = 1, TERM1 = 1	±90	to ±110	mV
$V_{REG}$	Regulator Output Voltage Range	$I_{VREG} = 200\mu\text{A}$	2.4	to 2.6	V

## OPERATING PRINCIPLE

Refer to the block diagram within the LTC3305 data sheet for its operating principle.

The LTC3305 balances batteries using an auxiliary battery or an alternate storage means as a charge reservoir. The LTC3305 controls external N Channel MOSFET switches in a preprogrammed sequence to connect a battery in the stack to the auxiliary battery. Charge is transferred to or from the auxiliary battery when it is connected to a battery in the stack.

The LTC3305 can operate in one of two modes, TIMER mode or CONTINUOUS mode, programmable via the MODE pin. Balancing operation begins once the CBOOST capacitor is charged to at least 6.95V. The EN1 and EN2 pins select the number of batteries in the stack.

EN1	EN2	Application
0	0	SHUTDOWN
0	1	2 Battery Stack
1	0	3 Battery Stack
1	1	4 Battery Stack

With the MODE pin set to 0 the LTC3305 will operate in the TIMER Mode. The  $\overline{\text{BAL}}$  pin will be pulled low, indicating that the part is enabled and balancing the battery stack. The balancing operation begins with the terminal of the auxiliary battery connected to the negative terminal of BAT1, the lowest battery in the stack. The bottom switches that connect the negative terminals of BAT1 to the auxiliary battery's negative terminal are turned on. After a 50ms delay, the voltages across the auxiliary battery and BAT1 are compared by the termination sense comparator. If the

voltage difference between the auxiliary battery and BAT1 is less than the selected termination voltage, the battery is deemed to be in a balance state with respect to the auxiliary battery. The bottom switches will be turned off and the next battery within the stack will be connected.

If the voltage difference between the auxiliary battery and BAT1 is greater than the selected termination voltage, the top switches that connect the positive terminal of BAT1 to the auxiliary battery's positive terminals through the PTC thermistor are turned on. Current is limited by the PTC thermistor. Figure 3 shows the startup battery current where the PTC is limiting as it heats up. Figure 4 is the steady state battery current after the PTC has reached its thermal equilibrium. After a 50ms delay, the termination-sense comparator starts to monitor the voltage across the auxiliary battery and the battery. The battery will remain connected to the auxiliary battery until the voltage difference decreases to the selected termination voltage or a  $t_{BAT}$  timeout occurs.

At this point all switches are turned off and the second battery in the stack will be connected to the auxiliary battery after a 50ms delay. This 50ms delay provides a break-before-make function before the next battery is connected. The cycle will be repeated for each battery in the stack.

Once all batteries in the stack are balanced the  $\overline{\text{DONE}}$  pin is pulled low, the  $\overline{\text{BAL}}$  pin is in its high state and the LTC3305 is put into a low power off state. The stack is deemed balanced when for a four battery stack, the termination-sense comparator detects  $V_{TERMINATE}$  on five consecutive cycles that connect each of the batteries to the auxiliary battery using the bottom switches only.

## OPERATING PRINCIPLE

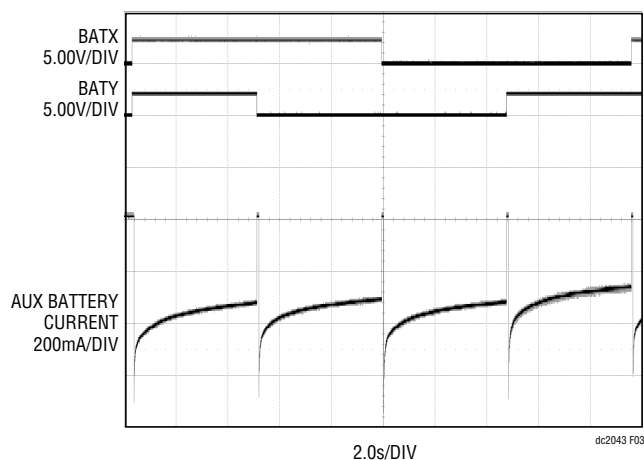


Figure 3. Start-Up Battery Balancing Current

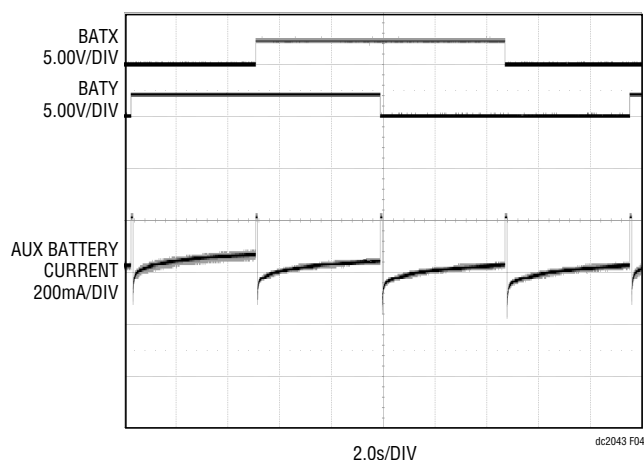


Figure 4. Steady State Battery Balancing Current

In TIMER mode, the balancing operation continues for a maximum of the programmed  $t_{ON}$  time. After the  $t_{ON}$  time, LTC3305 is put into a low power off state for a programmed  $t_{OFF}$  time, even though the batteries may not be balanced. Once the  $t_{OFF}$  time expires, the LTC3305 is put into the ON state, and normal operation resumes. The  $\overline{BAL}$  pin is in its high impedance state if the part is in the OFF state or when the part is in shutdown.

With the MODE pin set to 1, the LTC3305 will operate in the CONTINUOUS Mode. The part functions in much the same way as in the TIMER mode with the following differences.

1. There are no ON or OFF states. The balancing operation continues even if the stack is in balance. The balancing operation is terminated only if the part is put into shutdown. The  $\overline{BAL}$  pin is always pulled low.
2. In CONTINUOUS mode, the top switches are turned on and balancing operation on a battery is terminated by the  $t_{BAT}$  time out. Since the auxiliary cell remains connected to the battery until a  $t_{BAT}$  time out, its voltage can change before it connects to the next battery in the stack. As a result, when the stack is balanced and the DONE pin is pulled low, the voltages across individual batteries in the stack may differ by more than the programmed  $V_{TERMINATE}$ . In the worst case, when the capacity of the auxiliary cell is much smaller than the battery, the individual battery voltages will differ by twice the programmed  $V_{TERMINATE}$  when balanced.

The LTC3305 provides undervoltage and overvoltage threshold detection that can be programmed using resistors that are connected between the  $I_{SET}$ , VL and VH pins and ground. The voltages set on VL and VH are scaled by a factor of 10, setting the battery undervoltage and overvoltage thresholds, respectively.

When an undervoltage or overvoltage fault condition is detected, the corresponding  $\overline{UVFLT}$  or  $\overline{OVFLT}$  pin is pulled low. The balancing operation is not interrupted during this time. If the fault condition goes away during balancing, the corresponding fault pin is put into its high impedance state.

A number of components are included on the DC2043B to protect the circuit from damage when hot-plugging the battery connections to the board.

Clamping diode D100 prevents the BOOST pin on the LTC3305 from going excessively negative with respect to the V4 pin during hot plug. Likewise, D101 prevents the voltage at the CP pin from going excessively negative with respect to the CP pin.

Antiparallel Schottky diodes and a  $100\Omega$  resistor tie each power connection with its corresponding sense (Kelvin) connection. The resistor keeps the potential between the power and sense connections near zero while the diodes maintain the voltage difference to a few tenths of a volt even when transient currents want to flow between power and sense connections.

## OPERATING PRINCIPLE

During some hot-plug events, the gate-to-source voltage on some of the power FETs can approach the maximum VGS rating of the FETs. Back-to-back Zener diodes (15V nominal threshold) are included across all power-FET gate-source pins.

Inrush current between the sense connections and capacitors C6, C12–C15 is limited by resistors R107–R111. These resistors are pulse-power-rated. The higher pulse-power capability is a necessary requirement for these resistors. These resistors are 5Ω, 1206 except for the resistor in the BAT4\_KF net which is 2Ω, 1206 because, while it senses the voltage at the top of the battery stack, it also sinks a small amount of current to power the internals of the LTC3305.

TVS diodes D135 to D138 are listed as “OPT” on the schematic, and are not included on the DC2043B. However, a transient-voltage-suppressor diode is included across the battery stack to protect the LTC3305 from transients generated during hot plugging. The threshold voltage of the part is specified to lie between 66.7V and 73.7V.

Fuses are present on each of the 14 connections to external batteries. Seven power connections employ a 7A-rated fuse. The sense connections (XXX\_K) use 1A fuses. Note that the protection circuits described above are placed on the internal-to-the-board side of the fuses. This placement ensures isolation and disconnection of the protection circuits in the event of a steady-state fault condition.

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## QUICK START PROCEDURE

Using short twisted pair leads for any power connections, with all loads and power supplies off, refer to Figure 5 for the proper measurement and equipment setup.

Follow the procedure below:

1. Before connecting PS1-PS5 to the DC2043B, the power supplies must have its current limit set to 5A . For most power supplies with a current-limit-adjustment feature the procedure to set the current limit is as follows. Turn the voltage and current adjustment to minimum. Short the output terminals and turn the voltage adjustment to maximum. Adjust the current limit to 5A for PS1. Turn the voltage adjustment to minimum and remove the short between the output terminals. Repeat for PS2-PS5 The power supplies are now current limited to 5A .

- a. Initial Jumper and PS settings:

<b>JP1(MODE) = CONT</b>		<b>JP2 (EN) = SD</b>
<b>JP3(TERM1) = 1</b>		<b>JP4 (TERM2) = 1</b>
<b>PS1 = Off</b>	<b>PS2 = Off</b>	<b>PS3 = OFF</b>
<b>PS4 = Off</b>	<b>PS5 = Off</b>	<b>PS6 = Off</b>

2. Connect power supplies, load resistors and meters as shown in Figure 5. Turn on PS1 and slowly increase voltage to 2.0V while monitoring the input current. If the current remains less than 200mA, increase PS1 to 12.0V. Repeat for PS2-PS4.
3. Turn on PS5 and slowly increase voltage to 2.0V while monitoring the input current. If the current remains less than 200mA, increase PS5 to 11.8V. Turn on PS6 and slowly increase voltage to 2.0V while monitoring the input current. If the current remains less than 20mA, increase PS6 to 5.0V.
4. Measure the voltage from the VREG turret to ground. The voltage should read approximately 2.6V. Measure the voltage from the BOOST test point to V4. The voltage should read approximately 0V. No LED should be on.
5. Set JP2 to EN. Measure the voltage from the BOOST test point to V4. The voltage should read approximately 8.5V.
6. Measure the voltage from the I<sub>SET</sub> test point to ground. The voltage should read approximately 1.2V.

## QUICK START PROCEDURE

7. Measure the voltage from the VH test point to ground. The voltage should read approximately 1.52V.
8. Measure the voltage from the VL test point to ground. The voltage should read approximately 0.95V.
9. With JP1 set to CONT, JP2 set to EN, JP3 set to 1 and JP4 set to 1, observe that the BATX and BATY LEDs are cycling through their four states.
10. Decrease PS1 and PS5 to 9.4V and observe that while the BATX and BATY are off, the  $\overline{UVFLT}$  LED is on.
11. Increase PS1 and PS5 to 15.9V and observe that while the BATX and BATY are off, the  $\overline{OVFLT}$  LED is on. Decrease PS1 and PS2 to 12.0V.
12. Decrease PS2 to 11.5V. Set JP1 to TIMER. Observe that the BATX LED is off and BATY LED is on the majority of the time. Increase PS2 to 12V and observe that the balancing action stops. The BAL LED will be off and the DONE LED will be on.
13. Set JP1 to CONT and JP2 to SD. Set PS5 to 11.8V. Observe that balancing action has stopped and no LEDs are on. Set JP2 to EN and observe that balancing action starts.
14. Turn off all power supplies.

BATX LED	BATY LED	Active Battery
OFF	OFF	BAT1
OFF	ON	BAT2
ON	ON	BAT3
ON	OFF	BAT4

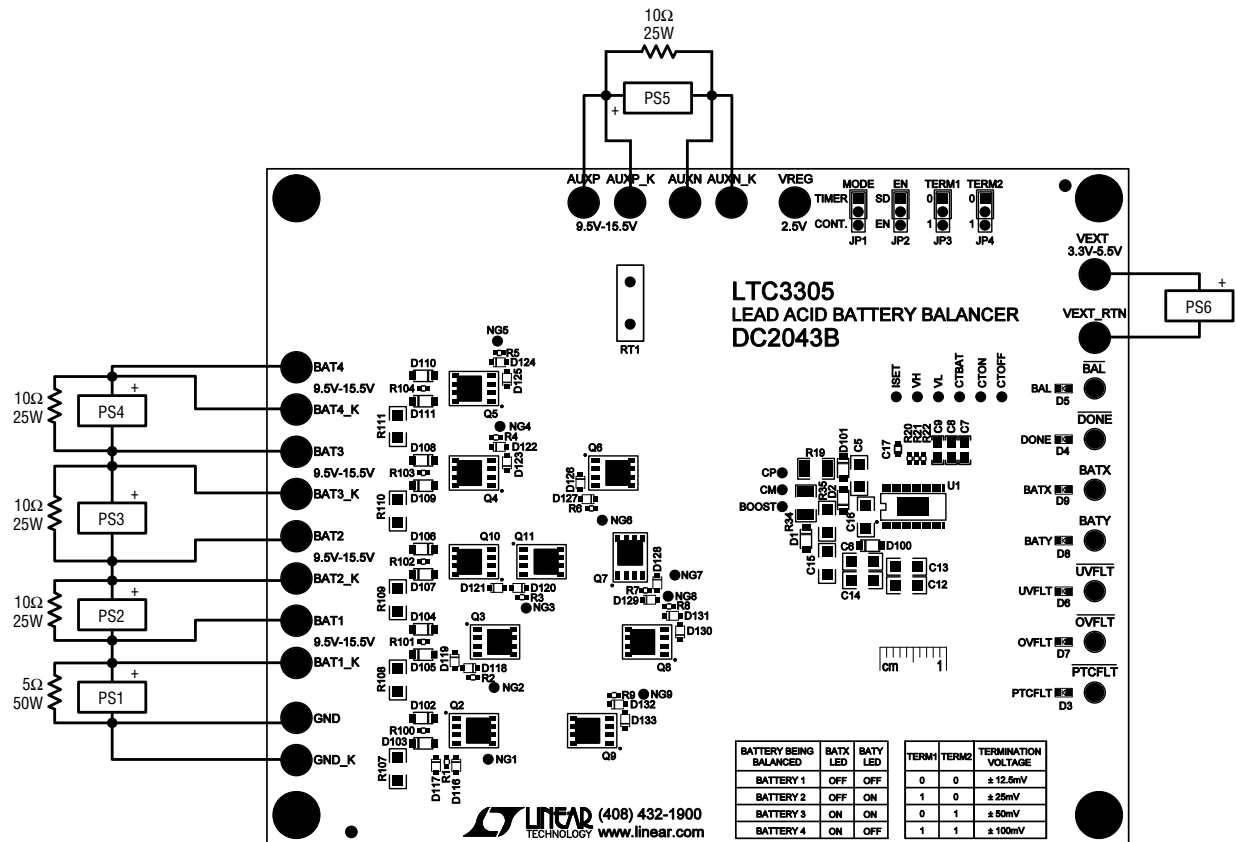


Figure 5. Proper Measurement Equipment Set-Up

# DEMO MANUAL DC2043B

## PARTS LIST

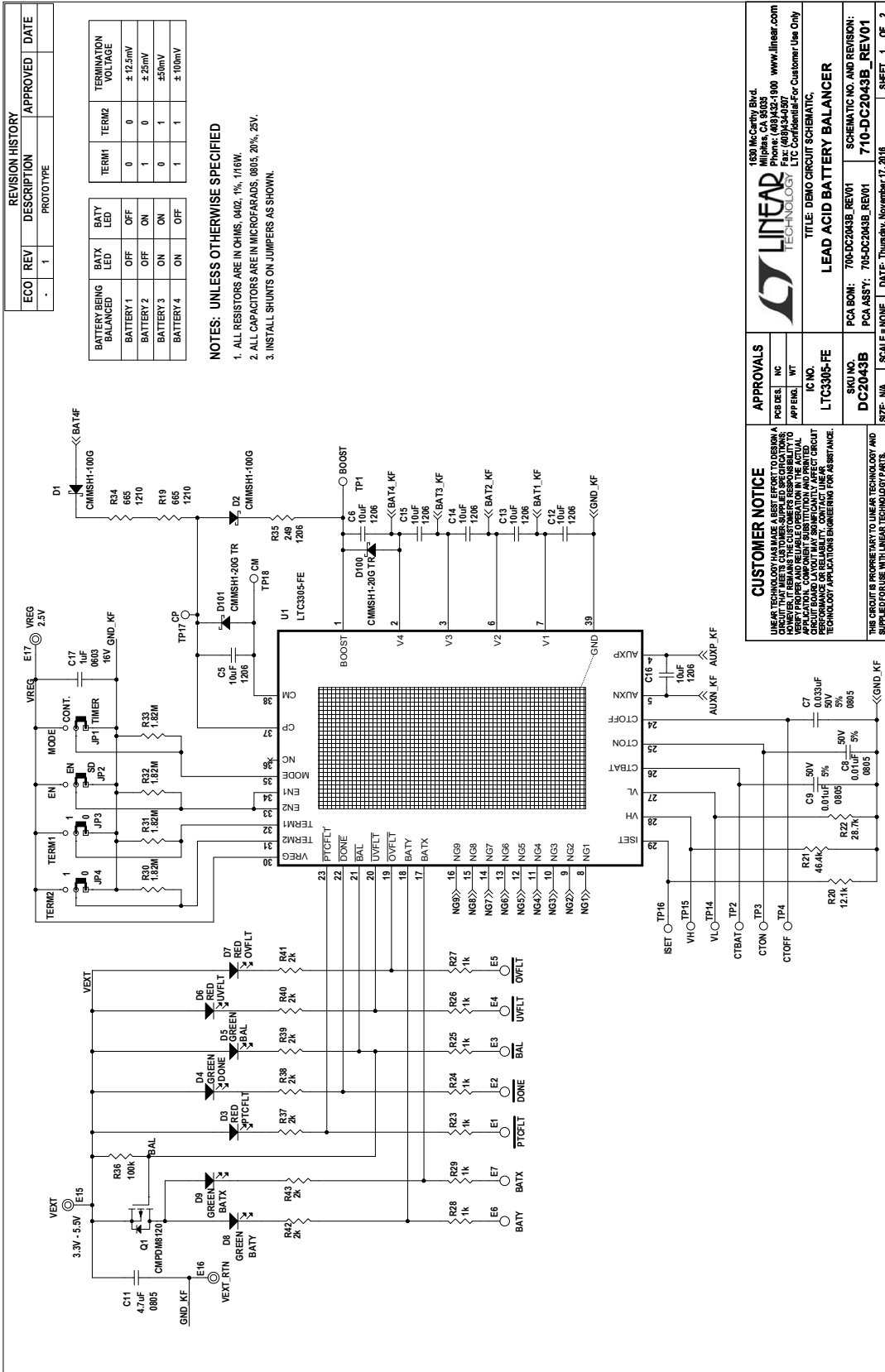
ITEM	QTY	REFERENCE	PART DESCRIPTION	MANUFACTURER/PART NUMBER
<b>Required Circuit Components</b>				
1	5	C1-C4, C11	CAP, 4.7 $\mu$ F, X7R, 25V, 10%, 0805	MURATA, GRM21BR71E475KA73L
2	7	C5, C6, C12-C16	CAP, 10 $\mu$ F, X7R, 25V, 20%, 1206	TDK, C3216X7R1E106M160AB
3	1	C7	CAP, 0.033 $\mu$ F, C0G, 50V, 5%, 0805, AUTOMOTIVE	TDK, CGA4J2C0G1H333J125AA
4	2	C8, C9	CAP, 0.01 $\mu$ F, C0G, 50V, 5%, 0805, AUTOMOTIVE	TDK, CGA4C2C0G1H103J060AA
5	1	C17	CAP, 1 $\mu$ F, X7R, 16V, 10%, 0603	KEMET, C0603C105K4RAC7867
6	2	D1, D2	DIODE, SCHOTTKY, 100V, 1A, SOD-123F	CENTRAL SEMI, CMMSH1-100G TR LEAD FREE
7	3	D3, D6, D7	LED, RED, CLEAR, 0603 SMD	LITE-ON TECHNOLOGY CORP, LTST-C193KRKT-5A
8	4	D4, D5, D8, D9	LED, GREEN, CLEAR, 0603 SMD	LITE-ON TECHNOLOGY CORP, LTST-C193KGKT-5A
9	16	D100-D115	DIODE, SCHOTTKY, 20V, 1A, SOD-123F	CENTRAL SEMI, CMMSH1-20G TR LEAD FREE
10	18	D116-D133	DIODE, ZENER, 15V, 250mW, SOD-323	CENTRAL SEMI, CMDZ5245B TR LEAD FREE
11	1	D134	DIODE, TVS, 60V, 400W, SMA	DIODES INC., SMAJ60A-13-F
12	7	F1, F3, F5, F7, F9, F11, F13	FUSE, BOARD MNT, 1A, 32VAC, 63VDC, 1206	Eaton, TR/3216FF1-R
13	7	F2, F4, F6, F8, F10, F12, F14	FUSE, BOARD MNT, 7A, 32VAC/VDC, 1206	Eaton, TR/3216FF7-R
14	1	Q1	XSTR., MOSFET, P-CH, 20V, 0.95A, SOT-23	CENTRAL SEMI, CMPDM8120 PBFREE
15	10	Q2-Q11	XSTR., MOSFET, N-CH, 100V, 60A, PPAK SO-8	VISHAY, SIR882DP-T1-GE3
16	8	R1, R2, R4-R9	RES., 6.04k $\Omega$ , 1%, 1/16W, 0402	VISHAY, CRCW04026K04FKED
17	1	R3	RES., 3.01k $\Omega$ , 1%, 1/16W, 0402	VISHAY, CRCW04023K01FKED
18	2	R10, R11	RES., 12.1k $\Omega$ , 1%, 1/8W, 0805	VISHAY, CRCW080512K1FKEA
19	7	R12-R18	RES., 10 $\Omega$ , 1%, 1/16W, 0402	VISHAY, CRCW040210R0FKED
20	2	R19, R34	RES., 665 $\Omega$ , 1%, 1/2W, 1210	VISHAY, CRCW1210665RFKEA
21	1	R20	RES., 12.1k $\Omega$ , 1%, 1/16W, 0402	VISHAY, CRCW040212K1FKED
22	1	R21	RES., 46.4k $\Omega$ , 1%, 1/16W, 0402	VISHAY, CRCW040246K4FKED
23	1	R22	RES., 28.7k $\Omega$ , 1%, 1/16W, 0402	VISHAY, CRCW040228K7FKED
24	7	R23-R29	RES., 1k $\Omega$ , 1%, 1/16W, 0402	NIC, NRC04F1001TRF
25	4	R30-R33	RES., 1.82M $\Omega$ , 1%, 1/16W, 0402	NIC, NRC04F1824TRF
26	1	R35	RES., 249 $\Omega$ , 1%, 1/4W, 1206	VISHAY, CRCW1206249RFKEA
27	1	R36	RES., 100k $\Omega$ , 1%, 1/16W, 0402	NIC, NRC04F1003TRF
28	7	R37-R43	RES., 2k $\Omega$ , 1%, 1/16W, 0402	NIC, NRC04F2001TRF
29	7	R100-R106	RES., 100 $\Omega$ , 1%, 1/16W, 0402	KOA SPEER, RK73H1ETTP1000F
30	4	R107-R110	RES., PULSE PROOF, 4.99 $\Omega$ , 1%, 1/2W, 1206	VISHAY, CRCW12064R99FKEAHP
31	1	R111	RES., PULSE PROOF, 2 $\Omega$ , 1%, 1/2W, 1206	VISHAY, CRCW12062R00FKEAHP
32	1	RT1	RES., THERMISTOR PTC, AUTOMOTIVE, 0.15 $\Omega$ , 20%, 2.3W, THT	MURATA, PTGLESARR15M1B51B0
33	1	U1	IC, LEAD-ACID BATTERY BALANCER, TSSOP-38	LINEAR TECHNOLOGY, LTC3305EFE#PBF

## PARTS LIST

ITEM	QTY	REFERENCE	PART DESCRIPTION	MANUFACTURER/PART NUMBER
<b>Optional Circuit Components</b>				
1	0	D135-D138	TVS DIODE 15VWM 24.4VC SMA	DIODES INCORPORATED, SMAJ15A-13-F
<b>Hardware: For Demo Board Only</b>				
1	7	E1-E7	TEST POINT, TURRET, 0.064" MTG. HOLE, 0.125" THICK PCB	MILL-MAX, 2308-4-00-80-00-00-07-0
2	17	E8-E24	TEST POINT, TURRET, 0.094", MTG. HOLE	MILL-MAX, 2501-2-00-80-00-00-07-0
3	4	JP1-JP4	CONN., HDR., MALE, 1x3, 2mm, THT, STR	WURTH ELEKTRONIK, 62000311121
4	2	LB1	LABEL SPEC, DEMO BOARD SERIAL NUMBER	BRADY, THT-96-717-10
5	4	MP1-MP4	STANDOFF, NYLON, SNAP-ON, 0.250"	KEYSTONE, 8831
6	1	PCB1	PCB, DC2043B	EAGLE ELECTRONICS, INC, 600-DC2043B
7	4	XJP1-XJP4	CONN., SHUNT, FEMALE, 2 POS, 2mm	WURTH ELEKTRONIK, 60800213421

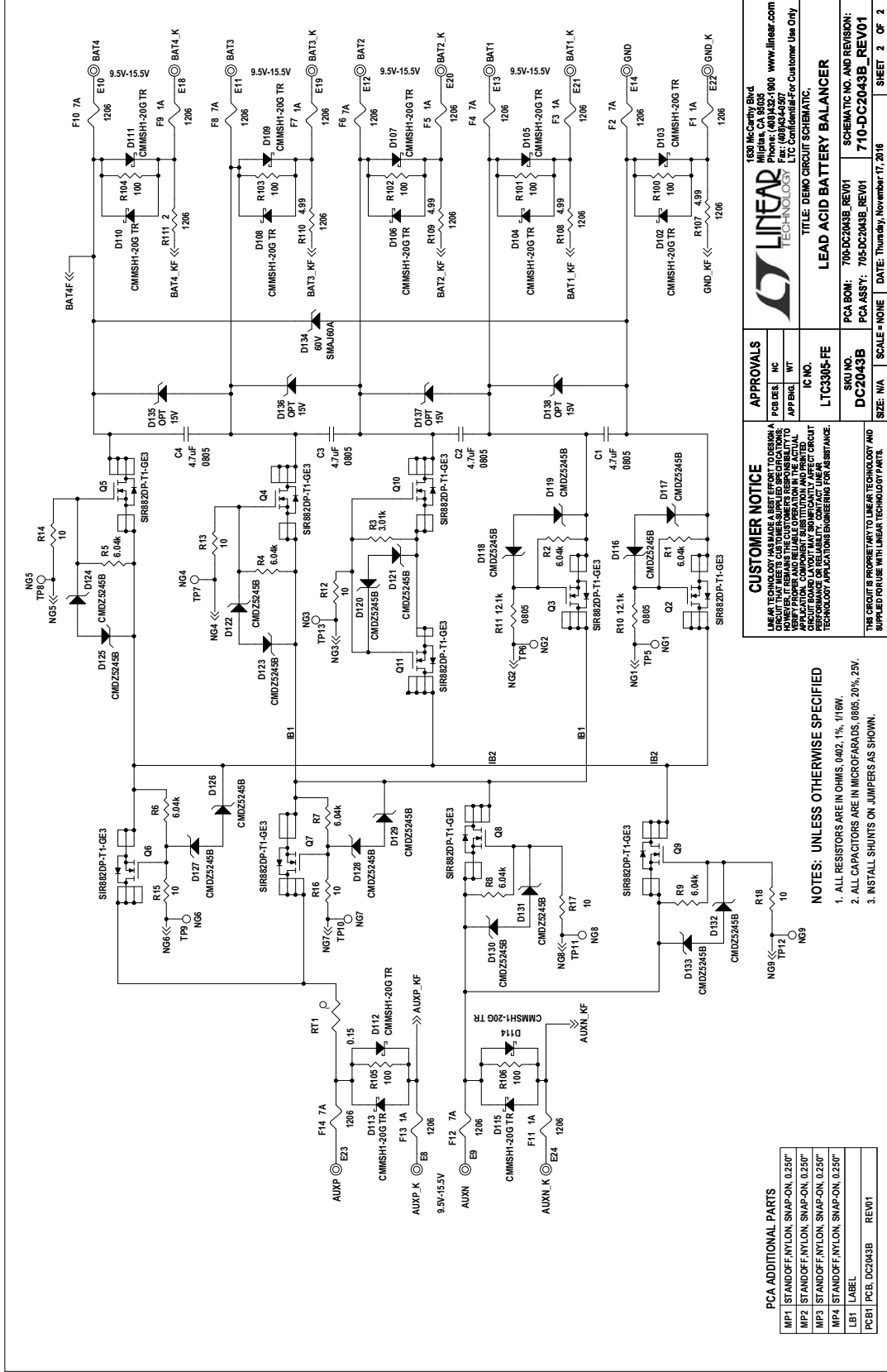
# DEMO MANUAL DC2043B

## SCHEMATIC DIAGRAM





**SCHEMATIC DIAGRAM**



<p><b>CUSTOMER NOTICE</b>                  LINEAR TECHNOLOGY HAS MADE A BEST EFFORT TO DESIGN A BOARD LAYOUT THAT IS UNCOMPROMISING. HOWEVER, IT REMAINS THE CUSTOMER'S RESPONSIBILITY TO VERIFY THE BOARD LAYOUT MEETS ALL APPLICATION REQUIREMENTS. COMPONENT SUBSTITUTION AND PRINTED CIRCUIT BOARD LAYOUT MAY SIGNIFICANTLY AFFECT CIRCUIT PERFORMANCE. LINEAR TECHNOLOGY ASSUMES NO LIABILITY FOR APPLICATIONS ENGINEERING FOR AS-BSTANCE.</p>	
<p><b>APPROVALS</b></p> <p>DESIGN: _____                  APP ENG: _____                  IC NO: LTC3905-FE</p>	<p>1830 McCarty Blvd                  Milpitas, CA 95035                  Phone: (408)432-1900 www.linear.com                  Fax: (408)432-1999                  Copyright © 2016 Linear Technology, Inc. For Customer Use Only</p>
<p>PCB NO: DC2043B                  PCA ASSY: 705-DC2043B_REV01                  SIZE: N/A</p>	<p>SCHEMATIC NO. AND REVISION:                  710-DC2043B_REV01</p>
<p>DATE: Thursday, November 17, 2016</p>	<p>SHEET 2 OF 2</p>

- NOTES: UNLESS OTHERWISE SPECIFIED**
1. ALL RESISTORS ARE IN OHMS, (k)0.2, 1%, (M)100k.
  2. ALL CAPACITORS ARE IN MICROFARADS, (M)0.001, 20%, 25V.
  3. INSTALL SHUNTS ON JUMPERS AS SHOWN.

<p><b>PCA ADDITIONAL PARTS</b></p>	
MP1	STANDOFF, NYLON, SNAP-ON, 0.250"
MP2	STANDOFF, NYLON, SNAP-ON, 0.250"
MP3	STANDOFF, NYLON, SNAP-ON, 0.250"
MP4	STANDOFF, NYLON, SNAP-ON, 0.250"
LB1	LABEL
PCB1	PCB, DC2043B REV01

# DEMO MANUAL DC2043B

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## DEMONSTRATION BOARD IMPORTANT NOTICE

Linear Technology Corporation (LTC) provides the enclosed product(s) under the following **AS IS** conditions:

This demonstration board (DEMO BOARD) kit being sold or provided by Linear Technology is intended for use for **ENGINEERING DEVELOPMENT OR EVALUATION PURPOSES ONLY** and is not provided by LTC for commercial use. As such, the DEMO BOARD herein may not be complete in terms of required design-, marketing-, and/or manufacturing-related protective considerations, including but not limited to product safety measures typically found in finished commercial goods. As a prototype, this product does not fall within the scope of the European Union directive on electromagnetic compatibility and therefore may or may not meet the technical requirements of the directive, or other regulations.

If this evaluation kit does not meet the specifications recited in the DEMO BOARD manual the kit may be returned within 30 days from the date of delivery for a full refund. **THE FOREGOING WARRANTY IS THE EXCLUSIVE WARRANTY MADE BY THE SELLER TO BUYER AND IS IN LIEU OF ALL OTHER WARRANTIES, EXPRESSED, IMPLIED, OR STATUTORY, INCLUDING ANY WARRANTY OF MERCHANTABILITY OR FITNESS FOR ANY PARTICULAR PURPOSE. EXCEPT TO THE EXTENT OF THIS INDEMNITY, NEITHER PARTY SHALL BE LIABLE TO THE OTHER FOR ANY INDIRECT, SPECIAL, INCIDENTAL, OR CONSEQUENTIAL DAMAGES.**

The user assumes all responsibility and liability for proper and safe handling of the goods. Further, the user releases LTC from all claims arising from the handling or use of the goods. Due to the open construction of the product, it is the user's responsibility to take any and all appropriate precautions with regard to electrostatic discharge. Also be aware that the products herein may not be regulatory compliant or agency certified (FCC, UL, CE, etc.).

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LTC currently services a variety of customers for products around the world, and therefore this transaction **is not exclusive**.

**Please read the DEMO BOARD manual prior to handling the product.** Persons handling this product must have electronics training and observe good laboratory practice standards. **Common sense is encouraged.**

This notice contains important safety information about temperatures and voltages. For further safety concerns, please contact a LTC application engineer.

Mailing Address:

Linear Technology  
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