

LTC4013EUFD 60V Synchronous Buck Multi-Chemistry Battery Charger

DESCRIPTION

Demonstration circuit 2374B is a multi-chemistry battery charger with maximum power point tracking (MPPT) featuring the [LTC®4013](#). The LTC4013 has 2 stage CC/CV charge cycles, 3 stage and 4 stage lead acid and Li-Ion battery algorithms.

The DC2374B is set up to operate from a 21.5V to 35V supply or from a solar panel and charges a six cell lead acid battery at 5A. There are optional input and output capacitors plus large inductor pads and parallel top and bottom FET pads to allow high power charging.

The LTC4013 is a 60V controller which makes it suitable for large battery stacks with up to a 60V supply or solar panel input. An MPPT burst mode feature allows the device to efficiently charge in low light levels. Since the LTC4013

is a controller, the power train can be sized from 1A to over 10A of charge current. The LTC4013 also has an NTC temperature compensated float voltage to help increase the battery life.

The operating frequency, charge voltage, low battery (LB) voltage setting and timing are configurable with external resistors and a capacitor. The different charging algorithms are set by two tri-state mode pins and the TIMER pin as shown in Table 1.

Refer to the LTC4013 data sheet for more details on the electrical and timing specifications.

[Design files for this circuit board are available.](#)

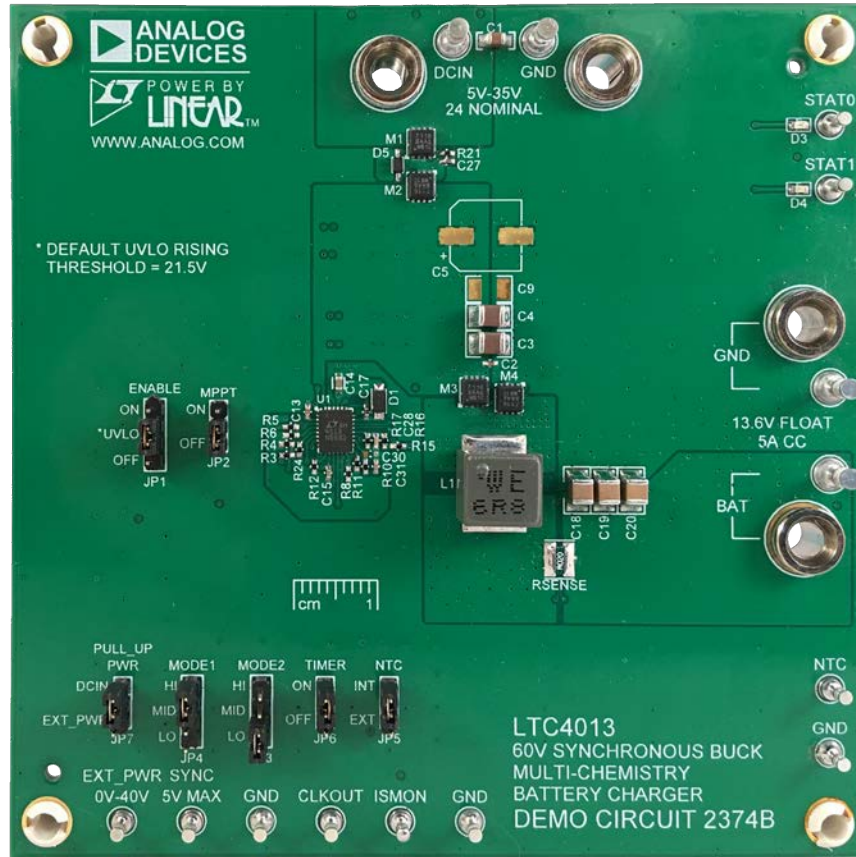
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PERFORMANCE SUMMARY Specifications are at T_A = 25°C

PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
Input Supply Range	ENABLE (JP1) = UVLO	21.5	24	35	V
	ENABLE (JP1) = ON, MPPT (JP2) = ON	5		35	V
Battery Float Voltage (V _{FLOAT})	MODE1 (JP4) = HI, MODE2 (JP3) = LO		13.6		V
	MODE1 (JP4) = MID, MODE2 (JP3) = LO		13.2		V
	MODE1 (JP4) = HI, MODE2 (JP3) = MID		14.2		V
	MODE1 (JP4) = MID, MODE2 (JP3) = MID		14.4		V
Battery Absorption Voltage (V _{ABS})	MODE1 (JP4) = HI, MODE2 (JP3) = LO		14.2		V
	MODE1 (JP4) = MID, MODE2 (JP3) = LO		14.4		V
Battery Equalization Voltage (V _{EQ})	MODE1 (JP4) = HI, MODE2 (JP3) = HI, TIMER (JP6) = CAP		16		V
	MODE1 (JP4) = MID, MODE2 (JP3) = HI, TIMER (JP6) = CAP		15.6		V
Recharge Voltage (V _{RECHRG})	MODE1 (JP4) = HI, MODE2 (JP3) = MID		13.77		V
	MODE1 (JP4) = MID, MODE2 (JP3) = MID		13.77		V
Low Battery (V _{LB})			10.4		V
MPPT Maximum Power Voltage (V _{PM}) to Open Circuit Voltage (V _{OC}) Ratio	MPPT (JP2) = ON		83.3		%
FBOC to DCIN Attenuation Ratio	MPPT (JP2) = ON		6.9		%

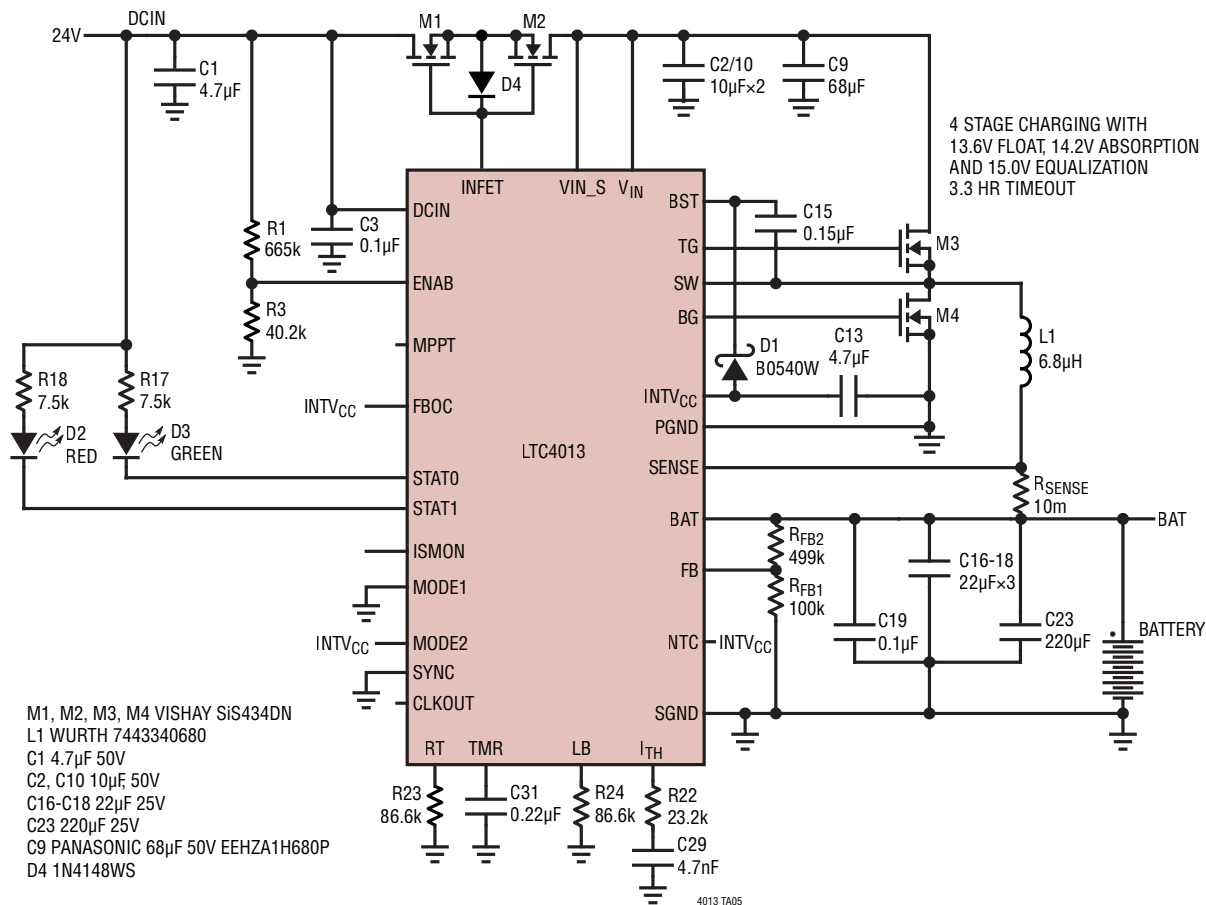
DEMO MANUAL DC2374B

BOARD PHOTO

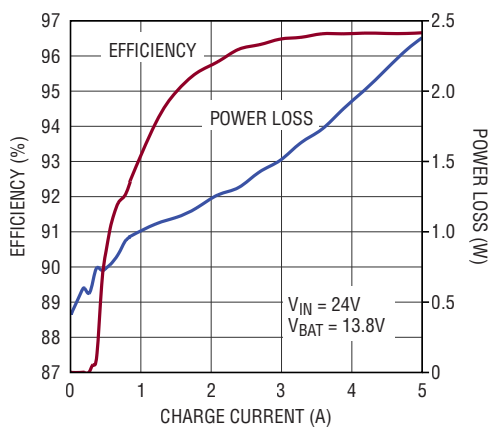


TYPICAL APPLICATION

24V 5A 6 Cell Lead Acid Charger with Absorption and Equalization Charging



Efficiency and Power Loss vs Charge Current



CHARGING OPTIONS

Table 1. LTC4013 Charging Algorithm Selection

MODE1	MODE2	TIMER	Charging Mode	V _{FLOAT} (V)	V _{ABS} (V)	V _{EQ} (V)	Recharge	TERMINATION	EQ Timeout
L	L	0V	2 Stage	13.6	-	-	-	None	None
L	L	CAP	2 Stage	13.6	-	-	-	3.33hrs	None
L	M	0V	2 Stage	14	-	-	-	None	None
L	M	CAP	2 Stage	14	-	-	-	3.33hrs	None
L	H	0V	N/A, Do Not Use	-	-	-	-	-	-
L	H	CAP	4 Stage	13.6	14.2	15	-	3.33hrs	50min
M	L	0V	3 Stage	13.2	14.4	-	-	C/10 (~14.1V)	None
M	L	CAP	3 Stage	13.2	14.4	-	-	3.33hrs	None
M	M	0V	Li-Ion	14.4	-	-	95.8% (13.77V)	C/10 (~14.3V)	None
M	M	CAP	Li-Ion	14.4	-	-	95.8% (13.77V)	3.33hrs	None
M	H	0V	N/A, Do Not Use	-	-	-	-	-	-
M	H	CAP	4 Stage	13.2	14.4	15.6	-	3.33hrs	25min
H	L	0V	3 Stage	13.6	14.2	-	-	C/10 (~14.1V)	None
H	L	CAP	3 Stage	13.6	14.2	-	-	3.33hrs	None
H	M	0V	Li-Ion	14.2	-	-	97.1 (13.77V)	C/10 (~14.1V)	None
H	M	CAP	Li-Ion	14.2	-	-	97.1 (13.77V)	3.33hrs	None
H	H	0V	N/A, Do Not Use	-	-	-	-	-	-
H	H	CAP	4 Stage	13.6	14.2	15	-	3.33hrs	25min

24V SUPPLY QUICK START PROCEDURE

The DC2374B is easy to set up to evaluate the performance of the LTC4013. Refer to Figure 1 and Figure 2 for proper measurement equipment setup.

NOTE: When measuring the input or output voltage ripple, care must be taken to avoid a long ground lead on the oscilloscope probe. Measure the input or output voltage ripple by touching the probe tip directly across the V_{IN} or V_{OUT} and GND terminals. See Figure 2 for proper scope probe technique.

1. Set the DC2374B to operate in a three stage lead acid battery charging mode by positioning the jumpers as listed below:

- JP1** ENABLE - UVLO
- JP2** MPPT - OFF
- JP3** MODE2 – LO

- JP4** MODE1 – HI
- JP5** NTC – INT
- JP6** TIMER – CAP
- JP7** PULL_UP PWR - DCIN

2. With power off, connect a 0V to 16V, 6A power supply (PS2) to BAT and GND terminals with a series ammeter and a voltmeter as shown in Figure 1.
3. With power off, connect a 5.1A load (LOAD1) to BAT and GND terminals in parallel with PS2 as shown in Figure 1.
4. Set PS2 to 10V and turn on PS2 and LOAD1.
5. With power off, connect a 0V to 35V, 5A power supply (PS1) to DCIN and GND terminals with a series ammeter and a voltmeter as shown in Figure 1.

24V SUPPLY QUICK START PROCEDURE

6. Set PS1 to 17V and then turn on.
7. Slowly increase PS1 until the STAT0 LED illuminates. DCIN is now above the UVLO rising threshold.

NOTE: PS1 can be increased from this voltage up to 35V. Make sure that the input voltage does not exceed 40V.

8. Observe that the battery charger current is only about 1A, 20%, and the voltage on the ISMON terminal measures about 0.2VDC. This is because the battery voltage is below the LB threshold. If the battery voltage remains below low bat for 25 minutes then the charge cycle is terminated.
9. Slowly increase PS2 until the battery current jumps up to about 5A, full load. ISMON reads close to 1V. The battery voltage is now above the low battery threshold.
10. Slowly increase PS2 until the battery current decreases to 4.5A. If the STAT0 LED is on and the STAT1 LED is off then the battery voltage is now approaching the absorption voltage and the charge timer has started. The battery will charge for about 3.3hrs before switching to float mode.
11. When the LTC4013 switches to float mode, the charge current will drop to 0A until the battery voltage is decreased below 13.6V.

To observe equalization mode, follow steps 12 thru 18. Otherwise skip to step 19.

NOTE: Equalization mode will not enable more than one time during a power on event. If an equalization cycle has already completed, power will need to be cycled in order to run a second equalization cycle.

12. Make sure PS1 is set above UVLO rising threshold and set PS2 to about 12V.
13. Make sure JP6, the TIMER jumper, is still in the CAP position. Set JP3, the MODE2 jumper, to the HI position. The STAT0 LED should be on and the STAT1 LED should be off. If not, power PS1 down, set JP3 to LO, turn PS1 back on, then set JP3 back to HI.
14. Increase PS2 until the battery voltage approaches the absorption voltage as done in step 10.
15. Continue increasing PS2 until the battery current drops below 500mA.
16. In about 3.33 hours the charge current will increase to about 1A. This is equalization mode.
17. Increase PS2 until the battery current starts to decrease. The battery voltage is approaching the equalization voltage.
18. After about 25 minutes in equalization mode the charge current will return to about 0A until the battery voltage is reduced below the float voltage of about 13.6V.
19. When done, turn off and disconnect all loads and power supplies.

NOTE: To evaluate the MPPT function, see the MPPT Quick Start Procedure section.

24V SUPPLY QUICK START PROCEDURE

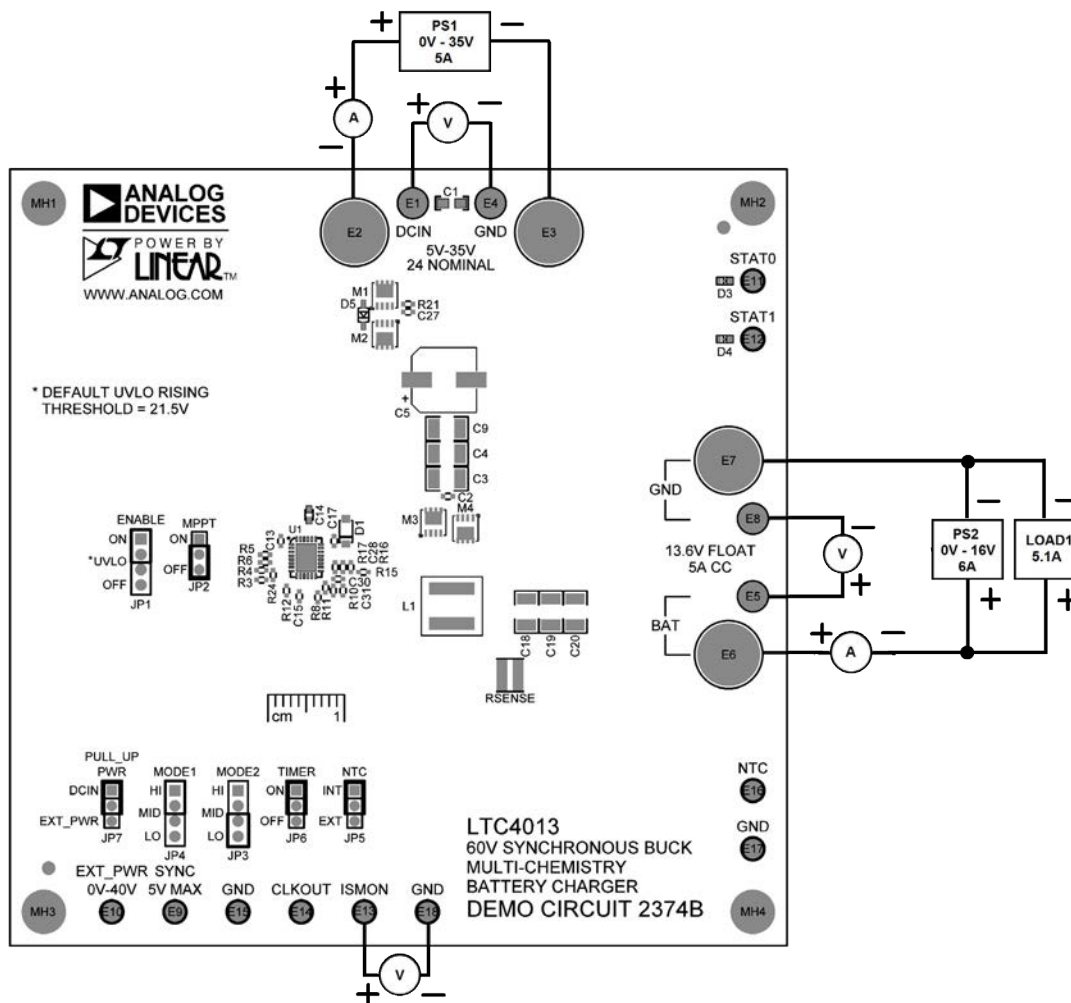


Figure 1. Proper Measurement Equipment Setup

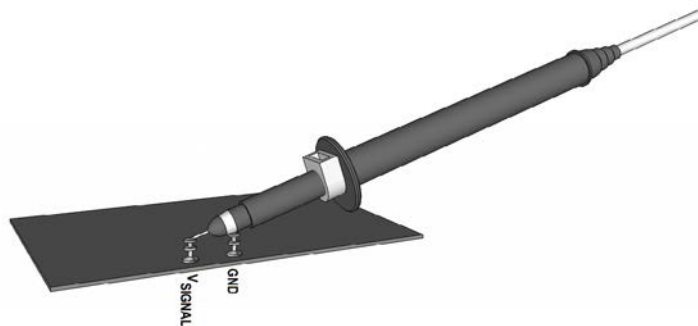


Figure 2. Measuring Input or Output Ripple

MPPT QUICK START PROCEDURE

The LTC4013 has a maximum power point tracking feature that regulates the input voltage to the maximum power voltage (V_{PM}) by adjusting the output of the charger. The LTC4013 MPPT function periodically stops charging, measures the open circuit voltage (V_{OC}), and then continues charging while regulating the input voltage. As the sunlight changes, the V_{OC} and V_{PM} also change. This board is setup to regulate a V_{PM} voltage of 83% of the measured V_{OC} . This ratio can be changed to match the solar panel by changing R2, R8, and R10. To change the V_{OC}/V_{PM} ratio, follow the procedure listed in the Maximum Power Point Tracking section in the LTC4013 data sheet.

There are a number of ways to test the MPPT function of the LTC4013. The most accurate way is to use a solar panel in sunlight, however it is difficult to control the sunlight conditions. Another method is to use a covered solar panel (dark panel) biased thru a controlled current source from 0A to the short circuit current (I_{SC}) of the panel as shown in Figure 3. The solar panel can be replaced with a string of silicon rectifier diodes that can handle the power dissipation of $V_f \cdot I_{SC}$. With these methods, increasing the current on the panel to I_{SC} produces the maximum V_{OC} for a full light condition. Reducing this current simulates lower light conditions.

A more simple method is to supply a voltage to DCIN with a series input resistor (R_{IN}) as shown in Figure 4. R_{IN} is calculated by $(V_{OC} - V_{PM})/I_{MP}$ where I_{MP} is the maximum power current. The supply current limit is set to I_{SC} and the voltage of the supply is set to the desired V_{OC} representing the desired sunlight. Set the power supply to the maximum V_{OC} to produce a full light condition. Reducing the supply voltage simulates lower light conditions.

To evaluate the LTC4013 MPPT function follow the procedure below:

1. Set the DC2374B to operate in MPPT mode with a three stage lead acid battery charging mode by positioning the jumpers as listed below:

- JP1** ENABLE - ON
- JP2** MPPT - ON
- JP3** MODE2 – LO
- JP4** MODE1 – HI

- JP5** NTC – INT
- JP6** TIMER – CAP
- JP7** PULL_UP PWR - DCIN

2. With power off, connect a 0V to 16V, 6A power supply (PS2) to BAT and GND terminals with a series ammeter and a voltmeter as shown in Figure 1.
3. With power off, connect a 5.1A load (LOAD1) to BAT and GND terminals in parallel with PS2 as shown in Figure 1.
4. Set PS2 to 10V and turn on PS2 and LOAD1.
5. With power off, connect a solar panel or solar panel simulator as previously discussed and refer to Figure 3 and Figure 4 as needed.
6. With a full or close to full light condition, observe that the battery charger current is only about 1A, 20%, and the voltage on the ISMON terminal measures about 0.2VDC. DCIN is also above the V_{PM} point at this time. This is because the battery voltage is below the Low Battery threshold. If the battery voltage remains below low bat for 25 minutes then the charger cycle is terminated. The solar panel can supply more power to the charger than needed at this point.
7. Slowly increase PS2 until the battery current jumps up to above 1A. The battery voltage is now above the low battery threshold. If the I_{MP} is less than the input current needed to provide full charge current, the LTC4013 will regulate the charge current below full load to obtain a DCIN voltage near the V_{PM} point for the measured V_{OC} .
8. If possible, vary the light conditions for the solar panel or simulator and observe the charge current is adjusted to maintain the VMP for the measured V_{OC} .

NOTE: If the charge current is reduced below C/10, ~ 500mA, and the battery voltage is over the low battery threshold, then the TEOC timer will start even if the battery voltage is not approaching the absorption voltage.

9. If possible, return the light source to near full light condition.

MPPT QUICK START PROCEDURE

10. Slowly increase PS2 until the battery current starts to decrease below 1A. The battery voltage is now approaching the absorption voltage. The timer will start if not already started from a low light condition.
11. When the timer has elapsed, the LTC4013 will switch to float mode and the charge current will drop to near 0A until the battery voltage is reduced below the float voltage.
12. When done, turn off and disconnect all loads and power supplies.

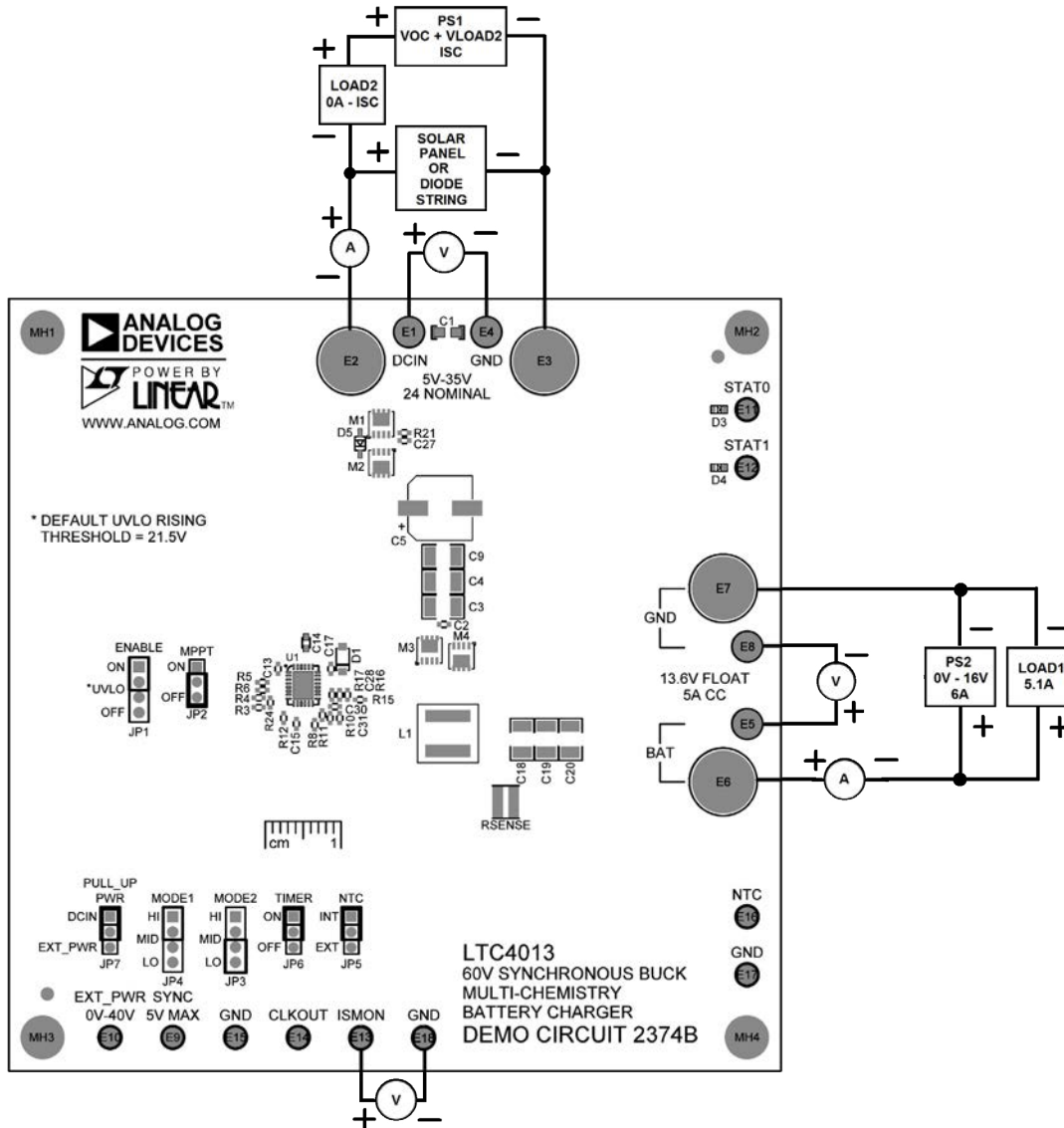


Figure 3. Solar Panel Simulator Using a Dark Solar Panel or Diode String

MPPT QUICK START PROCEDURE

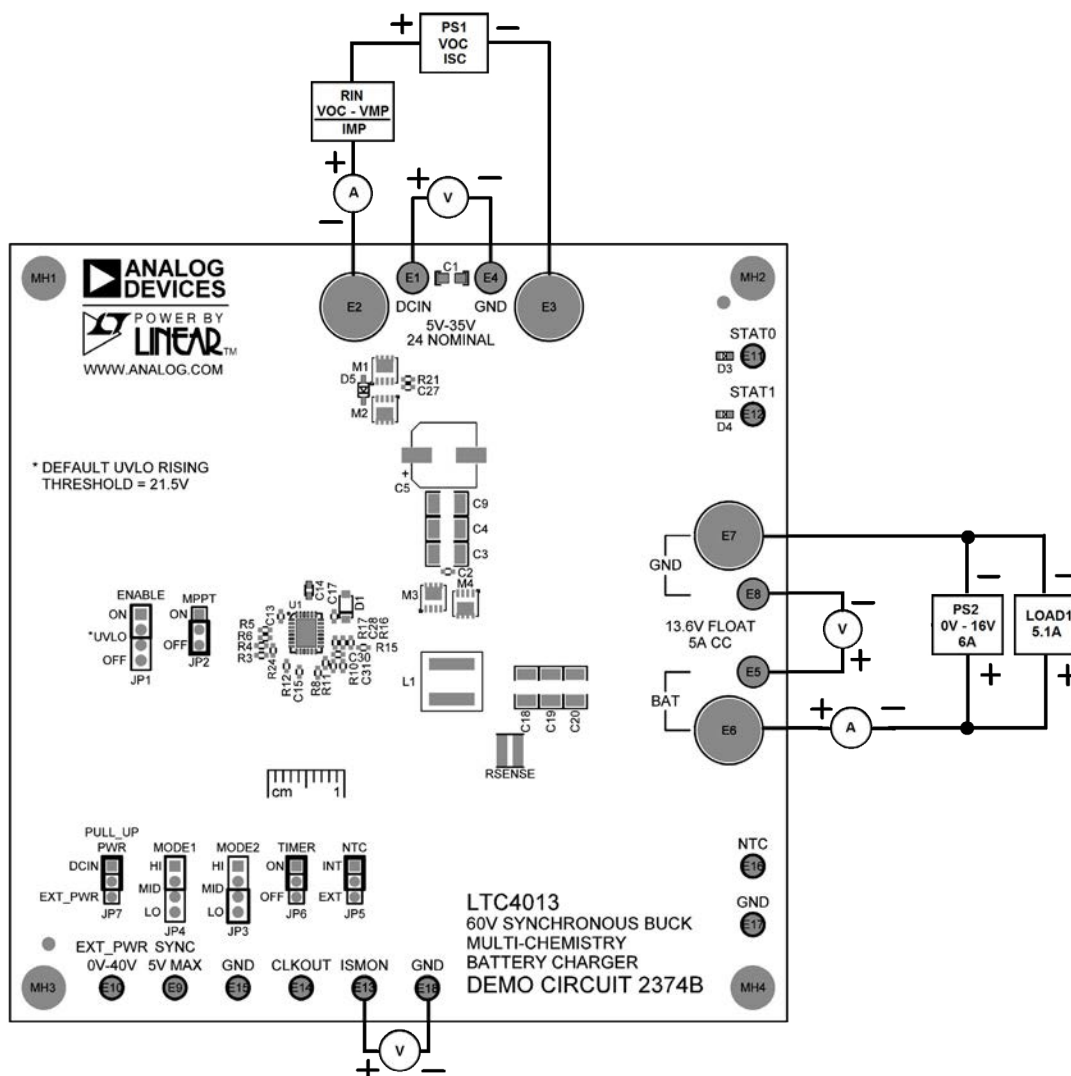


Figure 4. Solar Simulator Using a Power Supply with Series Resistor

APPLICATION INFORMATION

Changing Board Configuration

This board is optimized for a 24V to 14V lead acid battery with 5A charge current, however it can be modified for other charging topologies, different charge currents, plus different DCIN and battery voltages. The DC2374B can also accommodate higher power outputs. There are optional capacitors, inductor, FETs, and a catch diode on the bottom of the board that can be used for larger components if needed. The layout was designed with ample copper and vias to provide enough thermal relief for 300W. Refer to the data sheet for the sizing of all of the required components and changes as needed.

No Battery Operation

The LTC4013 will operate without a battery, however there needs to be at least 2V on the SENSE pin, V_{IN} must be above 4.5V, DCIN must be above V_{IN} and above V_{BAT} by about 100mV, plus the ENAB pin must also be above its rising threshold to startup. For single input FET applications V_{IN} will increase to $DCIN - V_f$ of the input FET body diode. For dual input FET applications a resistor can be used to bleed current across the first FET to allow V_{IN} to charge up. For

MPPT applications, the added resistor should provide an RC constant ($R \cdot C_{VIN}$) greater than 10ms.

One way to raise the SENSE pin above to 2V is to provide a weak pullup from $INTV_{CC}$ with a blocking diode on the BAT pin when no battery is present. V_{FLOAT} must be greater than $INTV_{CC}$ for this method. Refer to the “Starting Without a Battery” section of the LTC4013 data sheet for more information on this.

Connecting a High Voltage Battery

When connecting a battery to the DC2374B demo board, the battery will instantaneously charge the bulk capacitors on the BAT and the V_{IN} nodes. Since the battery and capacitors have very low ESR, the instantaneous current can be 10's or 100's of amps when the battery is first connected and can damage the components in its path. It is recommended to pre-charge the BAT terminals of the DC2374B prior to connecting a low ESR battery. This can be done by connecting the battery thru a current limiting resistor first, then short across the resistor. Refer to the Plugging in a Battery section of the LTC4013 data sheet for more information.

PARTS LIST

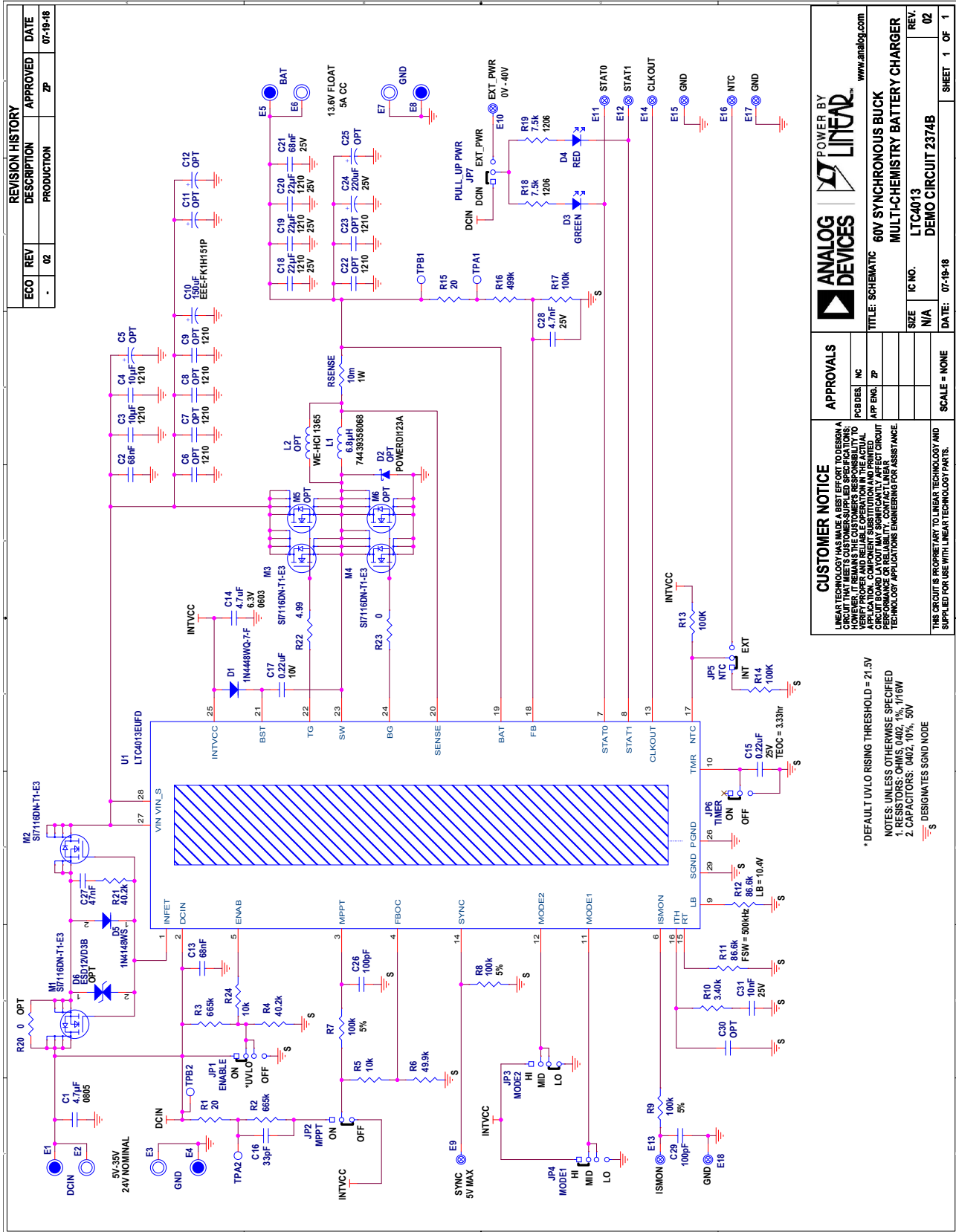
ITEM	QTY	REFERENCE	PART DESCRIPTION	MANUFACTURER/PART NUMBER
Required Circuit Components				
1	1	C1	CAP, CHIP, X5R, 4.7µF, ±10%, 50V, 0805	TDK, C2012X5R1H475K
2	3	C2, C13, C21	CAP, CHIP, X5R, 68nF, ±10%, 50V, 0402	TDK, CGA2B3X5R1H683M050BB
3	2	C3, C4	CAP, CHIP, X5R, 10µF, ±20%, 50V, 1210	TDK, C3225X5R1H106M250AB
4	1	C10	CAP, 150µF, ALUM. ELECT., 50V, 20%, 10x10.2mm RADIAL, FK Series, AEC-Q200	PANASONIC, EEE-FK1H151P
5	1	C14	CAP, CHIP, X5R, 4.7µF, ±20%, 6.3V, 0603	TAIYO YUDEN, JMK107BJ475MAHT
6	1	C15	CAP, CHIP, X5R, 0.22µF, ±10%, 25V, 0402	TAIYO YUDEN, TMK105BJ224KVHF
7	1	C16	CAP, CHIP, COG, 33pF, ±5%, 50V, 0402	JOHANSEN TECHNOLOGY, 500R07S330JV4T
8	1	C17	CAP, CHIP, X5R, 0.22µF, ±10%, 10V, 0402	TAIYO YUDEN, LMK105BJ224KV-F
9	3	C18-C20	CAP, CHIP, X5R, 22µF, ±20%, 25V, 1210	TAIYO YUDEN, TMK325BJ226MM-T
10	1	C24	CAP, 220µF, 25V, Alum. Electro, 20%, 8mm X 10.2mm	PANASONIC, EEH2C1E221P
11	2	C26, C29	CAP, CHIP, COG, 100pF, ±5%, 50V, 0402	TDK, CGJ2B2C0G1H101J050BA
12	1	C27	CAP, CHIP, X7R, 47nF, ±10%, 25V, 0402	MURATA, GCM155R71E473KA55D
13	1	C28	CAP, CHIP, X7R, 4.7nF, ±10%, 25V, 0402	MURATA, GRM155R71E472KA01D
14	1	C31	CAP, CHIP, X5R, 10nF, ±10%, 10V, 0402	KEMET, C0402C103K8PAC7867
15	1	D1	DIODE, GEN PURP, 75V, 250MA, SOD123	DIODES INC, 1N4448WQ-7-F
16	1	D5	DIODE, GEN PURP, 75V, 150MA, SOD323F	ON SEMICONDUCTOR, 1N4148WS
17	1	L1	IND, SMT, 6.8µH, ±20%	WURTH, 74439358068
18	4	M1, M2, M3, M4	MOSFET, N-CH, 40V, 10.5A, 1212-8	VISHAY SILICONIX, SI7116DN-T1-E3
19	2	R1, R15	RES, CHIP, 20Ω, ±1%, 1/16W, 0402	VISHAY, CRCW040220R0FKED
20	2	R2, R3	RES, CHIP, 665kΩ, ±1%, 0.1W, 0402	VISHAY, CRCW0402665KFKED
21	2	R4, R21	RES, CHIP, 40.2KΩ, ±1%, 0.1W, 0402	VISHAY, CRCW040240K2FKED
22	2	R5, R24	RES, CHIP, 10KΩ, ±1%, 1/16W, 0402	VISHAY, CRCW040210K0FKED
23	1	R6	RES, CHIP, 49.9KΩ, ±1%, 1/16W, 0402	VISHAY, CRCW040249K9FKED
24	3	R7-R9	RES, CHIP, 100KΩ, ±5%, 1/16W, 0402	VISHAY, CRCW0402100KJNED
25	1	R10	RES, CHIP, 3.40KΩ, ±1%, 1/16W, 0402	VISHAY, CRCW04023K40FKED
26	2	R11, R12	RES, CHIP, 86.6KΩ, ±1%, 1/16W, 0402	VISHAY, CRCW040286K6FKED
27	3	R13, R14, R17	RES, CHIP, 100KΩ, ±1%, 1/16W, 0402	VISHAY, CRCW0402100KFKED
28	1	R16	RES, CHIP, 499KΩ, ±1%, 1/16W, 0402	VISHAY, CRCW0402499KFKED
29	1	R22	RES, CHIP, 0Ω, ±1%, 1/16W, 0402	VISHAY, CRCW04020000Z0ED
30	1	R23	RES., 4.99 OHMS, 1%, 1/16W, 0402, AEC-Q200	VISHAY, CRCW04024R99FKEDC
31	1	RSENSE	RES, CHIP, 10mΩ, ±1%, 1W, 1632 LONG SIDE TERM	SUSUMU, PRL1632-R010-F-T1
32	1	U1	60V SYNC. BUCK MULTI-CHEMISTRY BATTERY CHARGER	ANALOG DEVICES, LTC4013EUFD#PBF

DEMO MANUAL DC2374B

PARTS LIST

ITEM	QTY	REFERENCE	PART DESCRIPTION	MANUFACTURER/PART NUMBER
Additional Demo Board Circuit Components				
33	0	C5 (OPT)	CAP, 68µF, 50V, Alum. Electro, 20%, 8mm x 10.2mm	PANASONIC, EEHZA1H680P
34	0	C6-C9, C22, C23 (OPT)	CAP, CHIP, X5R, 10µF, ±20%, 50V, 1210	TDK, C3225X5R1H106M250AB
35	0	C11, C12 (OPT)	CAP, 68µF, ALUM. ELECT., 50V, 20%, 8x10.2mm, RADIAL, AEC-Q200	PANASONIC, EEHZA1H680P
36	0	C25 (OPT)	CAP, 220µF, 25V, Alum. Electro, 20%, 8mm X 10.2mm	PANASONIC, EEHC1E221P
37	0	C30 (OPT)	CAP, CHIP, COG, 100pF, ±5%, 50V, 0402	TDK, CGJ2B2C0G1H101J050BA
38	0	D2 (OPT)	DIODE, SCHOTTKY, 60V, 3A, SMB	ON SEMICONDUCTOR, MBRS360BT3G
39	0	D6 (OPT)	DIODE, TVS, 12V, 15.5V, 350W, SOD323-2	MICRO COMMERCIAL, ESD12VD3B-TP
40	0	L2 (OPT)	IND, SMT, WE-HCI 1365	WURTH, WE-HCI 1365
41	0	M5, M6 (OPT)	MOSFET, N-CH, 40V, 35A, 1212-8	VISHAY SILICONIX, SIS434DN-T1-GE3
42	0	R20 (OPT)	RES, CHIP, 0Ω JUMPER, 1W, 2512	VISHAY, CRCW25120000Z0EG
Hardware: For Demo Board Only				
43	1	D3	DIODE, LED, GREEN, 0603	LITE-ON, LTST-C190KGKT
44	1	D4	DIODE, LED, RED, 0603	LUMEX, SML-LX0603SRW-TR
45	4	E1, E4, E5, E8	TURRET, 0.09 DIA	MILL-MAX, 2501-2-00-80-00-00-07-0
46	4	E2, E3, E6, E7	BANANA JACK, NON-INSULATED	KEYSTONE, 575-4
47	10	E9 - E18	TURRET, 0.061 DIA	MILL-MAX, 2308-2-00-80-00-00-07-0
48	3	JP1, JP3, JP4	HEADER, 4PINS, 2mm	WURTH, 62000411121
49	4	JP2, JP5-JP7	HEADER, 3PINS, 2mm	WURTH, 62000311121
50	7	XJP1-XJP7	SHUNT 2mm 1X2	WURTH, 60800213421
51	2	R18, R19	RES, CHIP, 7.5KΩ, ±1%, 1/4W, 1206	YAGEO, RC1206FR-077K5L
52	4	MH1-MH4	STANDOFF, NYLON 0.5"	KEYSTONE, 8833

SCHEMATIC DIAGRAM



**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.