LTC4162
35V/3.2A Multi-Cell Step-Down Battery Charger with PowerPath and I^{2}C Telemetry

DESCRIPTION

Demonstration circuit 2038A shows the LTC®4162 multi-cell step-down battery charger with PowerPath™ and I^{2}C telemetry operating with a configurable chemistry and cell count. The LTC4162 supports up to eight cells for Li-Ion, nine cells for LiFePO$_4$, and 6V, 12V, 18V, or 24V lead-acid batteries. Programmable and fully autonomous charge algorithms can be chosen for each of the chemistries.

The DC2038A is populated with one of many different IC options for the LTC4162, each suited to a specific chemistry, battery voltage, and default MPPT enabled state. The DC2038A can be easily configured for a specific use case by moving jumpers to set the number of cells that will be used in the application. The V$_{IN}$ voltage must then be appropriate for the cell count and chemistry selected.

Design files for this circuit board are available.

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

PERFORMANCE SUMMARY Specifications are at T$_A$ = 25°C

SYMBOL	PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
V$_{IN}$	DC2038A Input Voltage Range		5		35	V
V$_{BAT}$	DC2038A BAT Voltage Range		2.9		35	V
I$_{BAT}$	DC2038A Charge Current				3.2	A
V$_{OUT}$	System Voltage	V$_{IN}$ > V$_{BAT}$	V$_{IN}$ − 0.2V		V$_{IN}$	V
I$_{OUT}$	V$_{OUT}$ Load Current	I$_{BAT}$ = 0A			3.2	A

TYPICAL APPLICATION

One to Eight Cell, 3.2A Step-Down Switching Battery Charger with PowerPath
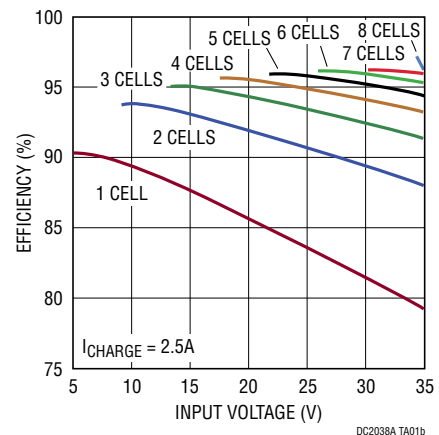

DC2038A TA01a
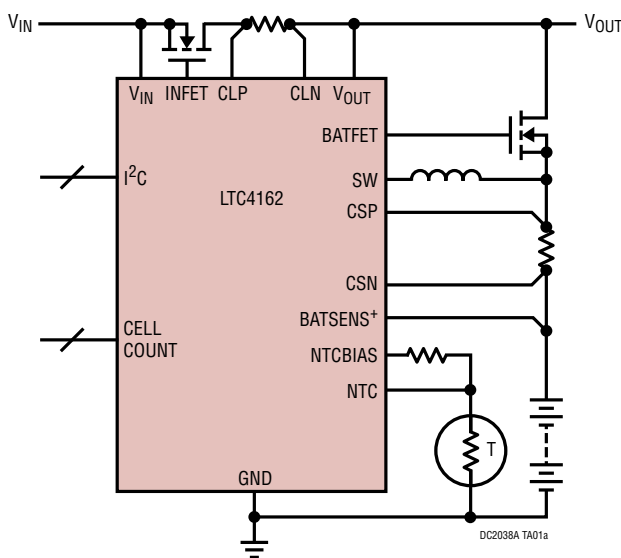
Efficiency vs Input Voltage

DC2038A TA01b

TABLE OF CONTENTS

DEMO BOARD VARIANTS

The LTC4162 is available in 18 variants which allows for compatibility with different battery chemistries and default charging characteristics. As a result, the DC2038A assemblies have been broken down by these same variants.

The only differences between DC2038A variants are:

1. The LTC4162 variant installed

2. The firmware programmed on the SAM D21 processor

Note that not all demo boards are available from Analog Devices, but any board can by converted into a board of any other variant. To do so, remove the LTC4162 (reference designator U1) from the demo board and place a new

LTC4162 IC of the desired variant into the U1 footprint. If the LTC4162 GUI will be used, reprogram the board through the GUI before attempting to use any other features of the GUI.

Table 1 below maps the demo board variants to the IC variants and gives a brief description of the difference between each IC variant. For more information about each LTC4162 variant, consult the relevant data sheet.

DC2038A variants featuring the adjustable versions of LTC4162 (with MPPT enabled or disabled by default) are available from Analog Devices.

Table 1. Demo Board Variants

BATTERY CHEMISTRY	VARIANT DESCRIPTION	MPPT OFF BY DEFAULT		MPPT ON BY DEFAULT	
		LTC4162 VARIANT	DEMO BOARD VARIANT	LTC4162 VARIANT	DEMO BOARD VARIANT
Li-Ion	Adjustable	LTC4162-LAD	DC2038A-A	LTC4162-LADM	DC2038A-J
	4.0V Fixed	LTC4162-L40	DC2038A-B	LTC4162-L40M	DC2038A-K
	4.1V Fixed	LTC4162-L41	DC2038A-C	LTC4162-L41M	DC2038A-L
	4.2V Fixed	LTC4162-L42	DC2038A-D	LTC4162-L42M	DC2038A-M
LiFePO$_4$	Adjustable	LTC4162-FAD	DC2038A-E	LTC4162-FADM	DC2038A-N
	3.6V Fixed	LTC4162-FST	DC2038A-F	LTC4162-FSTM	DC2038A-O
	3.8V Fixed	LTC4162-FFS	DC2038A-G	LTC4162-FFSM	DC2038A-P
Lead-Acid	Adjustable	LTC4162-SAD	DC2038A-H	LTC4162-SADM	DC2038A-Q
	Fixed	LTC4162-SST	DC2038A-I	LTC4162-SSTM	DC2038A-R

Gray = Unavailable from Analog Devices

QUICK START PROCEDURE

Refer to Figure 1 for the proper measurement equipment setup and jumper settings. Please follow the procedure below to familiarize yourself with the DC2038A.

1. Configure the CELLS1 and CELLS0 jumpers based on the LTC4162 chemistry as follows:

Li-Ion	LiFePO$_4$	LEAD ACID
3 Cells	4 Cells	6 Cells
CELLS1 = INTV$_{CC}$	CELLS1 = VCC2P5	CELLS1 = INTV$_{CC}$
CELLS0 = GND	CELLS0 = INTV$_{CC}$	CELLS0 = VCC2P5

2. Set JP3 = FIXED/EXT and JP4 = FIXED. This places a 10kΩ resistor on the NTC pin which simulates an NTC thermistor at 25°C and allows charging.

3. Configure the test equipment as shown in Figure 1. Leave the power supplies and loads in standby mode. Plug the Micro-B connector on DC2038A into a PC.

4. On the PC, update to the latest version of QuikEval™. Output power from PS1, then run QuikEval to launch the DC2038A GUI.

5. Enable PS2 and LD2. Within a few seconds, observe on the GUI that the battery is charging at 3.2A. The charger is operating in constant current (CC) mode.

6. The default 10mΩ value of RS2 sets the charging current to 3.2A. Similarly, the default 10mΩ value of RS1 sets the input current limit to 3.2A. Enable LD1 and observe a drop in the charge current being delivered to the battery as the input current is limited. Delivering current to the V$_{OUT}$ node is prioritized over charging the battery.

7. Turn PS2 up to 15V to simulate a battery at full charge. Observe the I$_{BAT}$ current drop to near zero and the I$_{IN}$ current decrease to only the 2A being provided to the load. Now, the charger is operating in constant voltage (CV mode).

8. Disable LD2, then disable PS1. By default, the GUI will force the LTC4162's telemetry on in a battery-powered state, so the data should continue to refresh. Observe a negative 2A on the I$_{BAT}$ meter, indicating that the emulated battery (PS2) is supplying power to the V$_{OUT}$ load.
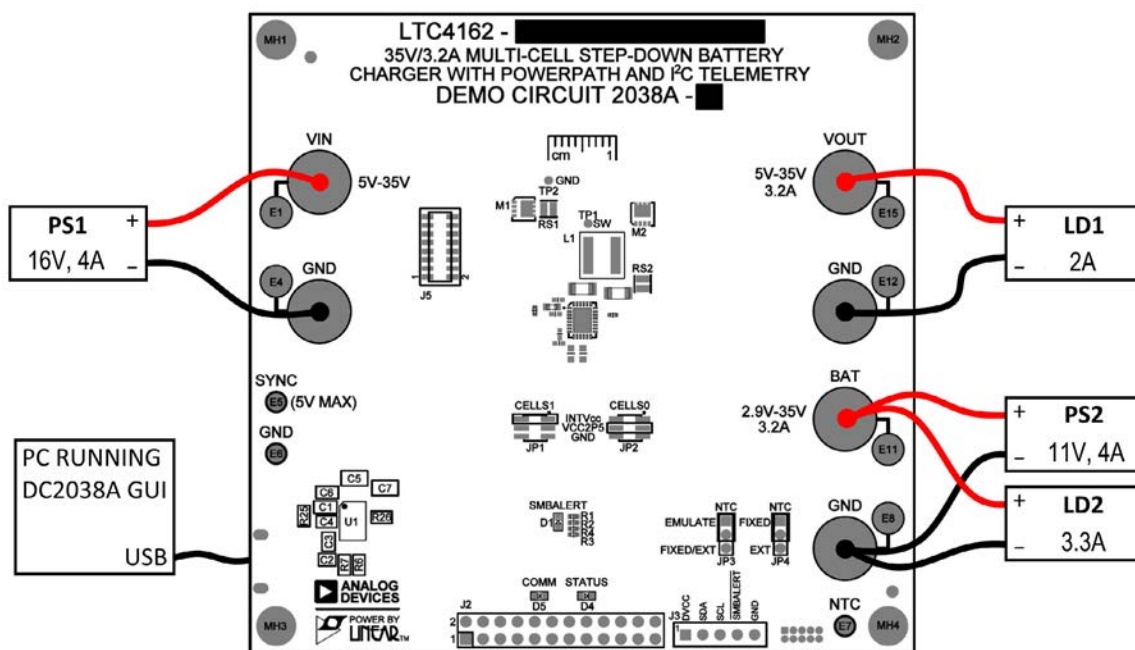

Figure 1. Quick Start Setup for the DC2038A Demo Board

Rev. 0

CONFIGURING CELL COUNT

Cell count is configured by moving the JP1 and JP2 shunts on the DC2038A demo board. The CELLS1 and CELLS0 inputs on the LTC4162 are three-level pins which can be pulled to INTV$_{CC}$, VCC2P5, or GND to configure the cell count.

Refer to Table 1 to configure CELLS1 and CELLS0 for a given cell count.

Figure 2. Cell Count Configuration Jumpers

Table 1. Cell Count Configuration

NUMBER OF CELLS				
Li-Ion	LiFePO$_4$	LEAD-ACID	CELLS1	CELLS0
1	1	3 (6V)	INTV$_{CC}$	INTV$_{CC}$
2	2	6 (12V)	INTV$_{CC}$	VCC2P5
3	3	9 (18V)	INTV$_{CC}$	GND
4	4	12 (24)	VCC2P5	INTV$_{CC}$
5	5	Disallowed	VCC2P5	VCC2P5
6	6	Disallowed	VCC2P5	GND
7	7	Disallowed	GND	INTV$_{CC}$
8	8	Disallowed	GND	VCC2P5
Disallowed	9	Disallowed	GND	GND

Gray = Default Settings

THEORY OF OPERATION

Introduction to the DC2038A

The DC2038A demonstration circuit features the LTC4162, a step-down battery charger controller that includes a comprehensive telemetry system. In addition to the telemetry system, the LTC4162 has two PowerPath FET controllers, and an MPPT function.

The LTC4162 is a CC/CV charger based on a synchronous step-down switching regulator. Charge voltage and current are configured in hardware, but can also be changed through I^{2}C commands. JEITA temperature controlled charging can optionally be enabled to adjust charging parameters based on configurable temperature regions.

The telemetry system features a 16-bit ADC for monitoring the operating parameters of the charger. The behavior of the charger is controlled by on-die DACs, with only the power MOSFETs and current sense resistors external to the LTC4162.

THEORY OF OPERATION

The LTC4162 has two PowerPath FET controllers which drive external power MOSFETs. One FET is between the input voltage, V_{IN}, and the system output node, V_{OUT}. The other FET is between battery stack at BAT, and the system output node, V_{OUT}. This allows either the input or battery stack to power the system output, and also protects against power backfeeding to these sources.

The dynamic MPPT algorithm ensures that the LTC4162 is operating at the maximum power point condition, even when the MPPT operating point is changing. Thus, if a photovoltaic cell becomes shaded due to clouds, the LTC4162 will adjust operation to the shaded MPPT.

Refer to the LTC4162 data sheet for more detailed descriptions of these functions.

NTC Thermistor Measurement

The battery charger can monitor the battery temperature using a negative temperature coefficient (NTC) thermistor. This measurement can be used to suspend charging based on the battery's temperature, or to employ a JEITA temperature qualified charging algorithm.

When the JP3 is set to EMULATE, the NTC connections are routed to an onboard electronic potentiometer which can be configured by the GUI to emulate the NTC resistor and emulate any temperature range as sensed by the LTC4162. This is configured from the factory to emulate room temperature and guarantee charging.

If JP3 is set to FIXED/EXT, then JP4 can be set to FIXED to route the NTC pin to an onboard 10kΩ resistor which emulates room temperature and guarantees charging. Otherwise, if JP4 is set to EXT, then the NTC pin is routed to the NTC turret for use with a real thermistor. In the EXT position, resistor placeholders are given to perform a dilute the thermistor network through hardware as described in the LTC4162 data sheet.

LTC4162 Programming SDK

To help with learning and development of LTC4162 applications, there exists an SDK that makes interfacing with the LTC4162 as simple as possible. The package includes a few example programs and comes fully equipped with register names and value formatting. Resources are given for both C code (with Arduino examples) and Python code. The SDK is so powerful and inclusive that the register list in the data sheet does not even need to be referenced during software development. This SDK can be downloaded from the LTC4162 product webpage.

Onboard Digital Interface

The LTC4162 demo board includes an Atmel SMART SAM D21 processor with an Arduino bootloader that makes it compatible with the Arduino IDE. This means users can prototype processor functionality directly in the free Arduino IDE. If the onboard firmware is changed, it can be restored at any time through the GUI (but the GUI will need to be launched manually as QuikEval will not recognize the board).

Debugging Custom Designs

The DC2038A's default firmware and engineering GUI tab are designed to give a high speed debugging environment for LTC4162 operation. This functionality can be easily extended to interface with your own custom LTC4162 circuit design. To use the engineering GUI tab with a custom circuit board, simply leave the LTC4162 on the DC2038A unpowered and connect your own board to the SMBus interface accessible through header J3. DV_{CC} can be safely back-driven with up to 5V to change the logic level.

Optional Demo Circuit Components

There are a few components on the demo board which may or may not be helpful in a particular application. Be sure to read the notes on the schematic for an explanation of why any nonstandard circuit components have been added to the demo board in an attempt to encompass all operating conditions in a single circuit.

GUI APPLICATION

Introduction to the GUI

The DC2038A GUI provides a graphical interface for some of the main features of the LTC4162. In addition, it provides an advanced debugging interface that can be used in evaluating operation of the DC2038A as well as a customer's own design.

To use the DC2038A, the PC must first have the proper software driver and GUI installed. Download the QuikEval software from www.analog.com and install the QuikEval software by running the executable ltcqev.exe. Follow the instructions to connect the DC2038A.

This manual provides an overview of the DC2038A GUI functions. For further GUI help, consult the Help Guide within the GUI (Window → Help Guide).

GUI Layout

The LTC4162 GUI is divided into tabs. Each tab shows a graphical representation of a group of associated registers from the LTC4162 with the exception of the Engineering tab; this tab can instead show all registers and is intended to be used for lower-level development and debugging purposes.
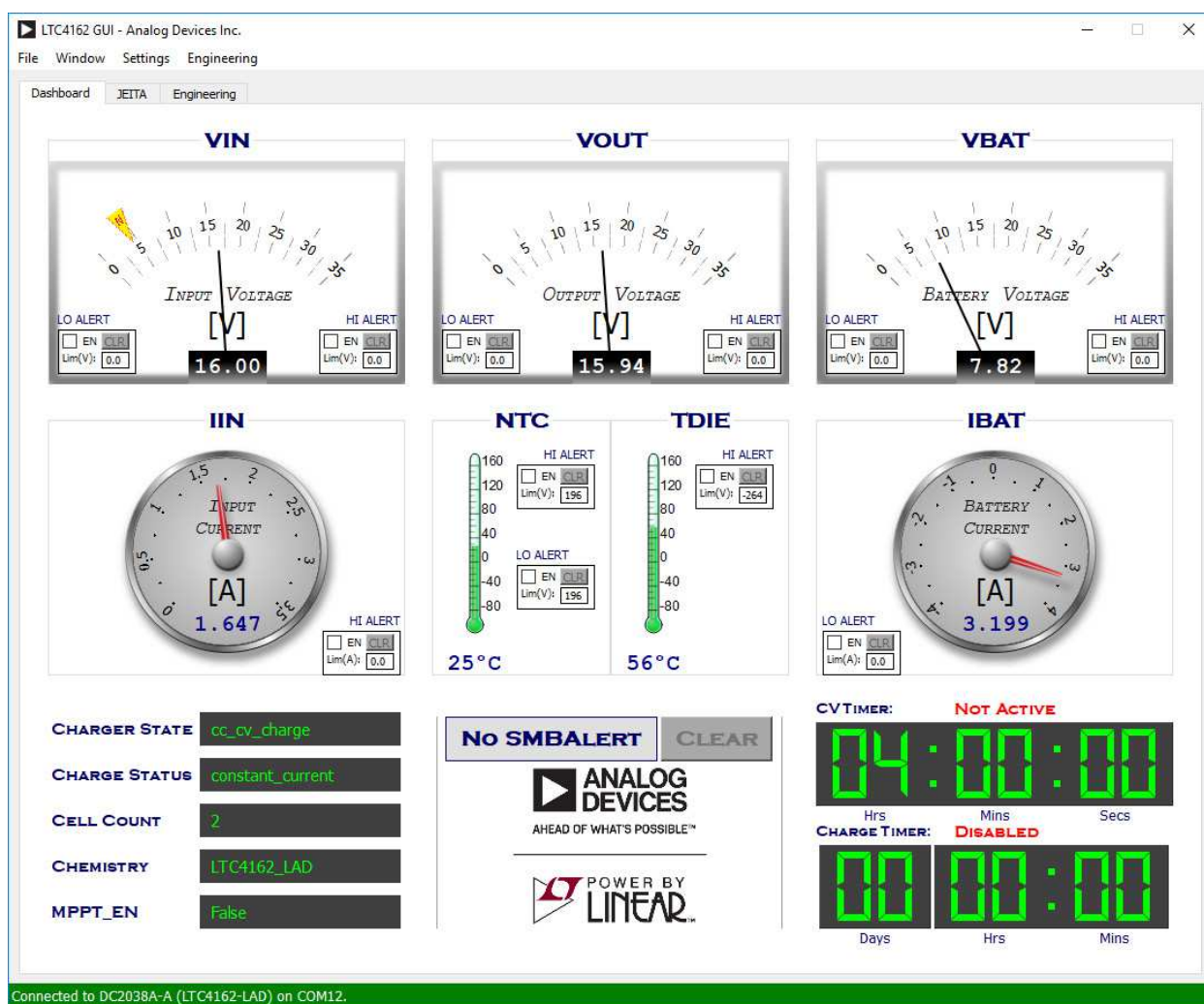

Figure 3. The Dashboard Tab

GUI APPLICATION

Each widget within the tabs of the GUI has a tooltip that will pop up if the mouse hovers over it for a few seconds. Tooltips contain detailed information about the register(s) associated with the widget such that the user does not need to consult the data sheet to understand a register.

Dashboard Tab

The Dashboard tab shows all the instantaneous state variables needed to monitor a charge cycle. The meters monitor all voltages and currents that are readable by the LTC4162. Charger state and configuration information

is also shown. By default, the GUI reads data from the LTC4162 every 200ms.

This tab also allows users to enable, clear, and set the limits for limit alerts associated with the system voltages, currents, and temperatures. The SMBALERT status is also shown (as detected by the onboard processor) and can be cleared as well.

JEITA Tab

The JEITA tab displays the JEITA settings including temperature region thresholds and the voltages and currents
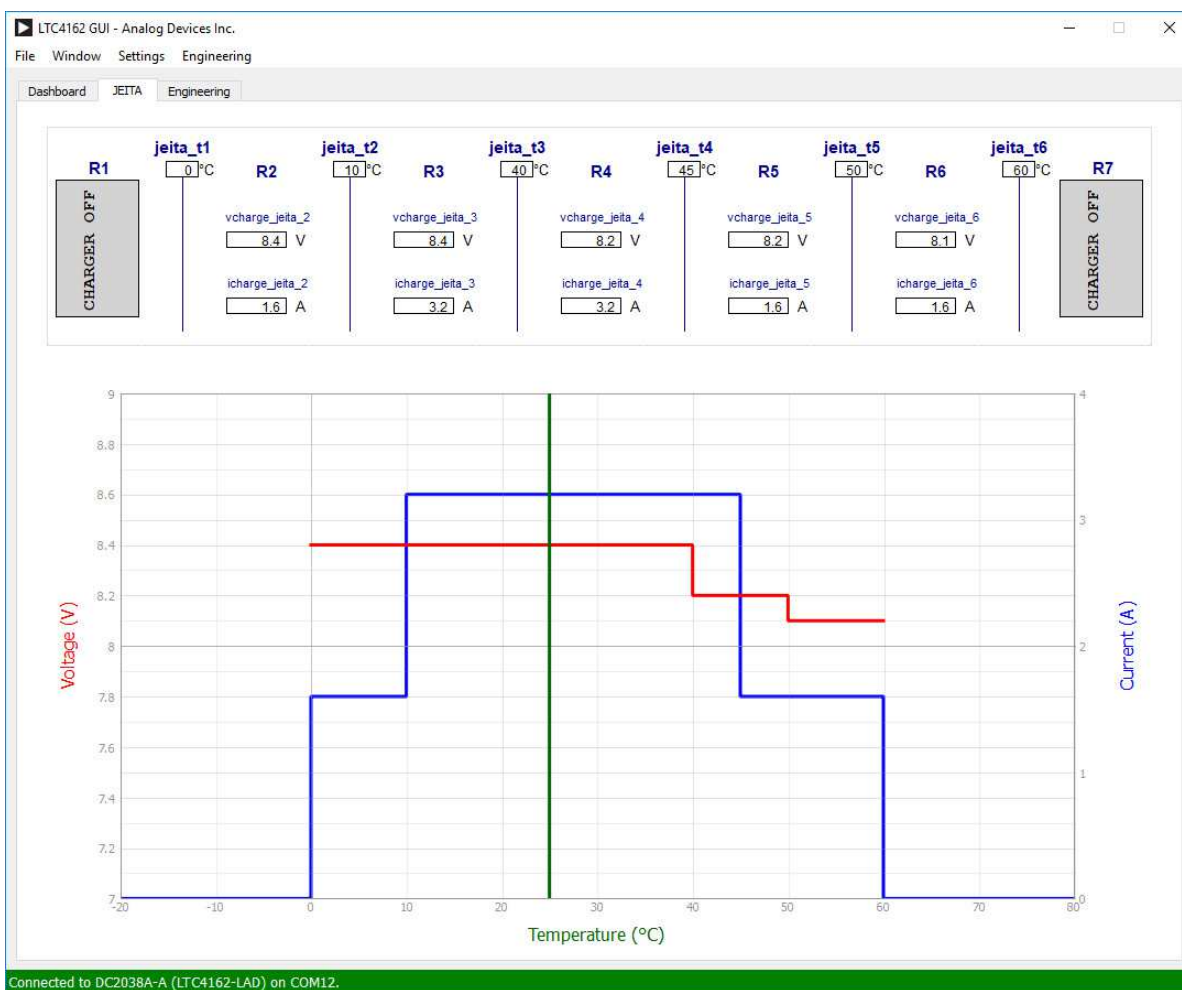

Figure 4. The JEITA Tab

Rev. 0

GUI APPLICATION

for each JEITA region. A plot shows these settings visually and also shows the current operating temperature as measured by the NTC so that the JEITA-based charge conditions are known. The JEITA tab is not visible for lead-acid variants.

Engineering Tab

The Engineering tab is an advanced debugging tool which allows high speed reading of any register. Register groupings can be displayed by activating the checkboxes in the Categories section.

To read a register, simply double-click the register name or value. To read all shown registers, double-click anywhere in the empty background space. To continuously read all shown registers, right-click and select Continuous Read from the context menu. When continuously reading, the GUI will poll all of the displayed registers as fast as pos-

sible. By default, a register entry will flash green when the new data is different from the previous data; this can be changed in the right-click context menu.

To write a register, right-click on a writable register and select Write… from the context menu. This will bring up a dialog with a few options for writing values.

For detailed information about a register, hovering over it for about a second will display the same tooltips as are visible in the other tabs of the GUI.

By default, register entries are displayed as formatted decimal values or Booleans. This can be changed to raw binary or hexadecimal notation by right-clicking on an entry and choosing Select Format.

Tabs can be added to the Engineering view by clicking the + button in the top-right corner. This allows the user to change between viewing different register groupings at ease.
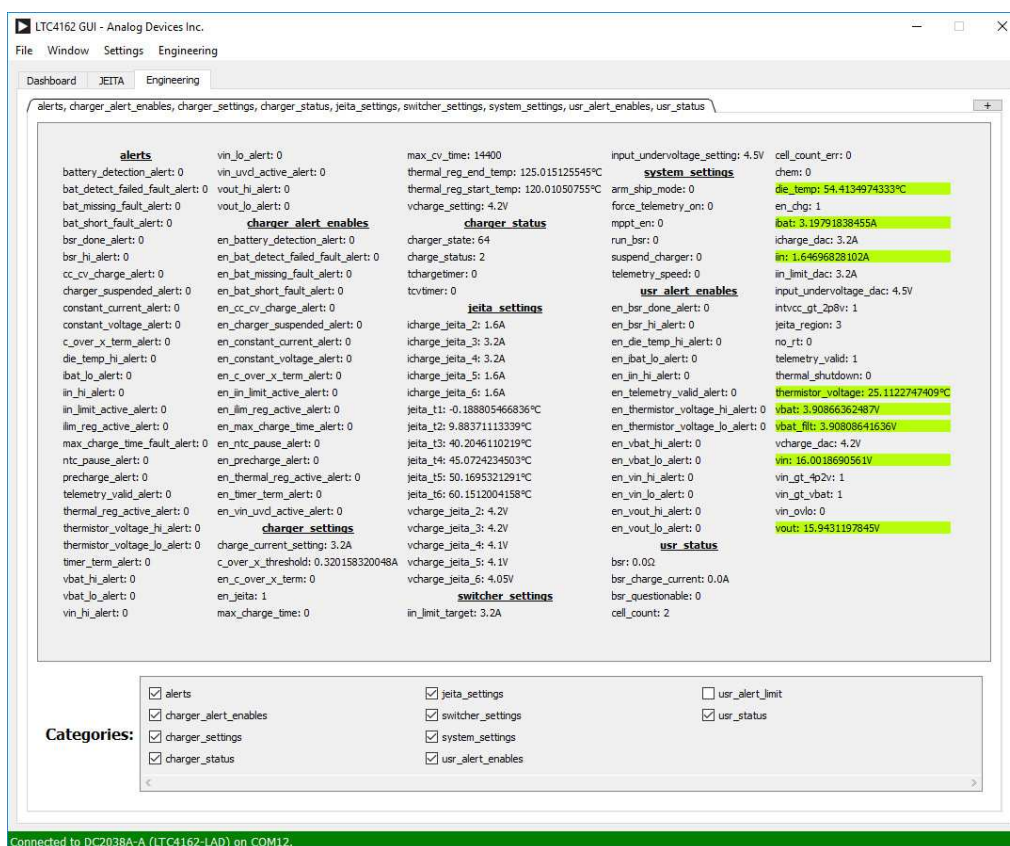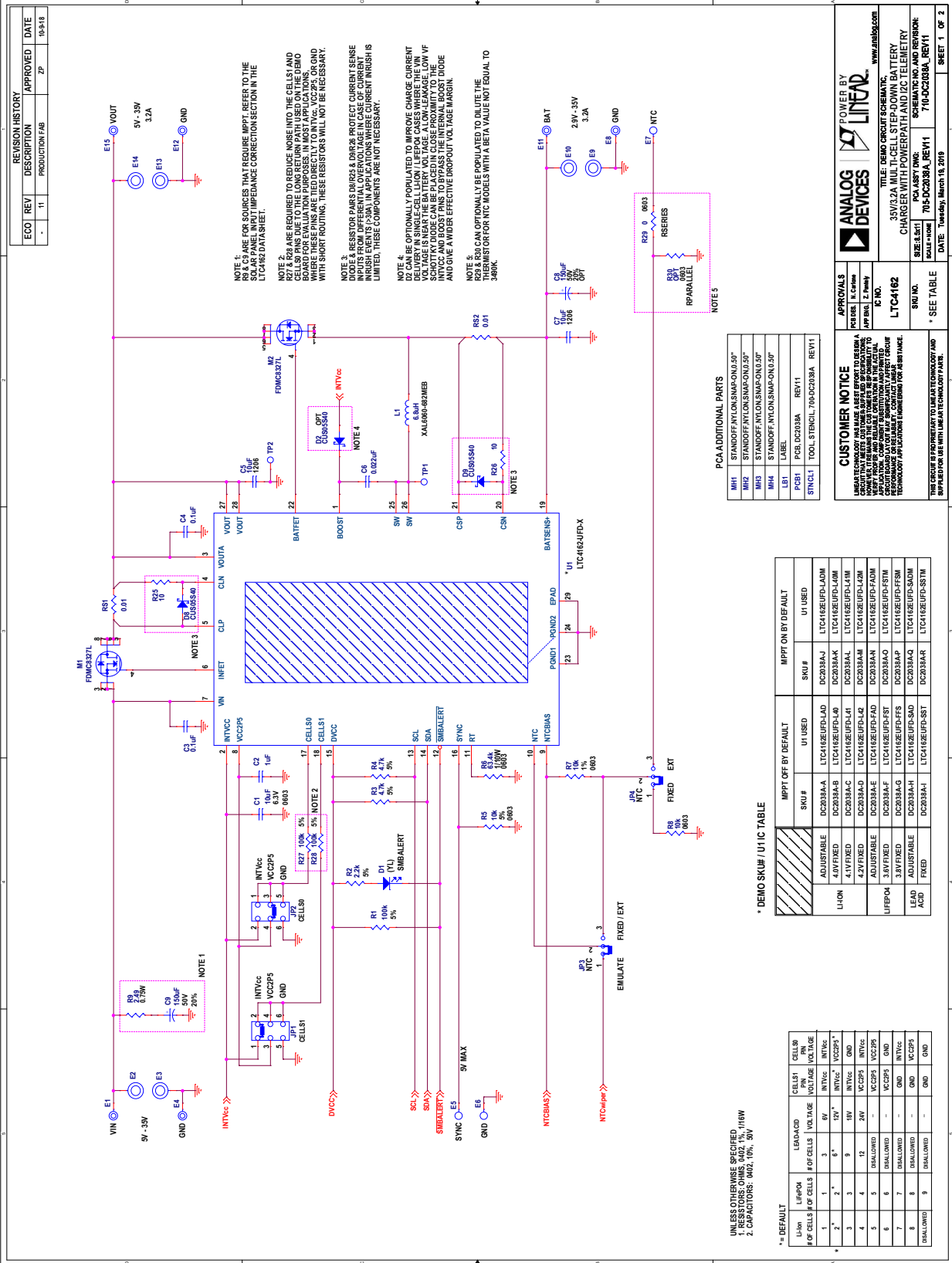

Figure 5. The Engineering Tab

PARTS LIST

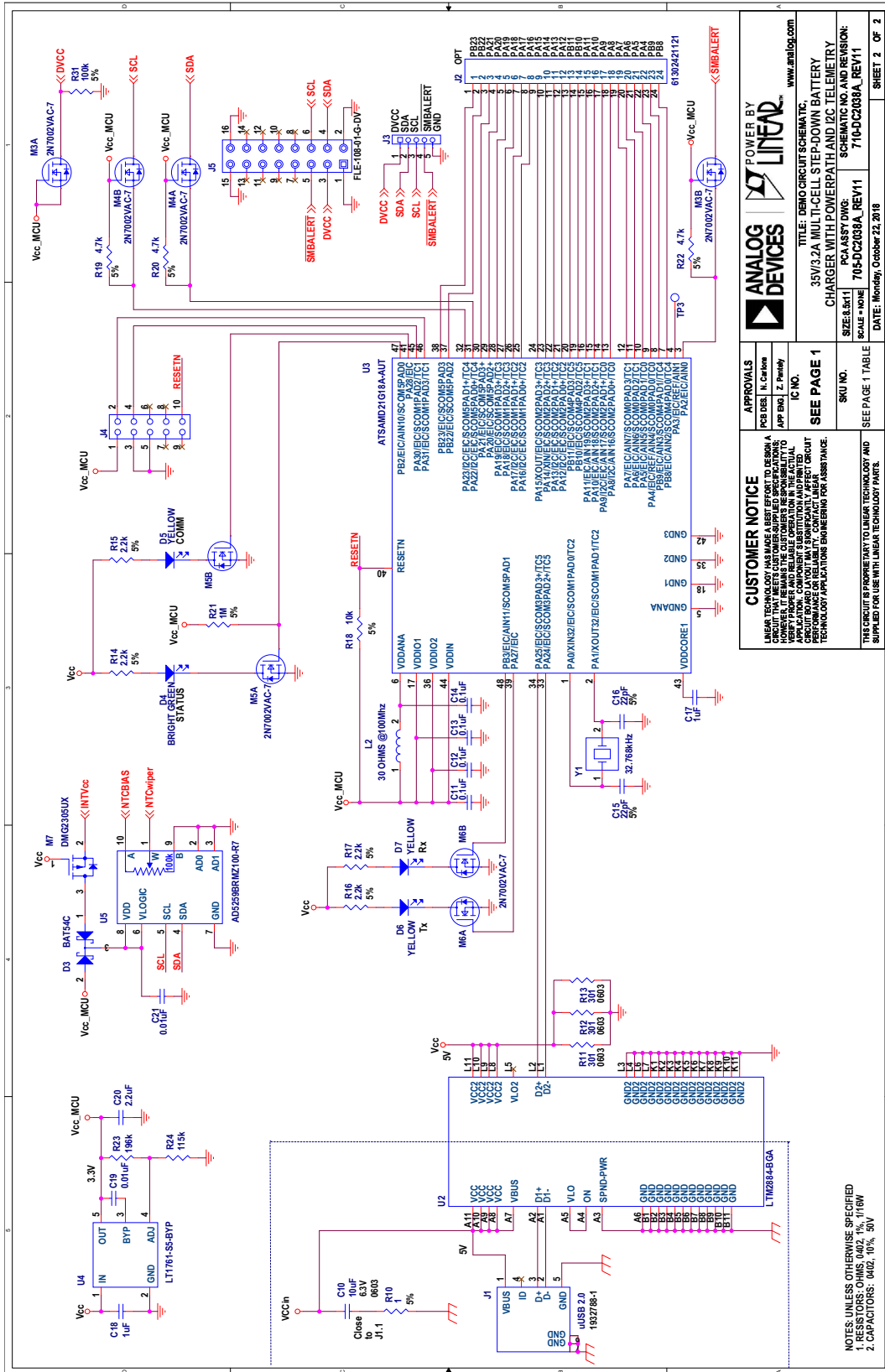| ITEM	QTY	REFERENCE	PART DESCRIPTION	MANUFACTURER/PART NUMBER
Required Circuit Components				
1	2	C1, C10	CAP, 10µF, X5R, 6.3V, 20%, 0603	MURATA, GRM188R60J106ME47D
2	1	C2	CAP, 1µF, X5R, 16V, 10%, 0402	AVX, 0402YD105KAT2A
3	2	C3, C4	CAP, 0.1µF, X7R, 50V, 10%, 0402	AVX, 04025C104KAT2A
4	2	C5, C7	CAP, 10µF, X5R, 50V, 10%, 1206	TAIYO YUDEN, UMK316BBJ106KL-T
5	1	C6	CAP, 0.022µF, X7R, 16V, 10%, 0402	AVX, 0402YC223KAT2A
6	1	C9	CAP, 150µF, ALUM ELECT, 50V, 20%, 10 x 10.2mm RADIAL, FK SERIES, AEC-Q200	PANASONIC, EEEFK1H151P
7	4	C11, C12, C13, C14	CAP, 0.1µF, X5R, 10V, 20%, 0402	WURTH ELEKTRONIK, 885012105010
8	2	C15, C16	CAP, 22pF, NP0, 50V, 5%, 0402	WURTH ELEKTRONIK, 885012005057
9	2	C17, C18	CAP, 1µF, BJ, 10V, 20%, 0402	TDK, CGB2A1JB1A105M033BC
10	2	C19, C21	CAP, 0.01µF, X7R, 25V,10%, 0402	WURTH ELEKTRONIK, 885012205050
11	1	C20	CAP, 2.2µF, X5R, 10V, 20%, 0402	WURTH ELEKTRONIK, 885012105013
12	1	D1	LED, SUPER YELLOW, MILKY WHITE DIFF, 0603	LUMEX, SML-LX0603SYW-TR
13	1	D3	DIODE, SCHOTTKY, 30V, 200mA, SOT23	DIODES INC, BAT54C-7-F
14	1	D4	LED, BRIGHT GREEN, WATERCLEAR, 0603	WURTH ELEKTRONIK, 150060VS75000
15	3	D5, D6, D7	LED, YELLOW, WATERCLEAR, 0603	WURTH ELEKTRONIK, 150060YS75000
16	2	D8, D9	DIODE, SCHOTTKY, 40V, 500mA, USC (SOD-323)	TOSHIBA, CUS05S40, H3F
17	6	E1, E4, E8, E11, E12, E15	TEST POINT, TURRET, 0.094", MTG HOLE	MILL-MAX, 2501-2-00-80-00-00-07-0
18	6	E2, E3, E9, E10, E13, E14	CONN, BANANA JACK, FEMALE, THT, NON-INSULATED, SWAGE	KEYSTONE, 575-4
19	3	E5, E6, E7	TEST POINT, TURRET, 0.064", MTG HOLE	MILL-MAX, 2308-2-00-80-00-00-07-0
20	1	J1	CONN, µUSB 2.0, RCPT, 5 PINS, 1 PORT, REVERSE MOUNT, R/A HORZ, TYPE B, FLANGELESS	TE CONNECTIVITY, 1932788-1
21	1	J3	CONN, HDR, MALE, 1x5, 2.54mm, VERT, STR, THT	SAMTEC, TSW-105-07-L-S
22	1	J4	CONN, HDR, MALE, 2x5, 1.27mm, VERT, STR, THT	WURTH ELEKTRONIK, 62201021121
23	1	J5	CONN, SOCKET, RCPT FEMALE, 2x8, 1.27mm, VERT, STR, SMT, FLE SERIES	SAMTEC, FLE-108-01-G-DV
24	2	JP1, JP2	CONN, HDR, MALE, 2x3, 1.27mm, VERT, STR, SMT	WURTH ELEKTRONIK, 62130621021
25	2	JP3, JP4	CONN, HDR, MALE, 1x3, 2mm, VERT, STR, THT, 10µ" AU	SAMTEC, TMM-103-02-L-S
26	1	L1	IND, 6.8µH, PWR, SHIELDED, 20%, 9A, 20.80mΩ, 6.56mm × 6.36mm, AEC-Q200, XAL6060	COILCRAFT, XAL6060-682MEB
27	1	L2	IND, 30Ω AT 100MHz, BEAD, 6A, 10mΩ, 0805	TDK, MPZ2012S300AT000
28	1	LB1	LABEL SPEC, DEMO BOARD SERIAL NUMBER	BRADY, THT-96-717-10
29	2	M1, M2	XSTR, MOSFET, N-CH, 40V, 14A, Power 33 (MLP 3.3Ax3.3) 8L	ON SEMICONDUCTOR, FDMC8327L
30	4	M3, M4, M5, M6	XSTR, MOSFET, DUAL N-CH, 0.28A, SOT-563	DIODES INC, 2N7002VAC-7
31	1	M7	XSTR, MOSFET, P-CH, 20V, 4.2A, SOT23	DIODES INC, DMG2305UX-13
32	4	MH1, MH2, MH3, MH4	STANDOFF, NYLON, SNAP-ON, 0.50"	KEYSTONE, 8833
33	1	PCB1	PCB, DC2038A	GORILLA CIRCUITS, 600-DC2038A
34	4	R1, R27, R28, R31	RES,100kΩ, 5%, 1/16W, 0402, AEC-Q200	NIC, NRC04J104TRF
35	5	R2, R14, R15, R16, R17	RES, 2.2kΩ, 5%, 1/16W, 0402, AEC-Q200	VISHAY, CRCW04022K20JNED

PARTS LIST

ITEM	QTY	REFERENCE	PART DESCRIPTION	MANUFACTURER/PART NUMBER
36	5	R3, R4, R19, R20, R22	RES, 4.7kΩ, 5%, 1/16W, 0402, AEC-Q200	NIC, NRC04J472TRF
37	1	R5	RES, 10kΩ, 5%, 1/10W, 0603, AEC-Q200	NIC, NRC06J103TRF
38	1	R6	RES, 63.4kΩ, 1%, 1/10W, 0603, AEC-Q200	VISHAY, CRCW060363K4FKEA
39	2	R7, R8	RES,10kΩ, 1%, 1/10W, 0603, AEC-Q200	VISHAY, CRCW060310K0FKEA
40	1	R9	RES, 2.49Ω, 1%, 3/4W, 1206, PULSE PROOF HIGH PWR, AEC-Q200	VISHAY, CRCW12062R49FKEAHP
41	1	R10	RES, 1Ω, 5%, 1/16W, 0402	KOA SPEER, RK73B1ETTP1R0J
42	3	R11, R12, R13	RES, 301Ω, 1%, 1/10W, 0603, AEC-Q200	PANASONIC, ERJ3EKF3010V
43	1	R18	RES, 10kΩ, 5%, 1/16W, 0402	YAGEO, RC0402JR-0710KL
44	1	R21	RES, 1MΩ, 5%, 1/16W, 0402	VISHAY, CRCW04021M00JNED
45	1	R23	RES, 196kΩ, 1%, 1/10W, 0603	VISHAY, CRCW0603196KFKEA
46	1	R24	RES, 115kΩ, 1%, 1/10W, 0603	NIC, NRC06F1153TRF
47	2	R25, R26	RES, 10Ω, 1%, 1/16W, 0402, AEC-Q200	NIC, NRC04F10R0TRF
48	1	R29	RES, 0Ω, 1/10W, 0603, 1A, AEC-Q200	ROHM, MCR03EZPJ000
49	2	RS1, RS2	RES, 0.01Ω, 1%, 1/3W, 0603, LONG-SIDE TERM, SENSE	SUSUMU, PRL0816-R010-F-T1
50	1	STNCL1	TOOL, STENCIL, 700-DC2038A	ANALOG DEVICES, 830-DC2038A
51	1	U1	IC, 35V/3.2A MULTI-CELL STEP DOWN BATTERY CHARGER WITH POWERPATH AND I^{2}C TELEMETRY, QFN-28(UFD) 4mm × 5mm	ANALOG DEVICES, LTC4162EUFD-xxx#PBF (IC VARIES BETWEEN DEMO CIRCUITS)
52	1	U2	IC, ISOLATED USB TRANSCEIVER, BGA-44	ANALOG DEVICES, LTM2884CY#PBF
53	1	U3	IC, MEMORY, MCU, 32BIT, 256kB FLASH, TQFP48	MICROCHIP, ATSAMD21G18A-AUT
54	1	U4	IC, REG LDO ADJ, 100mA, TSOT23-5	ANALOG DEVICES, LT1761ES5-BYP#PBF
55	1	U5	IC, POT DGTL, 100kΩ, 256POS, MSOP-10, NONVOLATILE, I^{2}C-COMPATIBLE	ANALOG DEVICES, AD5259BRMZ100-R7
56	2	XJP1, XJP2	CONN, SHUNT, FEMALE, 1x2, 1.27mm	WURTH ELEKTRONIK, 622002115121
57	2	XJP3, XJP4	CONN, SHUNT, FEMALE, 2 POS, 2mm	WURTH ELEKTRONIK, 60800213421
58	1	Y1	CRYSTAL, 32.768kHz, 12.5pF, 3.2x1.5mm SMD	ABRACON, ABS07-32.768kHz-4-T

SCHEMATIC DIAGRAM

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 NONINFRINGEMENT 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.

ANALOG DEVICES