Dust® Energy Harvesting Application Demo Board with E-Ink Display

DESCRIPTION

Demonstration circuit 2321A is a low power wireless sensor node development platform equipped with an E-ink display for user feedback. The system is capable of monitoring and managing its available energy, logging information from sensors and sharing this data over a wireless network.

The board is designed to connect to the DC2344A or DC2509A energy harvesting demonstration boards which output a regulated power supply as well as status information from energy harvesting ICs and their backup batteries. Two coulomb counters on the DC2321A allow the processor to monitor the energy output of these batteries which will vary depending on the amount of energy which can be harvested from the system's surroundings.

Data acquisition and general operation is controlled by the LTP5901-IPM a wireless sensor node, or mote. This module is integrated with Dust Networks' low power radio design as well as an ARM Cortex-M3 32-bit microprocessor which is embedded with SmartMesh IP™ networking software, allowing it to form a reliable network with other motes in even the noisiest of environments.

The board is configured with multiple programming headers for users to download their own software onto the mote. Source code for the demonstration application is available on the LTC website. The design allows for the simple installation of a user-developed circuit using a shield board which has access to all pins of the LTP5901-IPM. The ease of programming and the established connections to peripheral devices makes the DC2321A the perfect evaluation tool for a wireless sensor node system.

Please refer to the individual IC data sheets for the operation of each data management circuit. The application section of this demo manual describes the system level functionality of this board and the various ways it can be used in early design prototyping.

Design files for this circuit board are available at http://www.analog.com/DC2321A

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BOARD PHOTO

Figure 1. DC2321A Dust Wireless Sensor Node Development Platform with E-Ink Display

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SPECIFICATIONS

TYPE	PARAMETER	CONDITIONS	MIN	TYPICAL DEFAULT	MAX	UNITS	NOTES
Input	VCC		2.1	3.3V	3.76	V	
	EHVCC		2.1	3.3V	3.76	V	
	5VUSB			5	7	V	Power Either 5VUSB or 3V3USB Not Both
	3V3USB			3.3	3.76	V	
	Coulomb Counter Input	Absolute Max			6	V	J1 Pin 15 (Primary) or Pin 17 (Secondary)
		For Accurate Data	2.6		3.7	V	
Power/Energy Consumption	DC2321A Average Power	Default Program Loaded, Not Connected to GUI, Not Joining Network		10		µW	Powered from EHV_{CC} at 3.3V
		Default Program Loaded, Not Connected to GUI, Joined to Network		135		µW	
	Display Update Energy			22.7		mJ	
	GUI Data Read Energy			152		µJ	

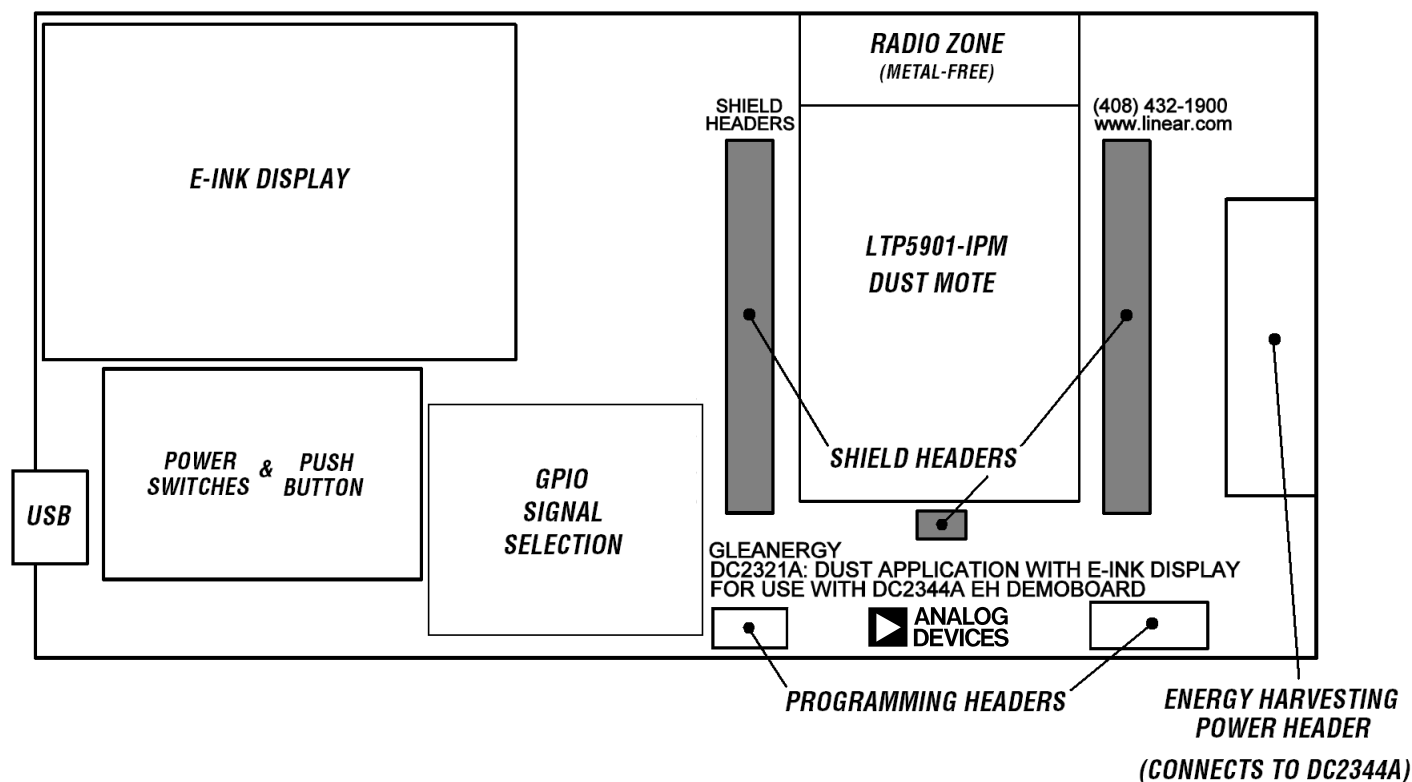## BOARD LAYOUT ORGANIZATION DIAGRAM

Figure 2. Board Layout Organization Diagram
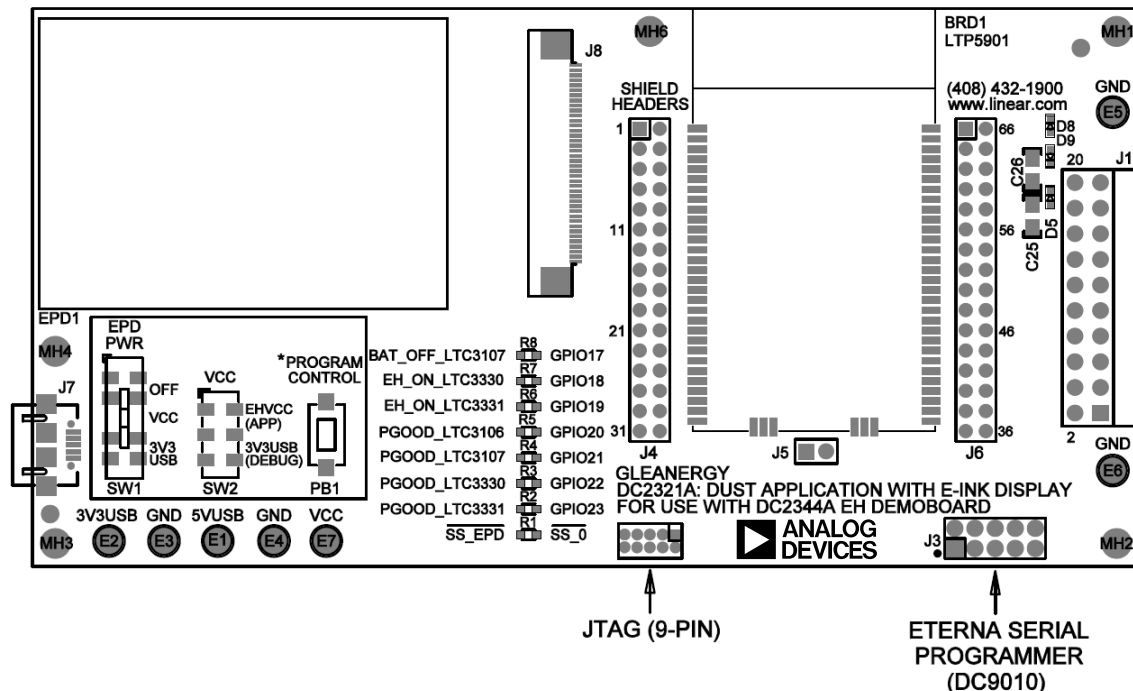
ASSEMBLY DRAWING
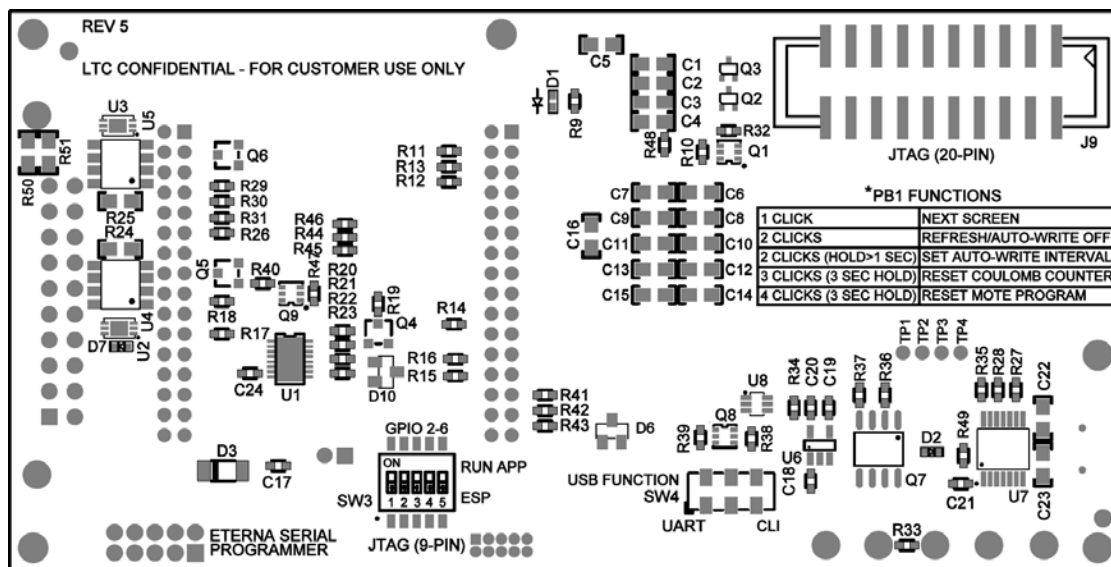

Figure 3a. DC2321A Top Assembly Drawing

Figure 3b. DC2321A Bottom Assembly Drawing

QUICK START PROCEDURE

Procedure for DC2321A with DC2344A/DC2509A:

1. Ensure the switches on DC2321A are as follows:

Table 1. Switch Positions for Procedure with Power Board

REFERENCE DESIGNATOR	POSITION
SW1	VCC
SW2	EHVCC
SW3	All ON
SW4	UART

2. Follow the DC2344A or DC2509A Quick Start Procedure to step 7. Once completed, remove LOAD1 (used in power board procedure) and connect DC2321A to DC2344A or DC2509A.

3. Observe as DC2321A displays the startup screen (WE and LTC logos) and then displays the LTC3330 as the energy source. Depending on the available amount of energy, the display may toggle between showing the source as the LTC3330 powered by a battery or powered by energy harvesting.

4. Press PB1 to show the status of all PGOOD and EH_ON signals from the ICs on the DC2344A or DC2509A.

Optional Continuation with GUI:

5. Download the QuikEval™ software from http://www.analog.com/en/design-center/design-tools-and-calculators and follow the installation instructions carefully.

6. On DC2321A, set SW1 = OFF to stop the display from updating.

7. Connect DC2321A to a computer using a USB cable. The GUI will be automatically downloaded from the web. Once it has finished installing, open the GUI.

8. On DC2344A or DC2509A, set SW7 = CCTR to route the batteries through the coulomb counters on DC2321A.

9. On the GUI, observe the average current of the primary battery.

10. Cover the solar panels on DC2344A with your hand or disable the power supply on DC2509A. Observe the current from the battery increase.

11. Apply reasonable light (>400 LUX) to the solar panels on DC2344A or enable the power supply on DC2509A. Observe the current from the battery drop to 0µA.
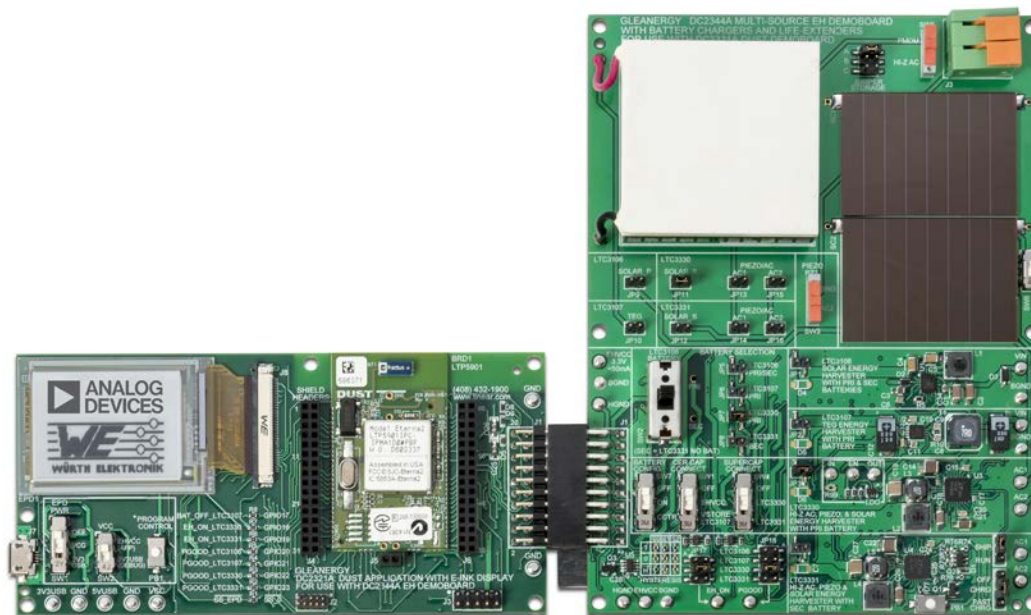

Figure 4. DC2321A Connected to DC2344A Energy Harvesting Board

QUICK START PROCEDURE

Procedure for DC2321A Standalone:

1. Ensure the switches on DC2321A are as follows:

**Table 2. Switch Positions for Procedure without Power Board**

REFERENCE DESIGNATOR	POSITION
SW1	VCC
SW2	EHVCC
SW3	All ON
SW4	UART

2. Configure the board as shown in Figure 5. This routes the board's power supply through the primary battery's coulomb counter.

3. To power the coulomb counters, either connect a USB cable **or** apply 5V to the 5VUSB turret using a power supply.

4. Observe as the DC2321A displays the startup screen (WE and LTC logos).

5. Press PB1 to go to the next screen (black background). Once there, press PB1 again to go to the coulomb counter screen. Observe that the voltage measurement for the PRI battery shows 3.3V and the charge increases with each write to the display (double-press PB1 to rewrite the same screen).

Optional Continuation with GUI:

6. Download the QuikEval software from http://www.ana-log.com/en/design-center/design-tools-and-calculators and follow the installation instructions carefully.

7. On DC2321A, set SW1 = OFF to stop the display from updating.

8. Connect DC2321A to a computer using a USB cable. The GUI will be automatically downloaded from the web. Once it has finished installing, open the GUI.

9. On the GUI, observe the average current on the primary battery monitor. This is the idle current of the board as it fulfills occasional data requests from the GUI.

10. Observe the charge on the primary battery monitor.

11. On DC2321A, set SW1 = VCC to update the display and re-allow updating. Observe the charge as it increases as a result of the display update.

Figure 5. Configuring DC2321A to Measure Application Energy Consumption

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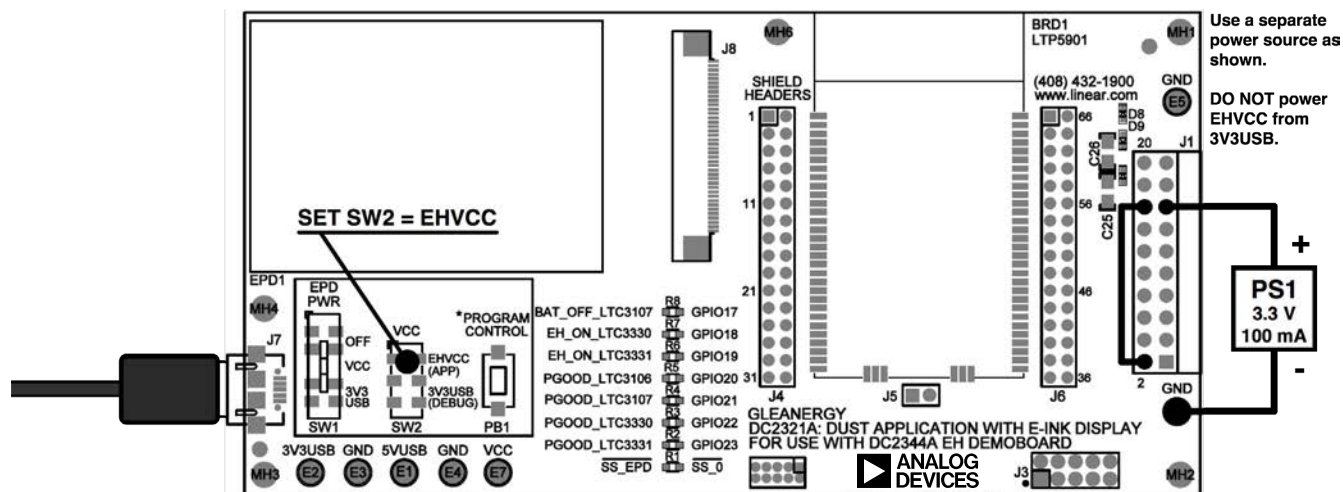
OPERATION OVERVIEW

DC2321A is a demonstration wireless sensor node system as well as a development platform which provides all of the tools necessary for users to create their own wireless sensor nodes.

Demonstration Program

The main purpose of the demonstration program on the mote is to show how the system executes the basic functions of a wireless sensor node. For information on the energy harvesting and storage operation of the system, refer to the DC2344A or DC2509A demo manual.

Once every second, the mote gathers data from its own sensors as well as the ICs and batteries on DC2344A or DC2509A. The ICs output status signals (EH_ON and PGOOD) which are read by the mote to determine which IC is providing power and whether the power is coming from a battery or harvested energy. Based on this data, the display is updated; if a PGOOD signal is present, it will assume that power is coming from the respective IC. If that IC outputs a high EH_ON signal, it will know that power is coming from an energy harvesting source; otherwise, if EH_ON is low, it will assume that power is coming from the battery. Because the LTC3106 does not output an EH_ON signal, the mote has no way to tell whether it is relying on EH power or a battery.

In addition to passing IC status outputs through the output header, DC2344A and DC2509A allow the batteries to be routed through coulomb counters on DC2321A. As a result, the mote is able to monitor the voltage, current, and charge of the batteries. This is useful for calculating the average power draw from the batteries under various levels of energy harvesting availability. If enough energy is available from the transducers, the battery will either be unused or will charge depending on which IC is used. In addition, removing EH sources and relying on battery power alone allows the mote to determine, for example, exactly how much energy is used in a specific portion of the program or how much average power is consumed in a one-second program cycle.

The mote also takes readings of the temperature using its built-in temperature sensor. In addition, the mote is capable of monitoring its own supply voltage. This is a useful feature for energy harvesting applications which do not use a battery. When relying on energy harvesting alone, the mote is able to monitor the amount of energy in the system based on the voltage of the supercapacitor (which must be connected to the output to use the demonstration program without a battery). Because voltage and capacitance are known, stored energy is known through the relation $E = \frac{1}{2}CV^2$.

The mote uses this information to determine if it can write to the display without killing its own power supply. The electronic paper display, EPD1, works well for long-term energy harvesting because it consumes no power in an idle state. However, a write to the display takes 22.7mJ of energy which is substantial relative to the average load of the application. The supercapacitor on DC2344A and DC2509A is sized accordingly to ensure that there is enough energy to write to the display once and leave enough energy stored that the voltage remaining on the supercapacitor is sufficient to keep the mote alive. Once a write occurs, the mote must wait until harvested energy is again sufficient for the next write. In this way, the mote monitors the system's energy storage to make program decisions which involve large load pulses.

OPERATION OVERVIEW

Summary Screen

In summary mode, the mote monitors the status outputs of the energy harvesting ICs and uses this information to determine which IC is supplying power and whether power is coming from the battery or entirely from an energy harvesting transducer. If a PGOOD signal is high, the mote will assume it is being powered by the corresponding IC. Depending on the EH_ON state of the selected IC, the mote will display the power source as a battery or an energy harvesting source. Because this information is determined using only the PGOOD and EH_ON signals, only one IC should be powered at a time and the output of the IC under evaluation must be routed to output header J1 on DC2344A or DC2509A in order for the mote to accurately detect its source.

IC Status Screen

The IC status screen shows all PGOOD and EH_ON signals for each IC in a way that is more clear and informative than the summary screen. Whereas the presence of multiple PGOOD signals will confuse the demonstration mode, the IC status screen simply displays all of the monitored status outputs. When a change in any IC status is detected, the screen will refresh to display the new information. This screen also displays the temperature in degrees Celsius and will update periodically if this temperature changes by a few degrees.

Battery Status Screen

The battery status screen shows all of the information gathered from each of the coulomb counters. Every time the screen is updated, the mote samples voltage and charge data from the batteries and stores a timestamp of the event. Using the change in charge evaluated over the difference between timestamps, a current measurement is calculated. As a result, the displayed current is the average current between two updates of the display. This works well for long-term monitoring of average power consumption, but can be significantly skewed at low currents if read in short intervals due to the resolution of the coulomb counters and the pulses of current required for a display write. For a more accurate measurement under these conditions, it is recommended that the GUI current meter is used to avoid constant display updates. For the secondary battery, a negative image (white background and black text) means that current or charge is flowing into the battery rather than being drawn.

The battery status screen can be set to auto-write data to the display at an interval set by the user. Refer to the push button functions for an explanation of this mode.

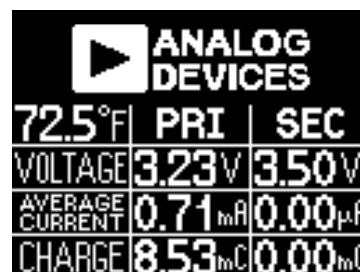Figure 6a. Summary Screen

Figure 6b. IC Status Screen

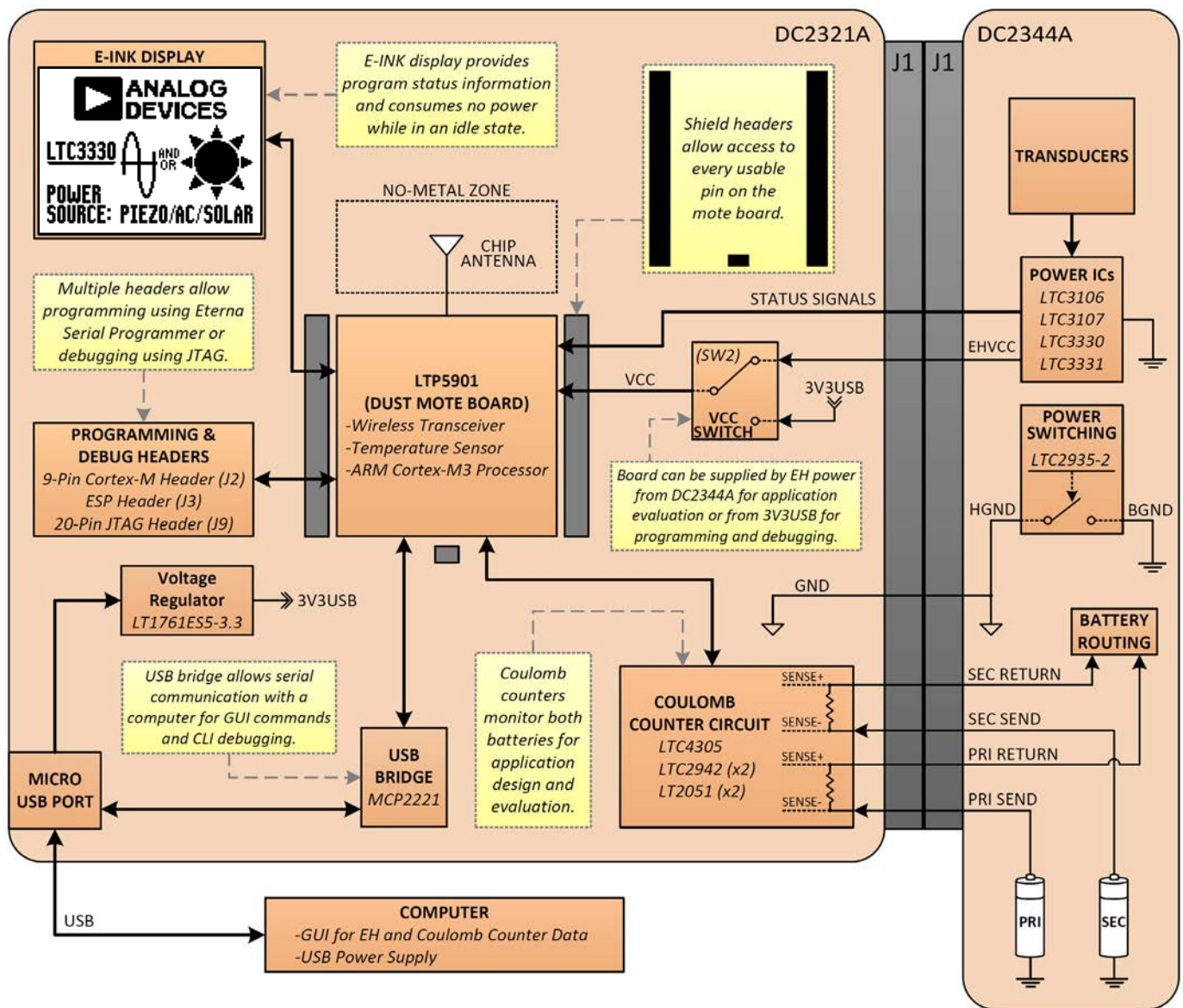Figure 6c. Battery Status Screen

BLOCK DIAGRAM

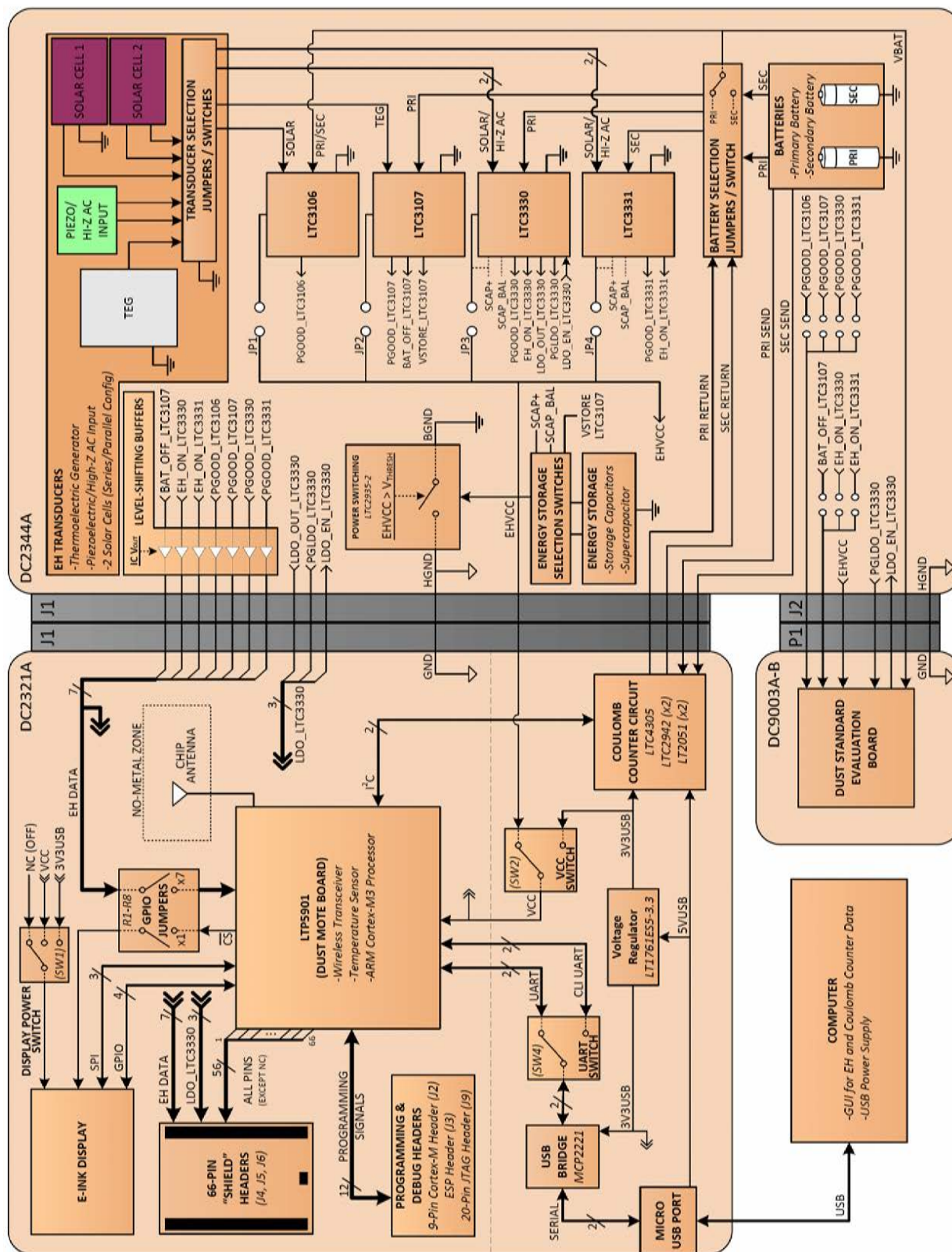**Figure 7. DC2321A Simplified Block Diagram**

BLOCK DIAGRAM

Figure 8. DC2344A and DC2321A Block Diagram

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Switch Functions

SW1: Selects display power source and WRITE_EPD signal. In the OFF position, the display is not powered and WRITE_EPD is low meaning that the display will not update. In the VCC position, the display is powered from the application power, VCC. In the 3V3USB position, the display is powered by the USB; in this position, the mote will still use power from VCC for SPI communication to the display. In both the VCC and 3V3USB positions, WRITE_EPD signal is high meaning that the display will update when necessary. Note that if SW2 is in the 3V3USB position, then VCC = 3V3USB and there is no difference between the VCC and 3V3USB option for SW1.

SW2: Selects source for VCC. In the EHVCC position, the board is in application mode and power for the application, VCC, comes from EHVCC on header J1. This mode is meant for EH evaluation purposes when using DC2344A or DC2509A. In the 3V3USB position, the board is in debug mode and power for the application, VCC, comes from the USB. This mode is meant for programming and debugging the mote while using USB power rather than battery or EH power from DC2344A or DC2509A. Note that if no USB is attached while in debug mode, extra power will be drawn from EHVCC.

SW3: Toggles GPIO connections on ESP signal lines. Five of the signals used by the Eterna® Serial Programmer can also be used as GPIO pins. SW3 allows the user to utilize these GPIOs in an application while allowing them to also be temporarily disconnected for programming. In the RUN APP position, the GPIO/ESP pins are routed to the shield headers in addition to the ESP header. For proper operation, the user should ensure that the programmer is physically disconnected from the ESP header, J3, while running the application. In the ESP position, the GPIO/ESP pins are routed only to the ESP header for programming.

SW4: Selects which UART is routed to the USB. In the UART position, the mote's general purpose UART is in communication with the USB. These UART lines are used for transmitting GUI data (or any custom user-defined commands) to or from a computer. In the CLI position, the mote's command line interface UART lines are in communication with the USB. The CLI is useful for setting some mote functions, reading network status information, and debugging code.

Turret Functions

5VUSB (E1): 5V USB power output.

3V3USB (E2): USB power output regulated to 3.3V.

GND (E3, E4, E5, E6): Ground. When a power board (DC2344A or DC2509A) is attached, GND on DC2321A is physically connected to HGND (header ground) on the power board. Once the power board reaches its programmable voltage output threshold, HGND is connected to BGND (the power board's ground) through a FET in order to complete the circuit and power DC2321A. See DC2344A or DC2509A documentation for further information.

VCC (E7): Application power. VCC powers the mote, the display (optionally), and any components associated with the application itself. For demonstration and monitoring purposes, 3V3USB powers USB communication, coulomb counters and anything else that would not be used in a final WSN application. The source for VCC is selected using SW2; VCC can either be powered by EHVCC (energy harvested power) for WSN application evaluation purposes, or by 3V3USB (USB power) for programming and code debugging purposes. See SW2 documentation for further information.

Push Button Functions (PB1)

1 CLICK: Goes to the next screen of the display.

2 CLICKS: Redisplays the current screen. If auto-write is on, it is turned off and the screen is redisplayed.

2 CLICKS (HOLD>1 SEC): Turn on auto-write and set the writing interval in seconds. With auto-write enabled, the mote will attempt to write to the display regularly at the interval set by the user. The write interval is equal to the duration that the button is held. If the mote detects that the supply has insufficient energy to write to the display, it will skip an interval.

3 CLICKS (3 SEC HOLD): Reset the coulomb counter's accumulated charge register for both batteries.

4 CLICKS (3 SEC HOLD): Restart the program on the mote. The mote will wait 5 seconds and then reset.

APPLICATION

Enabling Additional GPIOs

By default, only four GPIOs are unused and open for a user application. However, by disabling some of the GPIOs used in the demonstration application, a total of 18 GPIOs are available to the user. These modifications can be made by removing 0Ω jumper resistors from the board. Table 3 shows which resistors can be removed and which associated functions will be disabled.

Electronic Paper Display (EPD1)

The electronic paper display gives the user the ability to monitor the the power supply and the status of the mote's program. Because the display takes no power in an idle state, it is well-suited for long-term data acquisition with occasional user feedback.

However, an average write to the display can take about 22.7mJ. For many low power energy-harvesting applications, this is a substantial amount of energy when compared to a Dust mote program's average load power. As a result, coordinating a write to the display demonstrates how the system is able to monitor its energy storage and make program decisions based on how much energy is available.

The mote is able to internally read its own supply voltage. When the mote's power is supplied by DC2344A or DC2509A (SW2 = EHVCC), the supply voltage is generated across a known capacitance: either the output capacitor

of each individual IC, the bank of ceramic capacitors, or the supercapacitor. With the voltage across the capacitor known, the amount of available energy can be calculated $(E = \frac{1}{2}CV^2)$. In most cases, however, enough energy must be left in the capacitor to meet some minimum voltage requirement for the application; in this case, the remaining energy after an impulse needs to be enough to keep the capacitor voltage higher than the configurable power-fail threshold (2.25V default) of the LTC2935-2 power monitor on DC2344A or DC2509A. Otherwise, power to DC2321A will be switched off.

With the demonstration program loaded, the display has three screens: the summary screen, the EH status screen, and the battery status screen. A single press of PB1 allows the user to view the next screen. The summary and EH status screens each update automatically when the data has changed. These screens both monitor the PGOOD and EH_ON signals generated by the EH ICs and each screen displays the data in a different way.

Note that if an EH IC is using a battery and the harvested energy is almost, but not quite, enough to fully keep the output in regulation, the EH_ON signal will duty cycle. This causes the display to continuously refresh because new data is being detected. Although this accurately illustrates the status output of the IC, it also causes a greater drain on the battery due to the number of display writes needed. If this additional load power is undesirable, the display can be disabled using SW1.

Table 3. Additional GPIOs

SIGNAL		REFERENCE DESIGNATOR	GPIO	CONSEQUENCE
GROUP	**INDIVIDUAL**			
EH IC Status Signal	BAT_OFF_LTC3107	R8	GPIO17 (Pin 4)	Mote Does Not Know Whether LTC3107 Is Using EH or Battery
	EH_ON_LTC3330	R7	GPIO18 (Pin 5)	Mote Does Not Know Whether LTC3330 Is Using EH or Battery
	EH_ON_LTC3331	R6	GPIO19 (Pin 6)	Mote Does Not Know Whether LTC3331 Is Using EH or Battery
	PGOOD_LTC3106	R5	GPIO20 (Pin 45)	Mote Does Not Know if LTC3106 Has Reached Regulation
	PGOOD_LTC3107	R4	GPIO21 (Pin 26)	Mote Does Not Know if LTC3107 Has Reached Regulation
	PGOOD_LTC3330	R3	GPIO22 (Pin 25)	Mote Does Not Know if LTC3330 Has Reached Regulation
	PGOOD_LTC3331	R2	GPIO23 (Pin 21)	Mote Does Not Know if LTC3331 Has Reached Regulation
Switch Positions	WRITE_EPD (SW1)	R41	GPIO14 (Pin 27)	Mote Does Not Know if it Should Write to the Display
	SRC (SW2)	R42	GPIO0 (Pin 28)	Mote Does Not Know Whether it is Being Powered by EH or USB
USB	3V3USBVCC	R43	GPIO6 (Pin 33)	Mote Does Not Know if the Board Has USB Power
Display Driving	$\overline{SS\_EPD}$	R1	GPIO12 (Pin 44)	If Any of These Resistors are Removed, the Mote Cannot Properly Drive the Display.
	$\overline{PANEL\_ON}$	R44	GPIO13 (Pin 43)	
	RESET_EPD	R45	GPIO1 (Pin 63)	
	DCHG_EPD	R46	GPIO15 (Pin 64)	

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When USB is connected, the coulomb-counter circuit is powered and the battery status screen can be displayed. This screen does not update automatically when new data is detected. Instead, the user can double-click and hold PB1 to set an auto-write interval so that the display updates at a fixed time rate. The user can also just double-click PB1 to update the screen once; doing so will also turn off the auto-write feature.

Shield Headers

The LTP5901 is surrounded by three shield headers (J4, J5, and J6) which allow user access to every pin of the mote. For the NC and RESERVED pins on the mote, alternate signals have been routed to the respective header pins: 5VUSB, 3V3USB, LTC3330 LDO signals, and every EH IC status signal.

The DC2510A shield board allows the user to create a customized application directly on the DC2321A. This prototyping board features various footprints for popular surface mount IC packages as well as arrays of 2mm-pitch and 2.54mm-pitch through-hole pads for making connections. See the DC2510A demo manual for more information.

Coulomb Counters

DC2321A hosts a coulomb counter for each battery on the power board (DC2344A or DC2509A). With SW7 on the power board in the CCTR position, the batteries are routed out to header J1, through the sense resistors on DC2321A and back to the power board's battery routing jumpers. This configuration allows the coulomb counters on DC2321A to monitor the charge leaving or entering each battery. Between charge measurement intervals, the average current can be calculated by dividing the change in charge by the time between the measurements. The coulomb counters can also measure the voltage of each battery.

Because the power supply for the coulomb counters is drawn from one of the sense inputs, each coulomb counter's sense inputs are buffered with an LTC2051 dual zero-drift op amp package. As a result, the sense inputs each show the same voltage drop across the sense resistor, but the ICs take their power from 5VUSB instead of the batteries. USB power must be present in order to use the coulomb counter circuit.

The coulomb-counters have the same fixed I^2C address, so an LTC4305 I^2C bus multiplexer is used to communicate with each IC individually.

The coulomb counters are programmatically configured to use the lowest ADC prescaler available which gives them the finest precision possible for the default sense resistor value of 3.32Ω. This results in a charge value of about 36.22µC per bit. As a result, measurements of currents in µA range should be averaged over an appropriate amount of time to ensure accuracy.

The length of time between charge samples that will ensure an accurate current measurement can be determined by the relation:

$$t \geq \frac{2 \cdot C_{LSB}}{I} = \frac{2(36.22\mu C)}{I} = \frac{72.44}{I(\mu A)}$$

For example, if an average current of 10µA is being passed through a coulomb counter, there should be at least a t = 72.44 / 10 = 7.244-second delay between data measurements to guarantee an accurate measurement.

Data for battery voltage, average current, and charge can be viewed on the battery status screen as well as the GUI. The benefits of the coulomb counters are twofold. Firstly, they allow the user to find how much harvested energy needs to be available in order to stop using energy from the connected battery. Once the battery output current drops to a steady 0µA, this means that the load is being powered entirely by EH power. For the LTC3106 and LTC3331 energy harvesters, the secondary battery can be charged if there is sufficient energy; this is denoted by a white background on the display or a positive number on the GUI.

The second benefit of measuring the battery voltage is application development and the assessment of load power requirements. With energy harvesting sources disconnected from the IC that is powering the DC2321A, all of the power for the load comes from the battery. Under these conditions, the user can determine exactly how much average power is consumed by the mote's program and the general application. The resettable charge measurement also allows the user to determine exactly how much energy is used in a specific part of the program cycle; for example: a write to the display. Because the ability to expend this

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energy is directly related to the amount of energy storage on the power board, this information is invaluable in the power management design process of an efficient and durable energy harvesting system.

Coulomb Counter Notes for DC2344A/DC2509A

The coulomb counters will read wrong values if HGND of the power board (which connects to GND on DC2321A) is not connected to the battery ground reference, BGND. This connection is dependent on the level of EHVCC and the configuration of LTC2935-2. Alternatively, HGND and BGND can be tied together to disable the power-switching feature. See the DC2344A or DC2509A demo manual for more information.

Battery voltages over 3.7V can cause a small error in charge measurements. For best measurement results, and to prevent draining batteries during tests, it is recommended that a separate power supply, such as 3V3USB, is used to emulate the batteries. Refer to the Battery Removal/Emulation Instructions section in the DC2344A or DC2509A demo manuals.

If DC2321A is connected to DC2344A or DC2509A and an IC is being evaluated without a battery (or emulated battery) present, it is important that the respective battery selection jumper (JP5 to JP8) on the power board is removed, even if SW7 is in the OFF position. Otherwise, a leakage path can be created from the IC's battery input to ground through sneak paths in the coulomb counter circuit.

Programming and Debugging

DC2321A is designed to facilitate the writing and debugging of a program on the Dust mote. The board allows the mote to be programmed using either a JTAG programmer/debugger or an Eterna Serial Programmer (ESP). Documentation for getting started with software can be found at:

dustcloud.atlassian.net/wiki/display/OCSDK/Getting+Started

In programming/debugging mode, SW2 must be put in the 3V3USB position to power the entire board from the USB supply.

JTAG Debugger

There are two options for connecting a JTAG programmer to DC2321A. The default JTAG header (J2) has a reduced pin count and the adapter for this header can be purchased from SEGGER along with their JTAG debuggers. DC2321A also hosts a footprint for the standard 20-pin JTAG connector (J9) which can be purchased separately (see BOM) and mounted onto the back of the board. In order to use the JTAG debugger, the USB cable must be plugged in to provide power.

JTAG debuggers are intended for use with IAR Embedded Workbench IDE for development and debugging of a program on the mote. For more information on getting started with a JTAG debugger in IAR Workbench, refer to the aforementioned link.

The board can also communicate with a computer for debugging purposes. With SW4 in the CLI position, the mote's command line interface can be used with the GUI or any terminal client such as PuTTY. The CLI is useful for easily outputting data from the program on the mote by using the Dust Networks® On-Chip SDK version of a print() command.

Eterna Serial Programmer

The Eterna Serial Programmer can be connected to header J3 to program the mote. This programmer cannot be used as a debugger to step through code, but is instead useful for more advanced functions. The ESP can be used to rewrite fuse tables and load a program's compiled binary onto a mote. It can also be used as an alternative connection to the CLI port; in this case, SW4 can be set to UART and the user can monitor the GUI and the CLI at the same time. Otherwise, the user can only communicate with one at a time as determined by SW4.

In order to use the ESP, all five switches on SW3 need to be in the ESP position; once finished with the ESP, all five switches should go back to the RUN APP position. The USB cable can be plugged in when programming with the ESP, but it is not required. For more information on the ESP, see the Eterna Serial Programmer Guide.
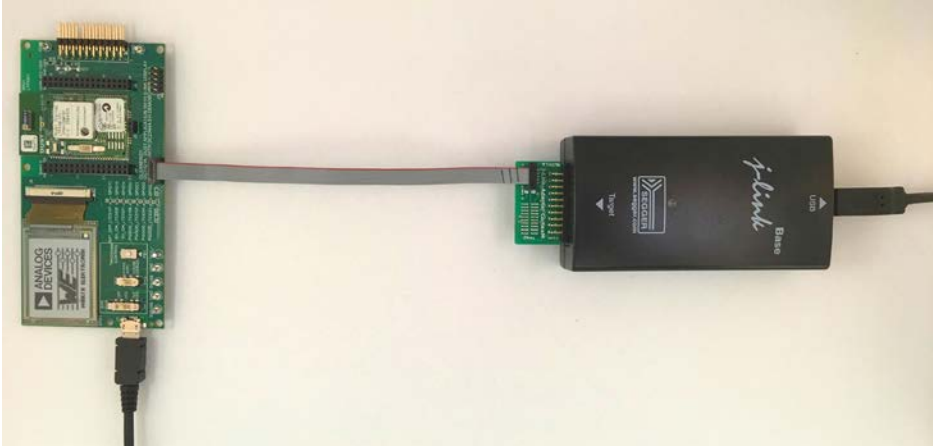
APPLICATION

Figure 9a. JTAG Connection with Reduced Pinout Adapter

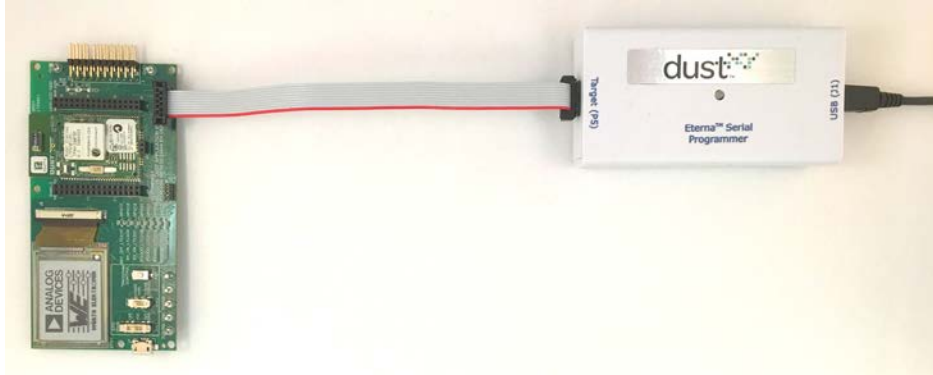**Figure 9b. JTAG Connection with Standard Connector (Not Populated, See BOM)**

Figure 10. Eterna Serial Programmer Connection
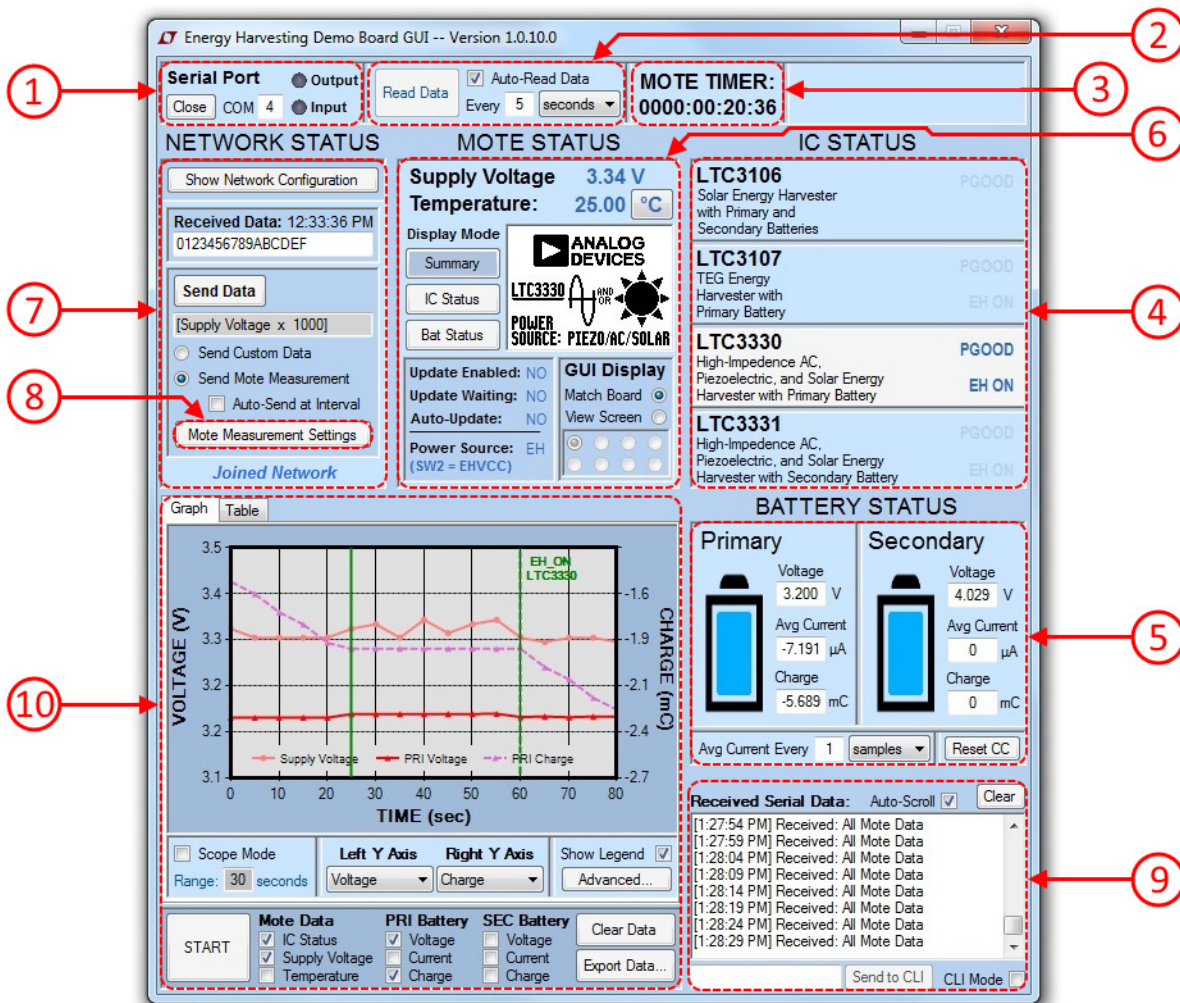
GUI APPLICATION

Figure 11. Energy Harvesting Demo Board GUI — Main Form

Overview

The GUI which accompanies DC2321A displays all of the data monitored by the mote in a user-friendly way that consumes much less energy than a write to the electronic paper display. Rather than stepping through display screens to read the mote's data, the GUI allows the user to view all of the information at once. In addition, long-term data logging is supported and the gathered data can be exported to a CSV file.

The GUI can also be used for changing network settings. From the GUI, the mote can be told to join a particular network or to stop using its radio function entirely.

Because the power consumption of DC2321A's default program is so low, frequent communication with the GUI can have a significant impact on the average power of the board. To alleviate this extra consumption, the rate at which the GUI automatically requests data can be adjusted or data requests can be sent manually instead.

GUI APPLICATION

1. Serial Port

The serial port section is used to open or close a serial port connection to DC2321A. This connection generally happens automatically when the GUI is opened. The board's COM port number is shown when the board is found and status lights blink when the GUI is sending or receiving data.

Figure 12. Serial Port Section

2. Data Reading

The data reading section controls when the GUI will request data from the mote. As long as the mote is connected to the GUI, the default program remains in a slave mode where it performs only its bare minimum checks once every second. This allows the DC2321A to consume the least energy possible. The GUI is configured from startup to request data from the mote on a fixed 10 second interval. This interval is user configurable and can be turned off entirely. If the Auto-Read Data checkbox is unselected, the auto-read function is disabled, and the Read Data button becomes enabled which allows the user to read data with manual requests at any time.
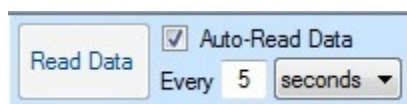

Figure 13. Data Reading Section

3. Mote Timer

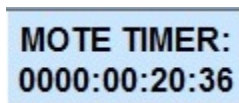The mote timer shows how long it has been since the mote's last reset.

Figure 14. Mote Timer

4. IC Status

The IC status section allows the user to monitor which PGOOD and EH_ON signals are present.

Figure 15. IC Status Section

5. Battery Status

The battery status section shows data gathered from the two coulomb counters. Voltage and charge data are acquired and measurement timestamps are used to calculate the current from the change in charge values over time.

To compensate for the granularity of the coulomb counters, the user has the option to average the current reading over a number of samples or a fixed time interval. If the battery current is in the µA range and data is being gathered at an interval less than 5 seconds (see Auto-Read Data section),

GUI APPLICATION

it is recommended to average the current reading for the sake of accuracy (see the Coulomb Counters section).

The coulomb counters can also be cleared if the Reset CC button is pressed. This will cause the charge to restart accumulating from 0μC. This is useful for calculating the total energy consumed by the application during some timespan or event.
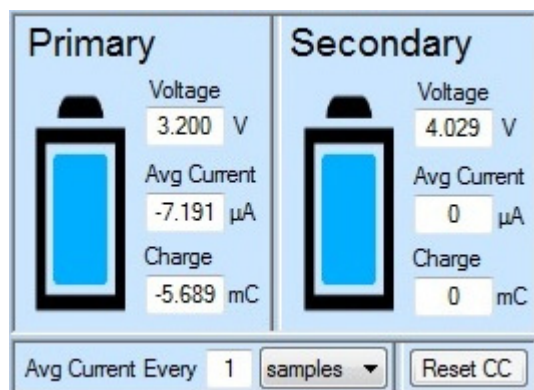

Figure 16. Battery Status Section

6. Mote Status

The mote status section shows various program information as well as some data from the mote's internal sensors. The mote has the ability to read its own supply voltage and is integrated with a temperature sensor. Monitoring the supply voltage is especially useful for energy harvesting applications because, in a case where no battery is connected, the voltage measurement combined with the known capacitance on the supply (configured on DC2344A or DC2509A) allows the processor to determine exactly how much energy is stored in the system:

$$E = \frac{1}{2}CV^2 = \frac{1}{2}C_{STORAGE}V_{SUPPLY}^2$$

If the GUI display is in Match Board mode, this section of the GUI has the ability to show the current screen on the DC2321A. This is especially useful for cases where the user would like to view a screen without consuming all of the energy required for a write. With SW1 = OFF, the display on the board will not update, but the display on the GUI will update with very little impact on energy consumption. In addition to showing the display, the Display Mode buttons allow the user to write a specific screen

from the GUI. In addition to showing a desired screen, this is useful for invoking a substantial pulse of energy consumption from DC2321A for the purpose of energy management evaluation.

Figure 17. Mote Status Section

If the GUI display is in View Screen mode, the user can view the possible displays of the summary screen.

This section also shows some of the demonstration program's status variables.

- Update Enabled means that display updates are enabled. This functionality is controlled by SW1. If SW1 = OFF, the display on DC2321A will not update. Otherwise, the display will update if the mote detects sufficient energy. The display on the GUI will always update.

- Update Waiting means that the DC2321A has new data that it wants to write to the display, but it cannot yet perform an update because there is not enough available energy in its supply. This will only occur when the board is being powered from DC2344A with no battery powering the selected IC. In this case, the mote will wait until enough energy is detected and then perform the screen update.

- Auto-Update is applicable only to the battery status screen. This means that an auto-refresh interval has been set and the battery status screen will update peri-

GUI APPLICATION

odically on a fixed interval. For more information about auto-refresh, see the Push Button Functions section.

- Power Source tells the user whether DC2321A is being powered by EHVCC (from DC2344A or DC2509A via J1) or by 3V3USB (from the USB via a voltage regulator). This is determined by SW2.

7. Network Status

The network status section allows the user to configure the network activity of the mote. By default, the mote is not configured to join a network. Clicking the Show Network Configuration button allows the user to view and modify some of the network settings. By toggling the Join checkbox, the user can configure the mote to join or leave a network. If the mote ever leaves a network, it will restart. Any time the mote restarts from software, there is a delay of about five seconds. The mote must also be manually restarted for a Network ID change to take effect. This panel also shows the mote's default MAC address; this MAC address is unique to the mote and also serves as its serial number.

Any data received by the mote is displayed in the Received Data text box in hexadecimal notation. The time that the message was received will also be shown.
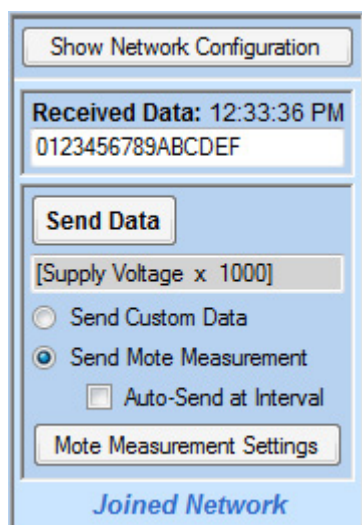

Figure 18a. Network Status Section

Figure 18b. Network Settings Section

Data can also be sent to a manager on the network by using the Send Data text box. In Send Custom Data mode, the user can manually send data by entering a hexadecimal value into the text box. In Send Mote Measurement mode, the user can tell the mote to send some of its own monitored data to the manager over the network. This data can be sent just once or, if Auto-Send at Interval is checked, it can be sent continuously on a user-defined interval. This functionality can be customized by clicking the Mote Measurement Settings button.

8. Mote Measurement Settings

In the Mote Measurement Settings window, the user is able to choose which type of data should be sent to the manager. This includes every piece of data that is displayed on the GUI, but there are a few extra features for evaluation purposes. For example, to test radio communication, the mote can be configured to send an incrementing value to the manager on every send. These data settings also allow users to transmit data from additional sensors that are connected to the inputs on the mote. All four of the mote's ADCs can be used to send custom voltage data to the manager. Also, the GUI allows the user to send the I^2C response of any compatible sensor over the network.
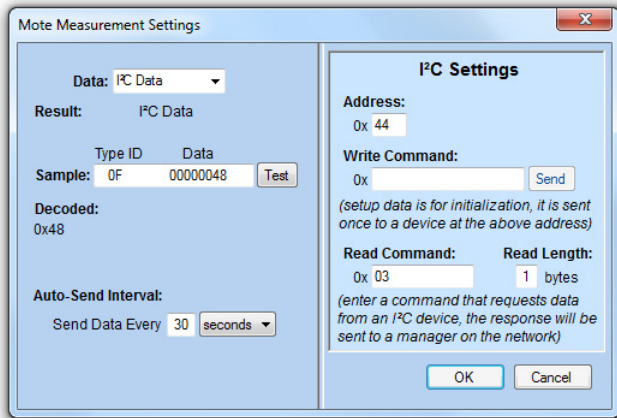
GUI APPLICATION

Figure 19. Mote Measurement Settings Window

If the I^2C data option is selected, the Mote Measurement Settings window expands to allow the user to input extra communication data in hexadecimal notation. The address of the I^2C device must be entered. The Setup Data text box allows the user to write I^2C data to the device without anticipating a response; this allows the user to initialize an I^2C device before requesting data. The Read Data Command text box should be filled in with the I^2C that is used to read the desired data. This command will be sent when the user hits the Send Data button in the network settings section; it can also be sent on a regular interval.

In order to preserve the precision of data as it is converted into a hexadecimal value, the data must be scaled up by some factor. The scaling value for the data is shown when a type of data is selected. This scaling value must be known when decoding the data on the receiving end of a transmission and the user must know this value if raw hexadecimal data is being decoded as is necessary when using APIExplorer. For example, sending a supply voltage measurement:

Actual Value:	= 3.2963 (V)
Scale Up by 1000:	= 3296.3 (mV)
Convert to Hex:	= 0x0CE0 [decimal dropped]
Received by Manager:	= 0x0CE0
Convert to Integer:	= 3296 (mV)
Scale Down by 1000:	= 3.296 (V)

Note that the actual data sent is prepended by a byte which is used to determine the type of data. This is not shown in the previous example.

The Sample text box allows users to see the data that would be received over the network. Instead of sending the data to the manager, the mote just sends it back to the GUI for a preview of what the data should look like and how it should be decoded. This is especially useful for troubleshooting I^2C communication.

The Auto-Send Interval Text box allows the user to define the automatic send interval (if used) for the data. This determines how frequently the mote will send this data to the manager.

9. Received Serial Data

The Received Serial Data text box shows a description of the data sent from the mote to the GUI and the time that data was received. The frequency of serial communication has an impact on power consumption, so this text box serves as an abridged log of recent communication.

In addition, this text box can be used for CLI monitoring and communication. SW4 on DC2321A determines whether the CLI port is connected to the computer. However, because the GUI does not know the position of this switch, it is the responsibility of the user to set the GUI into CLI Mode when SW4 is in the CLI position. CLI Mode suppresses UART communication used in the demonstration application so that the user can read and write to the CLI.

Commands can be sent to the CLI using the Send to CLI text box. Refer to the SmartMesh IP Mote CLI Guide for a complete list of commands.
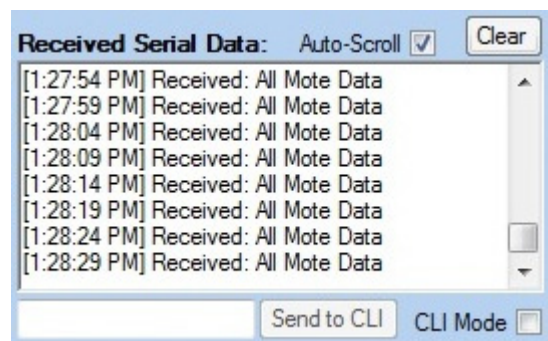

Figure 20. Received Serial Data Section

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GUI APPLICATION

10. Graph and Table

The GUI also supports long-term data logging. The graph and table provide a functional preview of the recorded information. Logging can be started and stopped using the Start button. A log can be cleared entirely using the Clear Data button. Also, any of the logged data (even that which is not shown on the graph or table) can be exported to a CSV file using the Export Data button. This exported data can be opened in Microsoft Excel or any CSV-compatible spreadsheet application.

Figure 21a. Graph Section

Figure 21b. Table Section

The checkboxes below the graph/table area determine which data will be shown on the GUI preview. Even though some data may not be shown at some times, all data is recorded and can be exported to a CSV file. All selected data will be shown on the table. However, since there are only two possible Y axes on the graph, only two types of data can be shown at once. As a result, selected data will only appear on the graph if its applicable Y Axis type is present. The Y Axis data types can be set using the Left Y Axis and Right Y Axis drop-down lists.

The graph has a few additional options. If Scope Mode is checked, the graph will snap to the most recent data points and it will only show the specified range of time on the X axis. The visibility of the legend can be toggled using the Show Legend checkbox.

The Advanced button allows the user to zoom in on a specific range for any axis type. This can be done while data is still being gathered.

There are a few types of events that will show up as vertical lines on the graph. If the IC Status checkbox is selected, a vertical green line will be shown to denote an IC status signal (PGOOD or EH_ON) transitioning high or low. A dashed line symbolizes a signal going low and a solid line symbolizes a signal going high. The graph will also denote a mote dead/alive event with a vertical blue line. In this case, when the mote becomes unresponsive, the line will be dashed. When the mote begins to respond again, the line will be solid.

For more information on graph events, the user can hover the mouse over a vertical line. For an IC Status event, this will show exactly which signal changed. The user can also hover the mouse over any series in the graph to display information about a data point.
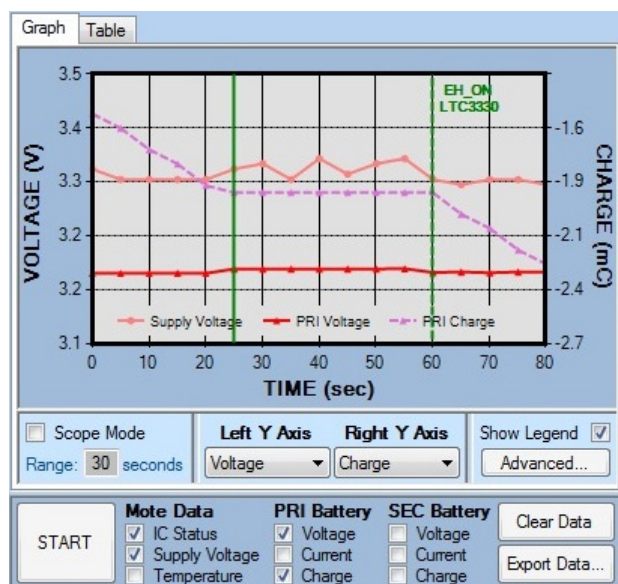
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Figure 22. APIExplorer Application

APIExplorer

To use the DC2321A's radio functionality, a Dust manager must also be present in the system. Network activity can be monitored and altered using various computer applications. APIExplorer provides a simple user interface for a manager/mote plugged into the USB port of the computer. A few different types of manager boards can be used, so refer to the documentation for the manager board to determine how it needs to be connected to a USB port (For example, DC9003A-A is a manager board which needs a DC9006A Eterna Interface Card to connect to a computer via a micro-USB port. DC2274A, however, can plug directly into a USB port).

APIExplorer is included in the SmartMesh® SDK software download which is available on the LTC website on any Dust mote/manager product web page. With only one board using APIExplorer, the SerialMux application is not needed and the board can be connected using its COM port name. This COM port (the API port) is the fourth of the four COM ports that appear when the board is connected to the computer. These ports can be viewed in Device Manager → Ports (COM & LPT). For more information, refer to the SmartMesh IP Tools Guide.

APIExplorer is a user interface for configuring and testing network transmission. For a detailed description of the commands, refer to the SmartMesh IP Manager API Guide.

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Network communication testing with this software is best used in conjunction with the DC2321A GUI because the GUI shows the mote's MAC address, network ID, and whether or not it has joined a network.

Network Setup

To communicate over the network, the mote and manager must be joined using the same network ID. DC2321A is configured to network ID 1228 by default, as are DC2274A-A modules that come in the Gleanergy energy harvesting kit. However, DC2274A-A modules purchased separately are configured to the default Dust evaluation kit network ID, 1229.

- To view or change the manager's network ID, refer to the example in the CLI Applications section of this manual.

- To view the mote's network ID, click the Show Network Settings button on the GUI. To change this network ID, enter the desired network ID into the appropriate text box and press Enter. Then, click the Reset Mote button.

To configure the mote to join the network, check the Join checkbox on the GUI and wait until the Network Status section shows *Joined Network*.

Note that any network configuration can also be done through the CLI.

Network Communication Testing Workflow

1. Send Data from Manager to Mote:

    a) Open APIExplorer and the DC2321A GUI.

    b) On the GUI, wait until the Network Status section shows *Joined Network*.

    c) On APIExplorer, select the send Data command.

    d) On the GUI, click the Show Network Configuration button.

    e) Fill in the data for the send Data command (right click to paste in APIExplorer):

    - Copy the mote's MAC address into the macAddress box on APIExplorer.

- Choose any priority.

- Set srcPort to 60000 (default).

- Set dstPort to 60000 (default).

- Set options to 0.

- Enter any hexadecimal value into the data box.

    f) On the GUI, click the Hide Network Config button.

    g) On APIExplorer, click the send button.

    h) On the GUI, observe the data shown in the Received Data text box.

2. Send Data from Mote to Manager:

    a) Open APIExplorer and the DC2321A GUI.

    b) On the GUI, wait until the network status section shows *Joined Network*.

    c) On APIExplorer, select the subscribe command.

    d) Fill in the data for the subscribe command:

    - Set filter to 11111111 to subscribe to all types of messages.

    - Set unackFilter to 00000000 to acknowledge all types of messages.

    e) On the GUI, send data in one of the following ways:

    - With Send Custom Data selected, enter a hexadecimal string into the text box and hit the Send Data button.

    - With Send Mote Measurement selected, click the Send Data button. The type of data sent can be configured by clicking the Mote Measurement Settings button. If Auto-Send at Interval is selected, the mote will repeatedly send the data at the interval that has been set. If the mote is configured to send data on an interval, it will continue to send the data whenever it is joined to the network, even if it is disconnected from the computer or reset.

    f) On APIExplorer, observe the data shown. If Send Mote Measurement was used, the value can be decoded as detailed in the Mote Measurement

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Settings section of this manual. The first byte of this data denotes the type of data sent and should be omitted from calculations.

CLI Applications

DC2321A has the ability to route the mote's command line interface (CLI) to the computer via USB. This allows the user to communicate directly with the mote using built-in text commands. In order to connect the CLI port to the computer, SW4 must be in the CLI position. Note that DC2321A cannot communicate with the GUI while SW4 is in this position.

This interface allows the user to easily read or modify network configuration settings within the mote or manager. For a detailed list of commands, see the SmartMesh IP Mote CLI Guide and the SmartMesh IP Embedded Manager CLI Guide. Because the SmartMesh IP library's print() function on the mote writes strings to the CLI port, this function is also useful for debugging code.

Figure 23. PuTTY Serial Setup

The CLI can be accessed through any serial terminal program such as PuTTY or HyperTerminal. For example, to communicate with the mote or manager using PuTTY:

1. Find the appropriate COM port:

   a) Find the COM port of DC2321A:

   - Option 1: Open the GUI (SW4 position does not matter). When the board connects, the COM port will be listed in the serial data section as shown in Figure 12. Close the serial port or close the GUI.

   - Option 2: Navigate to Device Manager → Ports (COM & LPT) and find the COM port listed for LTC Demo Board. If multiple LTC demo boards are connected to the computer, double-click the entries until DC2321A is found.

   b) Find the COM port of the manager's CLI:

   - Navigate to Device Manager → Ports (COM & LPT) and find the four COM ports that appear when the manager is connected to the computer. The CLI port is the third of the four COM ports.

2. Open PuTTY.

3. Set Connection Type to Serial.

4. Enter the COM port which hosts the mote or manager's CLI.

5. Ensure that Speed is set to 9600.

6. Click Open.

Once the serial port is open, the CLI can be used to configure the network. For example, to view the manager's network ID and then set it to 1228, type:

- login user

- get config netid

- set config netid 1228

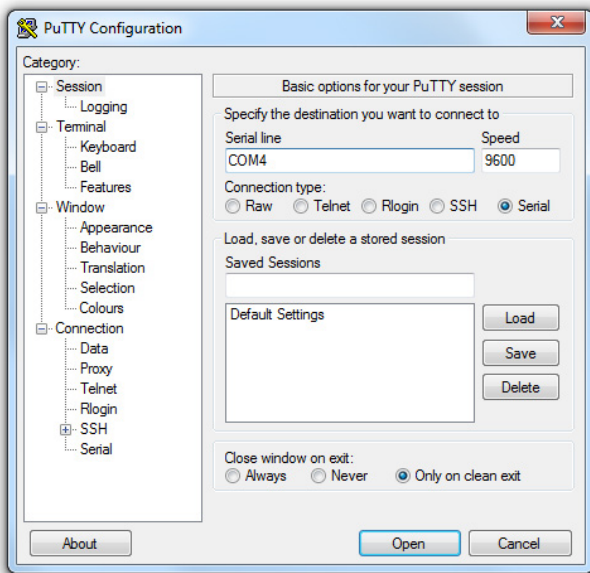A reset is required for this change to take effect.

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PARTS LIST

ITEM	QTY	REFERENCE	PART DESCRIPTION	MANUFACTURER/PART NUMBER
Required Circuit Components				
1	1	BRD1	SMARTMESH IP NODE, 2.4GHz, 802.15.4e, WIRELESS MOTE MODULE	ANALOG DEVICES, LTP5901IPC-IPMA1D0#PBF
2	10	R11 TO R17, R29 TO R31	RES, CHIP, 10MΩ, ±1%, 1/10W, 0603	SAMSUNG, RC1608F106CS
Display Components				
3	8	C1 TO C4, C10 TO C13	CAP, CHIP, 2.2µF, 25V, ±10%, X7R, 0805	WURTH, 885012207079
4	1	C5	CAP, CHIP, 1µF, 10V, ±10%, X7R, 0805	WURTH, 885012207022
5	6	C6 TO C9, C14 TO C15	CAP, CHIP, 2.2µF, 16V, ±10%, X7R, 0805	WURTH, 885012207052
6	1	C16	CAP, CHIP, 2.2µF, 10V, ±10%, X7R, 0805	WURTH, 885012207024
7	1	D1	DIODE, SCHOTTKY, 30V, 0.1A, SOD-523	CENTRAL SEMICONDUCTOR, CMOSH-3
8	1	EPD1	1.44" E-PAPER DISPLAY	PERVASIVE DISPLAYS, E1144CS021
9	1	Q1	MOSFET, N/P-CH, 20V, 660mA, SC70-6	VISHAY, SI1553CDL-T1-GE3
10	2	Q2, Q3	N-CHANNEL MOSFET, 60V, SOT-323	FAIRCHILD, 2N7002KW
11	1	R9	RES, CHIP, 2kΩ, ±1%, 1/10W, 0603	PANASONIC, ERJ-3EKF2001V
12	1	R10	RES, CHIP, 5.1MΩ, ±5%, 1/10W, 0603	PANASONIC, ERJ-3GEYJ515V
13	1	R48	RES, CHIP, 10MΩ, ±1%, 1/10W, 0603	SAMSUNG, RC1608F106CS
Additional Demo Board Circuit Components				
14	0	C22, C23 (OPT)	CAP, CHIP, 47pF, 10V, ±5%, C0G, 0603	WURTH, 885012006006
15	0	D3 (OPT)	DIODE ZENER 3.6V 500MW MINIMELF	MICRO COMMERCIAL, BZV55C3V6-TP
16	0	D4 (DOES NOT EXIST)	—	—
17	0	R27, R28 (OPT)	RES, CHIP, 0Ω, 1/10W, 0603	VISHAY, CRCW06030000Z0EA
Hardware For Demo Board Only				
18	2	C17, C21	CAP, CHIP, 0.22µF, 6.3V, ±10%, X7R, 0603	KEMET, C0603C224K9RACTU
19	3	C18, C25, C26	CAP, CHIP, 1µF, 10V, ±10%, X7R, 0603	WURTH, 885012206026
20	2	C19, C24	CAP, CHIP, 0.01µF, 6.3V, ±10%, X7R, 0603	KEMET, C0603C103K9RACTU
21	1	C20	CAP, CHIP, 10µF, 6.3V, ±20%, X5R, 0603	WURTH, 885012106006
22	5	D2, D5, D7 TO D9	DIODE, SCHOTTKY, 30V, 0.1A, SOD-523	CENTRAL SEMICONDUCTOR, CMOSH-3
23	2	D6, D10	DIODE, LOW LEAKAGE, 75V, 250MA, SOT23	CENTRAL SEMICONDUCTOR, CMPD6001
24	1	DB1	SHIELD BOARD FOR DC2321A	ANALOG DEVICES, DC2510A
25	7	E1 TO E7	TURRET, 0.061 DIA	MILL-MAX, 2308-2-00-80-00-00-07-0
26	1	J1	2X10, 20-PIN, RIGHT ANGLE MALE HEADER (WITH KEY PIN 14), 0.100"	WURTH, 61302021021
27	1	J2	2x5, 1.27MM PITCH, VERTICAL MALE HEADER (WITH KEY PIN 7)	WURTH, 62201021121
28	1	J3	2x5, 2.00MM PITCH, VERTICAL MALE HEADER	WURTH, 62001021121
29	2	J4, J6	2x16, 2MM PITCH, VERTICAL SOCKET	WURTH, 62003221821
30	1	J5	2-PIN, 2MM PITCH, VERTICAL SOCKET	WURTH, 62000211821
31	1	J7	MICRO USB CONNECTOR	WURTH, 629105136821
32	1	J8	40-PIN, 0.5MM PITCH, HORIZ FCP CONNECTOR WITH BOTTOM CONTACTS	WURTH, 68714014522

PARTS LIST

ITEM	QTY	REFERENCE	PART DESCRIPTION	MANUFACTURER/PART NUMBER
33	0	J9 (OPT)	CONN, HEADER, 2.54MM, 20POS, GOLD, SMD	SULLINS, SBH11-NBPC-D10-SM-BK
34	1	PB1	SWITCH, TACTILE, SPST-NO, 0.05A 12V	WURTH, 434111025826
35	2	Q8, Q9	MOSFET, N/P-CH, 20V, 660mA, SC70-6	VISHAY, SI1553CDL-T1-GE3
36	3	Q4, Q5, Q6	MOSFET N-CH 20V 4.1A SOT23	ZETEX, ZXMN2F30FHTA
37	1	Q7	MOSFET 2N-CH 30V 5.7A 8SOIC	ZETEX, ZXMN3F31DN8TA
38	17	R1 TO R8, R26, R32, R41 TO R46, R49	RES, CHIP, 0Ω, 1/10W, 0603	VISHAY, CRCW06030000Z0EA
39	1	R18	RES, CHIP, 2MΩ, 1/10W, ±5%, 0603	PANASONIC, ERJ-3GEYJ205V
40	1	R19	RES, CHIP, 5.1MΩ ±5%, 1/10W, 0603	PANASONIC, ERJ-3GEYJ515V
41	11	R20 TO R23, R35 TO R40, R47	RES, CHIP, 10kΩ, 1/10W, 0603	PANASONIC, ERJ-3EKF1002V
42	2	R24, R25	RES, CHIP, 3.32Ω, 1%, 1/8W, 0805	VISHAY, CRCW08053R32FKEA
43	2	R33, R34	RES, CHIP, 1kΩ, 1%, 1/10W, 0603	VISHAY, CRCW06031K00FKEA
44	2	R50, R51	RES, CHIP, 300M, 5%, 0805	VISHAY, CRCW0805300MJPEAHR
45	1	SW1	DP3T SLIDE SWITCH, 12mm × 3.5mm, 0.2A 12VDC	COPAL, CL-SB-23A-01T
46	2	SW2, SW4	DPDT SLIDE SWITCH, 8.5mm × 3.5mm, 0.2A 12VDC	COPAL, CL-SB-22A-01T
47	1	SW3	5xSPST, SMD, LOW PROFILE, DIP SWITCH, 1.27mm PITCH	WURTH, 416 131 160 805
48	1	U1	2-CHANNEL, 2-WIRE BUS MULTIPLEXER WITH CAPACITANCE BUFFERING	ANALOG DEVICES, LTC4305CDHD#PBF
49	2	U2, U3	BATTERY GAS GAUGE W/ TEMPERATURE & VOLTAGE MEASUREMENT	ANALOG DEVICES, LTC2942CDCB#TRMPBF
50	2	U4, U5	DUAL OP AMPS, CHOPPER, R-R OUTPUT, 8SO	ANALOG DEVICES, LTC2051CS8#PBF
51	1	U6	3.3V, 100 mA, LOW NOISE, LDO MICROPOWER REGULATOR, TSOT23-5	ANALOG DEVICES, LT1761ES5-3.3#PBF
52	1	U7	IC USB TO I^{2}C BRIDGE DEVICE 14TS	MICROCHIP, MCP2221-I/ST
53	1	U8	IC, UHS UNIV. CONFIG. TWO-INPUT GATES, SC70-6	FAIRCHILD, NC7SZ58P6X
54	0.001	—	665 DOUBLE-SIDED TAPE, 1" x 1296", (CUT TO 1" x 1.5" FOR EPD1)	3M, 665-1X1296 (Kit Qty = # Reels, Round Up)
55	5	STANDOFF (NOT IN EH KIT)*	STANDOFF, HEX .625"L, 4-40, THR NYLON	KEYSTONE, 1902F
56	5	SCREW (NOT IN EH KIT)*	SCREW, MACH, PHIL, 4-40, .250 IN, NYLON	B&F FASTENER SUPPLY, NY PMS 440 0025 PH
57	1	—	FAB, PRINTED CIRCUIT BOARD	DEMO CIRCUIT 2321A
58	2	—	STENCILS TOP & BOTTOM	STENCILS, DC2321A

*Parts labeled NOT IN EH KIT (items 55 and 56) are omitted from boards used in Wurth Elektronik's Gleanergy EH / WSN Development Platform. These parts will be populated on boards built by Linear Technology.

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.

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