TI Designs: TIDA-01452
I3Mote for Industrial Internet of Things Reference Design

Description

This reference design introduces a platform called the Intelligent Industrial Internet (I3) Mote. The I3Mote is designed as an open and universal hardware platform targeting process/factory automation and building automation connectivity and sensing deployments. By using the most advanced low-power components to address wireless and wired connectivity, onboard computing, and sensing, the platform is designed for early prototyping and easy deployment with a small form factor and robust performance.

Resources

TIDA-01452	Design Folder
CC2650	Product Folder
MSP432P401R	Product Folder
HDC1080	Product Folder
OPT3001	Product Folder
bq25505	Product Folder
TPS62737	Product Folder
TPS61222	Product Folder
TPS610981	Product Folder
TS5A3160	Product Folder
CSD75208W1015	Product Folder

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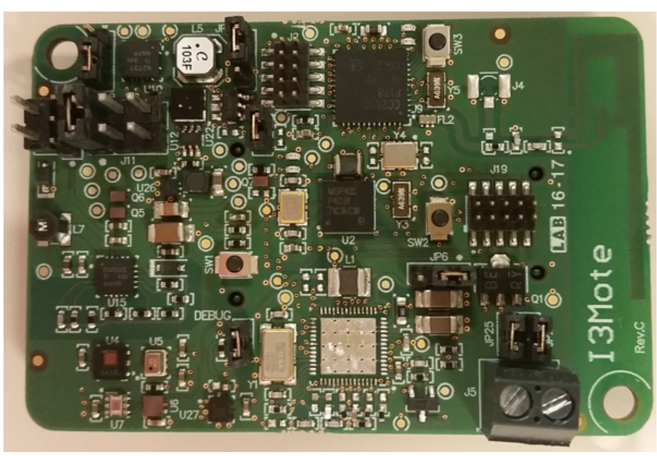
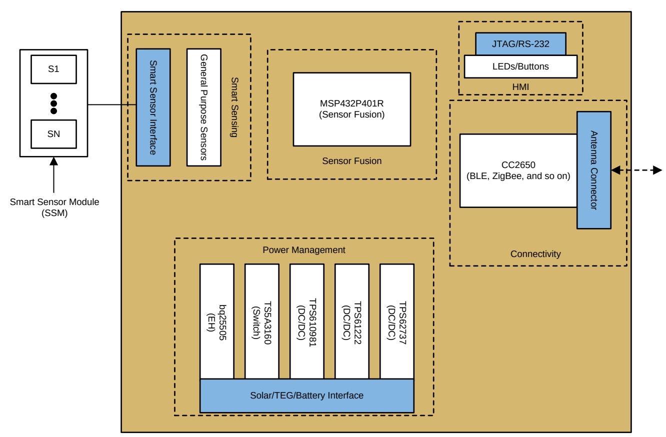


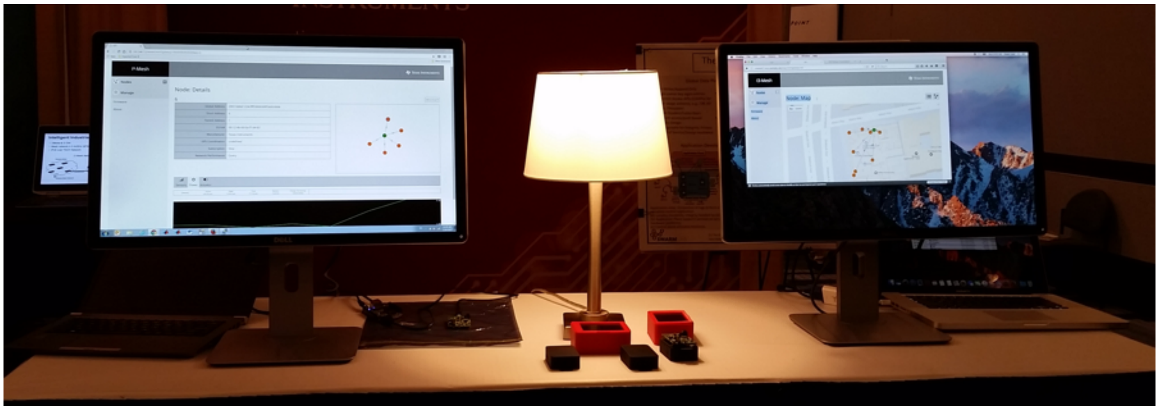
Features

- Built-in Sensors (Temperature, Humidity, Acceleration, Ambient Light, Pressure) and Smart Sensor Interface (SSI) to Enable Multimodal Sensor Extension
- Industrial-Grade Wireless Connectivity With 99.999% Reliability and Battery Life > 10 Years
- Multiple Power Sources, Which Can Be USB (5-V DC), Batteries (2×AA, 2×AAA, or CR2032 Coin-Cell), Energy Harvesting Sources (Indoor Light, TEG) Adaptably Selectable

Applications

- Process Management and Automation
- Field Transmitters and Wireless and Wired Sensor Network
- Factory Remote Condition Monitoring for Sensors and Actuators
- Factory Predictive Maintenance
- Commercial Building Automation





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1 System Description

The Intelligent Industrial Internet Mote (I3Mote) is a development platform that can be used as a reference design to quickly establish a wireless network that enables data extraction from various types of industrial sensors. The I3Mote platform is targeted at industrial applications, including but not limited to: process management, automation, factory automation, field transmitters, and predictive maintenance. The I3Mote has been designed to fulfill early prototyping and early deployment needs in the aforementioned fields. Different engineering or prototyping factors have been defined, whose aim is to facilitate in-lab prototyping, while a compact and integrated version is devoted to field evaluation and deployment. The device has been engineered to meet the industrial-grade performance and ultra-low-power consumption. The I3Mote combines an advanced low-power wireless system on chip (SoC), the CC2650, featuring an ARM® Cortex®-M3 core and a 2.4-GHz compliant radio that is able to support IEEE802.15.4 on 2.4 GHz, *Bluetooth*®, Bluetooth low energy, and so on. In addition, the I3Mote includes a dedicated ARM Cortex-M4F MSP432™ to provide sensor fusion processing capacity to the I3Mote.

Figure 1 shows some of the key features of the I3Mote. The main features of the I3Mote are: Built-in sensors (temperature, humidity, acceleration, ambient light, pressure) and smart sensor interface (SSI) to enable multimodal extension and an industrial-grade wireless connectivity with 99.999% reliability and a battery life of over 10 years. Multi-source and energy harvesting from thermoelectric generator (TEG) or solar or indoor light sources. Power sources can be USB (5-V DC), batteries (2×AA, 2×AAA, or CR2032 coin-cell batteries), or energy harvesting sources (for example, solar, TEG). Platform is built upon open source hardware and software.

1.1 Key System Specifications

Table 1 shows the subsystems and component parameters of the I3Mote.

Table 1. Subsystems and Component Parameters

SUBSYSTEM	PARTS	PARAMETERS	PACKAGE/PIN	FUNCTION
Connectivity	CC2650	48-MHz MCU, 128KB Flash, 20KB RAM, AES-128	7×7/48-pin QFN	BLE or ZigBee®
	Antenna (built-in and external)	—	—	—
Sensor fusion	MSP432P401R	48 MHz, 256KB Flash, 64KB RAM, 14-bit ADC, AES-256	5×5/80-pin BGA	Sensor fusion application
	EEPROM: 24LC256-I/SN-ND	Size: 32 kB, I^2C interface	8-pin PDIP	NVM configuration storage
Smart sensing	HDC1080	Relative humidity accuracy ±2% (typical), temperature accuracy ±0.2°C, 14-bit resolution, 100-nA sleep current	6-pin WSON	Humidity
	OPT3001	Human eye response, peak spectral sensitivity 550 nm, spectral bandwidth 460 to 655 nm	6-pin USON	Optical sensor
	BMP280	Pressure range: 300 to 1100 hPa Relative accuracy: ±0.12 hPa Absolute accuracy: ±1 hPa 2.7 µA at 1-Hz sampling rate	8-pin LGA metal-lid	Pressure sensor
	LIS2HH12	Three-axis linear accelerometer. Full scales of 2g/4g/8g and is capable of measuring accelerations with output data rates from 10 to 800 Hz.	3×3/24-pin QFN	Accelerometer
	SSI connector	SPI/4, I2C/2, PWM/1, GPIO/2, 3.3V DC/3, 5V DC/3, x2V DC/3, GND/4	N/A	20-pin female connector to smart sensor module (SSM)
Power management or energy harvesting	BQ25505	Energy harvesting device	20-pin VQFN	Power management between battery and energy harvesting
	TPS610981	≈90% efficiency for 10-µA load; 300-nA quiescent current	6 pin WSON	Boost or bypass from the battery or the energy harvesting source
	TPS62737	>90% efficiency for I_{OUT} > 10 µA	14-pin VQFN	3-V DC output for the circuitry other than SSM
	TPS61222	95% for typical operating conditions	SC-70	5-V DC output for SSM
	TS5A3160	1-Ω SPDT analog switch	SOT-23	Analog switch for 3-V DC for SSM
	CSD75208W1015	FET	1.0 mm × 1.5 mm Wafer Level Package	Power or-ing, power switching

2 System Overview

2.1 Block Diagram

The I3Mote is composed of the five main subsystems: connectivity subsystem, sensor fusion subsystem, smart sensing subsystem, power management and energy harvesting subsystem, and human machine interface (HMI). Figure 1 shows the block diagram and each subsystem of the I3Mote.

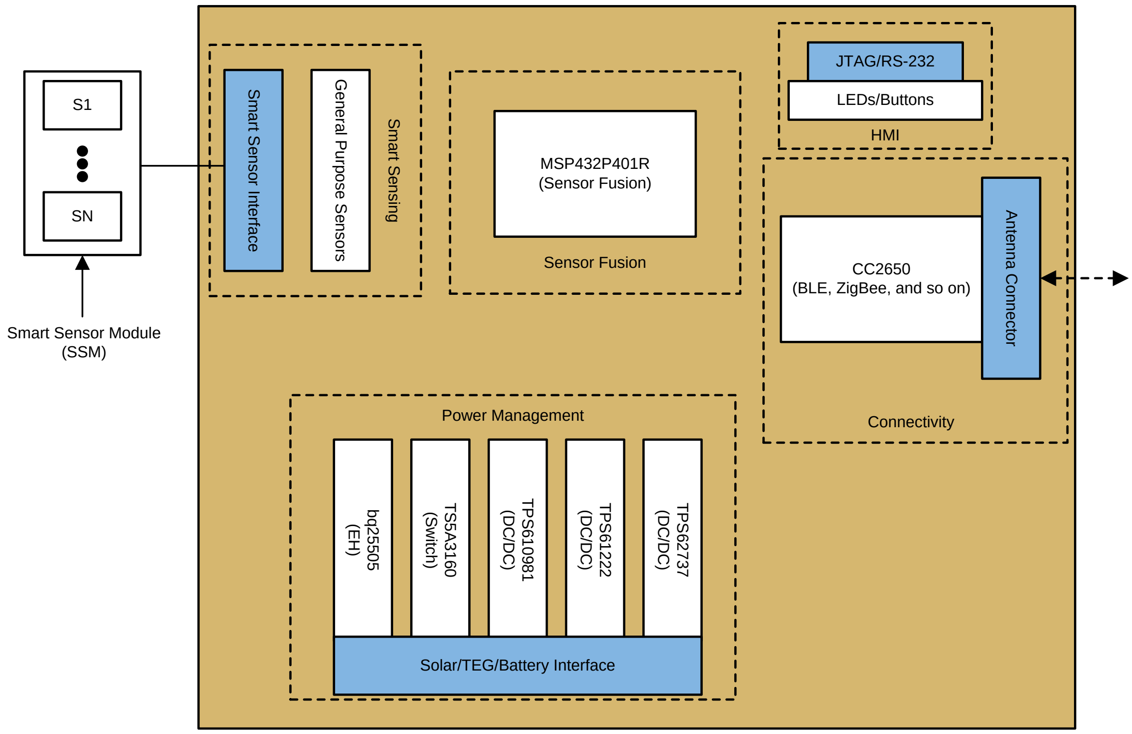

Figure 1. I3Mote Features

2.2 Highlighted Products

2.2.1 CC2650

The CC2650 device is a wireless MCU targeting *Bluetooth*®, ZigBee® and 6LoWPAN, and ZigBee RF4CE remote control applications.

The device is a member of the CC26xx family of cost-effective, ultra-low-power, 2.4-GHz RF devices. Its very low-active RF and MCU current and low-power mode current consumption provide excellent battery lifetime and allow for operation on small coin-cell batteries and in energy-harvesting applications.

The CC2650 device contains a 32-bit ARM Cortex-M3 processor that runs at 48 MHz as the main processor and a rich peripheral feature set that includes a unique ultra-low-power sensor controller. This sensor controller is ideal for interfacing external sensors and for collecting analog and digital data autonomously while the rest of the system is in sleep mode. Thus, the CC2650 device is ideal for applications within a whole range of products including industrial, consumer electronics, and medical.

The Bluetooth low energy controller and the IEEE 802.15.4 MAC are embedded into ROM and are partly running on a separate ARM Cortex-M0 processor. This architecture improves overall system performance and power consumption and frees up flash memory for the application.

The Bluetooth and ZigBee stacks are available free of charge from TI.com.

2.2.2 MSP432P401R

The SimpleLink™ MSP432P401x microcontrollers (MCUs) are optimized wireless host MCUs with an integrated 14-bit analog-to-digital converter (ADC) capable of up to 16 ENOB delivering ultra-low-power performance, including 80 µA/MHz in active power and 660 nA in standby power with FPU and DSP extensions. As an optimized wireless host MCU, the MSP432P401x allows developers to add high-precision analog and memory extension to applications based on SimpleLink wireless connectivity solutions.

The MSP432P401x devices are part of the SimpleLink MCU platform, which consists of Wi-Fi®, Bluetooth low energy, Sub-1 GHz, and host MCUs. All share a common, easy-to-use development environment with a single core software development kit (SDK) and rich tool set. A one-time integration of the SimpleLink platform lets one add any combination of devices from the portfolio into a design. The ultimate goal of the SimpleLink platform is to achieve 100 percent code reuse when the design requirements change. For more information, visit www.TI.com/simplelink.

MSP432P401x devices are supported by a comprehensive ecosystem of tools, software, documentation, training, and support to get development started quickly. The MSP-EXP432P401R LaunchPad™ development kit or MSP-TS432PZ100 target socket board (with additional MCU sample) along with the free SimpleLink MSP432 SDK is all one needs to get started.

2.2.3 HDC1080

The HDC1080 is a digital humidity sensor with integrated temperature sensor that provides excellent measurement accuracy at very low power. The HDC1080 operates over a wide supply range, and is a low-cost, low-power alternative to competitive solutions in a wide range of common applications. The innovative Wafer Level Chip Scale Package (WLCSP) simplifies board design with the use of an ultra-compact package. The sensing element of the HDC1080 is placed on the bottom part of the device, which makes the HDC1080 more robust against dirt, dust, and other environmental contaminants. The humidity and temperature sensors are factory calibrated and the calibration data is stored in the on-chip non-volatile memory.

2.2.4 OPT3001

The OPT3001 is a sensor that measures the intensity of visible light. The spectral response of the sensor tightly matches the photopic response of the human eye and includes significant infrared rejection.

The OPT3001 is a single-chip lux meter, measuring the intensity of light as visible by the human eye. The precision spectral response and strong IR rejection of the device enables the OPT3001 to accurately meter the intensity of light as seen by the human eye regardless of light source. The strong IR rejection also aids in maintaining high accuracy when industrial design calls for mounting the sensor under dark glass for aesthetics. The OPT3001 is designed for systems that create light-based experiences for humans, and an ideal preferred replacement for photodiodes, photoresistors, or other ambient light sensors with less human eye matching and IR rejection.

Measurements can be made from 0.01 lux up to 83k lux without manually selecting full-scale ranges by using the built-in, full-scale setting feature. This capability allows light measurement over a 23-bit effective dynamic range. The digital operation is flexible for system integration. Measurements can be either continuous or single shot. The control and interrupt system features autonomous operation, allowing the processor to sleep while the sensor searches for appropriate wake-up events to report via the interrupt pin. The digital output is reported over an I^2C- and SMBus-compatible, two-wire serial interface.

The low-power consumption and low-power supply voltage capability of the OPT3001 enhance the battery life of battery-powered systems.

2.2.5 bq25505

The bq25505 device is specifically designed to efficiently extract the microwatts (µW) to milliwatts (mW) of power generated from a variety of DC energy harvesting, high-impedance sources like photovoltaic (solar) or TEGs without collapsing those sources. The battery-management features of the bq25505 ensure that a secondary rechargeable battery is not overcharged by this extracted power, with voltage boosted, nor depleted beyond safe limits by a system load. The integrated multiplexer gate drivers autonomously switch the system load to a primary non-rechargeable battery if the secondary battery voltage falls below the user-defined VBAT_OK threshold.

2.2.6 TPS62737

The TPS6273x family provides a highly integrated ultra-low-power buck converter solution that is well suited for meeting the special needs of ultra-low-power applications such as energy harvesting. The TPS6273x provides the system with an externally programmable regulated supply to preserve the overall efficiency of the power management stage compared to a linear step-down converter. This regulator is intended to step-down the voltage from an energy storage element such as a battery or super capacitor to supply the rail to low-voltage electronics. The regulated output has been optimized to provide high efficiency across low-output currents (<10 µA) to high currents (200 mA).

The TPS6273x integrates an optimized hysteretic controller for low-power applications. The internal circuitry uses a time-based sampling system to reduce the average quiescent current.

To further assist users in the strict management of their energy budgets, the TPS6273x toggles the input power-good indicator to signal an attached microprocessor when the voltage on the input supply has dropped below a preset critical level. This signal is intended to trigger the reduction of load currents to prevent the system from entering an undervoltage condition. In addition, independent enable signals allow the system to control whether the converter is regulating the output, monitoring only the input voltage, or to shut down in an ultra-low quiescent sleep state.

The input power-good threshold and output regulator levels are programmed independently through external resistors.

All the capabilities of TPS6273x are packed into a small footprint 14-lead 3.5-mm×3.5-mm QFN package (RGY).

2.2.7 TPS61222

The TPS6122x family devices provide a power-supply solution for products powered by either a single-cell, two-cell, or three-cell alkaline, NiCd or NiMH, or one-cell Li-Ion or Li-polymer battery. Possible output currents depend on the input-to-output voltage ratio. The boost converter is based on a hysteretic controller topology using synchronous rectification to obtain maximum efficiency at minimal quiescent currents. The output voltage of the adjustable version can be programmed by an external resistor divider, or is set internally to a fixed output voltage. The converter can be switched off by a featured enable pin. While being switched off, battery drain is minimized. The device is offered in a 6-pin SC-70 package (DCK) measuring 2 mm × 2 mm to enable small circuit layout size.

2.2.8 TPS610981

The TPS61098x is an ultra-low-power solution for products powered by either a one-cell or two-cell alkaline, NiCd or NiMH, one-cell coin cell or one-cell Li-Ion or Li-polymer battery. It integrates either a low-dropout linear regulator (LDO) or a load switch with a boost converter and provides two output rails. The boost output V_MAIN is designed as an always-on supply for a main system, and the LDO or load switch output V_SUB is to power peripheral devices.

The TPS61098x has two modes controlled by MODE pin: Active mode and low-power mode. In active mode, both outputs are enabled with enhanced response performance. In low-power mode, the LDO or load switch is disabled to disconnect peripherals. The TPS61098x consumes only 300 nA of quiescent current and can achieve up to an 88% efficiency at a 10-µA load in low-power mode.

The TPS61098x supports automatic pass-through function. When input voltage is higher than a pass-through threshold, the boost converter stops switching and passes the input voltage to the VMAIN rail; when input voltage is lower than the threshold, the boost works in boost mode and regulates output at the target value. The TPS61098x provides different versions for different output set values.

The TPS61098x can provide up to a 50-mA total output current at a 0.7-V input to a 3.3-V output conversion. The boost is based on a hysteretic controller topology using synchronous rectifier to obtain maximum efficiency at minimal quiescent current.

The TPS61098x is available in a 1.5-mm×1.5-mm WSON package to enable small circuit layout size.

2.2.9 TS5A3160

The TS5A3160 device is a single-pole double-throw (SPDT) analog switch that is designed to operate from 1.65 to 5.5 V. The device offers a low on-state resistance and an excellent channel-to-channel on-state resistance matching. The device has excellent total harmonic distortion (THD) performance and consumes very low power. These features make this device suitable for portable audio applications.

2.2.10 CSD75208W1015

The CSD75208W1015 device is designed to deliver the lowest on-resistance and gate charge in the smallest outline possible with excellent thermal characteristics in an ultra-low profile. Low on-resistance coupled with the small footprint and low profile make the device ideal for battery operated space constrained applications.

3 Hardware, Software, Testing Requirements, and Test Results

3.1 Required Hardware and Software

3.1.1 Hardware

Figure 2 shows the general partitioning of the hardware. The following subsections go through each part in detail.

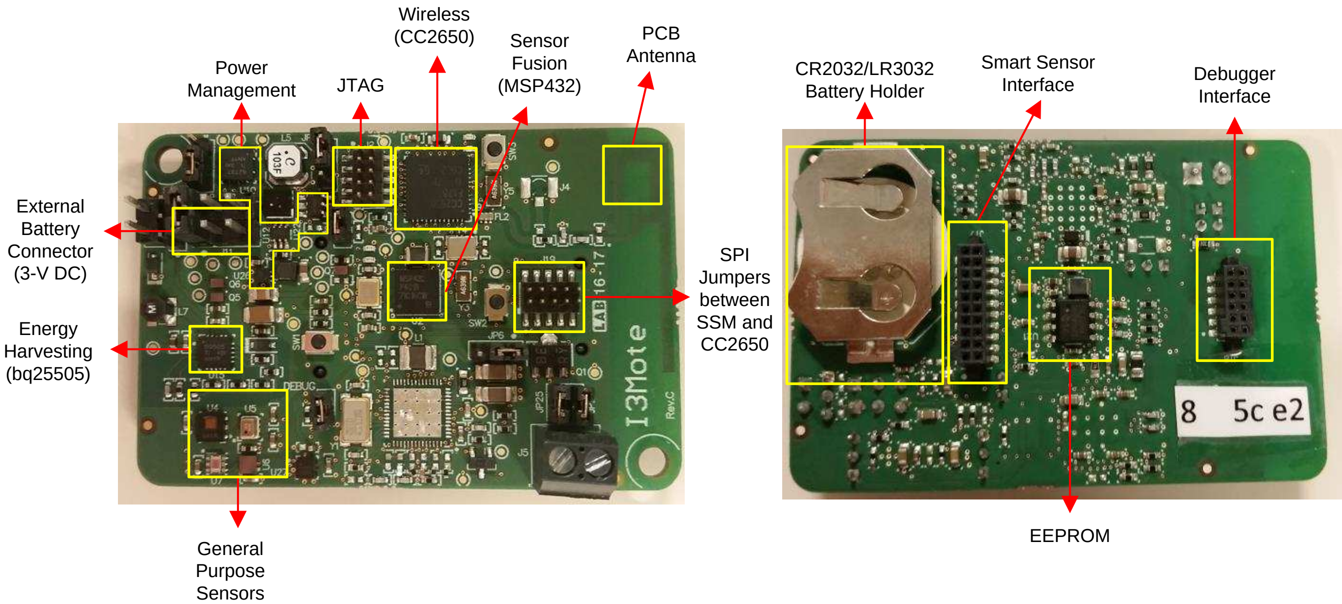

Figure 2. I3Mote Hardware Component Description

3.1.1.1 Power Management Unit

Two main voltages exist in the system: 3-V DC and 5-V DC. 3-V DC is used for MCUs, sensors, and switches. 5-V DC is only used when a smart sensor module (SSM) is connected to SSI, assuming that SSM uses 5-V DC. A 3-V DC power system can provide up to a 200-mA current to the system while 5-V DC can provide up to a 200-mA current to the system. These voltages can be provided from AA or AAA batteries, a coin-cell battery, or an energy harvesting source using an onboard DC/DC converter.

The bq25505 device is an energy harvester capable of collecting energy from thermoelectric or solar sources. The energy can be stored into a large capacitor reservoir or secondary rechargeable battery. Once the charge in that bank is accumulated sufficiently, the system will be powered from the reservoir. Alternatively, if sufficient charge has not been collected, a backup non-rechargeable battery (such as a AA or AAA) provides power to the system. The bq25505 device indicates the actively used power source (harvesting cells or battery) to the MCU by using a GPIO.

- Energy harvesting:
  The bq25505 regulates the energy provided by the energy harvesting cells. This device is specifically designed to efficiently extract μW to mW of power generated from high-impedance solar cells due to collapsing the cells using maximum power point tracking (MPPT). The harvested power is stored in a ceramic super-capacitor reservoir or a rechargeable battery. The bq25505 also manages a backup battery, which is used when there is not sufficient ambient energy to power the sensor node. Furthermore, by changing the values of the external resistors, developers can set the voltage levels of the energy reservoir that allow the bq25505 to properly connect and disconnect the two power sources to the load. Developers can also program the MPPT sampling network to optimize input power provided by the solar cell or TEG (see Section 3.1.5).

- Primary and secondary batteries:
  An embedded CR2032 cell battery can be used as a backup battery for the continual sensing operation. This battery type was chosen due to its ubiquity and its small size. The onboard battery holder can be used both as a backup non-rechargeable battery (primary) and as the rechargeable battery (secondary). A CR2032 lithium coin cell is ideal for these purposes. The output voltage of the battery is relatively constant until the battery is nearly depleted. At this stage, the voltage begins to decrease exponentially until the battery is depleted in full. The temperature characteristics of lithium-ion batteries are superior to that of alkaline cells. However, the operating temperature range of the CR2032 is more limiting than the other components used in this TI Design.
- Power switches control:
  The I3Mote provides software control to independently switch on or off different blocks of the circuit. For this purpose, the I3Mote includes a TS5A3160 single-pole double-throw (SPDT) analog switch. The switch enables the SSI of a 3-V output. Additionally, there is a specific boost converter to enable 5 V at the SSI.

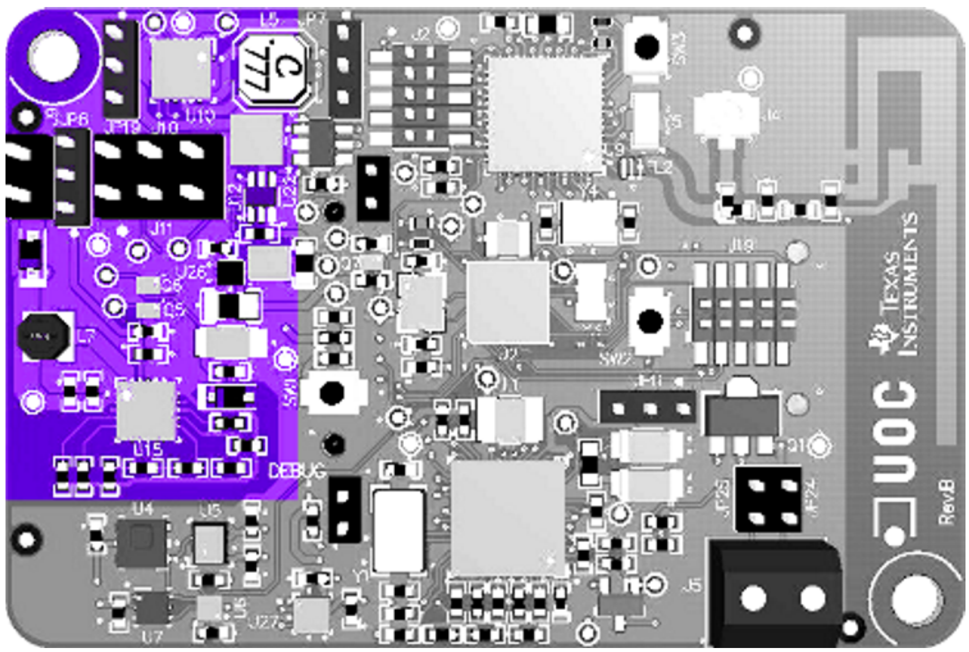

Figure 3. Power Management Subsystem of I3Mote

3.1.1.2 Data Fusion

- MSP432
  The MSP432 MCU platform is built around the high-performance ARM Cortex-M4F core, featuring DSP extensions and an integrated floating-point unit (FPU). The MSP432 MCU consumes only 95 µA/MHz in active mode and 850 nA in standby mode (including RTC), and its main purpose is to interface with the data fusion core for smart sensing of the board. That includes having full access to the different sources of data, either through SPI to the CC2650 or with direct access to the SSI.
- Onboard memory
  The I3Mote supports the non-volatile memory, 24LC256, which is a 32K × 8 (256 Kb) Serial Electrically Erasable PROM (EEPROM). This device is capable of both random and sequential reads up to the 256K boundary. The 24LC256 is accessed by a two-wire serial interface (compatible I^2C), accessible from to both the MSP432 and the CC2650.

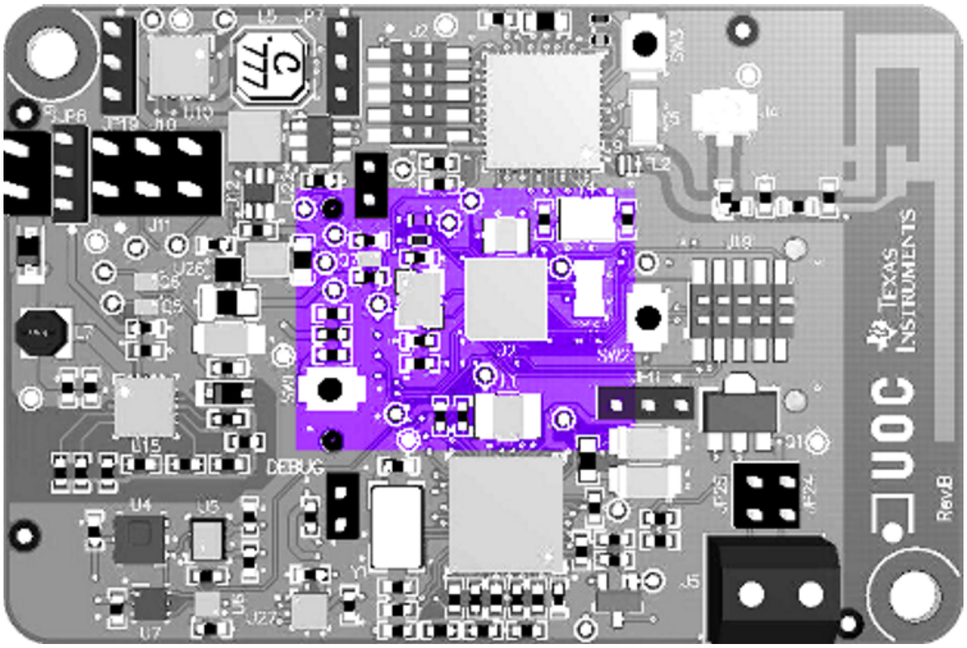

Figure 4. Data Fusion Subsystem on I3Mote

- SSI:
  SSI is a 2×10, 1.27-mm expansion header designed to connect to an SSM (for example, one based on PGA900). This interface can be used when developers want to develop their own sensor boards for their own application (such as vibration monitoring, motor prognostics, and so on) The SSI includes the following ports:
  - SPI port (+IRQ line)
  - I^2C
  - Two PWM pins
  - Two 14-bit single ADC lines or one differential pair
  - 4- to 20-mA bus lines
  - 3-V DC power supply
  - 5-V DC power supply with switch on and off control

See Figure 5 for the detailed SSI schematic.

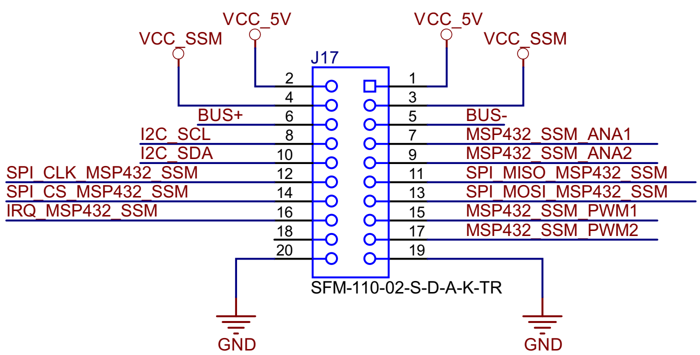

Figure 5. SSI on I3Mote

3.1.1.3 Wireless Communications

- CC2650 multi-standard wireless MCU

  Figure 6 shows the wireless communications part on the I3Mote. The CC2650 device is a multi-standard wireless MCU targeting industrial, consumer electronics, and medical applications using Bluetooth, Bluetooth low energy, ZigBee, 6LoWPAN, and so on.

  The CC2650 has a 32-bit ARM Cortex-M3 running at 48 MHz and featuring 20KB of ultra-low-leakage SRAM and 128KB of flash. The radio controller is built around a 32-bit ARM Cortex-M0 processor and is in charge of running the IEEE 802.15.4 and Bluetooth low energy time-sensitive code. In addition, the CC2650 includes various communication and cryptography peripherals (that is, 1×UART, 2×SPI, 1×I^{2}C, 8×12-bit ADC, AES-128, and TRNG).

  The CC2650 Cortex-M3 consumes 61 µA/MHz in active mode and 1 µA in standby mode (RTC and RAM retention included).

- Antennas

  The I3Mote includes a PCB Inverted F Antenna. The antenna is designed to be used with 2.4-GHz transmitters and receivers. The maximum gain is measured to be 3.3 dB and its overall size is 25.7 × 7.5 mm^2. Alternatively, the I3Mote contains a 50-Ω U-FL connector to use with any standard 2.4-GHz external antenna.

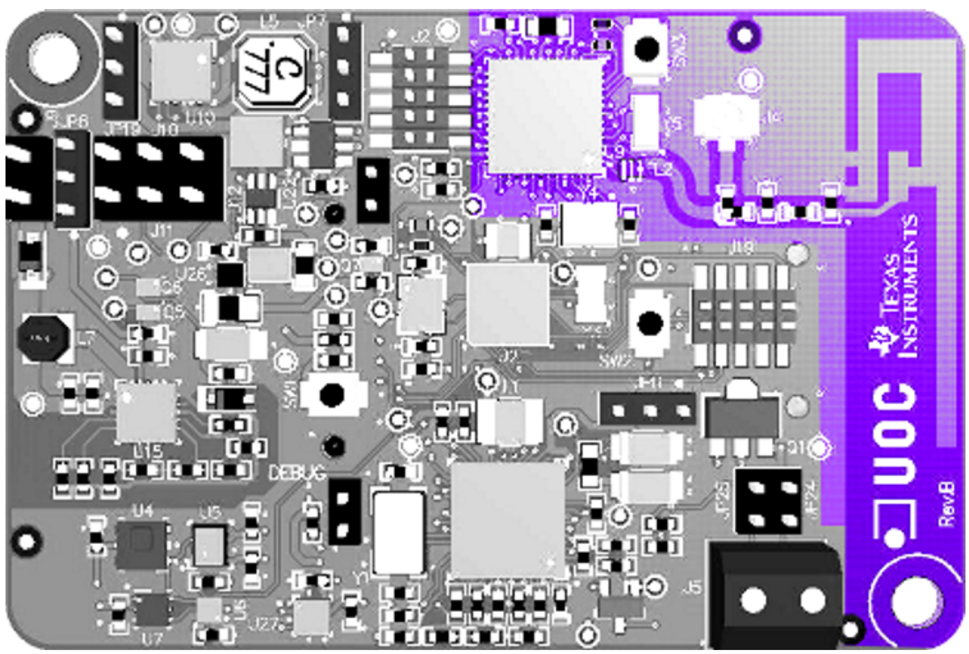

Figure 6. Wireless Communications Subsystem on I3Mote

3.1.1.4 Onboard General Purpose Sensors

The I3Mote features onboard general purpose sensors with a temperature sensor, a humidity sensor, ambient light sensors, a pressure sensor, and accelerometer. This reference design uses the following sensors: OPT3001 (ambient light sensor), HDC1080 (humidity and temperature), BMP280 (pressure), and LIS2HH12 (accelerometer).

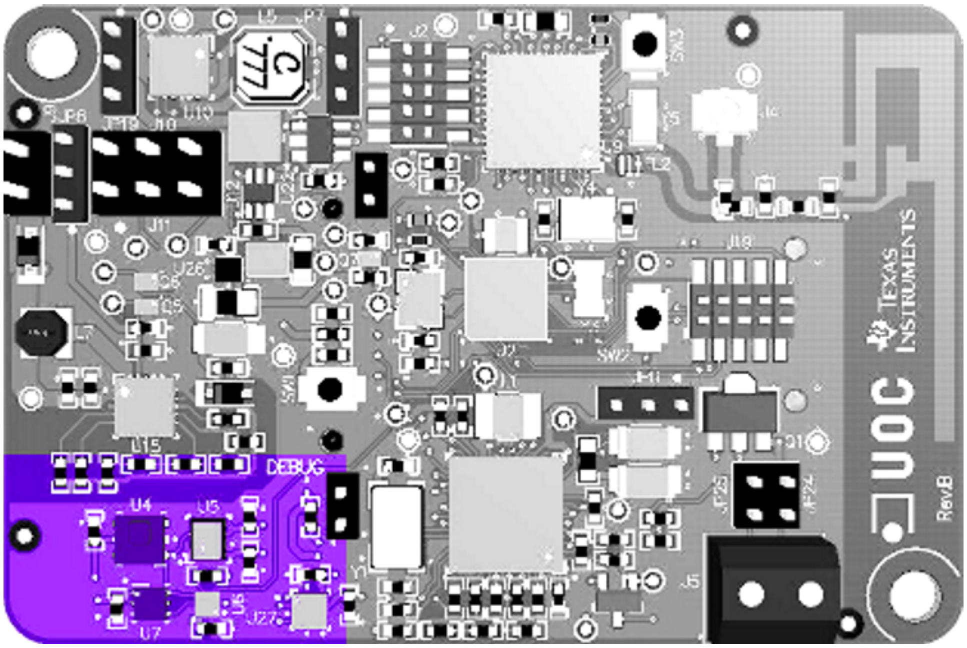

Figure 7. Onboard General Purpose Sensors Subsystem on I3Mote

3.1.1.5 Serial Debug (USB Virtual Ports)

The I3Mote may need a separate USB daughterboard for debugging or coding flashing purposes. Figure 8 shows the I3Mote daughterboard and the debug port that provide USB debug capabilities such as UART debug, code flashing, and so on. The daughterboard contains an FT2232 chip that provides two virtual serial ports to communicate with the MSP432 and CC2650 onboard. The first serial port (/dev/ttyUSB0) is connected to the MSP432 and the second serial port (/dev/ttyUSB1) is connected to the CC2650. In addition to communications with the MSP432 and the CC2650 respectively, the FT2232 chip can also be used to program both chips using their respective boot loading capabilities. Finally, the daughterboard can provide an additional power source through USB power supply while the I3Mote is in diagnostic operation. In this mode, the battery current will not be drained.

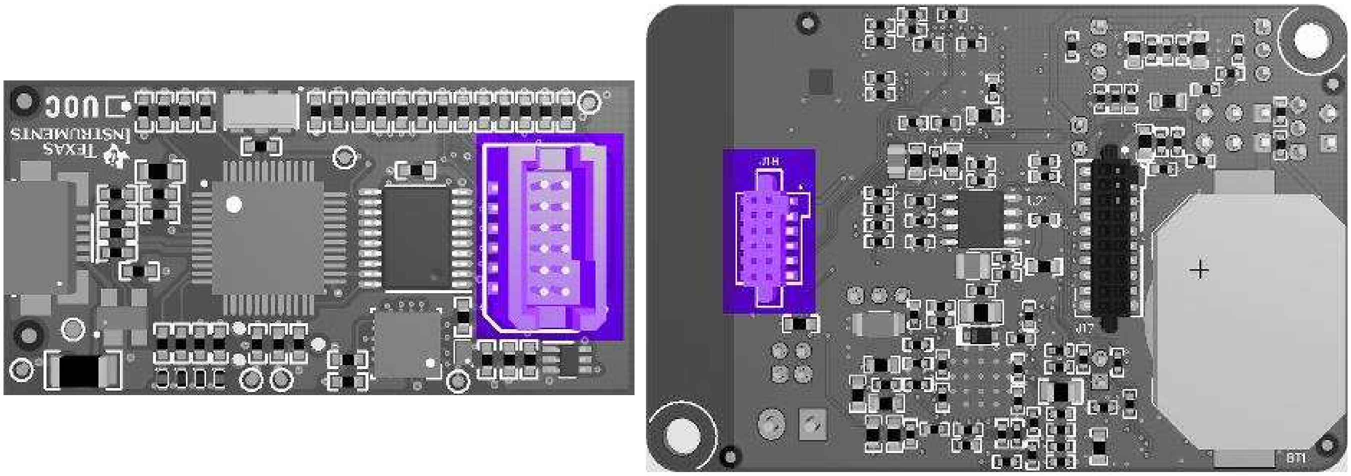

Figure 8. Serial Debug Port and Daughter Card That Can Be Attached to I3Mote

3.1.2 Software

The software stack available on the I3Mote supports the following.

3.1.2.1 CC2650 MCU

The following can be downloaded for the CC2650 MCU:

- TI-RTOS product (downloadable from TI-RTOS web page)
- TI BLE-Stack or ZigBee with 802.15.4 MAC
- Sensor data reading and command and accusation example. Examples are given in the TI BLE-Stack

3.1.2.2 MSP432P401R

The following can be downloaded from the MSP432 MCU:

- TI-RTOS product (downloadable from the TI-RTOS webpage)

3.1.3 I3Mote Setup

This section describes methods on how to power up the I3Mote and how to connect the various modules in the I3Mote.

3.1.3.1 *Power-up*

The following subsections describe jumper settings used to power up the I3Mote from different power sources.

3.1.3.1.1 *Jumper Settings*

The jumpers displayed in Figure 9 and Figure 10 in blue and red are required for the I3Mote to operate when using a battery, energy harvesting source, or USB. The red jumper enables the I3Mote main power, whereas the blue jumper enables the 5-V boost converter (only required when 5-V DC is used on the SSM).

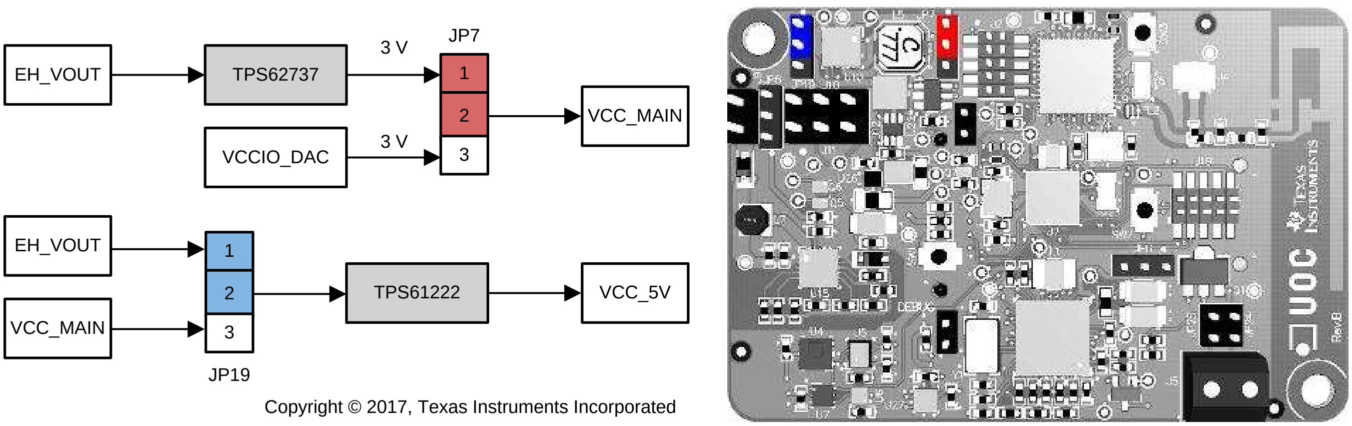

Figure 9. VCC Main Power Enable (Red) and 5-V Output Enable (Blue)

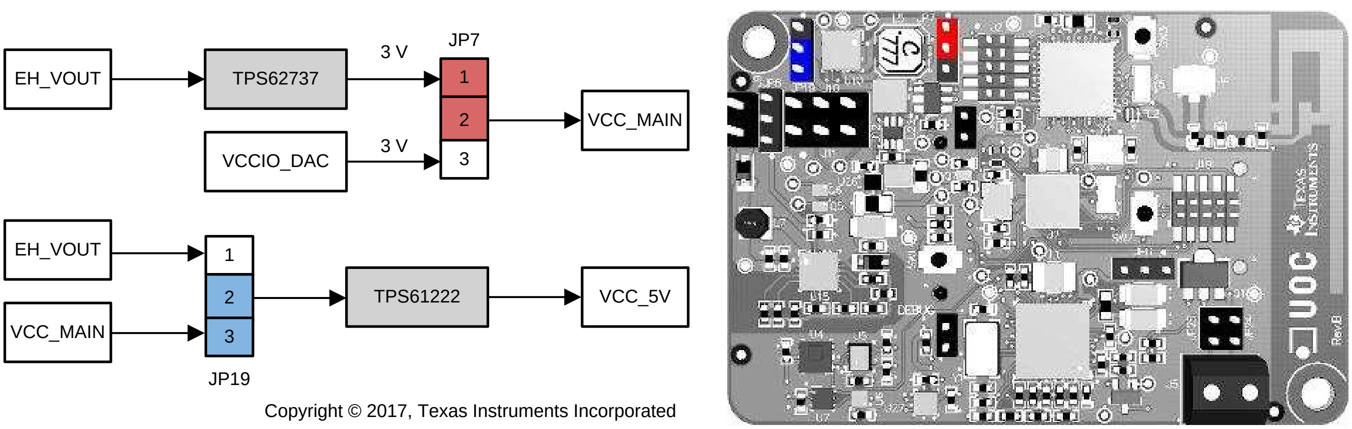

Figure 10. VCC Main Power Enable (Red) and 5-V Output Enable (Blue)

3.1.3.1.2 External Power Sources

The I3Mote can be powered from three different sources, as shown in Figure 11. First, it can be powered from an external primary battery (blue). Second, it can be powered from an external rechargeable battery (green). Finally, it can be powered from a micro USB connector through the USB daughterboard. For typical power configurations, see Section 3.1.4. When the USB power source needs to be used, connect the USB daughterboard to the board and connect the micro USB cable to the daughter card. The battery power will automatically be turned off and the power will be provided through the USB cable. For low-power applications, *never leave the USB daughterboard unpowered from the USB cable with the battery connected* as the battery will power the USB daughtercard and there will be current consumption henceforth.

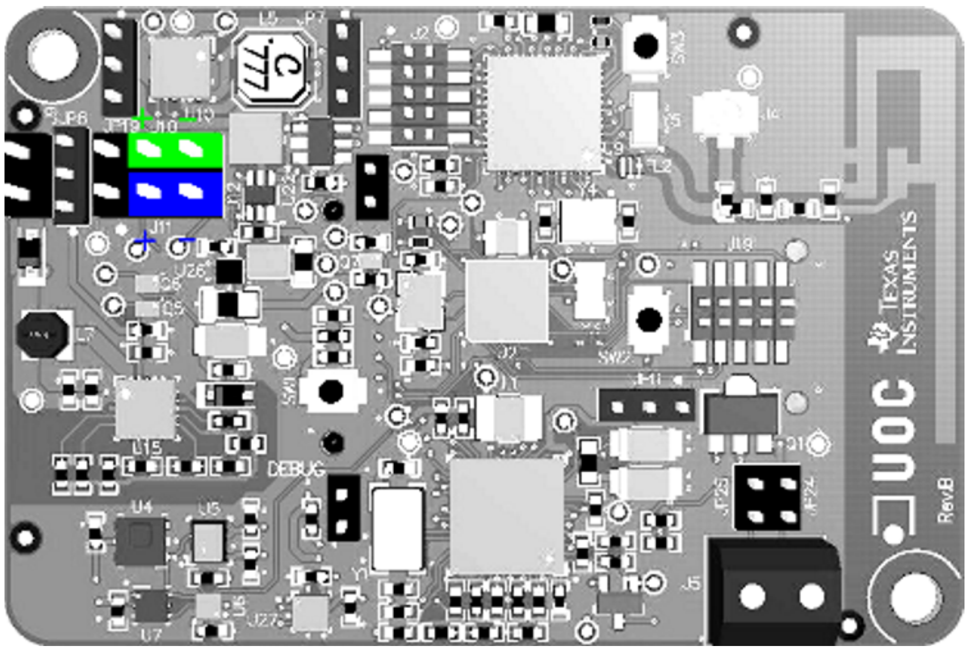

Figure 11. Primary Battery Input (Blue) and Secondary Rechargeable Battery Input (Green)

3.1.3.1.3 Battery Setup

The onboard battery holder—the CR2032 form factor—can be used either as the non-rechargeable battery (primary) or as the rechargeable battery (secondary).

- To use it as primary battery, short J11 pins 1-2 (blue), and leave J10 pin 1 floating. J10 pins 2-3 can still be used to connect an external secondary battery or supercapacitor.
- To use it as secondary battery, short J10 pins 1-2, and leave J11 Pin 1 floating. J11 pins 2-3 can still be used to connect an external primary battery.

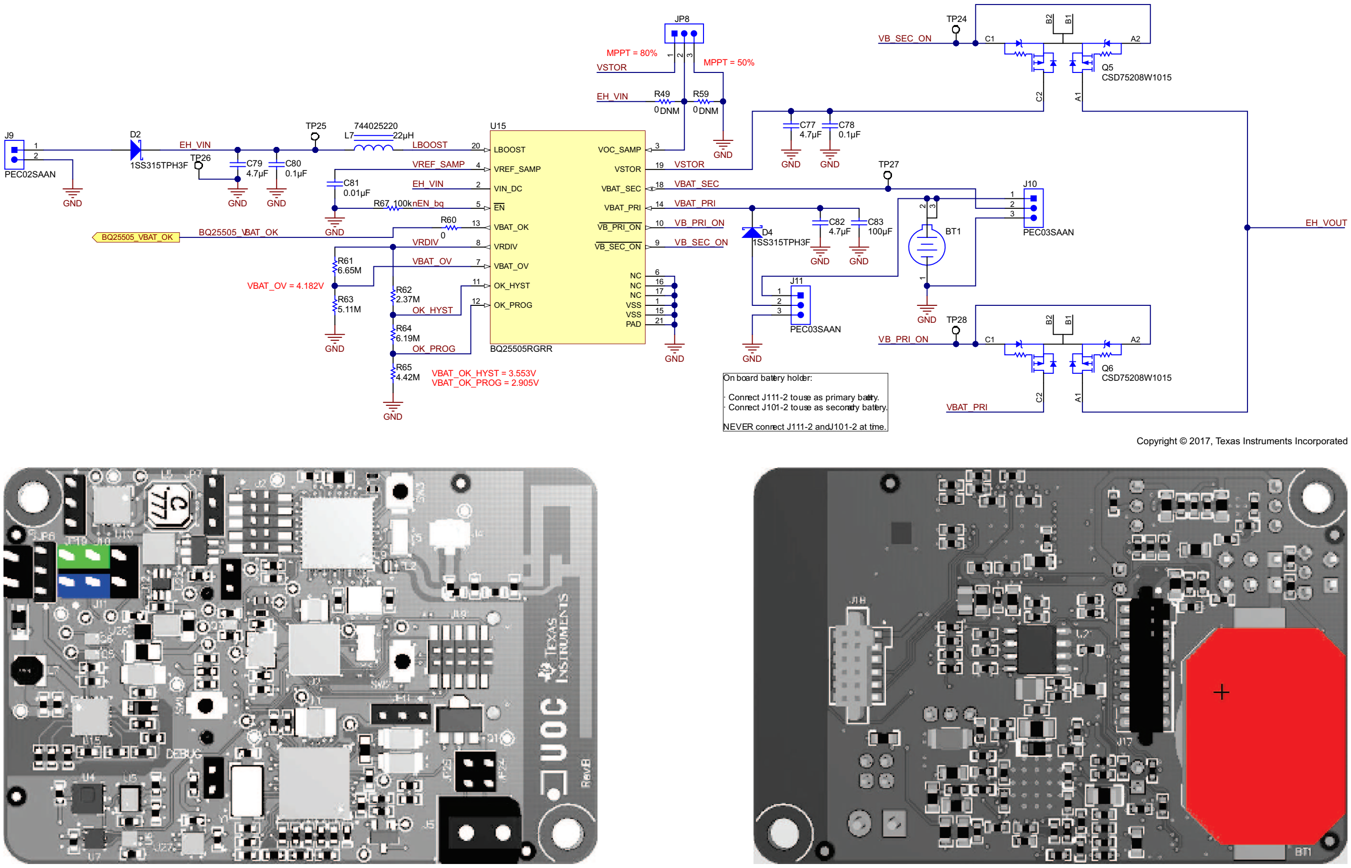

Figure 12. CR2032 Battery Holder (Red); Jumper Settings to use CR2032 as Primary Battery (Blue) or Secondary Battery (Green)

3.1.3.1.4 Software Control

The I3Mote provides software control to independently switch on and off different blocks of the circuit.

Table 2. Power Control Settings Through Software (1)

SIGNAL	MSP432	CC2650	FUNCTION
SSM_PWR_nEN	P2.5	DIO_25	Enables the SSI 3-V output
SSM_5V_EN	P7.7	DIO_28	Enables the SSI 5-V output
VBAT_OK	P2.6	DIO_27	Interrupt to let MSP432 or CC2650 know the usage of energy harvesting source or primary battery as a power source

(1) The control lines should be managed from one of the two MCUs

3.1.3.2 Programming and Debugging

The I3Mote contains two processors based on the ARM Cortex-M architecture: MSP432 and CC2650. Each processor can be programed and debugged using a daisy-chained JTAG interface. For that purpose, a 10-pin standard ARM JTAG connector is available as displayed in Figure 13.

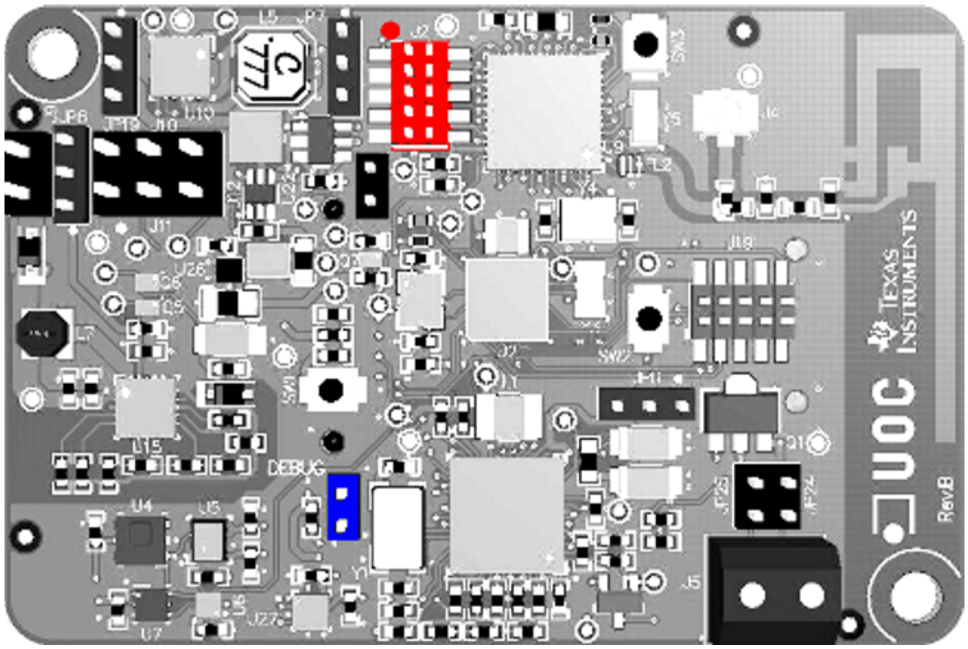

Figure 13. Daisy-Chained JTAG for MSP430™ and CC2650

CAUTION

Note that for JTAG debugging and programming, JP1 needs to be closed. For low-power modes in real deployment, JP1 needs to be open.

NOTE: In addition to the JTAG interface, both processors can be programmed and debugged directly from the USB through the I3Mote daughterboard.

3.1.3.3 Module Interconnection Settings

3.1.3.3.1 SPI for SSM

The I3Mote provides the SPI to SSMs. SPIs are widely used for several devices. Either of the following options is possible:

- Disconnect jumpers (J19 connector) to enable data path through MSP432 from SSM.
- Short jumpers (J19 connector) to enable direct path to CC2650 from SSM.

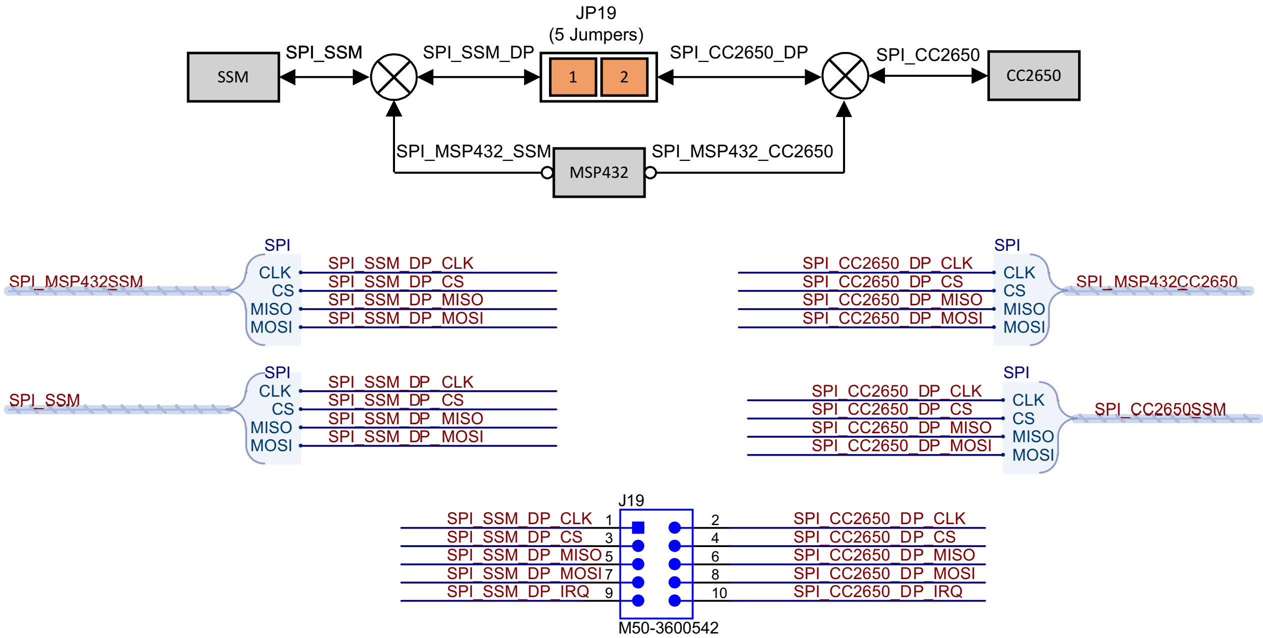

Figure 14. Settings to Connect SSM-SPI With CC2560 Directly or Through MSP432

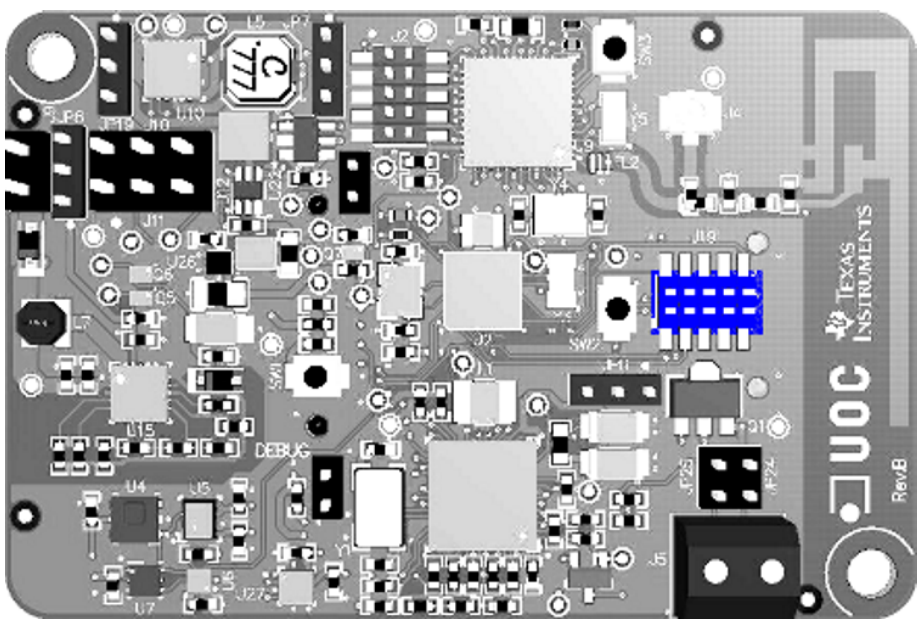

Figure 15. Jumper Settings for MSP432 Data Path J19: 1-2, 3-4, 5-6, 7-8, 9-10

3.1.4 Settings for Typical Power Source Configurations

This section describes several typical power configuration settings.

- Configuration 1: External 2×AA or 2×AAA batteries

  Use 2×AA or 2×AAA batteries to power up the board. Note that the USB daughterboard can be connected as well with the USB powering the device. In this case, the battery will be automatically turned off and the current from the batteries will not be drained. *Also for low-power operation with the battery, JP1 should be open.*

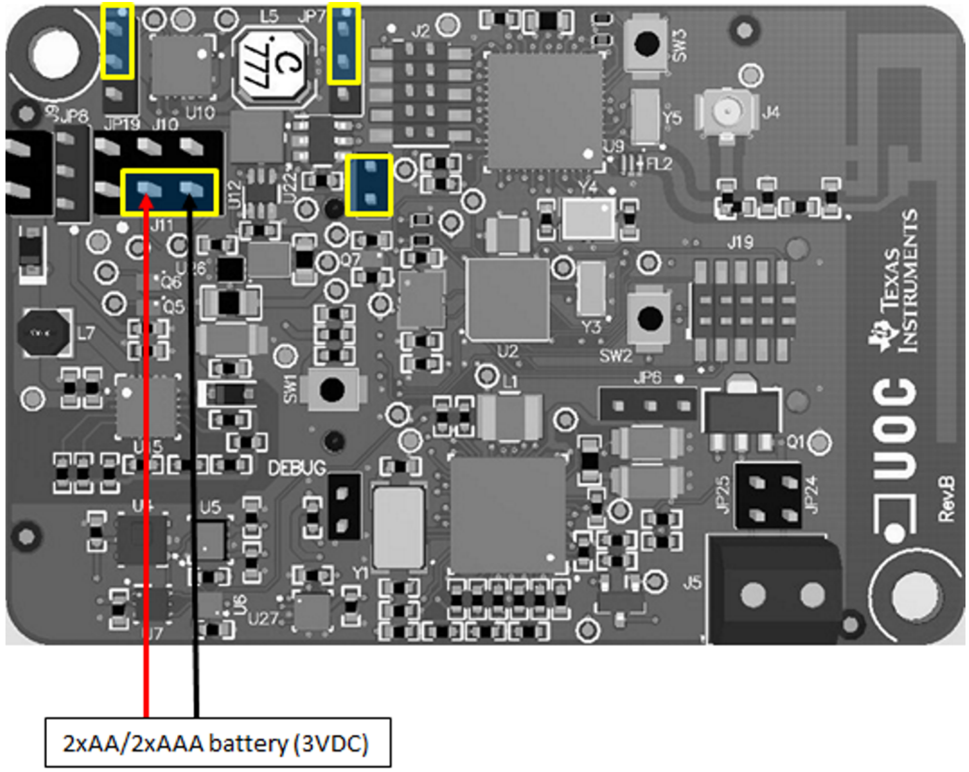

Figure 16. Jumper Configuration When Using 2×AA or 2×AAA Batteries as Power Source

- Configuration 2: CR2032

  Use the CR2032 coin-cell battery only with an onboard coin-cell battery holder. Note that the USB daughterboard can be connected as well with the USB powering the device. In this case, the battery will be automatically turned off. *Also for low-power operation with the battery, JP1 should be open.*

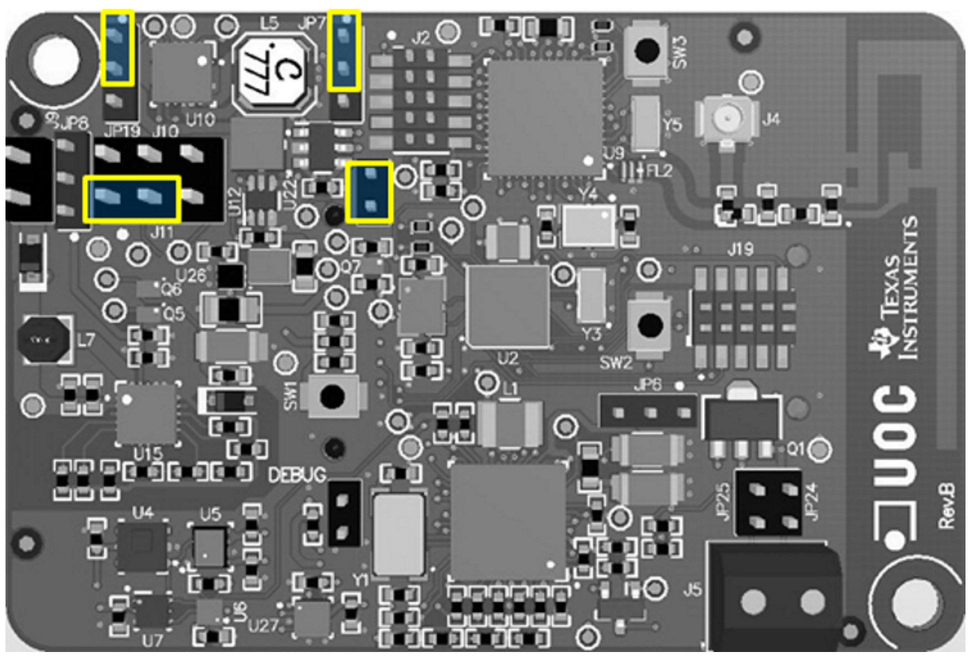

Figure 17. Jumper Configuration When Using Coin-Cell Battery as Power Source

- Configuration 3: External 2×AA or 2×AAA batteries and energy harvesting source

  Use 2×AA or 2×AAA batteries, an energy harvesting source (such as an indoor solar panel; for a solar panel, we can use the Fujikura FDSC-FSC8FG), and a supercapacitor or rechargeable battery to power up the board. Note that the USB daughterboard can be connected as well with the USB powering the device. In this case, the battery will be automatically turned off and the current from the batteries will not be drained. *Also for low-power operation with the battery, JP1 should be open.*

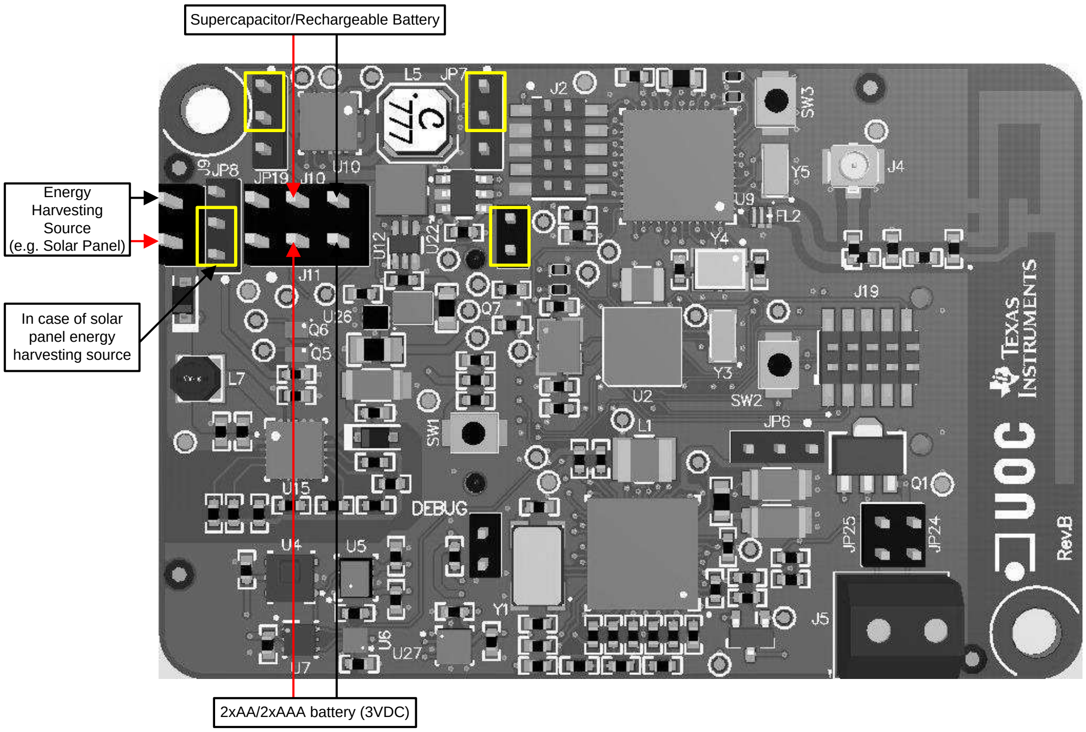

Figure 18. Jumper Configuration When Using 2×AA or 2×AAA Batteries and Energy Harvesting Source as Power Source

- Configuration 4: CR2032 and energy harvesting source

  Use the CR2032 coin-cell battery, an energy harvesting source (such as an indoor solar panel; for a solar panel, we can use the Fujikura FDSC-FSC8FG), and a supercapacitor or rechargeable battery to power up the board. Note that the USB daughterboard can be connected as well with the USB powering the device. In this case, the battery will be automatically turned off. *Also for low-power operation with the battery, JP1 should be open.*

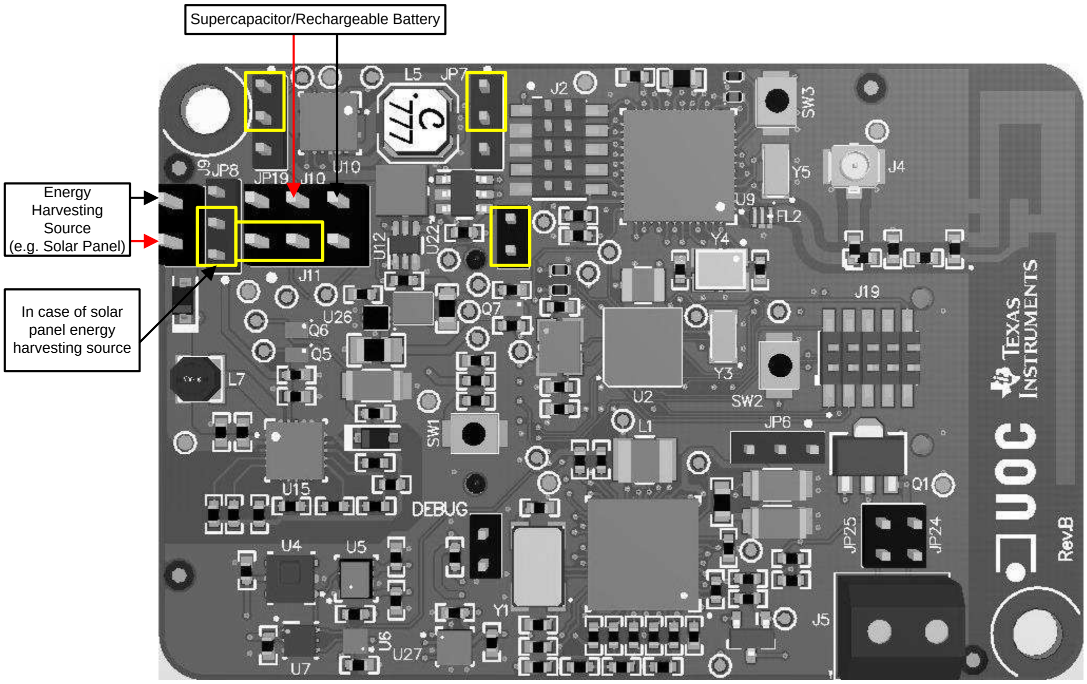

Figure 19. Jumper Configuration When Using Coin-Cell Battery (CR2032) and Energy Harvesting Source as Power Source

3.1.5 Advanced Power Settings

This section describes several options that developers can take for advanced power settings with an energy harvesting source. In the following subsections, the default values are selected, but developers can select their own values for their applications.

3.1.5.1 bq25505 Configuration

3.1.5.1.1 Overvoltage Protection

The bq25505 prevents rechargeable batteries or capacitive storage elements from being exposed to excessive charging voltages. The overvoltage (VBAT_OV) threshold level is set using external resistors. This is also the voltage value to which the charger will regulate the VSTOR/VBAT_SEC pin when the input has sufficient power. The VBAT_OV threshold when the battery voltage is rising is given using Equation 1:

$$VBAT\_OV = \frac{3}{2} VBIAS\left(1 + \frac{R_{OV2}}{R_{OV1}}\right) \quad (1)$$

The standard factory assembly is:

- $R_{OV2} = 6.65\ \text{M}\Omega$
- $R_{OV1} = 5.1\text{M}\Omega$

With these values, $VBAT\_OV = 4.182\ \text{V}$

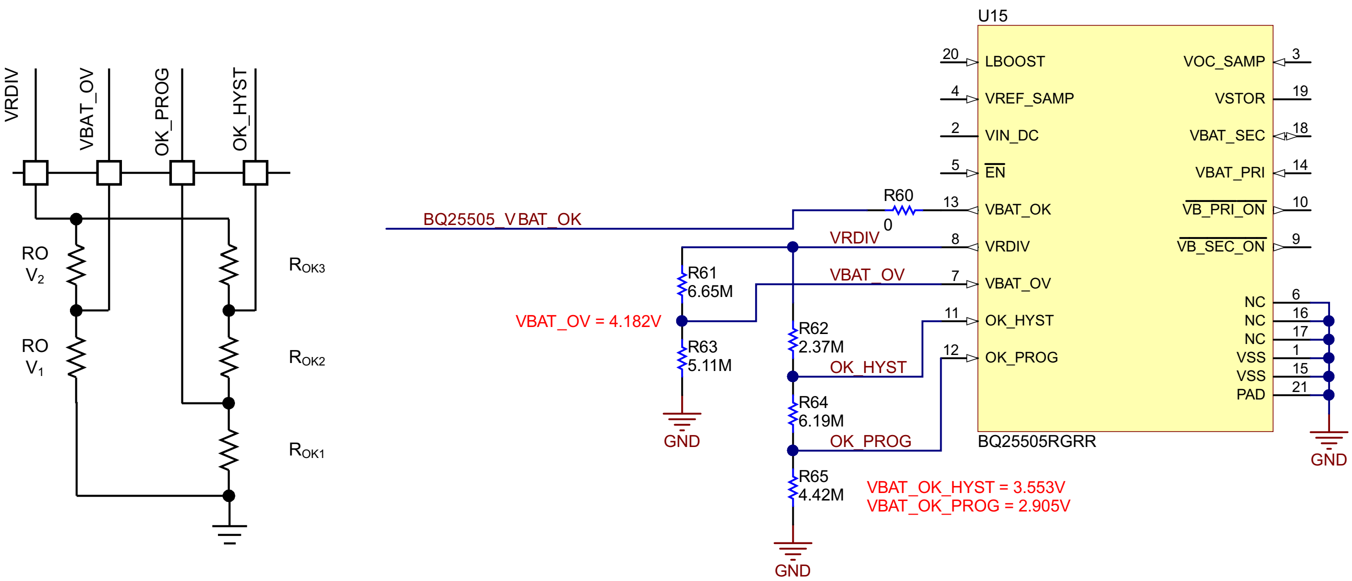

Figure 20. bq25505 Settings

3.1.5.1.2 Battery Voltage in Operating Range (VBAT_OK output)

The bq25505 allows the user to set a programmable voltage in between the VBAT_UV and VBAT_OV settings to indicate whether the VSTOR (battery or capacitor) voltage is at an acceptable level. When the battery voltage is decreasing, the threshold is set using Equation 2:

$$VBAT\_OK\_PROG = VBIAS\left(1 + \frac{R_{OK2}}{R_{OK1}}\right) \tag{2}$$

When the battery voltage is increasing, the threshold is set using Equation 3:

$$VBAT\_OK\ HYST = VBIAS\left(1 + \frac{R_{OK3} + R_{OK2}}{R_{OK1}}\right) \tag{3}$$

The standard factory assembly is:

- $R_{OK3} = 2.37\ M\Omega$
- $R_{OK2} = 6.19\ M\Omega$
- $R_{OK1} = 4.42\ M\Omega$

With these values, $VBAT\_OK\_PROG = 3.553\ V$ and $VBAT\_OK\_HYST = 2.905\ V$.

3.1.5.1.3 MPPT Settings

MPPT is implemented in order to maximize the power extracted from an energy harvester source. The boost converter indirectly modulates the input impedance of the main boost charger by regulating the charger's input voltage, as sensed by the VIN_DC pin, to the sampled reference voltage stored on the VREF_SAMP pin. The MPPT circuit obtains a new reference voltage every 16 s (typical) by periodically disabling the charger for 256 ms (typical) and sampling a fraction of the harvester's open-circuit voltage (VOC). For solar harvesters, the MPP is typically 70% to 80% of VOC and for thermoelectric harvesters, the MPP is typically 50%. The following jumper settings are for different energy harvesting sources:

- Solar or indoor light (JP8 1-2): Tying VOC_SAMP to VSTOR internally sets the MPPT to 80% of VOC.
- Thermal (JP8 2-3): Tying VOC_SAMP to GND internally sets the MPPT to 50% of VOC.
- If input source does not have either 80% or 50% of VOC as its MPP, the exact ratio for MPPT can be optimized to meet the needs of the input source being used by connecting external resistors ROC1 (R59) and ROC2 (R49):

$$VREF\_SAMP = VIN\_DC\ (OpenCircuit)\left(\frac{R_{OC1}}{R_{OC1} + R_{OC2}}\right) \tag{4}$$

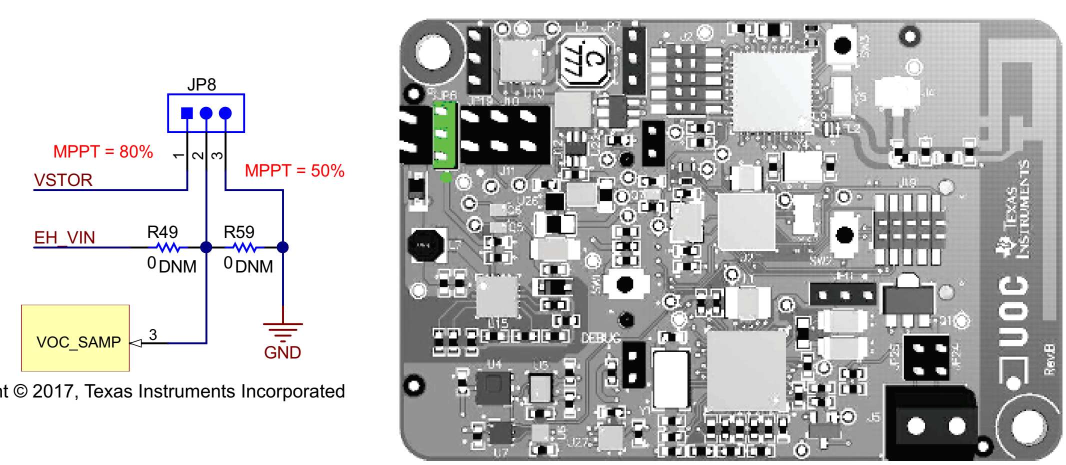

Figure 21. Default Solar MPPT: JP8 Connect 1-2; Default Thermal MPPT: JP8: Connect 2-3

3.1.5.2 Main Power Regulator Settings

The main power DC/DC (V_MAIN) can be adjust through resistors R88, R89, and R90.

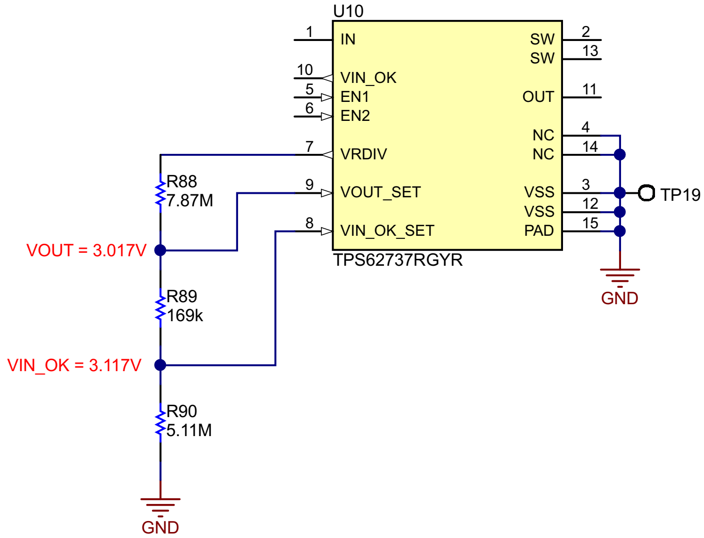

Figure 22. VCC Main Power Settings

4 Design Files

4.1 Schematics

To download the schematics, see the design files at TIDA-01452.

4.2 Bill of Materials

To download the bill of materials (BOM), see the design files at TIDA-01452.

4.3 Altium Project

To download the Altium project files, see the design files at TIDA-01452.

4.4 Gerber Files

To download the Gerber files, see the design files at TIDA-01452.

4.5 Assembly Drawings

To download the assembly drawings, see the design files at TIDA-01452.

5 Related Documentation

1. Texas Instruments, *CC2650 SimpleLink™ Multistandard Wireless MCU*, CC2650 Datasheet (SWRS158)
2. Texas Instruments, *MSP432P401R, MSP432P401M SimpleLink™ Mixed-Signal Microcontrollers*, MSP432P401R Datasheet (SLAS826)
3. Texas Instruments, *HDC1080 Low Power, High Accuracy Digital Humidity Sensor with Temperature Sensor*, HDC1080 Datasheet (SNAS672)
4. Texas Instruments, *OPT3001 Ambient Light Sensor (ALS)*, OPT3001 Datasheet (SBOS681)
5. Texas Instruments, *bq25505 Ultra Low-Power Boost Charger With Battery Management and Autonomous Power Multiplexer for Primary Battery in Energy Harvester Applications*, bq25505 Datasheet (SLUSBJ3)
6. Texas Instruments, *TPS6273x Programmable Output Voltage Ultra-Low Power Buck Converter With Up to 50 mA / 200 mA Output Current*, TPS62737 Datasheet (SLVSBO4)
7. Texas Instruments, *TPS6122x Low Input Voltage, 0.7V Boost Converter With 5.5μA Quiescent Current*, TPS61222 Datasheet (SLVS776)
8. Texas Instruments, *TPS61098x Ultra-Low Quiescent Current Synchronous Boost with Integrated LDO/Load Switch*, TPS610981 Datasheet (SLVS873)
9. Texas Instruments, *TS5A3160 1-Ω SPDT Analog Switch*, TS5A3160 Datasheet (SCDS216)
10. Texas Instruments, *CSD75208W1015 Dual 20-V Common Source P-Channel NexFET™ Power MOSFET*, CSD75208W1015 Datasheet (SLPS512)
11. Texas Instruments, *Energy Harvesting Ambient Light and Environment Sensor Node for Sub-1 GHz Networks Reference Design*, TIDA-00488 Design Guide (TIDUB22)

5.1 Trademarks

Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Original (May 2017) to A Revision	Page
• Updated board image	1
• Deleted "Optional 12- to 36-V DC Industrial Power Line" from the *Features* bulleted list	1
• Updated *Figure 2: I3Mote Hardware Component Description* with new board image	8
• Deleted "Connector to 24- to 36-V DC line" from *Figure 2: I3Mote Hardware Component Description*	8