TI Designs
Wi-Fi® System Powered by Two AA Batteries Extends Battery Life by Using Long Power Off Periods

TEXAS INSTRUMENTS

TI Designs

TI Designs provide the foundation that you need including methodology, testing, and design files to quickly evaluate and customize the system. TI Designs help *you* accelerate your time to market.

Design Resources

TIDA-00372	Tool Folder Containing Design Files
TPS61029	Product Folder
TPL5110	Product Folder
TCSD25310Q2	Product Folder

TI E2E™ Community

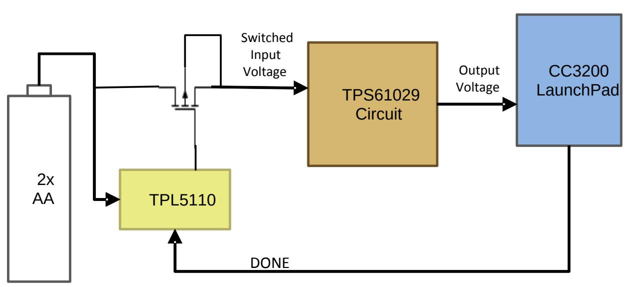
ASK Our E2E Experts
WEBENCH® Calculator Tools

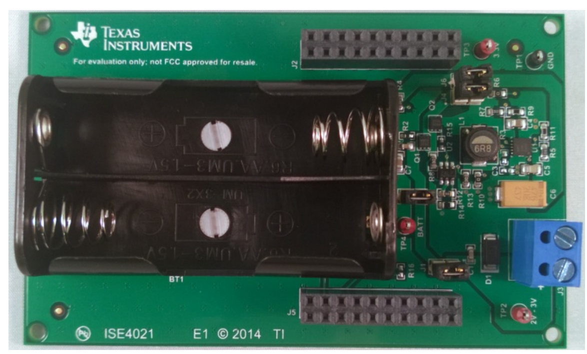
Design Features

- Powered By Two AA Batteries
- 60-nA Standby Current
- Adjustable Power Cycle Time
- Long Battery Life—Up to Six Years When Transmitting Every Two Hours
- Supplies Regulated 3.3 V for Analog Components

Featured Applications

- Building Automation
- Internet of Things (IoT)
- Smart Sensor
- Home Automation
- Preventive Maintenance Sensor





An IMPORTANT NOTICE at the end of this TI reference design addresses authorized use, intellectual property matters and other important disclaimers and information.

1 Key System Specifications

Table 1. Specifications

PARAMETER	SPECIFICATION	DETAILS
Operating conditions	0°C to 85°C	See Section 8.5
Battery voltage	2.5 V to 3.2 V	See Section 7.4
Power cycle time	Adjustable	See Section 4.2
Battery life	Greater than two years	See Section 8

2 System Description

The TIDA-00372 reference design is a power supply design intended for use in systems using the CC3200 or CC3100 IoT solutions, though it can easily be adapted for use with similar systems. While the CC3100 and CC3200 work very well when powered directly from two AA batteries, other components in a system may not work at the low voltages the batteries provide. In some situations, component performance improves with a regulated supply voltage. Because of this improvement, the TIDA-00372 PCB design includes a boost converter to provide a regulated 3.3-V output. The design also utilizes a timer that is powered directly from the battery to switch the system power off and on with a period that is adjustable up to two hours. The timer helps to save power during long power OFF periods.

2.1 Applications

The TIDA-00372 reference design has many possible applications when used with the CC3200 SimpleLink™ Wi-Fi® and IoT Single-Chip Wireless MCU. The hardware is optimized for use as an unattended sensor that must provide data at long, fixed intervals up to two hours. A system utilizing this circuit can power on just long enough to collect data from any attached sensors or equipment, connect to a network, write data to a cloud location, then disconnect and power down. Even longer periods between transmissions can be accomplished in the software. Examples of applications where this functionality is useful are:

1. Outdoor temperature monitor for a heat pump that provides feedback instructing when to change modes
2. Temperature monitor in several locations inside a refrigeration unit
3. Gas sensors
4. A weather station
5. A sunlight monitor
6. A pH sensor for an aquarium or other liquids

3 Block Diagram

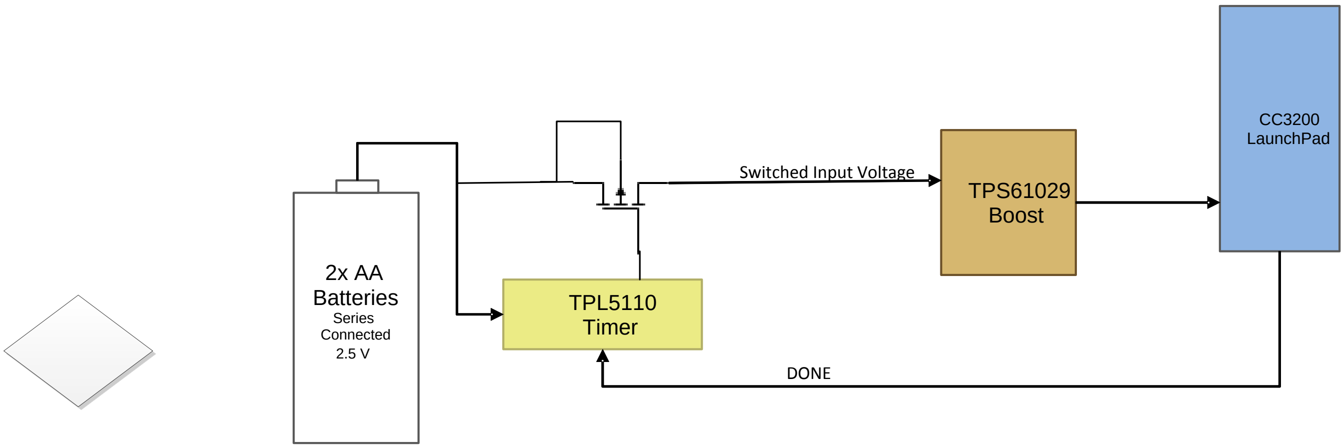


Figure 1. TIDA-00372 Block Diagram

3.1 Highlighted Products

The TIDA-00372 reference design features the following devices:

- TPL5110 (Section 3.1.1): *Nano-Power System Timer for Power Gating*
- TPS61029 (Section 3.1.2): *96% Efficient Synchronous Boost Converter*
- CSD25310Q2 (Section 3.1.3): *20 V P-Channel NexFET™*

3.1.1 TPL5110 Description

The TPL5110 Nano Timer is a low-power timer with an integrated MOSFET driver ideal for power gating in duty-cycled or battery-powered applications.

Consuming only 35 nA, the TPL5110 device can enable the power supply line and drastically reduce the overall system stand by current during the sleep time. Such power savings enable the use of significantly smaller batteries and make the device well-suited for energy harvesting or wireless sensor applications.

The TPL5110 device provides selectable timing intervals from 100 ms to 7200 s and is designed for power gating applications. In addition, the TPL5110 has a unique One-shot feature where the timer only powers the MOSFET for one cycle. The TPL5110 is available in a 6-pin SOT23 package.

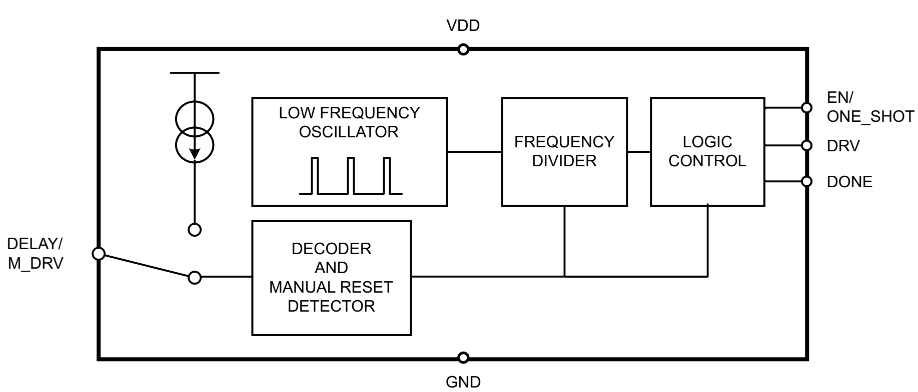


Figure 2. TPL5110 Functional Block Diagram

3.1.2 TPS61029 Description

The TPS6102x family of devices provide a power supply solution for products powered by either a one-cell, two-cell, or three-cell alkaline, NiCd or NiMH, or one-cell Li-Ion or Li-polymer battery. Output currents can go as high as 200 mA while using a single-cell alkaline battery, and discharge it down to 0.9 V. The device can also be used for generating 5 V at 500 mA from a 3.3-V rail or a Li-Ion battery. The boost converter is based on a fixed-frequency, pulse width modulation (PWM) controller using a synchronous rectifier to obtain maximum efficiency. At low load currents the converter enters the power save mode to maintain a high efficiency over a wide-load current range. The Power Save mode can be disabled, forcing the converter to operate at a fixed switching frequency. The maximum peak current in the boost switch is limited to a value of 1800 mA for the TPS61029 device.

The TPS6102x devices keep the output voltage regulated even when the input voltage exceeds the nominal output voltage. The output voltage can be programmed by an external resistor divider, or is fixed internally on the chip. The converter can be disabled to minimize battery drain. During shutdown, the load is completely disconnected from the battery. A low-EMI mode is implemented to reduce ringing and, in effect, lower-radiated electromagnetic energy when the converter enters the discontinuous conduction mode. The device is packaged in a 10-pin VSON PowerPAD™ package measuring 3 mm × 3 mm (DRC).

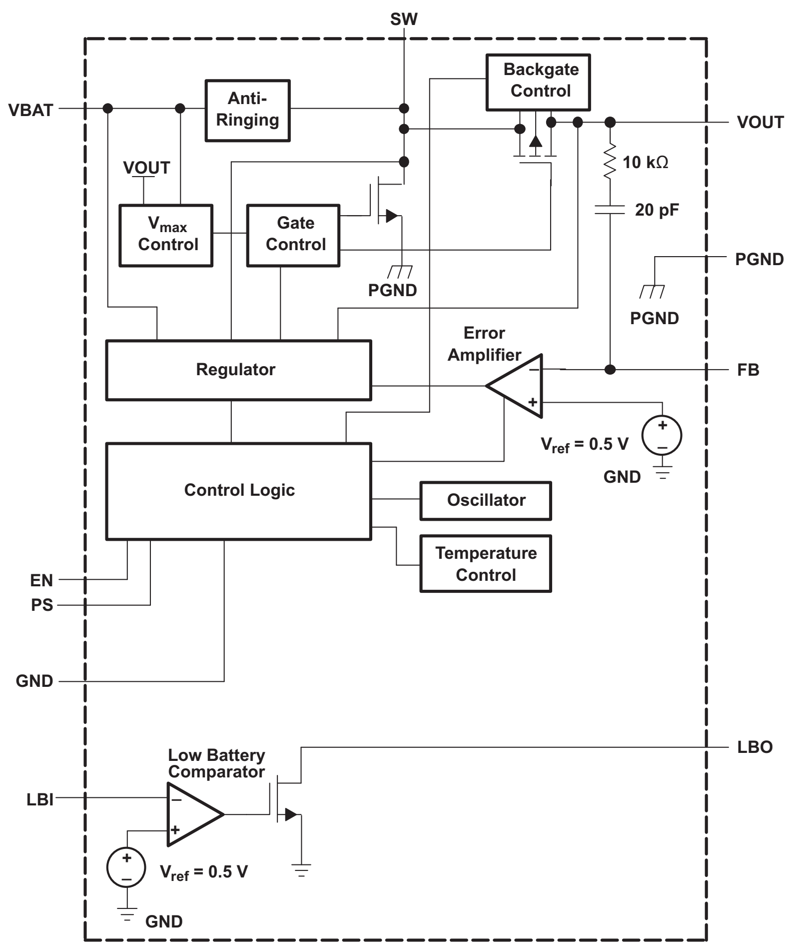


Figure 3. TPS61029 Functional Block Diagram

3.1.3 CSD25310Q2 Description

This 19.9-mΩ, –20-V P-channel 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. The devices low on resistance coupled with an extremely small footprint in a SON 2 mm × 2 mm plastic package make the device ideal for battery-operated, space-constrained operations.

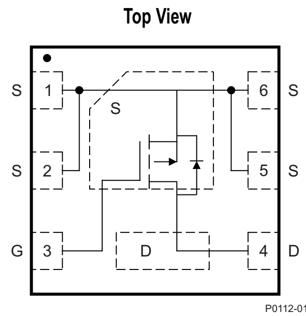


Figure 4. CSD25310Q2 Connections

4 System Design Theory

4.1 Circuit Overview

The circuitry for the TIDA-00372 reference design PCB consists of a TPL5110 timer and a TPS61029 boost converter. A holder for two AA size batteries is provided. There is also a connector, J3, which can be used to connect a power supply instead of the batteries. Two CSD25310Q2 transistors are used. Transistor Q1 serves as a rectifier with a low voltage drop. No current can flow to Q2 or the boost converter if the batteries are inserted backward or if a power supply connected to J3 is connected backwards. Q2 is a power switch that is controlled by the TPL5110. Various jumpers are used to provide bypass functions, re-route signals, or provide a means to measure current. Figure 13 shows the schematic.

The TIDA-00372 PCB is in a BoosterPack form factor that plugs into the CC3200 LaunchPad PCB to form a complete system.

4.2 TPL5110 Nano-Power Timer Operation

A TPL5110 timer is included to provide a power ON and power OFF function, which is necessary because a switching power supply is powering the CC3200 in this system. While the CC3200 can remain on in a very-low current state, the switching power supply itself consumes power while it regulates the output voltage. To improve battery life, the switching power supply must be powered off.

The TPL5110 timer can be set to create a pulse period between 100 ms and 7200 seconds. The timer is set by selecting resistors of appropriate values for R12 and R14. For testing purposes, the period is set for approximately one minute. Resistors R12 and R14 were chosen from Table 3 of the TPL5110 Datasheet [1].

The Schottky diodes D2 and C8 provide the power for the TPL5110. The anode of D2 is connected directly to the battery and J3 power. D2 has a forward voltage of less than 0.2 V at the current level required for this circuit. The reason a separate rectifier is used for the TPL5110 is that the minimum supply voltage for the TPL5110 is 1.8 V. When the boost converter requires a high current, such as right after Q2 is switched on, the battery voltage can drop below 1.8 V if the battery is already significantly discharged. Isolating the TPL5110 VCC connection with D2 ensures that C8 does not discharge into the main power path. The supply current for the TPL5110 is 50 nA in normal operation. C8 was chosen to be 1 µF so that the voltage drops only 0.1 V if C8 has to power the TPL5110 for one second. Using C8 to prevent a voltage drop ensures that the TPL5110 does not reset if the battery voltage drops for a short time. Without the D2 orC8 circuit, the startup current transient of the boost converter could reduce the battery voltage enough to force the TPL5110 to reset and the system would not start.

The TPL5110 EN/ONE_SHOT pin is pulled high through R8 to configure the TPL5110 as a timer. The TPL5110 DRV output controls the gate of Q2, which switches the power to the boost converter. If Q2 is on, the system is on. If Q2 is off, the only current draw in the system is the TPL5110. Figure 5 from the timing diagrams of the TPL5110 datasheet shows how the DRV signal is controlled.

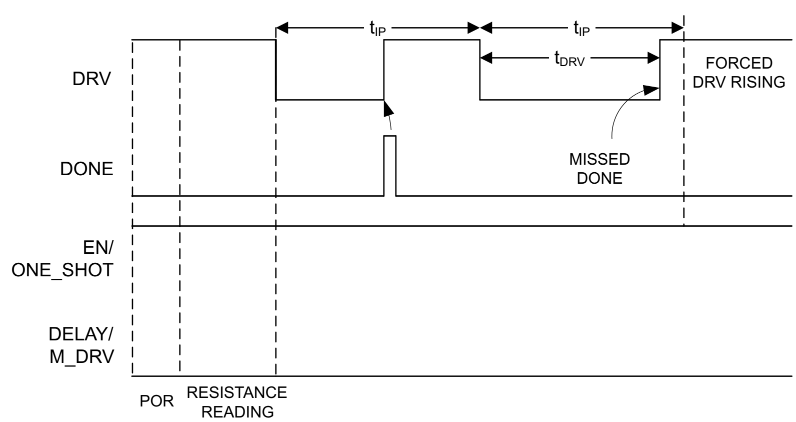


Figure 5. TPL5110 Timing Diagram

The amount of time that the DRV is held low is determined by the DONE pin. R13 pulls the DONE pin down when the boost is on but the CC3200 device has yet to be configured. The R13 is set to 2.67 kΩ to meet the pull-down requirements of the CC3200. The DONE pin is controlled by the GPIO 12 pin of the CC3200 device. The application running in the CC3200 application processor must be programmed to set GPIO 12 low during normal operation and high when the application has finished. When the DONE pin transitions high, the TPL5110 sets the DRV pin to high, which turns Q2 off. The CC3200 system is then off.

4.3 TPS61029 Boost Converter

The TPS61029 boost controller was chosen for this application because of its small size, wide input voltage range of 0.9 V to 6.5 V, and 1800-mA switch current limit. The high switch current and minimum Vin are desirable to accommodate the high currents required during system startup and transmission.

The TPS61029 output voltage is set with resistors R5 and R11. R5 is chosen to be 1 MΩ in accordance with the TPS61029 datasheet design procedure. Using the formula from the datasheet, R11 comes out to 178 kΩ. The input capacitor is set to 47 µF. This value helps to maintain the TPS61029 input voltage during load transients when the battery is becoming depleted. The output capacitors and inductor are set with the recommended values from the data sheet. The inductor is 6.8 µH. The TDK SLF6028T-6R8M1R5-PF inductor was chosen for its 1.5-A capacity. A 2.2-µF ceramic capacitor and a 47-µF tantalum capacitor are connected in parallel for the output capacitors. This capacity supports a total load current of 0.65 A, which is sufficient for most designs that include a CC3200 in addition to various analog peripheral components.

The PS pin (pin 8 on the TPS61029 device), allows a power-save mode when the pin is pulled low. This feature reduces the amount of current necessary to supply the TPS61029 when output loads are very light. This function is enabled in the TIDA-00372 PCB by pulling pin 8 low through R10.

The low battery comparator is set up on the TPS61029, though the low battery output is not used in the system software. Resistors R7 and R9 set the pin 7 low-battery threshold of 1.78 V. R4 provides a pull up for the low battery output, pin 4.

Pin 1 is the enable pin and it is pulled up to the switched input voltage through R6.

4.4 Other Circuit Features

J1, J6, and J7 are provided to allow easy current measurements of the power supply input voltage, battery voltage, and the +3.3-V supply. J4 bypasses the power switch to allow continuous operation of the CC3200 LaunchPad. J2 and J5 are 20-pin header connectors that connect to the CC3200 LaunchPad.

5 Software Description

In order for the TIDA-00372 reference design to work, the CC3200 software must be written in order to interface the CC3200 LaunchPad to the subsystem of the reference design. For test purposes, the HIB application from the CC3200 SDK was modified. Note that this test data is from using SDK version 1.0.0 for the CC3200 silicon revision R1. This application is designed to showcase the hibernate state as a power saving tool in a networking context, or in this case, a User Datagram Protocol (UDP) client. The example was designed so that the device wakes up periodically from hibernate, broadcasts a message, and then enters hibernate again. For this design, a DONE signal was added to trigger the TPL5110 to turn the power off so that DONE signal occurs just before entering hibernate. The hibernate code was left in place so that the CC3200 enters hibernate if the TPL5110 does not turn off the power first.

Creating the DONE signal required several changes to main.c in the original HIB application. Because the DONE signal is connected on GPIO 12, the global variable PWR_CONTROL is defined and set to “12” in the global variable section. The PWR_CONTROL is used as a parameter for the GPIO_SET_IF function to configure the GPIO port. This port is set up in the added function PwrControlConfigure. The PwrControlConfigure function is called after the PinMuxConfig function:

5.1 PwrControlConfigure Function

```
void
PwrControlConfigure()
{
    //
    // Get the port and pin number for the pwr control pin
    //
    GPIO_IF_GetPortNPin(PWR_CONTROL,
                       &pwrControlPort,
                       &pwrControlPin);
    //
    // Set the pwr_control pin low
    //
    GPIO_IF_SET(PWR_CONTROL, pwrControlPort, pwrControlPin, 0);
}
```

5.2 Code Snippet Showing the DONE Signal Creation

The call to set the DONE signal is in the EnterHIBernate function, which is directly before the function call to enter hibernate.

```
    GPIO_IF_Set(PWR_CONTROL, pwrControlPort, pwrControlPin, 1);
    MAP_UtilsDelay(80000);
    GPIO_IF_Set(PWR_CONTROL, pwrControlPort, pwrControlPin, 0);

    //
    // Enter HIBernate mode
    //
    MAP_PRCMHibernateEnter();
```

5.3 Added GPIO in the PINMUX File

The GPIO pin 12 must be defined in the pin mux file pin_mux_config.c before compiling the application.

```
    // Configure PIN_03 for GPIO Output -- GPIO 12

    //
    PinTypeGPIO(PIN_03, PIN_MODE_0, false);
    GPIODirModeSet(GPIOA1_BASE, 0x10, GPIO_DIR_MODE_OUT);
```

In order to use the application with a user’s specific access point, the common.h file in the library must be modified with the Access Point (AP) name and appropriate credentials.

6 Getting Started

The following sections assume that the user has installed the C3200 SDK, Code Composer Studio™ (CCS), and UniFlash software to program the FLASH device on the LaunchPad and the TI Pin Mux Utility for ARM® Processors. TI recommends that the user be familiar with CC3200 Project 0 from the CC3200 wiki site, as this ensures that Code Composer Studio is properly set up for the CC3200, and that the CCS UniFlash utility is installed.

6.1 System Setup

Before assembling the TIDA-00372 PCB with the CC3200 LaunchPad, the user must follow the programming instructions in the CC3200 SimpleLink™ Wi-Fi® and IoT Solution With MCU LaunchPad™ Getting Started Guide (the user's guide for Project 0 on the CC3200 wiki). Afterwards, use the UniFlash tool to program the CC3200 LaunchPad with the modified HIB example .bin file that has been compiled to connect to the user's chosen access point. Restart the LaunchPad and use a terminal program to monitor the program output to ensure that the CC3200 device is connecting to the access point. This application operates the same way the HIB application does without the LaunchPad connected to the TIDA-00372 BoosterPack.

The TIDA-00372 BoosterPack PCB plugs into the CC3200 LaunchPad PCB. Figure 6 shows the correct orientation.

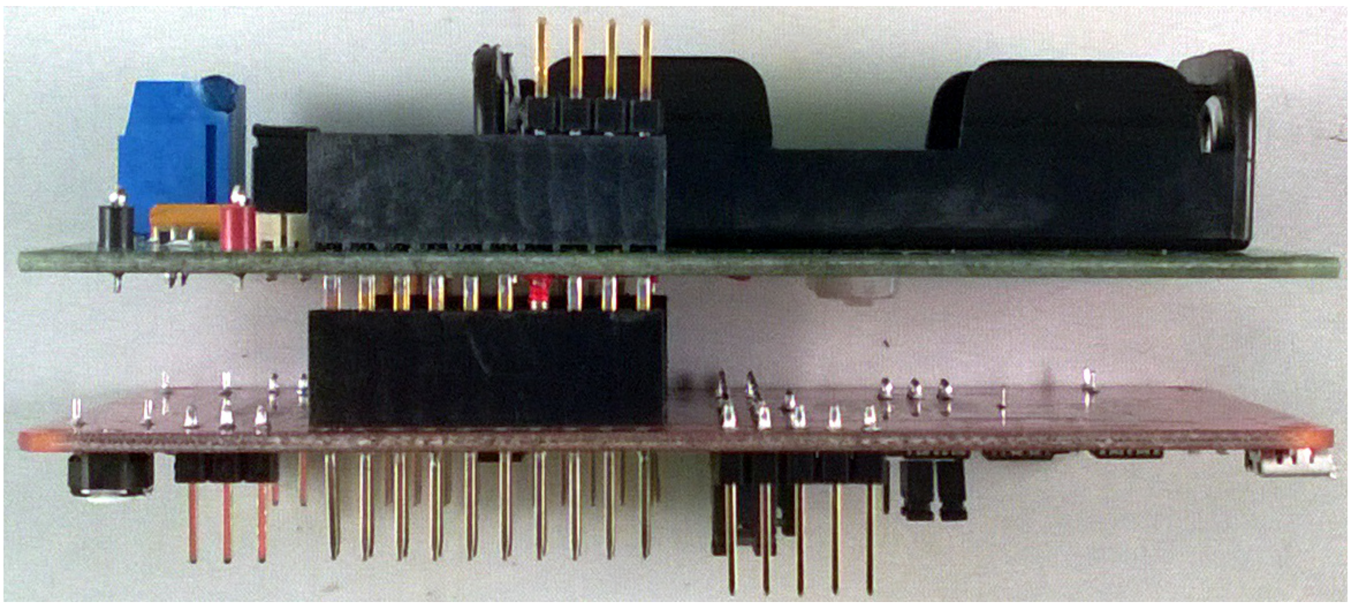


Figure 6. Side View of Assembled Boards

With the BoosterPack PCB connected to the LaunchPad, remove jumpers from J1, J4, and J7 from the BoosterPack PCB and remove jumpers from J13 and J15 of the LaunchPad. Make sure there is no jumper from P1-1 to P3-1 on the LaunchPad. Connect a USB cable from the LaunchPad to a host computer. Install two AA batteries into the LaunchPad. Reinstall J7 on the BoosterPack PCB. The system is now operational. The user can monitor the processor console using a terminal application on his or her computer.

To further reduce the power consumption, connections to several LEDs on the LaunchPad were removed in order to ensure that the LEDs do not add to the measured power consumption. In the tests in Section 7, only the red LED D7 was connected. R3, R125, and R126 were removed. R27, R32, and R43 were also removed to ensure that no power is dissipated in U6 and U10. The jumpers from J2 and J3 were removed, too.

7 Test Data

7.1 Hardware Setup

The TIDA-00372 BoosterPack and CC3200 LaunchPad system cycles between the powered ON state and the OFF state with a one-minute period. To predict the battery life, the battery current must be measured in both states. For the ON state, the current is very dynamic and is best measured with an oscilloscope equipped with a current probe. For the OFF state, the current is so low that the oscilloscope current probe cannot measure it, so a Digital Multi Meter (DMM) can be used for the measurement. To measure the ON-state battery current, a loop of wire was connected to the pins of J7 on the BoosterPack. The oscilloscope current probe was clamped onto the loop. For the OFF-state current, the DMM current probe leads were connected across J7. The DMM was set for the 100-µA range (the lowest available on the available DMM). To eliminate the voltage drop across the DMM, J7 was installed so that the BoosterPack could complete the ON state. Without J7 installed the voltage becomes too low for the ON state to complete. All measurements were made at room temperature, approximately 23°C.

Alkaline batteries were used during the current measurement tests. The batteries were not new, but had not been used for long. The series voltage for the batteries used during most tests measured 2.95 V before powering the system ON. Some tests were conducted with batteries that had been depleted further to verify system operation at lower voltages.

7.2 ON-OFF Current Measurements

7.2.1 OFF-State Current Measurement

For the OFF state, the measured battery output current was 0.06 µA with the 2.95-V battery pair. The user must ensure that the jumper is removed from J1 before making this battery output current measurement; if not, the leakage current of D1 affects the measurement. This measured current is very close to the normal ON-state current for the TPL5110 device, which is 35 to 50 nA. Additional current leakage could be due to leakage in C2 and C8.

7.2.2 ON-State Current Measurements

The system stays on between 4.0 and 5.0 seconds in the ON state. The reason for this is that the IP address is assigned to the system by the access point (AP) through Dynamic Host Configuration Protocol (DHCP). For most connection trials, the ON time lasted about 4.2 seconds, but on occasion, it lasted 4.8 seconds. Figure 7 and Figure 8 show different measurements of time and battery current corresponding to different amounts of time required to get an IP address.

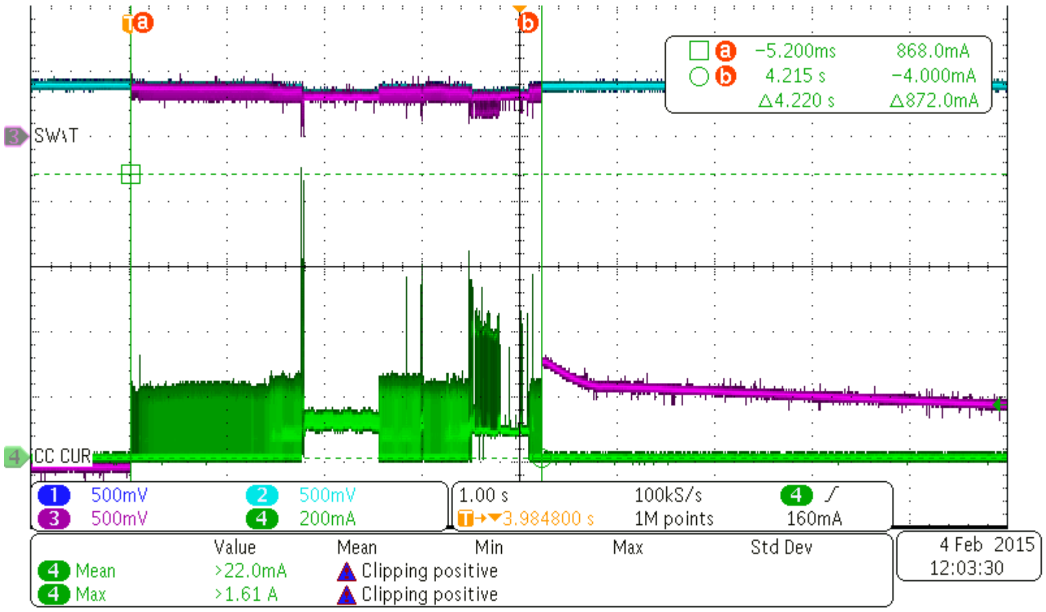


Figure 7. Short ON Period

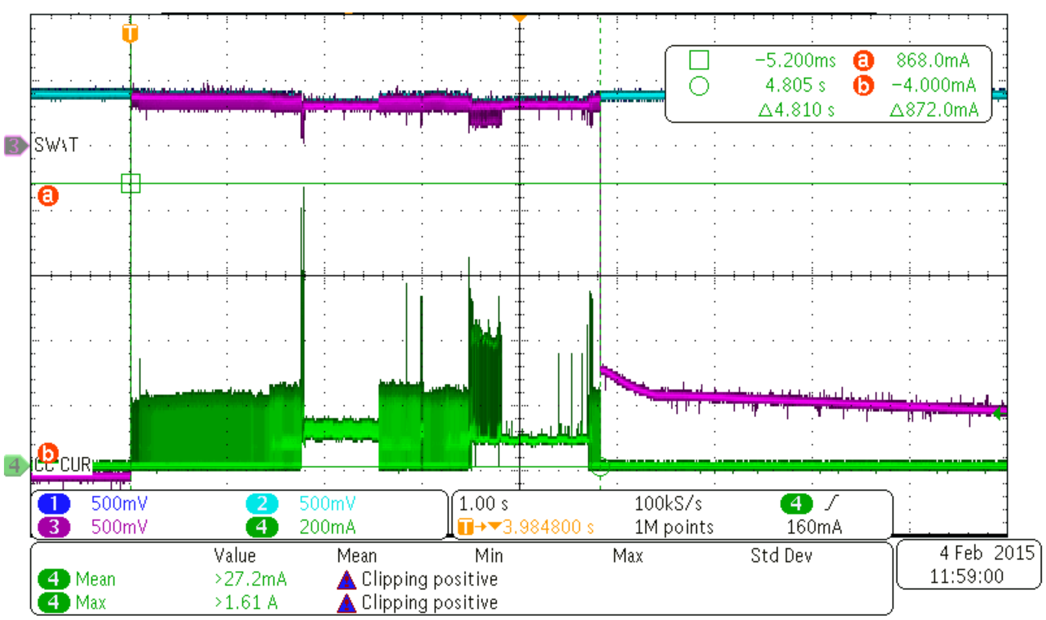


Figure 8. Long ON Period

In the previous Figure 7 and Figure 8, there are four signals shown in the oscilloscope trace. Channel 1 (dark blue) is the output of the 3.3-V boost regulator, channel 2 (light blue) is the battery voltage, channel 3 (purple) is the drain connection on Q2, and channel 4 (green) is the battery current measured through J7.

7.3 On-Hibernate Current Measurements

7.3.1 Hibernate State Current Measurement

As mentioned earlier, the application software cycles through hibernate power mode if the power is not switched off by the TPL5110. To test this mode, a jumper was installed on J4 of the TIDA-00372 PCB. The hibernate state current was measured with the DMM connected across J7. Again, the average function of the DMM was used to calculate a long term average of the current.

The length of the hibernate state is set by a timer in the CC3200 application. During the hibernate mode state, the average battery current was 237 µA.

The hibernate current measurement contains the sum of all of the leakage currents for the CC3200 LaunchPad circuits, the hibernate current for the CC3200, and the current required by the TPS61029 boost power supply to maintain the regulated 3.3-V output.

7.3.2 ON-State Current Measurements

Figure 9 and Figure 10 show the ON-state current captures. Note that there are still two time intervals, but they are shorter than for ON-OFF operation shown in Section 7.2 by about two seconds.

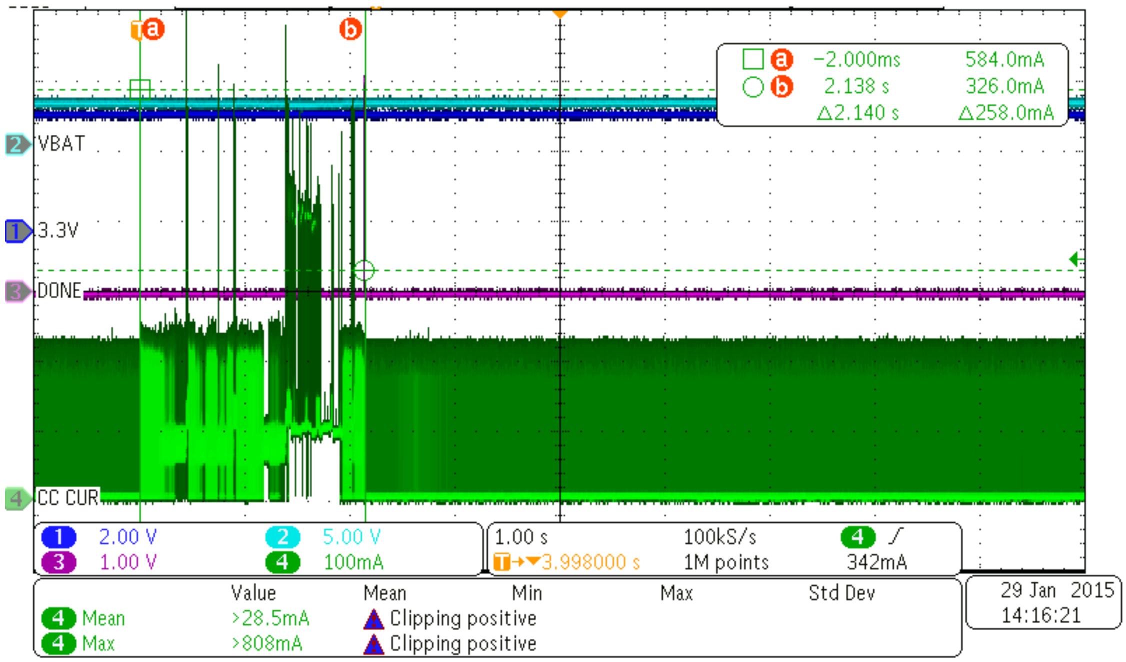


Figure 9. Short Duration Hibernate

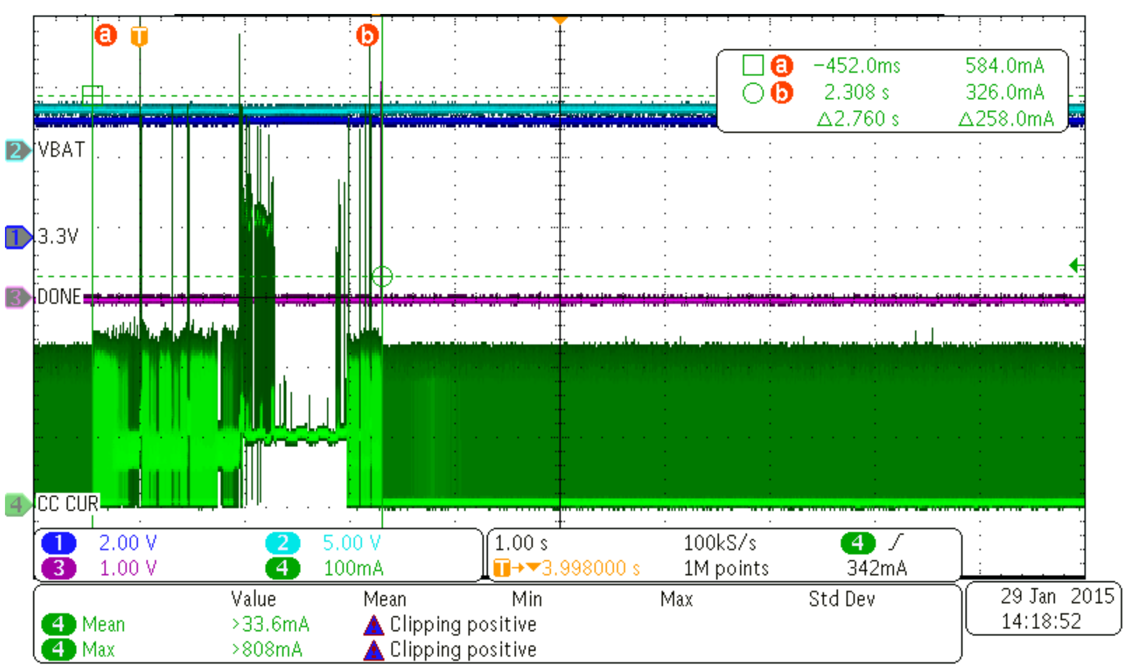


Figure 10. Long Duration Hibernate

For both Figure 9 and Figure 10, channel 1 (dark blue) is the output of the 3.3-V boost regulator, channel 2 (light blue) is the battery voltage, and channel 4 (green) is the battery current measured through J7. Channel 3 is disconnected.

7.3.3 Hibernate Mode Current Measurements for the CC3200

To compare how the entire system performs in terms of the CC3200 alone, the hibernate mode current was measured solely for the CC3200 and its FLASH memory. Figure 11 shows the oscilloscope capture. For this test, the current was measured through J12 of the LaunchPad. A CC3200MOD LaunchPad was used for this test. Notice that the hibernate time is slightly different than the time measurements in Section 7.3.2. This difference in hibernate time is due to differences in the hardware performance and is to be expected. For this test, the hibernate current was measured as 5 µA with a DMM.

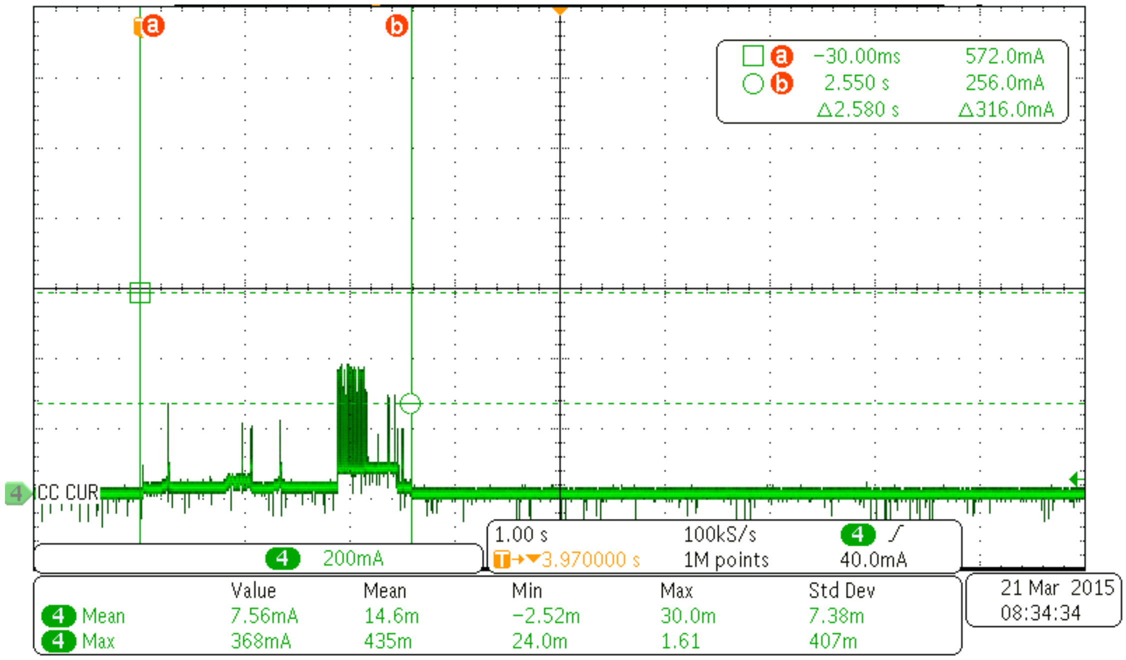


Figure 11. Current for CC3200, its FLASH, and NO Other System Components

7.4 Input Voltage Range

The lowest battery voltage that can power the TIDA-00372 PCB is 2.5 V. Below 2.5 V, the internal resistance of the battery increases such that the high current transients drop the voltage low enough that the boost regulator can no longer regulate the output voltage and the system can never connect to the AP. This battery voltage was tested with a pair of depleted batteries that measured 2.502 V when connected in series.

7.5 TPS61029 Efficiency

To measure the efficiency of the TPS61029 circuit, the input currents, output currents, and voltages were measured using an oscilloscope just as the current was measured for the tests in Section 7.3. Input current was measured through J7 and the input voltage was the battery voltage measured at TP4. The output current was measured through J6 and the output voltage was measured at TP3. The voltage and current data taken was averaged for the duration that the power was on, from which the efficiency was calculated. Table 2 shows the averaged data and the calculated power supply efficiency.

Table 2. Power Supply Efficiency

PARAMETER	VOLTAGE (V)	CURRENT (A)	POWER (W)
Input	2.941	0.0481	0.1413
Output	3.327	0.0386	0.1284
Efficiency	–	–	90.9%

8 Battery Life Estimate Calculation

8.1 ON-OFF Battery Life Estimate

In order to estimate the battery life, the average ON current, the OFF current, the ON time and the OFF time are needed. The OFF current is known from Section 7.2.1 The ON-OFF cycle time can be chosen based on system requirements. For the battery life estimates, a period of one hour is being chosen.

To determine the ON-state current and time, the oscilloscope data for the previous Figure 7, Figure 8, Figure 9, and Figure 10 were saved at the same time the traces were captured for post-test analysis. To calculate the average
ON current, only the data points from power up to power down were considered. The average current was then calculated from this data. The ON time is calculated by subtracting the sample time stamp at power ON from the sample time stamp for power OFF. For the data in Figure 7, the average current during ON time is 55.67 mA with an ON time of 4.214 seconds. For the data in Figure 8, the average current during ON time is 58.69 mA with an ON time of 4.815 seconds.

The battery life of an alkaline AA battery varies from manufacturer to manufacturer. For the purposes of this analysis, the Energizer E91 AA battery will be used since it has an available data sheet. The datasheet shows that the capacity of one battery is about 2150 milliampere-hours (mAh) when discharged with a 100 mA load. The average current for the two cases above is less than 60 mA, so using 2150 mAh as the capacity for each battery should be a conservative estimate of the battery life.

The system cannot use all of the battery capacity. This is because of the internal resistance of the batteries. Once the battery has been depleted to about 2.5 V unloaded, the battery voltage will drop significantly during the high current peaks required for data transmission. If the voltage drop in the battery and across the power switch reduces the voltage at the TPS61029 regulator input below 0.9 V, the regulator ceases to regulate and the regulator output voltage drops. If the output voltage drops below 2.41 V, the CC3200 resets. Once this occurs, the CC3200 enters a state where it can never finish connecting to the access point. Because of this response, it is assumed that only 85% of the estimated battery capacity can be used, which leads to a useful battery capacity of 2150 mAh × 0.85 = 1827.5 mAh.

To determine the battery life, the power consumption of the system must first be represented in milliamps used in one hour. To determine the power consumption of the system, use the following Equation 1 to find the average current in one hour:

$$I_A = \left[(I_W \times t_W) + (I_S(t_C - t_W)) \right] / t_C$$

where

- I_A = average current over one hour (mA)
- I_w =ON-state average current (mA)
- I_s = OFF-state average current (mA)
- t_w = length of time the system is ON (ms)
- t_c = length of time for one ON-OFF cycle (ms) = 3,600,000/n
- n = number of ON-OFF cycles per hour (1)

NOTE: 3,600,000 is the number of milliseconds in one hour.

For the shorter period in Figure 7, I_A = 0.06524 mA. For the longer period in Figure 8, I_A = 0.07855 mA. Note that for the number of wakeups, n = 1 for both cases.

Use Equation 2 to estimate the number of hours the battery will last.

$$\text{Battery Life} = \text{Battery Capacity} \ / \ I_A \tag{2}$$

The battery capacity is divided by I_A from Equation 1.

For the shorter period in Figure 7, battery life = 28,014.3 hours, about 1,167.3 days or 3.2 years. For the longer period in Figure 8, battery life = 23,264.8 hours, which is about 969.4 days or 2.7 years. Observations of the system indicate that the shorter period happens more frequently than the longer period, so a conservative estimate would be the average of the two = 2.91 years. Table 3 shows that if the number of power ON-OFF cycles per hour changes, the battery life estimate changes.

Table 3. Battery Life Versus Number of ON-OFF Cycles Per Hour With ON-OFF Power Cycling

NUMBER OF CYCLES PER HOUR	LENGTH OF ON-OFF CYCLE (MINUTES)	BATTERY LIFE ESTIMATE (YEARS)
0.5	120	5.81
0.6	100	4.84
0.75	80	3.87
1	60	2.91
2	30	1.45
3	20	0.97
4	15	0.73
5	12	0.58
6	10	0.48
7	8.57	0.42
8	7.5	0.36

For a real system based on this design, the results will vary. Connection times vary between access points. Having multiple stations trying to connect to the access point also affects the ON time. Longer OFF periods may affect the time it takes for the system to connect to the access point as well. Observing the system tested above in the lab, the shorter duration ON cycle was more frequent than the longer duration cycle, but this could change if the OFF time was lengthened. Recall that the ON-OFF cycle time is about one minute. Adding additional power loads also reduces battery life. This design is intended to have additional analog circuitry attached, so a larger power load is expected.

8.2 ON-Hibernate Battery Life Estimate

For the ON-Hibernate case, the battery life estimate equations are the same as Equation 1 and Equation 2 in Section 8.1.

For the shorter period in Figure 9, I_A = 0.2819 mA, so battery life = 6,482.6 hours = 0.74 years. For the longer period in Figure 10, I_A = 0.2966 mA, so battery life = 6,161.2 hours = about 0.7 years. The average of the two = 0.72 years. Changing the number of cycles per hour results in the battery life estimates in Table 4.

Table 4. Battery Life Versus Number of ON-Hibernate Cycles Per Hour

NUMBER OF CYCLES PER HOUR	LENGTH OF ON-HIB CYCLE (MINUTES)	BATTERY LIFE ESTIMATE (YEARS)
0.5	120	0.79
0.6	100	0.78
0.75	80	0.76
1	60	0.72
2	30	0.61
3	20	0.53
4	15	0.47
5	12	0.42
6	10	0.38
7	8.57	0.35
8	7.5	0.32

Note that, even with a two-hour cycle time, the battery life estimate is only about 0.79 years. This battery life estimate can largely be attributed to the current required by the power supply during hibernate mode.

8.3 ON-Hibernate Battery Life Estimate Solely for CC3200

This section uses Equation 1 and Equation 2 from Section 8.1 to estimate battery life. Figure 11 shows the oscilloscope data. In this case, I_A = 0.031 mA, so the battery life = 58,924 hours = 6.73 years. Changing the number of cycles per hour results in the battery life estimates shown in Table 5.

Table 5. Battery Life Versus Number of ON-Hibernate Cycles Per Hour

NUMBER OF CYCLES PER HOUR	LENGTH OF ON-HIB CYCLE (MINUTES)	BATTERY LIFE ESTIMATE (YEARS)
0.5	120	11.59
0.6	100	10.12
0.75	80	8.51
1	60	6.73
2	30	3.66
3	20	2.51
4	15	1.91
5	12	1.54
6	10	1.30
7	8.57	1.12
8	7.5	0.98

If the system hibernates for two hours between radio transmissions, the calculated battery life is 11.59 hours. The shelf life of an AA battery is only ten years, so it is possible for the system life to be limited by battery aging. This test case represents an ideal system.

8.4 Battery Life Comparison

Figure 12 shows the plotted data from Table 3, Table 4, and Table 5. The dotted gray line is the ideal current for the CC3200 and its FLASH memory. The red line is the data for a system that needs a boost converter that keeps the power on continuously. This system uses a great deal of energy between Wi-Fi transmissions. The black line is the data for a system that requires a boost converter and has the power switched off to save energy between the Wi-Fi transmissions.

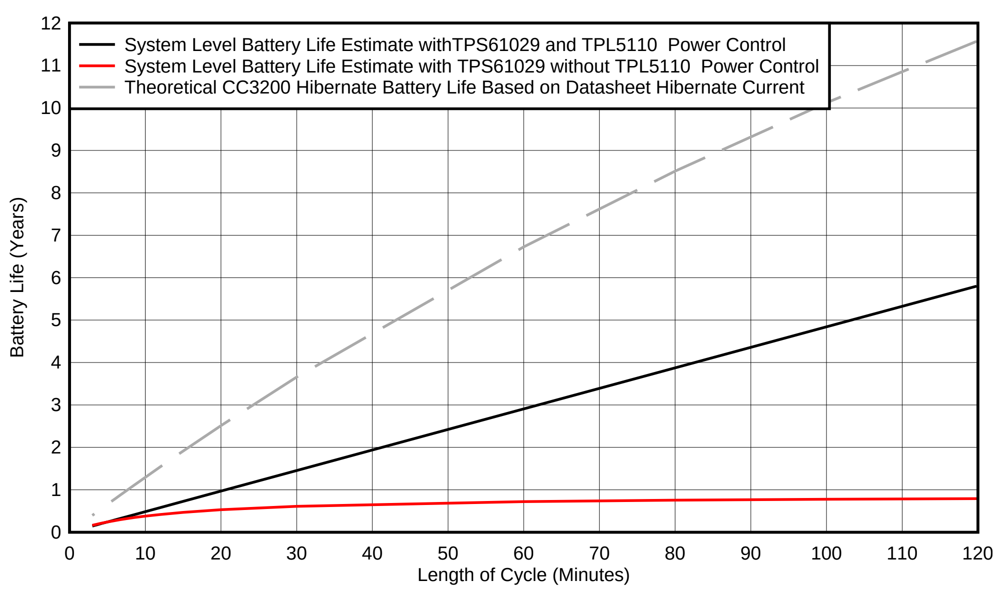


Figure 12. Comparison of Battery Life Estimates for TPL5110 Controlled ON-OFF and Application Controlled Hibernate

8.5 System Changes That Could Affect Battery Life

The tests in Section 7 and the battery life estimates above are for a small system. Adding sensors or other secondary circuitry to the basic system presented here increases the current consumption while the system is ON, so battery life is reduced correspondingly. Excessive leakage currents in components connected to the battery, such as surge devices and capacitors, reduce battery life by wasting power when the system is supposed to be off. If using hibernate mode instead of using the TPL5110 power cycling circuit, any additional circuitry also affects the current consumed during hibernate mode. Minimize this leakage by only enabling additional circuits for the amount of time they are required using load switches or other means and paying close attention to the leakage current ratings of components that are always connected to the battery.

Different access points (APs or routers) interact differently with the SimpleLink device, so the amount of time required to make a connection varies depending upon the hardware a user has.

Batteries from different manufacturers may have different internal impedances for a given state of charge. Also, standard alkaline batteries lose capacity quickly as their temperature drops, limiting their useful battery life in cold conditions. Operation of this system below 0°C requires the use of dry electrolyte batteries such as lithium AA cells.

There are factors that can increase battery life that were not explored in this reference design. Using DHCP to acquire an IP address from the AP adds significantly to the system ON time. If using a static IP address is an option, the ON time can be reduced by hundreds of milliseconds. Reducing transmit power can improve battery life significantly. Lithium AA cells also improve battery life due to their improved discharge specifications and lower internal resistance.

For the TPL5110 controlled timing, periods of greater than 120 minutes are only possible by making a change in the software to write a value to the system FLASH such that the system wakes up every 120 minutes, but only sends data when a certain wake-up count value is reached. For instance, when the count value reaches five, the Wi-Fi connection and transmission is made and the count value resets to zero. This setup enables the sending of data every twelve hours. The battery life is limited by the ten-year shelf life of the battery.

8.6 Serial FLASH Memory Lifetime

The serial FLASH memory device used in this design has a write and erase cycle limit of 100,000 cycles. The CC3200 writes calibration data to the FLASH device at every startup. Because the TIDA-00372 reference design cycles the power to the CC3200 frequently, the FLASH lifetime must be considered when choosing the period of the ON-OFF cycle. If the user chooses a one hour ON-OFF period, then there is one write cycle per hour, which is twenty-four write cycles per day. The total memory life calculates to:

Memory life (days) = 100,000 / 24n

where

- 100,000 = number of FLASH memory write cycles during FLASH life
- n = number of ON-OFF cycles per hour (3)

The memory life in years calculates to:

Memory life (years) = Memory life (days) / 365 (4)

For a one hour ON-OFF period, the memory life is 4,167 days or 11.4 years. Shorter ON-OFF periods reduce the memory life.

9 Design Files

To download the project design files, see the design files at TIDA-00372.

9.1 Schematics

To download the schematic, see the design files at TIDA-00372.

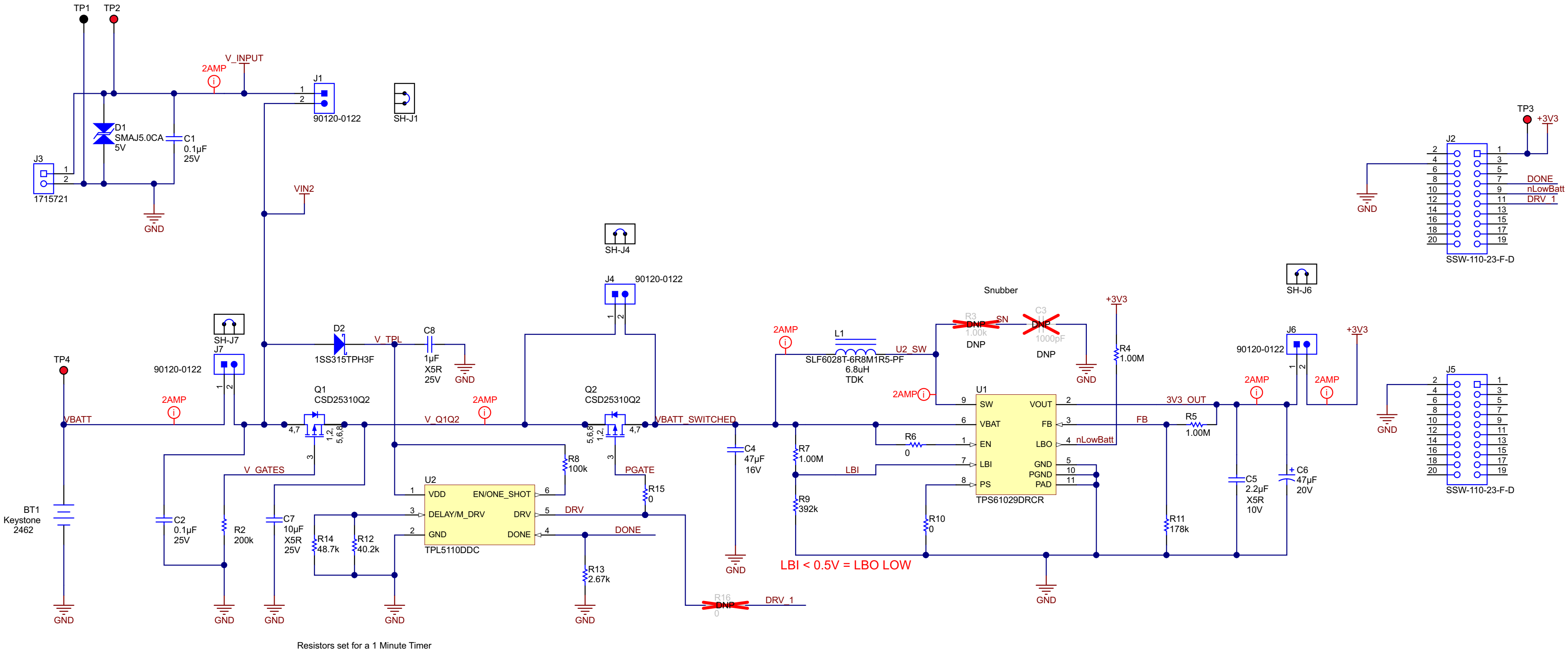


Figure 13. TIDA-00372 Schematic

9.2 Bill of Materials

To download the bill of materials (BOM), see the design files at TIDA-00372.

9.3 Assembly Drawings

To download the assembly drawings, see the design files at TIDA-00372.

9.4 Layout Design Notes

The circuits in the TIDA-00372 reference design are simple. Because the intent of this design is to maximize battery life, all power traces were made very large to reduce losses. The layout for the TPS61029 follows the recommendations of the TPS1029 datasheet as much as possible. A ground plane is included, but there is additional ground copper included in the otherwise unused sections of the external layers to further reduce ground impedance.

9.5 Gerber Files

To download the Gerber files, see the design files at TIDA-00372.

9.6 Layer Plots

To download the layer plots, see the design files at TIDA-00372.

9.7 Altium Project

To download the Altium project files, see the design files at TIDA-00372.

9.8 PCB Fabrication Drawing

To download the PCB fabrication drawing, see the design files at TIDA-00372.

9.9 Software Files

To download the software files, see the design files at TIDA-00372.

10 References

1. Texas Instruments, *TPL5110 Ultra Low Power Timer with MOS driver and MOSFET Power ON*, Data Sheet, (SNAS650).
2. Texas Instruments, *TPS61029 Adjustable, 1.8-A Switch, 96% Efficient Boost Converter*, Data Sheet, (SLVS451).
3. Texas Instruments, *CC3200 SimpleLink™ Wi-Fi® and Internet-of-Things solution Single-Chip Wireless MCU*, (SWAS032).
4. Texas Instruments, *CSD25310Q2 20-V P-Channel NexFET Power MOSFET*, Data Sheet, (SLPS459).
5. Texas Instruments, *CC31xx & CC32xx*, Wiki, http://processors.wiki.ti.com/index.php/CC31xx_&_CC32xx?DCMP=cc3100cc3200&HQS=simplelinkwifi-wiki.
6. Energizer®, Energizer E91 Product Datasheet, http://data.energizer.com/PDFs/E91.pdf.

11 Acknowledgments

The author would like to thank Ben Gilboa, Eyal Mendel, Beatrice Fankem, Asaf Even Chen, and Aaron Lee from the Texas Instruments SimpleLink™ Wi-Fi® team; Chris Glaser from the Low-Power DC-to-DC team and Christina Lam from the Building Automation team for their help in designing the hardware and getting software for this system.

12 About the Author

MARK KNAPP is a Systems Architect at Texas Instruments Incorporated where he is responsible for developing reference design solutions for the Building Automation segment. He has an extensive background in video camera systems and infrared imaging systems for Military, Automotive and Industrial applications. Mark earned his BSEE at the University of Michigan-Dearborn and his MSEE at the University of Texas at Dallas.

IMPORTANT NOTICE FOR TI REFERENCE DESIGNS

Texas Instruments Incorporated ("TI") reference designs are solely intended to assist designers ("Buyers") who are developing systems that incorporate TI semiconductor products (also referred to herein as "components"). Buyer understands and agrees that Buyer remains responsible for using its independent analysis, evaluation and judgment in designing Buyer's systems and products.

TI reference designs have been created using standard laboratory conditions and engineering practices. **TI has not conducted any testing other than that specifically described in the published documentation for a particular reference design.** TI may make corrections, enhancements, improvements and other changes to its reference designs.

Buyers are authorized to use TI reference designs with the TI component(s) identified in each particular reference design and to modify the reference design in the development of their end products. HOWEVER, NO OTHER LICENSE, EXPRESS OR IMPLIED, BY ESTOPPEL OR OTHERWISE TO ANY OTHER TI INTELLECTUAL PROPERTY RIGHT, AND NO LICENSE TO ANY THIRD PARTY TECHNOLOGY OR INTELLECTUAL PROPERTY RIGHT, IS GRANTED HEREIN, including but not limited to any patent right, copyright, mask work right, or other intellectual property right relating to any combination, machine, or process in which TI components or services are used. Information published by TI regarding third-party products or services does not constitute a license to use such products or services, or a warranty or endorsement thereof. Use of such information may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

TI REFERENCE DESIGNS ARE PROVIDED "AS IS". TI MAKES NO WARRANTIES OR REPRESENTATIONS WITH REGARD TO THE REFERENCE DESIGNS OR USE OF THE REFERENCE DESIGNS, EXPRESS, IMPLIED OR STATUTORY, INCLUDING ACCURACY OR COMPLETENESS. TI DISCLAIMS ANY WARRANTY OF TITLE AND ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE, QUIET ENJOYMENT, QUIET POSSESSION, AND NON-INFRINGEMENT OF ANY THIRD PARTY INTELLECTUAL PROPERTY RIGHTS WITH REGARD TO TI REFERENCE DESIGNS OR USE THEREOF. TI SHALL NOT BE LIABLE FOR AND SHALL NOT DEFEND OR INDEMNIFY BUYERS AGAINST ANY THIRD PARTY INFRINGEMENT CLAIM THAT RELATES TO OR IS BASED ON A COMBINATION OF COMPONENTS PROVIDED IN A TI REFERENCE DESIGN. IN NO EVENT SHALL TI BE LIABLE FOR ANY ACTUAL, SPECIAL, INCIDENTAL, CONSEQUENTIAL OR INDIRECT DAMAGES, HOWEVER CAUSED, ON ANY THEORY OF LIABILITY AND WHETHER OR NOT TI HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES, ARISING IN ANY WAY OUT OF TI REFERENCE DESIGNS OR BUYER'S USE OF TI REFERENCE DESIGNS.

TI reserves the right to make corrections, enhancements, improvements and other changes to its semiconductor products and services per JESD46, latest issue, and to discontinue any product or service per JESD48, latest issue. Buyers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All semiconductor products are sold subject to TI's terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its components to the specifications applicable at the time of sale, in accordance with the warranty in TI's terms and conditions of sale of semiconductor products. Testing and other quality control techniques for TI components are used to the extent TI deems necessary to support this warranty. Except where mandated by applicable law, testing of all parameters of each component is not necessarily performed.

TI assumes no liability for applications assistance or the design of Buyers' products. Buyers are responsible for their products and applications using TI components. To minimize the risks associated with Buyers' products and applications, Buyers should provide adequate design and operating safeguards.

Reproduction of significant portions of TI information in TI data books, data sheets or reference designs is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. TI is not responsible or liable for such altered documentation. Information of third parties may be subject to additional restrictions.

Buyer acknowledges and agrees that it is solely responsible for compliance with all legal, regulatory and safety-related requirements concerning its products, and any use of TI components in its applications, notwithstanding any applications-related information or support that may be provided by TI. Buyer represents and agrees that it has all the necessary expertise to create and implement safeguards that anticipate dangerous failures, monitor failures and their consequences, lessen the likelihood of dangerous failures and take appropriate remedial actions. Buyer will fully indemnify TI and its representatives against any damages arising out of the use of any TI components in Buyer's safety-critical applications.

In some cases, TI components may be promoted specifically to facilitate safety-related applications. With such components, TI's goal is to help enable customers to design and create their own end-product solutions that meet applicable functional safety standards and requirements. Nonetheless, such components are subject to these terms.

No TI components are authorized for use in FDA Class III (or similar life-critical medical equipment) unless authorized officers of the parties have executed an agreement specifically governing such use.

Only those TI components that TI has specifically designated as military grade or "enhanced plastic" are designed and intended for use in military/aerospace applications or environments. Buyer acknowledges and agrees that any military or aerospace use of TI components that have ***not*** been so designated is solely at Buyer's risk, and Buyer is solely responsible for compliance with all legal and regulatory requirements in connection with such use.

TI has specifically designated certain components as meeting ISO/TS16949 requirements, mainly for automotive use. In any case of use of non-designated products, TI will not be responsible for any failure to meet ISO/TS16949.

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265