APPLICATION NOTE

How to Maximize the Battery Life of Your Portable IoT Devices

Introduction

The Internet of things (IoT) is experiencing exponential growth right now. By year 2020, the number of IoT devices will be three times of the world population. IoT finds widespread applications in consumer, medical or industrial segments. For many of these applications, the life of users can be at stake if the IoT device's battery does not live up to expectations. For instance, it is a nuisance if a user has to frequently re-charge their hearing aid device. Implantable medical devices must last for years, and failing to operate for the reported battery life expectation can have dire consequences. For smart city or asset tracking applications, the battery life expectation is equally high. A smart meter that is being installed in every household, or a tiny asset tracker embedded into every asset will need to have long battery life, as it does not make any business sense to replace the faulty or short-life battery over a wide deployment location. Therefore, the ability to measure and predict the battery life of a device is more crucial than ever.

Figure 1: Keysight KS833A1B event-based power analysis

- Detect design weaknesses with quick and effortless event-based power consumption analysis
- Automatically correlates critical RF and non-RF events of your device to the power consumed to identify the areas consuming the most current
- Simplify battery life estimation with automated measurement and monitoring suite

KEYSIGHT TECHNOLOGIES

This application note describes how to use the Keysight X8712A IoT device battery life optimization test solution to quickly detect design weaknesses and estimate the battery life of an IoT device. We will also explain how to perform contactless signaling control of the device under test (DUT) and put the DUT into various operation modes to validate the battery life performance under many real-world operation conditions.

The X8712A solution includes a software suite that simplifies measurement setup and allows users to easily control and set up instrument settings. Users can easily perform event-based power consumption analysis to understand what RF and sub-circuit events are causing battery charge consumption. This will help users to make hardware and firmware changes that will optimize your battery's runtime.

Table of Contents

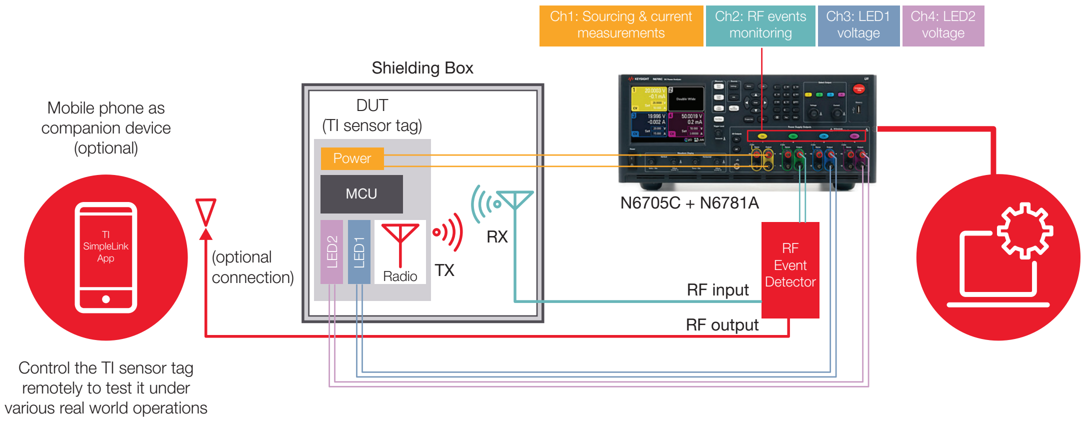


Figure 2: Diagram illustrating the overall X8712A solution setup

Measurement Preparation

The following instruments, software and accessories are required to perform the measurements.

Item	Model	Requirements
Keysight DC power analyzer	N6705B/C	Quantity: 1
Keysight source measure unit	N6781A [1]	Quantity: 2 or more
Keysight RF event detector	X8712AD	Quantity: 1
USB cable (to power up the X8712AD using the USB port of N6705B/C)	–	Quantity: 1 (supplied with X8712AD)
Keysight KS833A1B Event-based Power Analysis Software (license required)	KS833A1B	Refer to X8712A datasheet
Keysight IO Libraries Suite	–	Refer to X8712A datasheet
Keysight TAP deployment version (license required)	KS8000A	Refer to X8712A datasheet
Optional Items		
Shield box (Tescom or any other brand)	–	Quantity: 1 (only required for RF event monitoring, to filter surrounding interfering signals)
Your *Bluetooth*® Low Energy (BLE) device or Keysight BLE sensor tag demonstration kit	–	–
(Figure 3)	Custom part	Quantity: 1

1. For other supported source measure modules, please refer to the X8712A datasheet and user guide.

Cable kit to connect the DUT to N6705B/C

DUT (Modified Texas Instruments BLE sensor tag)

Figure 3: Keysight BLE sensor tag demonstration kit

Measurement Configuration

Connect the PC, instruments and accessories as shown in Figure 4.

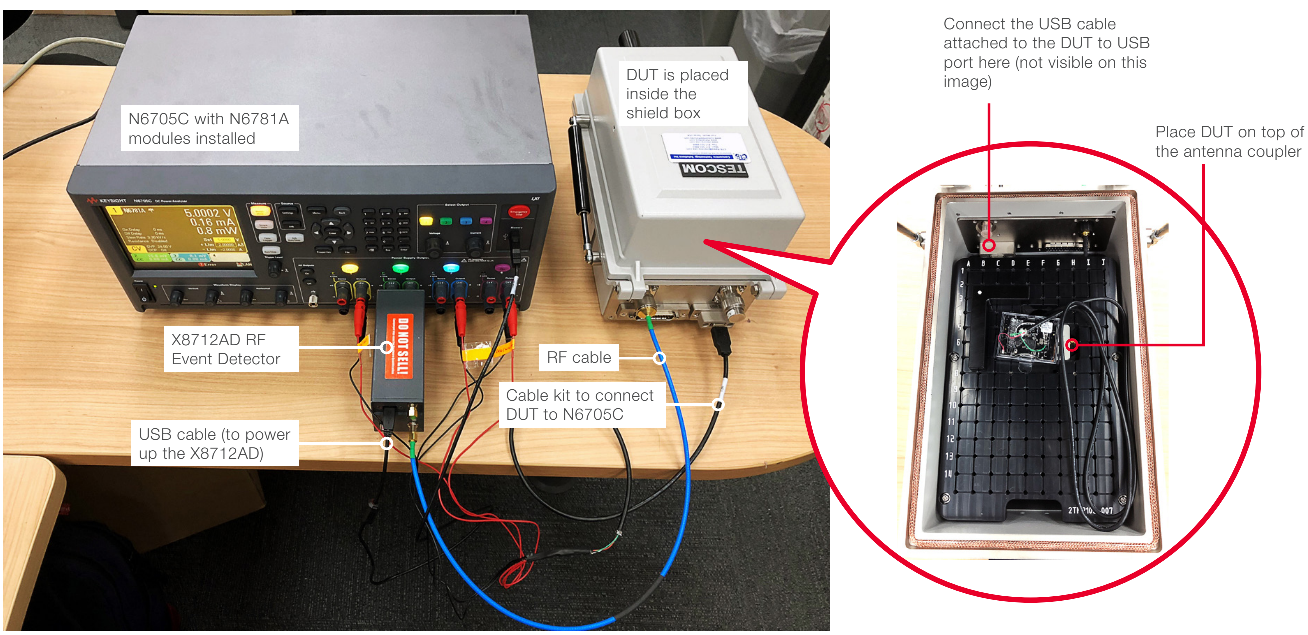


Figure 4: Connection diagram using Texas Instruments BLE sensor tag as the device under test

1. Install two or more N6781A SMUs to the N6705C main frame.
2. Connect the N6705C to PC using GPIB, LAN or USB cable.
3. Connect RF event detector to Channel 2 of the N6705C.
4. Connect RF cable from the shield box RF port to the RF event detector input port.
5. DUT connection: (Note that this section will be DUT and measurement dependent. The procedures below are specific to Keysight BLE sensor tag demonstration kit and can be leveraged for your BLE device):
   - Connect the USB cable attached to the BLE sensor tag (DUT) to the USB port inside the shield box as shown in Figure 4. The USB cable should go through a hole in the middle of the shield box and connect to the USB port inside the shield box.
   - Connect cable kit from the shield box's USB port to the N6705C Ch1, Ch 3 and Ch4.

   Note: The above two steps will accomplish the following configurations:

   - The power supply line of the DUT is connected to Ch1 of the N6705C. Ch1 will be configured as a battery emulator to power up the DUT.
   - Two LEDs inside the DUT are connected to Ch3 and Ch4 of N6705C. Ch3 and Ch4 will be configured as voltmeter to measure the supply voltages of the LEDs.
6. Power up the N6705C and check that the N6781A SMUs are connected properly to the front panel display of N6705C.

Software Preparation

Three software are required for these measurements.

Download and install Keysight IO Libraries Suite and Keysight KS8000A Test Automation Deployment System from the Keysight website. Note that a license is required for the KS8000A and you may request a 30-day trial license from the KS8000A webpage. Keysight offers the license of the IO Libraries Suite at no charge.

Download and install Keysight KS833A1B Event-based Power Analysis software from the Keysight website. A license is also required for the KS833A1B software.

For detailed installation procedures of the X8712A, refer to the X8712A User's Guide (**http://literature.cdn.keysight.com/litweb/pdf/X8712-90001.pdf**).

Note: The KS833A1B software supports demo mode without connecting to the instruments. You may recall a setting/data file to try out the analysis feature of this solution.

How to Perform Event-Based Power Consumption Analysis and Battery Life Measurements

Keysight X8712A can perform both RF and non-RF event-based power consumption analysis to quickly detect design weaknesses. With event-based power consumption analysis, users can easily obtain the current consumption in percentage for each key subsystem events (examples: RF, pump, sensor, alarm, LED activities) to identify events that consuming the most current and require optimization. Users can also easily configure this solution to measure the overall battery life of the IoT device.

Procedure:

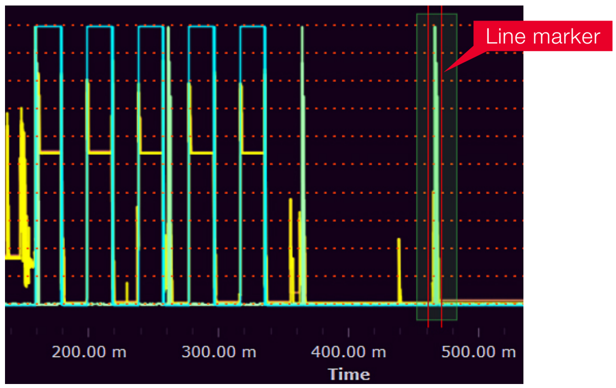
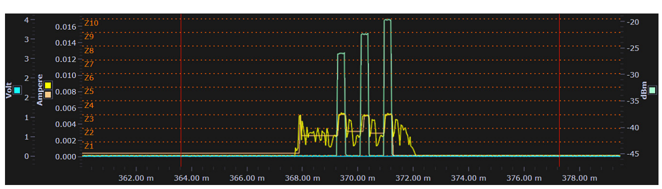
Task	Keystrokes
1. Launch KS833A1B software	Click **{Windows Start button}**, **{Keysight Event-based Power Analysis}**.
2. Connect to N6705C and initiate acquisition	Click the drop-down arrow in **{Settings}** panel to select the N6705C. Then press **{connect}**.
3. Recall a setting file	Click **{File}**, **{Open}**. Go to path **C:\Program Files\Keysight\EBPA** Double click on "SensorTagDemonstration.analysis" Now you should see a display similar to what is shown in Figure 1. The settings below are applied. Ch1: battery emulator, 5 V Ch2: power detector Ch3: voltage meter Sample size: 20000 Time interval: 40 us
4. Perform event-based power analysis	Click **{Connect}** again at **{Settings}** panel. Click **{Acquire}** at top left corner of the window to start the measurement acquisition. Wait a few seconds for acquisition to complete.

Note: This software supports demo mode without connecting to the instrument. You may skip this step and proceed to step 3 to recall a setting/data file.

Note: Older software versions may not have the 'SensorTagDemonstration.analysis' file in the EBPA folder. Please install the latest version from the X8712A website.

Note: If you only have two SMU modules installed in the N6705C, you can disable Channel 3 by unchecking the {enable} checkbox under {Channel 3}.

Click {Edit} if the {Settings} panel is greyed out.

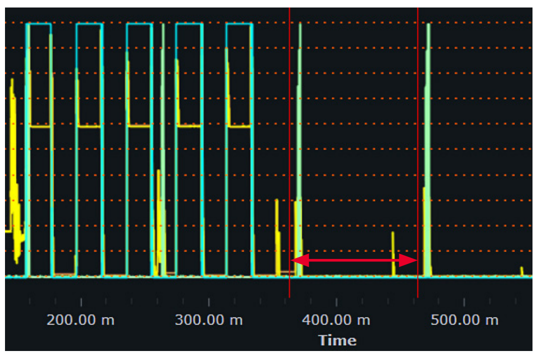
Task	Keystrokes
5. Change the analysis window by moving the pair of red line markers in the main chart window.	Place your cursor on top of one of the red line markers in the main chart window until you see {<=>}. Click and drag to move the line marker. Move both line markers to positions as shown in the screen shot below (surround one of the BLE burst). 
6. Zoom in to analyze the BLE event	Move your cursor to the empty space at the top left corner of the BLE burst. Click and drag to zoom in.  After zooming in, you should see the three BLE advertising signals as shown below. 

Task	Keystrokes
7. Perform event-based power consumption analysis of the BLE event	Click on the {Analyze} button in the middle of the UI. Uncheck {CCDF} to have a larger view in the zoomed window.

Now you can see the current consumption breakdown by event in % in the {Current Consumption} chart, and the event occupied time in % in the {Occupied Time} chart.

> Note: The event-based power analysis results shown in the bottom half of the window is based on data within the analysis window (between the two red line markers)

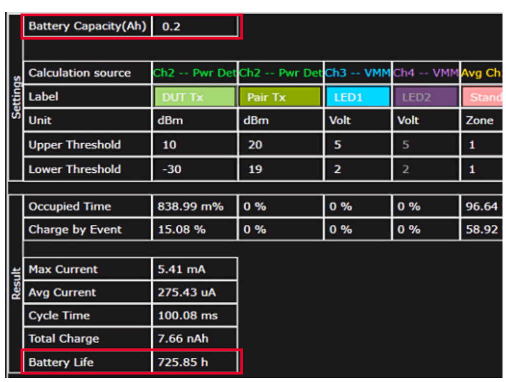
Task	Keystrokes
8. Perform battery life estimation	To zoom out, double click on any space in the main chart window. Move the pair of line markers to surround one full cycle of the BLE signal as shown below.



> Note: You may zoom in to two of the BLE bursts to have more precise placement of the line markers.

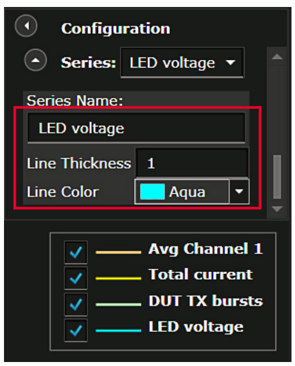
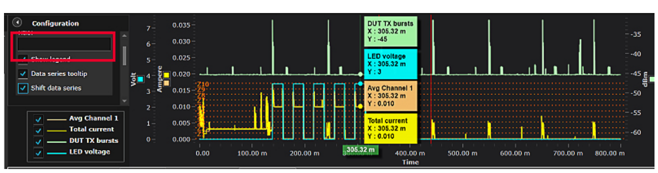
Click {Analyze}.

With the default 'Battery capacity' of 0.2 Ah, the battery life of this recurring BLE advertising event is around 726 hours.



Battery Capacity(Ah)	0.2				
Calculation source	Ch2 -- Pwr Det	Ch2 -- Pwr Det	Ch3 -- VMM	Ch4 -- VMM	Avg Ch
Label	DUT Tx	Pair Tx	LED1	LED2	Stand
Unit	dBm	dBm	Volt	Volt	Zone
Upper Threshold	10	20	5	5	1
Lower Threshold	-30	19	2	2	1
Occupied Time	838.99 m%	0 %	0 %	0 %	96.64
Charge by Event	15.08 %	0 %	0 %	0 %	58.92
Max Current	5.41 mA				
Avg Current	275.43 uA				
Cycle Time	100.08 ms				
Total Charge	7.66 nAh				
Battery Life	725.85 h				

> Note: You may change the 'Battery Capacity' according to the battery you use in your DUT, and click {Analyze} again to see the updated battery life.

Task	Keystrokes
9. Display legend of the channels and turn on or turn off a channel	On the {Configuration} panel, click on the {Show legend} checkbox. Turn on or turn off a channel/waveform using the checkbox beside the channel. 
10. Change the label for a channel	Scroll down on the {Configuration} panel until you see {Series}. Click on the drop-down arrow beside {Series}, select a channel and type in a name in the column under 'Series Name:'. Example: "Total current" for Channel 1, "DUT TX bursts" for Channel 2, "LED voltage" for Channel 3. 
11. Turn on data series tooltips and shift data series	You may also turn on the data series tooltip and shift the data series by checking these boxes under {Configuration} panel.  Congratulations! You have now learned the key functions and basic settings of the X8712A.

Note: You may change the 'Battery Capacity' according to the battery you use in your DUT, and click {Analyze} again to see the updated battery life.

How to Configure Current Zones and Trigger Settings to Enable More Accurate Analysis

One of the key features of the X8712A is to enable event-based power consumption analysis to help designers pinpoint events consuming the most current, therefore allowing them to easily detect design weaknesses. There are two types of event segregations in the X8712A, which are based on physical events and current events.

What are physical events and current events?

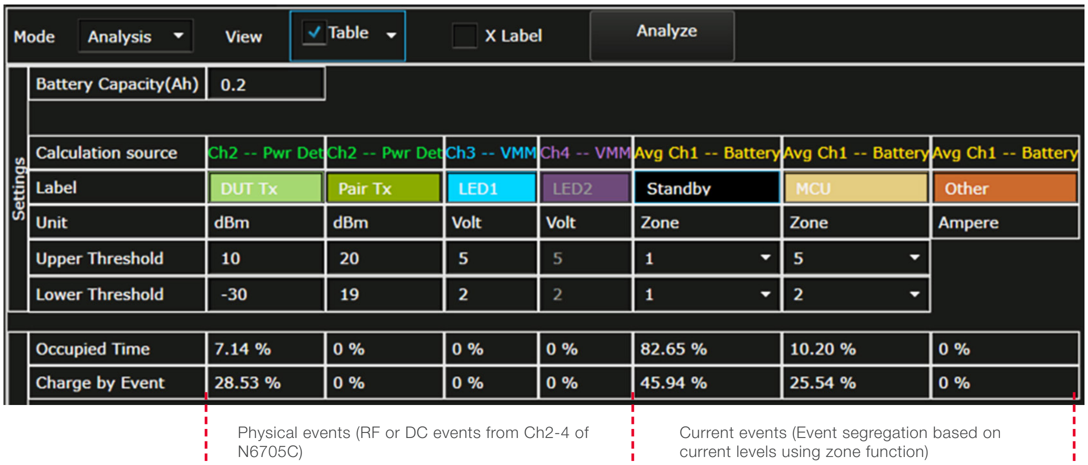


Figure 5: Physical events and current events

Physical events

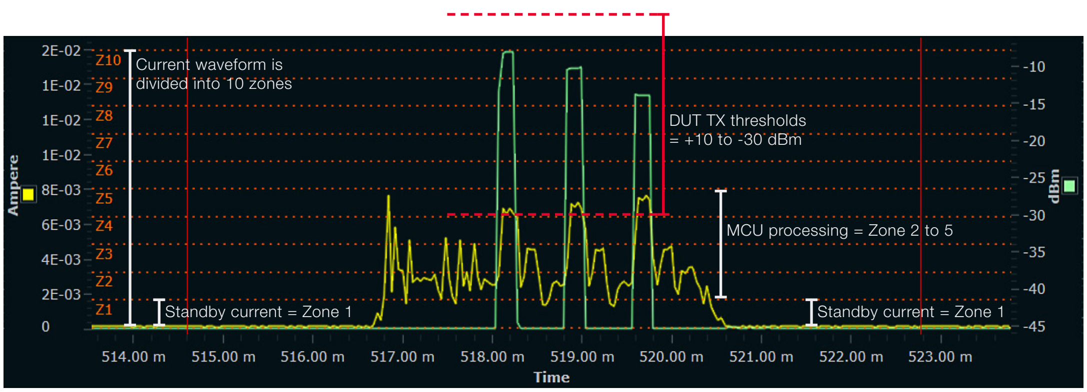
RF and DC signal waveforms captured by Channel 2 to Channel 4 of the N6705C are known as physical events (examples: RF bursts, voltage or current waveforms). For accurate event-based power analysis, the thresholds of these events need to be set up according to the captured signal levels. For instance, in Figure 6, the RF bursts (green waveform) are around -10 to -15 dBm, so setting the upper and lower thresholds for ‘DUT Tx’ at ‘+10’ and ‘-30 dBm’ will allow the software to calculate synchronized current consumption during this period as ‘Percentage of charge/current consumed during DUT Tx event’.

Current events

Current events are other non-physical events derived using an averaged current waveform of Channel 1. The Average Channel 1 waveform is averaged and divided into a number of equally spaced zones. Users can segregate events such as standby, pre-processing, post-processing or other non-physical events by applying the right upper and lower thresholds based on the zones that the waveform resides in. For instance, standby mode current always resides in Zone 1, and therefore both the upper and lower thresholds should be set to Z1 (Figure 6).

Event priority

The events on the left of the table have higher priority than events on the right. For instance, 'DUT TX' event has the higher priority compared to 'MCU' event. The current consumption data during the DUT TX time duration will be used to calculate the current consumption % for DUT TX even though these data points are also in Zone 5 for the MCU event.



Settings							
Calculation source	Ch2 -- Pwr Det	Ch2 -- Pwr Det	Ch3 -- VMM	Ch4 -- VMM	Avg Ch1 -- Battery	Avg Ch1 -- Battery	Avg Ch1 -- Battery
Label	DUT Tx	Pair Tx	LED1	LED2	Standby	MCU	Other
Unit	dBm	dBm	Volt	Volt	Zone	Zone	Ampere
Upper Threshold	10	20	5	5	1	5	
Lower Threshold	-30	19	2	2	1	2	
Occupied Time	11.60 %	0 %	0 %	0 %	53.59 %	34.81 %	0 %
Charge by Event	29.94 %	0 %	0 %	0 %	20.67 %	49.39 %	0 %

% charge consumed during DUT TX event

User can break the current waveforms into different segments using "current zones function".
Example: Standby current waveform is in Z1 (zone 1)
MCU pre/post-processing current waveform is in Z2-Z5

Figure 6: Threshold settings for physical events and current events

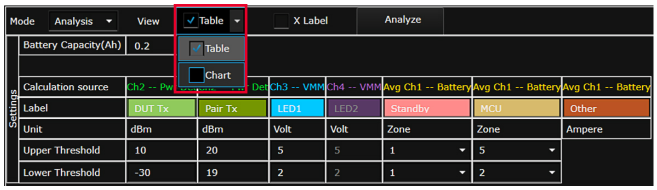
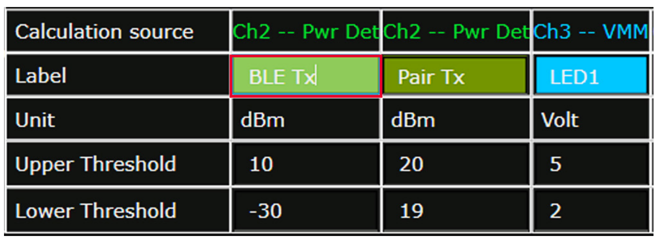
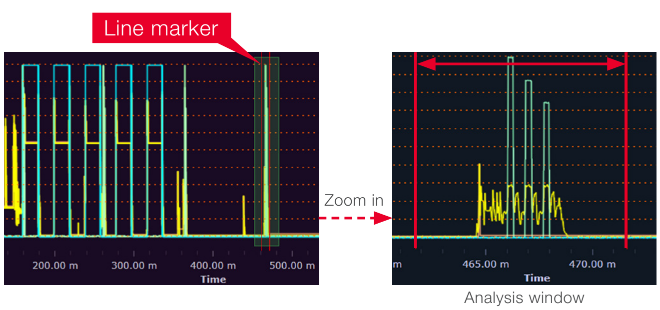
Putting the correct upper and lower thresholds is important for accurate event-based power consumption analysis. In the following section, we will explain how to set up the right thresholds to enable accurate event-based power consumption analysis.

We will also explain how to make use of trigger settings to allow more flexible capturing of the current consumption of infrequently transmitting devices such as LoRa® devices, which have long sleep time intervals in between packets transmission.

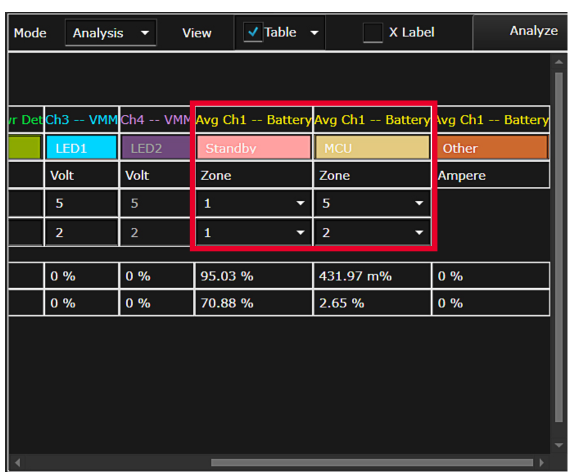
Instruction	Keystrokes
1. Launch the KS833A1B software	Click {Windows Start button}, {Keysight Event-based Power Analysis}.
2. Connect to N6705C and initiate acquisition	Click the drop-down arrow in {Settings} panel to select the N6705C. Then press {connect}.
3. Recall a setting file	Click {File}, {Open} Go to path C:\Program Files\Keysight\EBPA\ Double click on "SensorTagDemonstration.analysis" The following settings are pre-set. Ch1: battery emulator, 5 V Ch2: power detector Ch3: voltage meter Sample size: 20000 Time interval: 40 us
4. Perform event-based power analysis	Click {Connect} again at {Settings} panel. Click {Acquire} to start the measurement acquisition. Wait for a few seconds for acquisition to complete.

Note: Older software version may not have the 'SensorTagDemonstration. analysis' file in the EBPA folder. Please install the latest version from the X8712A website.

Note: If you only have two SMU modules installed in the N6705C, you can disable Channel 3 by unchecking the {Enable} checkbox under {Channel 3}.

<table>
<tr><th>Instruction</th><th>Keystrokes</th></tr>
<tr><td>4. Apply the right settings and thresholds for {Calculation Source}</td><td></td></tr>
<tr><td>i. Turn off the chart view to display the whole table</td><td>Click on the drop-down arrow beside {Table} and uncheck {Chart}. Now you should be able to view the whole table.

</td></tr>
<tr><td>ii. Change the label of the RF event.</td><td>Select {DUT Tx} and key in ‘BLE Tx’. The label of ‘Ch2—Pwr Detector’ has been updated.

</td></tr>
<tr><td>iii. Zoom into one of the BLE burst</td><td>Move the two line markers to surround one of the BLE burst (see figure below).
Move your cursor to the empty space at top left corner of the BLE burst. Click and drag to zoom in.


Click {Analyze}.
Now you can see the current consumption breakdown by event in % in the {Current Consumption} chart and the event occupied time in % in the {Occupied Time} chart.</td></tr>
</table>

Instruction	Keystrokes
iii. Change the upper and lower thresholds for Physical Events (Ch2-4)	Try to vary the {Upper Threshold} of {Ch2—Pwr Detector} from the default ‘10dBm’ to ‘-25dBm’. Turn on chart views: Click on the drop-down arrow beside {Table}, check {Chart}. Click on {Analyze}. Observe the changes in the green label or green bar on these charts.  With upper/lower thresholds of 10 dBm and -30 dB With upper/lower thresholds of -25 dBm and -30 dBm You may change the upper and lower thresholds of Ch3 and Ch4 to see the impact to the analysis results.
iv. Changing the upper and lower threshold for Current Events (Avg Ch1 -- battery)	On the {Calculation Source} table, scroll to the right to view the ‘current events’ such as {Standby} and {MCU}.  Click on the arrow key below {zones} to modify the settings.

Note: As you have chosen a smaller range for upper (-25 dBm) and lower (-30 dBm) thresholds, some of the BLE bursts are out of the range and are therefore not captured as an BLE TX event. Hence the ‘Current Consumption’ chart shows a drop in the percentage of current consumption for the BLE TX event.

Note: Putting the correct upper and lower thresholds is important for accurate event-based power consumption analysis.

<table>
<tr><th>Instruction</th><th>Keystrokes</th></tr>
<tr><td></td><td>
As standby current is always very low, select Zone 1 (Z1) for both {Upper Threshold} and {Lower threshold}.
MCU pre-processing and post-processing currents are in Zone 2 to Zone 5, hence apply Z5 and Z2 as the {Upper Threshold} and {Lower Threshold}.
You may change the thresholds to other zone values to see the impact. Click {Analyze} to view the results.


Current events
</td></tr>
<tr><td>5. Changing the acquisition duration or time span</td><td>
In the {Settings} panel, look for {Sample & Duration}. Set the following:
Sample size: 40000
Time interval (s): 80 u
Press {Acquire}/{Edit} to start the acquisition.
Now you have just extended the time span to 3.2 s.
</td></tr>
<tr><td>6. Setting up triggered measurements</td><td>
On the {Settings} panel, scroll to the bottom for {Trigger}. Apply the following {Trigger} settings:
(Click {Edit} if the settings are greyed out.)
Mode: Triggered
Source: Channel 2
Level (dBm): -25
Press {Acquire}/{Edit} to start the acquisition. Observe changes in the captured waveform in the main chart window. Now you have just set up the software to start measurement acquisition when the Ch2 RF waveform rises above -25 dBm.
</td></tr>
</table>

Note: To turn on, turn off or change the number of zones, go to {Settings} panel, {Zone}.

Note: Congratulations! You have learned how to set up the right threshold levels to achieve more accurate event-based power consumption analysis.

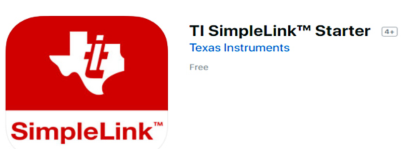
How to Perform Contactless Signaling Control of the Device to Validate Real-World Battery Life Performance

The X8712A solution can support current consumption analysis and battery life measurements of wireless devices with any short or long range wireless format. The X8712AD RF event detector comes with an RF output port that is connected to the input port via a power splitting device. Users can connect the RF output port to a companion device directly, or wirelessly through an antenna. Through this RF path, the companion device will be able to communicate with the DUT that is placed inside a shield box. Figure 2 shows the use of a mobile phone as a companion device to communicate and control the BLE sensor tag, acting as the DUT, inside a shield box.

With this solution, users can use the companion device to remotely control the DUT and put the DUT into various real-world operations to validate its actual battery life.

Measurement preparations:

The following additional items are required for this measurement.

Item	Model	Requirements
An additional N6781A SMU module	N6781A	Total required: 4 (pre-installed into the N6705C)
2.4 GHz antenna with cable	–	Quantity: 1
Your companion device or mobile phone pre-installed with Texas Instruments SimpleLink Mobile Application for use with the Keysight BLE sensor tag demonstration kit 	–	–

Connect the 2.4 GHz antenna with cable to the RF output port of the X8712AD

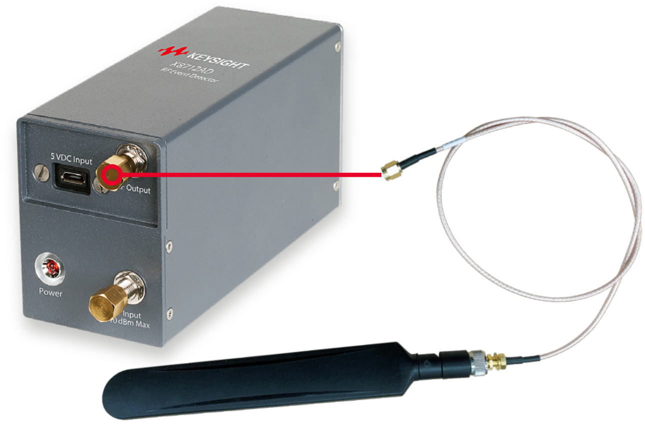
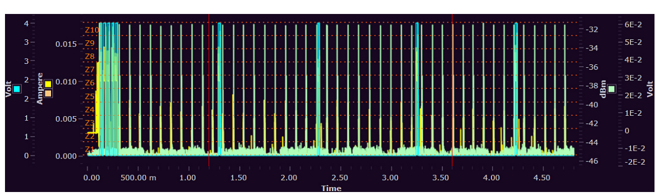
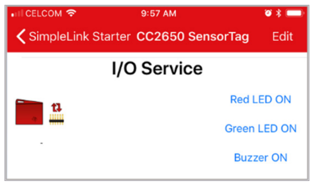


Figure 7: Connection diagram of the 2.4 GHz antenna

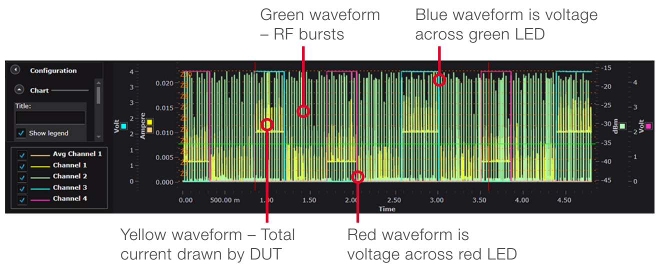
Instruction	Keystrokes
1. Launch KS833A1B software	Click {Windows Start button}, {Keysight Event-based Power Analysis}.
2. Connect to the N6705C and initiate acquisition	Click the drop-down arrow in {Settings} panel to select the N6705C. Then press {connect}.
3. Recall a setting file	Click {File}, {Open} Go to path C:\Program Files\Keysight\EBPA\ Double click on "SensorTagDemonstration.analysis" Click {Connect} again to load the instrument settings. Now you should see the settings below: Ch1: battery emulator, 5 V Ch2: power detector Ch3: voltage meter Sample size: 20000 Time interval: 40 us
4. Modify the settings	Under {Sample & Duration} Sample size: 60000 Time interval: 80 us Under {Channel 4} Enable: (tick) Module: Voltage Meter
5. Verify the settings	Click {Acquire} to start acquisition. Wait for a few seconds and the following waveforms should be displayed. 

<table>
<tr><th>Instruction</th><th>Keystrokes</th></tr>
<tr><td>6. Establish DUT connection with mobile phone</td><td>Launch the SimpleLink App on the mobile phone.
Place the phone close to and in parallel with the 2.4 GHz antenna.
On the mobile phone screen, look for ‘CC2650 Sensor Tag’ in the detected BLE devices list.
Click on ‘CC2650’, then ‘Sensor View’ to view the sensor tag settings.
Scroll down until you see ‘I/O Service’.
Try to toggle the ‘Red LED, Green LED and Buzzer’ and observe the sensor tag inside the shield box to confirm you are connected to the right sensor tag.

</td></tr>
<tr><td>7. Setup trigger settings</td><td>In the KS833A1B software, click on {Edit} to enable setting changes.
Under {Trigger}, set up the following:
Mode: Triggered
Source: Channel 4
Level: 1.5 V
Time Variable: 10 s
Status: Without reset</td></tr>
<tr><td>8. Use the SimpleLink App on the mobile phone to control the DUT and put it into various operation modes, and acquire the waveforms.</td><td>Click on {Acquire} to start the acquisition.
On the SimpleLink App, alternately click on the ‘red LED on’ and ‘green LED on’ 8-10 times quickly to turn on and turn off the LEDs.
Wait for a few seconds for the software to complete the measurement acquisition.
Now you should see captured waveform similar to the screenshot below. Click on the checkbox beside {Channel 4} to turn on Ch 4 waveform.</td></tr>
</table>

Note: With the above settings, the measurement acquisition will only start when the red LED is turned on (Channel 4 is wired to measure the voltage across the red LED).

Note: You may need to repeat this step a few times and adjust the speed of turning on and off the LEDs until you get similar waveforms as below.

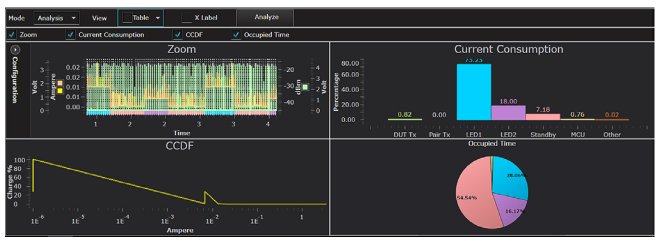
Instruction	Keystrokes



9. Perform event-based power analysis

Move the pair of red line markers to cover at least one red and one blue pulse. Click on {Analyze}.

The analysis shows that the two subsystems that consume the most current is LED1 and LED2. RF transmission (DUT Tx) consumes very little current compared to the LEDs.



The battery life based on a battery capacity of 0.2 Ah is around 50 hours. (Battery life results may vary based on how fast you toggled the LED on/off button on the mobile app).

Max Current	22.42 mA
Avg Current	3.97 mA
Cycle Time	2.74 s
Total Charge	3.03 uAh
Battery Life	50.34 h

Congratulations! You have successfully used a companion device to control the DUT and performed event-based power consumption analysis under real operation modes.

Note: The BLE sensor tag (DUT) will go into standby mode after three minutes. When it is in standby mode, it will not be listed or will be greyed out on the mobile app. You may toggle the power supply (Channel 1) from the front panel of N6705C to wake up the sensor tag.

Summary

The Keysight X8712A IoT device battery life optimization solution is an integrated solution with all the necessary hardware and software that enables you to perform detailed current consumption analysis to detect design weaknesses quickly and easily. The X8712A allows you to visualize and capture detailed current consumption waveform over a wide range from nA to A, with a fast 20 us sampling rate. With its event-based power consumption analysis feature, you can now easily correlate device current consumption with subsystem events, such as RF on, pump on, vibrator on, display on and so on, to identify which events consume the most current and therefore require optimization. With a clear understanding of the key RF or non-RF event occupancy time and the amount of current consumed by each event, you can now easily obtain the estimated battery life of your device. Reduce your test development and testing time from weeks to days with the X8712A; in a typical application, it will just take a few minutes to collect, plot and correlate all the data to understand the device current consumption behavior.

More Information

Keysight X8712A solution webpage.
www.keysight.com/find/x8712a

Keysight X8712A datasheet.
https://literature.cdn.keysight.com/litweb/pdf/5992-3085EN.pdf

Keysight X8712A user's guide.
http://literature.cdn.keysight.com/litweb/pdf/X8712-90001.pdf

Keysight Test Automation Platform.
www.keysight.com/find/tap

Keysight IO libraries suite.
www.keysight.com/find/iolibs