Overview

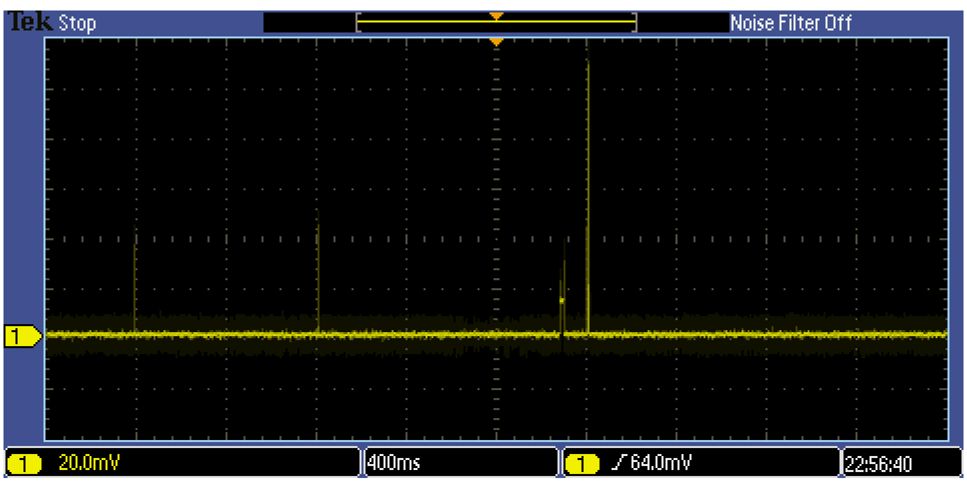
The power measurements of the ultra-low power wireless (such as BT LE) are complex and cannot be made with a single measurement device. This complexity is caused by the power consumption consisting of two distinct types:

- Infrequent, small power consumption in the range of a few milliamps.
- Base power consumption in the range of a few micro amps.

As these two types of power consumption are spread in amount by a factor of 1000 and in time by an even greater amount.

The only method to measure the power consumption is to measure each of the components separately and combine.

The picture below gives an example of the current draw. The Y axis is current times 10 and the X axis is time:



Methodology: Method #1

After much analysis of the waveforms, the current for a BT LE sensor consists of the following components (nRF51822 BTLE example):

- Base current. This base current consists of the Nordic nRF51822 being in power down mode. In the sensor, this base current also includes the current consumption of the accelerometer.
- LFCLK calibration. Every X1 seconds (typically 8), the Nordic nRF51822 power up and calibrates the on board LFCLK.
- Every X2 seconds, the Nordic wakes up and primarily resets the watchdogtimer. For the sensor, this includes reading the accelerometer data and filtering it
- Every X3 seconds (typically a little over eight), the Nordic wakes up and broadcasts the advertising message on three RF bands (to avoid interference).

The base current is measured with a high (micro amp) accuracy Tektronix DMM4020 meter or Keithley 2280S precision power supply. The measurement is checked by measuring a reference DC load. The reference DC load is checking against a 4W Keithley 2100 meter. An independent measurement can also be made with a current sense amplifier.

The other loads are measured using a Tektronix MSO2024B oscilloscope with 1X probe measuring the voltage drop over a 10 ohm resistor between a CR2032 battery and the unit under test. Measurement accuracy is checked by measuring a reference DC load. The reference DC load is checking against a 4W Keithley 2100 meter.

All of the resulting measurements are put into spreadsheet along with data from the supplied battery data sheet to calculate expected lifetimes.

Methodology: Method #2

In method #2, we charge a supercap and measure the voltage drop over time caused by the sensor. This method eliminates some of the risks of method #1.

The target size of the supercap is big enough that the time measured below is 60-90 seconds or more.

Method #2 steps:

- Collect test equipment: a stopwatch, a Keithley 6.5 digit multimeter, a decade box, and a bench power supply.
- Connect the equipment plus the unit under test according to the attached diagram. Connections must be either banana jacks or soldered for good results.
- Adjust the power supply so that the voltage read by the multimeter is 3.10V
- Turn on SW1 and leave SW2 in the neutral position. Leave for at least 1-5 minutes to allow the capacitor to completely soak.
- Put SW2 in the position to connect to the sensor.
- Turn SW1 off and start the stopwatch at the same time.
- Wait with the stopwatch until the voltage is at 3.00V. Try to stop the stopwatch exactly at 3.00V.
- Record the time.
- Repeatedly do the above steps:
    - SW2 should be moved to the decade box position instead of the sensor position.
    - Using Ohm's law and method #1, estimate the value of the resistor. Refine the value of the resistor during each iteration until the number of seconds to reach 3.00V is the same as the measurement with the sensor (+/- 1 second). (Or if you have measurements above and below within 3 seconds, they can be weighted averaged.)
- Record the results in the spreadsheet.

Methodology: Method #3

In method #3, we use a device to take multiple current readings over a period and average them.

Methodology: Method #3A

In this version of method #3, we use a Keithley 2280S-32-6 Precision Measurement DC Power supply. This device measures the current from the power supply's control loop so it does not affect the measurement. Steps:

- Program the voltage (typically 3V) and current limit (typically 0.1A).
- On the Measure Settings menu, set NPLC to 3
- On the Data Buffers menu, set Size to 2500
- On the Graph menu, press enter on View Graph.
- Connect device/sensor/unit under test.
- Turn on power.

Wait until the initial start-up power consumption has passed, then wait an additional 15 minutes. The mean value under the Graph is the average current.

The sample rate is set by the NPLC value (please see Keithley documentation for more information). The value of 3 has been found by trial and error to get a stable reading for most products. Some products may need this adjusted.

Risks

- The current implementation of the sensor only allows communications between the sensor and the hub in a single direction (sensor to hub). The sensor is pretty much an internal state machine with very little change in current consumption based on external factors. Other devices may have more complex state machines.
- Lifetime is measured from battery installation (typically at the factory).
- The code can be over 100K bytes. We believe that we have identified all regular “high” current consumption modes but nothing can be guaranteed.
- We typically have no specification from the battery vendor for the life of the battery at our current levels. 99% of the time, we are drawing a few micro-amps and less than 1% of the time drawing milliamps. For the calculations, we are using the battery life at 200 micro amps and a voltage cutoff of 1.8V (a compromise).
- We typically have not seen enough production of sensors to add corrections for distribution from chip to chip to the estimate.
- For lithium coin cell technology: As the lifetime is so large and the battery pretty much stays at a particular voltage most of its life, there is little opportunity to validate the total power consumption.
- Although the methodology used is common in such very low current with periodic spikes, we have not found a better way to verify that the sensors are going to last as long as calculated.

Results

Badge Rev 102/103

Frank Dunn's team performed a detailed measurement on one Chinese built badge, results of Method 2 and Method 3 are described below. They proceeded to spot checked two other badges with method 3 and got similar results (within 2uA).

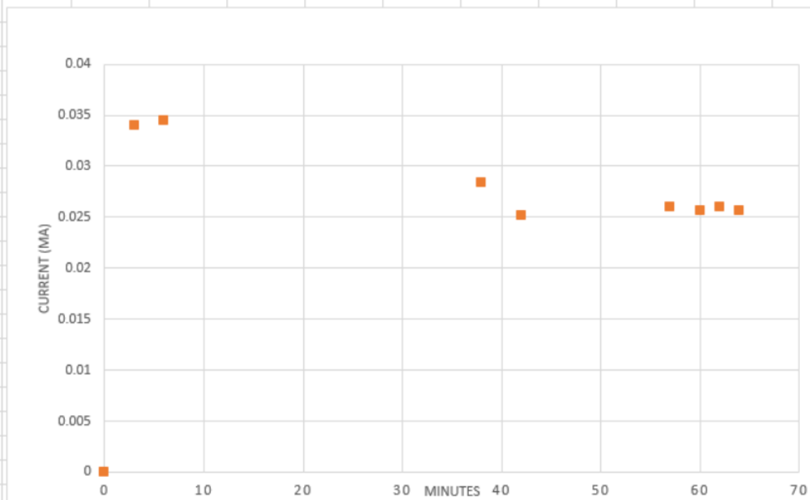
METHOD 2

Badge power measurement
using keithley 2280S
Method #3 test
using code - July4a_16 r103

Votage set to 3.0V
Jlink removed from fixture

Settings	
NPLC	3
Size	2500

Minutes	Avg Current (mA)	Notes		
0	0	powered on		
3	0.0340			
6	0.0345			
38	0.02836			
42	0.02518			
57	0.0260			
60	0.0257			
62	0.0260			
64	0.0257			
0.060				
0.0596			v=ir	
0.0594			r=v/i	
0.0597			v=3, i=	
		active	86956.5	ohms
		sleep	116959	ohms
23	27			



Active current draw = 34uA

Sleep current draw = 23uA

METHOD 3

Method 2 Measurement				
Using small supercap				
3.1v to 3.0v				
		Active		
badge		Decade box		
Time		Resistance	Time	
51.6		87K	50.3	
49.84		88K	51	
52.26				
average		3.40909E-05	Amps current	
51.23333				
		Asleep		
badge		Decade box		
Time		Resistance	Time	
74.8		117K	67.9	
75.3		129K	74.5	
75.1		130K	75.0	
average		2.30769E-05	Amps current	
75.06667				

Active current draw = 34uA

Sleep current draw = 26uA

ESTIMATED BATTERY LIFE

RESULTS	
Assumptions	
Batteries: 270mAh x 2. Capacity (mAh)	540
Batteries: 270mAh x 2. Capacity (uAs)	32400000
On average the badge is asleep for 12h/day	50%
Average Sleep Current Draw (uA/s)	34
Average Active Current Draw (uA/s)	24.5
Average current draw in 1 day active use (uA/s)	29.25
DFU Current draw	0
Estimated battery life in years during use (yrs)	2.11
Estimated battery life in storage, sleep 100% (yrs)	2.52

Badge Rev 110/111

Orange points in graph below show badge with damaged accel that will not sleep. Blue points show badge with good accel that sleeps after 30min into test.

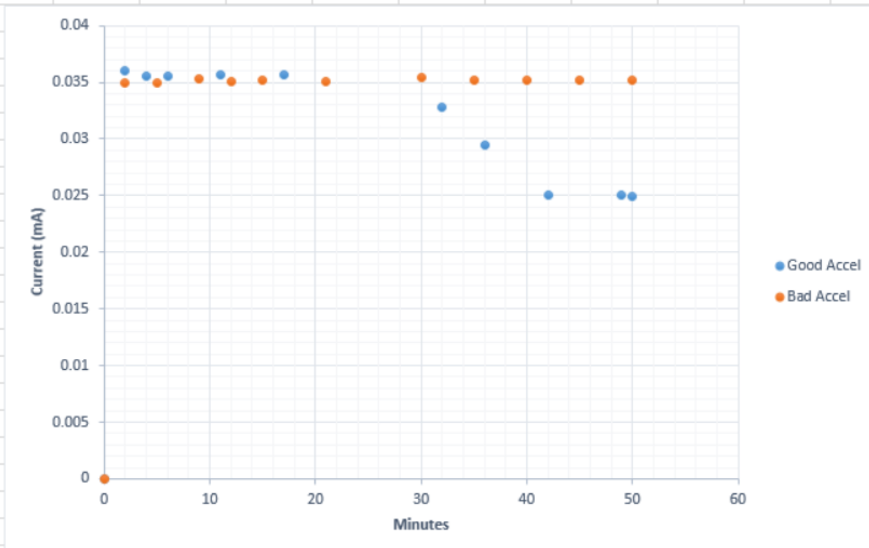
Badge power measurement
using keithley 2280S
Method #3 test
using code - July9a_16 r110

Settings	
NPLC	3
Size	2500

Votage set to 3.0V
Jlink removed from fixture

Good accel		
Minutes	Avg Current (mA)	Notes
0	0	powered on
2	0.0360	
4	0.0355	
6	0.0356	
11	0.03565	
17	0.0357	
32	0.0328	
36	0.02950	
42	0.02502	
49	0.02503	
50	0.02498	

Degraded Accel		
Minutes	Avg Current (mA)	Notes
0	0	powered on
2	0.0350	
5	0.0350	
9	0.0353	
12	0.0351	
15	0.0352	
21	0.0350	
30	0.03541	
35	0.0352	
40	0.0352	
45	0.0352	
50	0.0352	



RESULTS

Assumptions	
Batteries: 270mAh x 2. Capacity (mAh)	540
Batteries: 270mAh x 2. Capacity (uAs)	32400000
On average the badge is asleep for 12h/day	50%
Average Sleep Current Draw (uA/s)	35.1735
Average Active Current Draw (uA/s)	25.01
Average current draw in 1 day active use (uA/s)	30.09176
DFU Current draw	0
Estimated battery life in years, no sleep (yrs)	1.75
Estimated battery life in years, sleep 50% (yrs)	2.05
Estimated battery life in storage, sleep 100% (yrs)	2.46

Attachments

- Diagram of test setup for Method #2