

Keysight Technologies

Five Tips for Optimizing Battery Drain on IoT Devices

Application Note

Powering the IOT revolution

The widespread success wide spread of IOoT applications is visible in the number of devices we use every day: smart-phones, tablets, e-readers, GPS units, wearable patient monitors, heart-rate monitors, and many more. Some attribute this success to the long-awaited convergence of highly integrated technology, wide bandwidths, application rich content, and attractive pricing.

Of course, the insatiable demand for anytime, anywhere access leads to end-user expectations that increase the pressure on product designers. As an example, visit any product-review page and one of the biggest issues --or opportunities --becomes clear: battery life.

The power challenge stems from two shared issues. One is the is long periods of standby operation between bursts of intense RF activity. The resulting current drain is pulsed with extremely high peak current, low duty cycle and low average values. Accurately measuring the profile of dynamic current drain can be difficult and challenging with many of today's existing tools.

Battery life is critical to end users

Power management is an often overlooked yet critical area for both consumer and industrial IoT devices. In a battery powered device, optimizing dynamic as well as static power is imperative. We can all relate to the anxiety caused when our mobile phone's battery is low. Battery run-time is one of the easiest product characteristics for an end user to recognize.

To maximize battery life, you may use a variety of advanced power-management techniques. For example, sub circuits can be rapidly turned on and off to help reduce overall power consumption. As the device transitions between different operating states, this creates dynamic dynamic current consumption that ranges from sub-micro amperes to amperes.

Measuring these dynamic changes is essential to understanding power consumption and battery life. However, handling a 1,000,000-to-1 ratio between minimum and maximum current levels is not possible with typical tools: digital multi meters (DMMs), oscilloscopes, current probes, conventional source/measure units (SMUs), or multiple shunt resistors. Using these tools can result in poor results, inaccurate understanding and daily frustration. Below are the five tips that help you to optimize your battery drain test on your IoT devices.

Tip 1. Gain Deeper Insights into Current Drain Waveforms of a Battery Run Time

Tip 2. Improve Measurement Accuracy to Ensure Longer Battery Run Time Power-saving Modes

Tip 3. Analyze Distribution Profiles to Optimize Battery Run Time

Tip 4. How to Emulate a Device's Battery Test with More Realistic Results

Tip 5. Simplify Validation of a Battery's Capacity and Energy Ratings

TIP 1: View Current Drain Waveforms for Deep Insights into Battery Run Time

Gain deeper insights into device operation to optimize battery run time.

To simply validate battery run time, you can either measure the run time directly or measure current drain for a prolonged period and extrapolate based on stated battery capacity. However, optimizing run time requires several tests to gain additional insights. You must test and characterize the device, its sub-circuits and the battery, both independently and in combination. Detailed battery drain analysis offers deeper insights into device operation that enable you to optimize run time.

High-speed, high-resolution current drain digitization yields deeper insights for optimizing battery run time.

Digitizing the battery current drain at 50 kSa/s or greater and with a wide dynamic measurement range yields deep insights into battery run time. Each approach has advantages and limitations:

- Current probes such as the Keysight N2820A, used with digital oscilloscopes, provide high-speed current waveform digitization. However, accuracy and noise performance depend on the oscilloscope to which the current probe is attached.
- A high-end DMM, such as the Keysight 34470A, can provide several digits of precision with good accuracy, but the small display may not show waveform details. You may have to move the data to a computer for full-resolution analysis.
- A fast data acquisition system and an accurate current shunt can provide better accuracy and wider range than a current probe and oscilloscope. However, you must minimize the current shunt peak voltage drop so that it does not unduly affect the DUT, keeping in mind that a very small shunt voltage drop limits the measurement dynamic range and accuracy.
- Some specialized source/measure units (SMUs), such as the Keysight N6781A and B2900 Series, combine DC sourcing with a high-speed digitizing, wide-dynamic-range measurement system that can accurately characterize current drain without the voltage burden of an external shunt resistor.
- A device current waveform analyzer, such as the Keysight CX3300 Series, has exceptional precision, accuracy, and bandwidth. These features, combined with a large display, let you see waveform features that were never visible on other devices.

Example of deep insights from a device's current drain waveforms:

As one example, Figure 1 shows the current drain on an operating wearable fitness monitor measured by the Keysight N6781A SMU. The N6781A is a battery emulator tailored for powering mobile devices up to 20 W and measuring current drain from nA to A at over 195 kSa/s. Its wide dynamic measurement range and high-speed digitizing quickly yield deep insights for optimizing battery run time. The N6785A SMU module has the same capabilities, but can provide 80 W.

The insights gained include:

- Idle current base level value
- Idle period duration
- Current drain values and durations of activities during the idle period
- Transmit current value and RF power amp power added efficiency (PAE)
- Transmit current duration

Accurate current drain measurements yield deep insights that enable exceptional battery run time for your devices

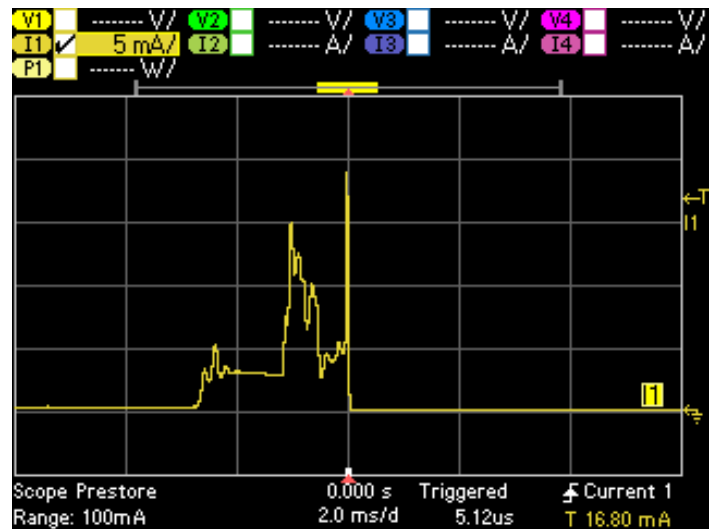


Figure 1. Wearable fitness monitor current drain waveform shown on the N6705B DC Power Analyzer with an N6781A SMU installed

TIP 2: Improve Measurement Accuracy to Ensure Longer Battery Run Time in Power-saving Operating Modes

Evaluating a device's current drain in sleep modes is fundamental to optimizing battery run time.

Most IoT devices spend the majority of their time in standby or other low-power modes. The device occasionally wakes up and briefly enters an active state to process data or communicate. The resulting current drain has the following characteristics:

- Long period of tenths to tens of seconds
- Extremely low duty cycle of tenths to several percent
- Extremely high crest factor (100 or higher)
- Wide dynamic range (up to 600,000:1 current ratio between operating and sleep modes)

Although the sleep/standby power consumption is very low, these low-power modes consume much of the battery's capacity. The long times spent in low-power modes requires unprecedented accuracy to optimize battery run time, which can be challenging for conventional test equipment. Even if the instrument (including digitizing data acquisition equipment) can adequately integrate the measurement over an appropriate duration, its fixed measurement range may not have sufficient dynamic range to accurately measure both the peak pulse and baseline sleep currents. Because of waveform's relatively high peak value, the instrument's offset error for the required measurement range is often comparable to the average value, resulting in unacceptably high measurement error. Workarounds may improve some measurement aspect, but they usually have other tradeoffs, such as limiting bandwidth.

Current drain measurement example for a power-savings mode

Consider a wireless temperature transmitter's that has a pulsed current drain with the following characteristics:

- Period of 4 seconds
- Duty cycle of 0.17%
- Crest factor of 400

Because the power level is under 20 W, a Keysight N6781A DC SMU was used to power and measure the temperature transmitter's current drain. The SMU includes a high-speed digitizer for measuring current drain on wireless devices. The current drain was first measured using the SMU's fixed 100-mA measurement range, as shown in Figure 2. This is comparable to using conventional test equipment. However, the N6781A also includes an innovative, seamlessly ranging measurement system that continuously digitizes a device's current drain from nanoamps to amps at more than 195 KSa/sec. This provides accurate measurements over a greatly extended dynamic range. Figure 3 captures the improved result with the N6781A's seamless ranging.

The seamless ranging yielded the following results:

- 100x improvement in sleep current base measurement error, from 115% to 1.15%
- 75x improvement in overall average current measurement error, from 18.9% to 0.245%
- 5x improvement in the noise floor, from 47 μ A to 10 μ A_{pp}, and high speed digitizing yields greater insight into sleep activities

Furthermore, the high-speed digitizing yielded greater insights into both sleep and transmit activities. Combined with seamless measurement ranging, this provides useful insights for evaluating power-savings operating modes when optimizing battery run time.

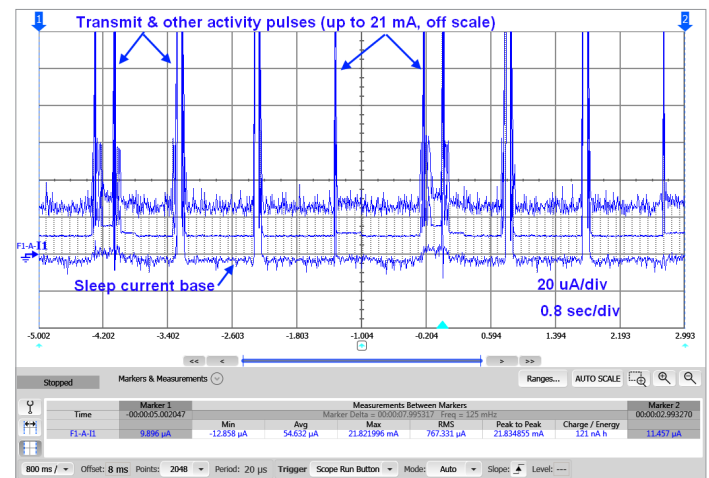


Figure 2. Wireless temperature transmitter current drain measurement shown using the 14585A software and an N6781A set to a fixed measurement range

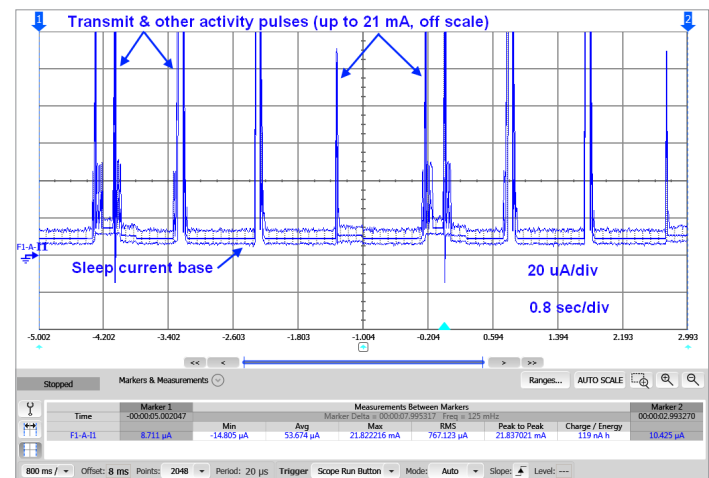


Figure 3. Wireless temperature transmitter current drain, measurement shown using the 14585A software and an N6781A using seamless ranging

TIP 3: Analyze Distribution Profiles to Optimize Battery Run Time

To optimize battery run time, you want a quick and easy visual to quantify the impact of design changes on a wireless mobile device's long-term current drain.

The activities of various sub-circuits in IoT devices may vary widely, depending on user behavior, program settings, the wireless environment, and the complexity of the device itself. The associated sub-circuit current drain varies correspondingly. Validating improvements from design changes requires you to log current drain over a substantial duration to average out random behavior. However, you need more detail about the impact of design changes when you are optimizing battery run time. Did you get the expected improvement? How do you determine which sub-circuits and activities were impacted? You can manually scroll through the data logs to estimate levels and durations of specific current bursts, but this approach has several drawbacks:

- It is extremely time consuming.
- Many values are estimates at best, due to the long-term random nature.
- It is easy to reach incorrect conclusions because of the difficulty of examining and quantifying countless millisecond-duration activities in up to hours-long data logs.

While long-term logging of a device's current drain is necessary, visual inspection of data log details is problematic. You need alternate methods to quickly and effectively analyze long-term current drain logs.

Analyzing probability distribution function profiles quickly and concisely illustrates and quantifies detail differences in long-term current drain resulting from design changes.

You can analyze the probability distribution function (PDF) of the long-term current drain to quickly and concisely visualize and quantify the impact of design changes. A PDF plots the current drain over time against the relative frequency of occurrence of the given current level, with the total being 100%. Histograms are the most common form of PDF, but complementary cumulative distribution functions (CCDFs) work particularly well for quickly illustrating long-term current drain and quantifying the impact of design changes.

What is a CCDF?

- Cumulative distribution function (CDF) = $\int \text{PDF}$ (area under curve = 1 or 100%).
- Complementary cumulative distribution function (CCDF) = $1 - \text{CDF}$.

A CCDF profile goes from 0% to 100% probability, while a CCDF profile goes from 100% to 0%, as shown in Figure 4. This image was captured using a Keysight N6781A with 14585A software. The X-axis is the current drain's amplitude and the Y-axis is its relative frequency of occurrence. Horizontal shifts in the profile are amplitude-related, and vertical shifts are time-related. You can use these shifts to quickly analyze and quantify detail differences in design changes, for optimizing battery run time.

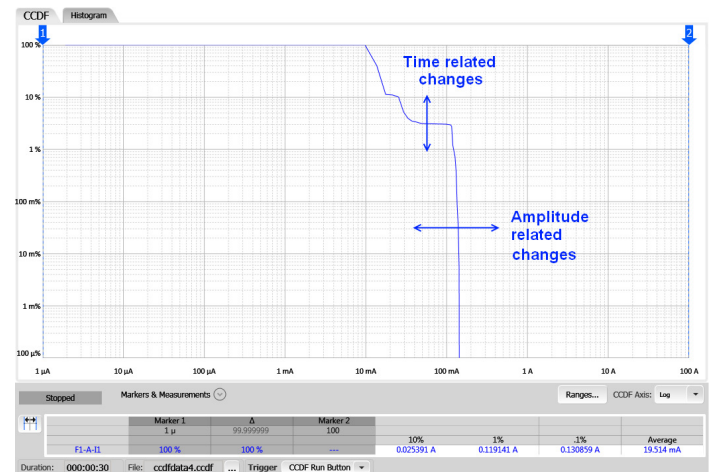


Figure 4. CCDF profile of a device's standby current drain using the N6781A and 14585A software

The CX3300 Series device current waveform analyzer also has a CCDF feature, and you can optionally display it with the FFT graph, as shown in Figure 5.

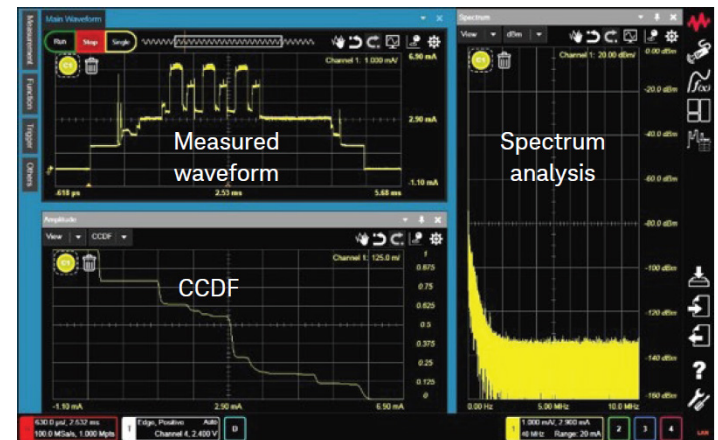


Figure 5. CCDF profile displayed with FFT on a CX3300 Series instrument.

Evaluating CCDF profiles to analyze power savings for a mobile phone's standby operation.

To extend battery run time for standby, mobile phones often employ discontinuous receive (DRX) operation. Compared to continuous receive, the power savings depends on, among other things, the level of sleep current you can achieve during inactive periods and how much you can minimize the receive activity time.

To evaluate a mobile phone's power savings, we used the N6781A DC SMU and 14585A software to log long-term current drain for continuous and discontinuous RX standby operation. As shown in Figure 6, we used the 14585A software to display and compare CCDF profiles of the two current drains to quickly and easily identify and analyze details of the power savings. By quantifying the vertical and horizontal shifts between the two profiles we found:

- A (vertical) change of 2.8% of RX activity at 128 mA returned 18% power savings
- A (horizontal) change of 11.9 mA in idle current returned 55% power savings
- The remaining 27% power savings came from reduced baseband activity
- The total power savings was 85.5%

As you can see, the CCDF helps you quickly and visually identify and quantify the detailed impact of design changes on sub-circuits and associated activities, which would be tedious with traditional approaches.

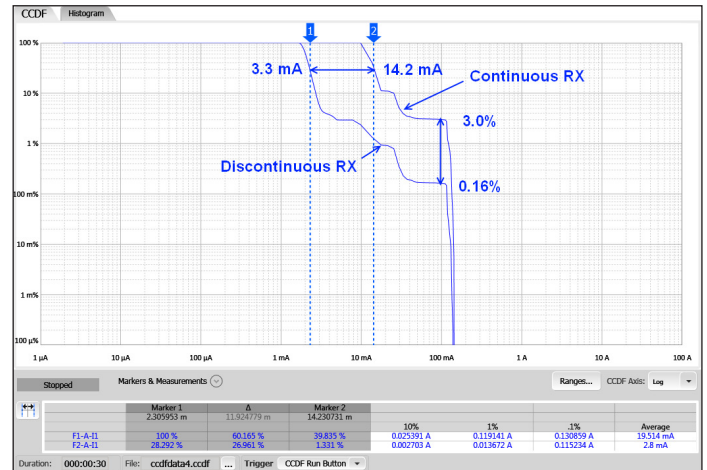


Figure 6. Analyzing a mobile phone's standby power savings details using CCDF profiles.

TIP 4: How to Emulate Devices' Battery test with More Realistic Results

Key consideration when powering a mobile device with a DC source is getting current drain test results comparable to that of using a battery, when optimizing battery run-time.

Batteries are very non-ideal energy sources because they interact with the device, influencing its resultant current drain. Accurate current drain results are essential for optimizing your device's battery run time. You must take the battery's characteristics into consideration when powering your device with a DC source to ensure your current drain results properly simulate battery current drain.

Figure 7 shows the pulsed current drain and voltage response on a battery-powered device. This shows that a battery has substantial series output impedance, causing its output voltage to drop proportionally to the device's current drain. Many devices adapt and adjust accordingly to compensate for the battery's characteristics. Specifically, the battery drops proportionally with current and the battery resistance is 150 mΩ.

A general purpose DC source strives to be an ideal voltage source with zero output impedance by using remote sensing feedback to keep its output voltage fixed. Unlike a battery, however, its voltage does not drop with load current. Also, feedback regulation has finite response time, which leads to voltage drop and overshoot during loading and unloading transitions. A substantially large transient voltage drop can even trigger a device's low battery voltage shutdown. Figure 8 shows the same measurements made in Figure 7 using a general purpose DC source instead of the battery. The very different voltage response results in a current drain 10% higher than when using the battery.

- Figure 7. A device powered by a battery
- Figure 8. General purpose DC source powering the same device

A battery emulator DC Source produces device current drain comparable to an actual battery.

DC sources tailored for battery emulation have these characteristics:

- Current sinking in addition to sourcing, to emulate a battery's charging current capabilities
- Programmable series output resistance to emulate a battery's impedance
- Extremely fast load transient response to minimize voltage drops and overshoots, and accurately emulate a battery's dynamic voltage response

Figure 9 shows the same measurements made in Figure 7 using a Keysight N6781A SMU with battery emulation capabilities, in place of the battery. The SMU's series output resistance was set to match the battery's 150 mΩ value. Both the voltage response and resultant current drain were comparable to those of the battery.

When powering your device with a DC source, emulate the battery's characteristics for current drain results comparable to those of a battery. A general purpose DC source does not behave like a battery, but a DC source with battery emulation capabilities helps ensure more accurate results. Both the N6781A (up to 20 W) and N6785A (up to 80 W) have programmable output resistance.

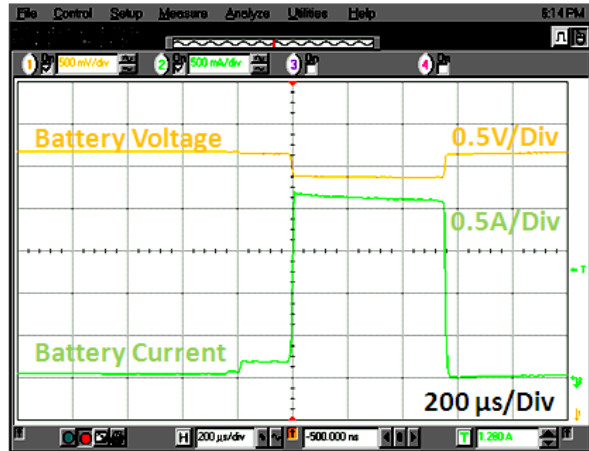


Figure 7. A device powered by a battery

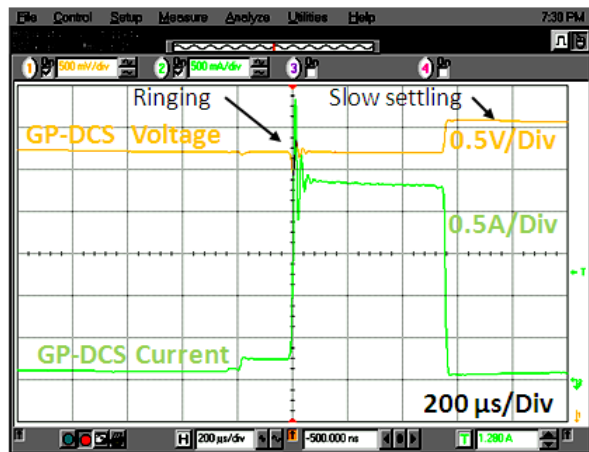


Figure 8. General purpose DC source powering the same device

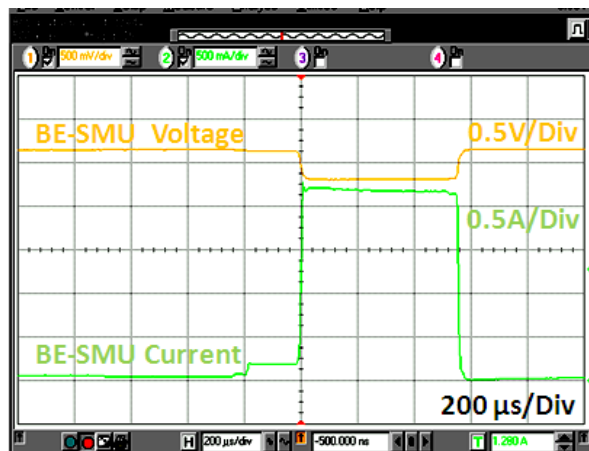


Figure 9. Keysight N6781A battery emulator SMU powering the same device

TIP 5: Simplify Validating a Battery's Capacity and Energy Ratings

A key part of determining a mobile device's run time is validating the battery's capacity and energy ratings.

If you determine a device's run time based solely on a manufacturer's data sheet without validating the battery's capacity and energy ratings, your results will likely be inaccurate. The data sheet capacity is often based on ideal conditions and represents the maximum possible charge. Actual capacity usually ends up being less when used in a real application.

Battery capacity is the amount of charge in ampere-hours (Ah) or milliamp-hours (mAh) the battery is specified to hold. This differs from the battery's energy rating, which is in watt-hours (Wh). The energy rating is usually the battery's capacity (Ah) times its stated nominal voltage (V). Depending on your application, one value may be more important than the other, so it is important to validate both values. Temperature and battery age also affect the charge obtained from the battery, so you must also take these into account when measuring run time.

Validating a battery's stated capacity and energy ratings requires accurate voltage and current logging under precisely controlled conditions.

Very small differences in charging (for rechargeable batteries) and discharging conditions can lead to large differences in the capacity and energy obtained from a battery. That is why it is paramount to precisely replicate and control all conditions for achieving good results. One key condition is the discharge rate, usually stated as a constant current discharge at some ratio of the Ah capacity rating, referred to as the C rate. The C rate is the reciprocal of the battery run time. Higher discharge rates lead to lower capacity and energy delivery, so a C rate of 0.3 would theoretically fully discharge the battery in 3.33 hours. For a 2-Ah battery, a C rate of 0.3 would be 0.6 A constant current discharge. The measured energy rating may differ from that based on the stated nominal voltage, as the actual battery run down voltage profile may slightly change the result. Precisely controlling test conditions while accurately logging the battery's current and voltage ensures accurate, consistent results when determining the battery's capacity and energy ratings.

Example of validating a battery's capacity and energy ratings:

We used the setup depicted in figure 10 to discharge a rechargeable lithium ion battery at a fixed C rate. The full 2-quadrant capability on the Keysight N6781A and N6785A source/measure units makes them well suited for use as a precision high-performance electronic load as well as a precision DC source. We quickly configured a constant current discharge of 0.3 A with 3.0-V cutoff voltage and long-term data logging to validate the capacity and energy ratings using the companion Keysight 14585A software. The validation results and energy ratings of the battery are shown in Figure 11. Placing measurement markers at the start and cutoff voltage points on the data log revealed the battery delivered 879 mAh and 3.32 Wh, both significantly lower than the 1 Ah and 3.6 Wh ratings on the battery's data sheet. The next steps are to identify what factors lead to the difference and to assess whether additional capacity can be extracted from the battery. As this example shows, you should validate the battery's capacity and energy content rather than relying on the product's data sheet.

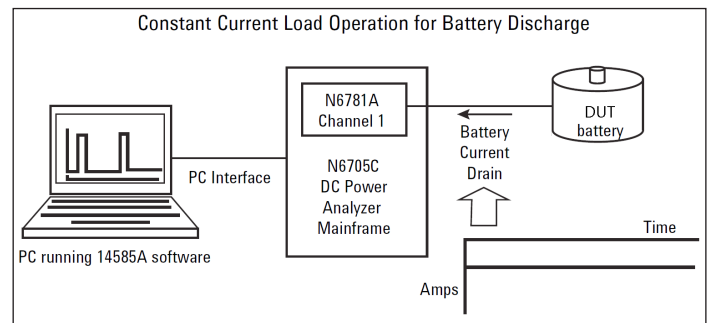


Figure 10. Using a constant current load to discharge a battery at a fixed C rate.

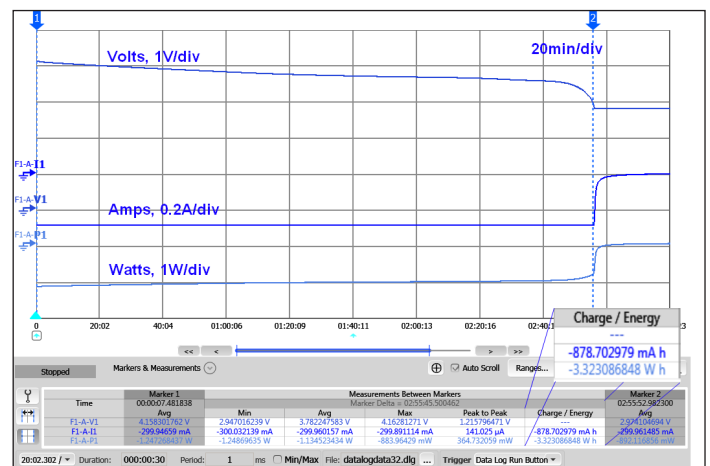


Figure 11. Measuring a battery's capacity and energy using the 14585A software and N6781A SMU.

One tool particularly well-suited for this task is the Automatic Current and Power Profiler of the CX3300 device current waveform analyzer. It automatically divides the waveform into segments and provides a complete analysis of each waveform segment in both graphical and tabular format.

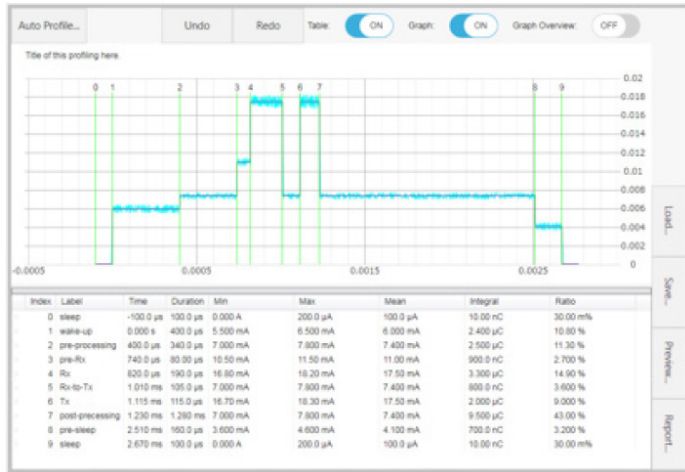


Figure 12. Using the Automatic Current and Power Profiler on the CX3300 to analyze current drain.

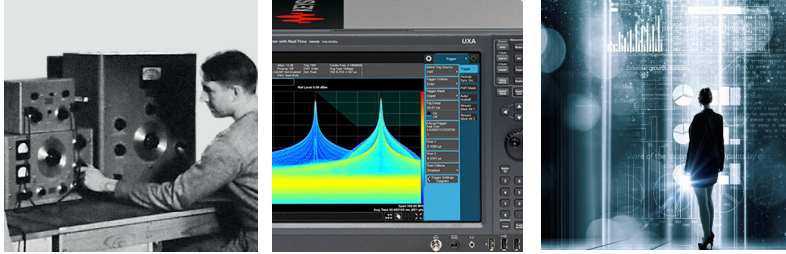
Conclusion

As battery-powered IoT devices have come an important part of everyone's life, battery consumption becomes a critical factor of the device's performance. More and more studies are focused on improving the power efficiency of low power devices. We hope these tips help you overcome your design challenges. For more information, kindly visit <http://www.keysight.com/find/iot>.

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