Using Battery Drain Analysis to Improve Mobile-Device Operating Time

Using specialized tools and analysis techniques can help you create mobile-device designs that extend battery life.

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Battery operating time continues to be a critical factor in the design of mobile wireless devices. With the trend toward smaller and lighter mobile devices, using a larger battery is not a viable option. Instead, designs must get the most out of the battery. Analysis of battery current drain can help with optimizing the battery operating time of these devices.

Battery drain analysis is more than estimating battery life. Battery drain analysis entails testing and characterizing the device, its subcircuits, and the battery, both independently and in combination. It includes employing methods of characterizing current drain out of the battery using different device operating modes and parameters, thereby providing insight into how device operation affects battery drain. This enables analysis of design tradeoffs that impact current drain, so that the device can be designed to maximize battery life.

Examples of how battery drain analysis during the design stage of a mobile wireless device can be used to extend battery life include:

- Analyzing differences in current drain due to variations made in data transmission to optimize operating life. Some variations include packet size versus number of packets, and number of data channels used versus transmit time.
- Quantifying differences in current drain due to changes made in digital baseband operation to optimize the power efficiency of data processing.
- Identifying anomalous behaviors and measuring their effects on power consumption. Anomalies include unusually long or high pulses, and random overloads that lead to early low-voltage shutdown and reduced battery operating time.

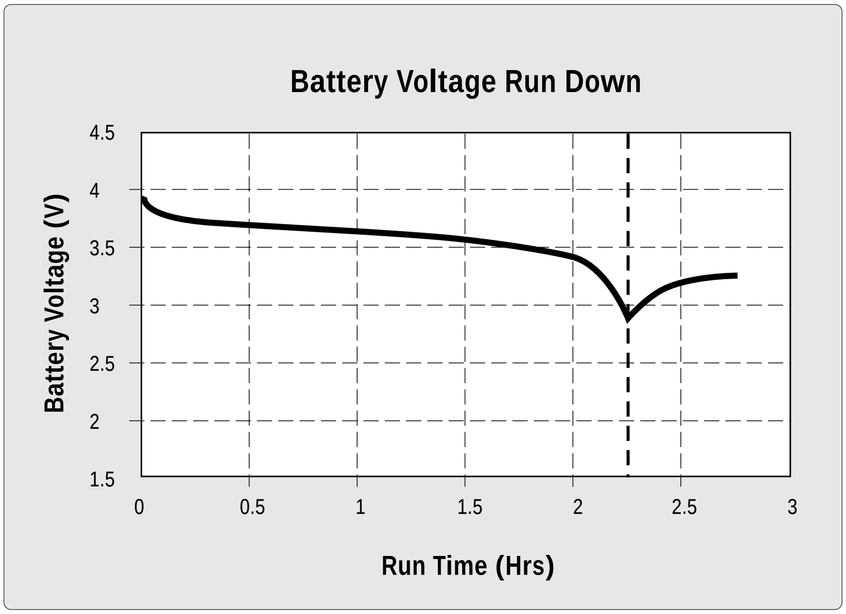


Figure 1. A battery voltage rundown time test is a straightforward method to measure battery operating time, but it does not provide DUT current drain or other information.

- Quantifying the current-drain distribution to help with determining the dynamic power and current requirements, allowing selection of the appropriate battery, power regulator, and power-management circuits.

Traditional Approaches

Reviewing traditional methods employed for validating battery life serves as a basis for discussing why these approaches are not adequate for battery drain analysis, and for describing a better system.

One traditional approach to validating battery operating time is to use a voltage-rundown-time test. With a fully charged battery, the device under test (DUT) is placed into the operating mode to be validated. The battery voltage is logged against time as the DUT runs and finally shuts down. On **figure 1**, the voltage inflection point at 2.25 hours shows how long the DUT ran before its low-voltage shutdown occurred.

This approach has several advantages. It is relatively simple to implement. Voltage measurement is straightforward and does not affect the accuracy of the result. Due to the slow rate of change, a low sampling rate is adequate. Finally, because it is a full-duration test, the user can run a benchmark type of test with dynamic operating conditions that simulate real-world conditions.

One disadvantage of this approach is that it is relatively time-consuming. Once started, it must be run to completion to determine operating time. Another disadvantage is that the results depend on the initial state of the battery, which can vary considerably and is not necessarily representative of a typical battery. Further, the only result yielded is operating time. Validating the DUT current drain and battery capacity provides a much higher level of confidence in the operating-time result.

An alternative method for determining battery operating time is to make a current-drain measurement. Again with a fully charged battery, the DUT is placed into the operating mode to be evaluated. The average current drain is then measured for a defined period of time deemed representative of the overall run time. The operating time is then calculated by dividing the stated battery capacity in milliamp-hours by the measured current drain in milliamps.

The advantages to this approach are that battery operating time is determined in much less time than the full run time, and the average current drain is now quantified. If the stated battery capacity is representative for the DUT loading, operating time should be reasonably accurate.

A disadvantage of the current-drain approach is that due to the high-speed, high-amplitude pulsed loading, the current needs to be sampled at a high rate to ensure that an accurate average value is obtained. One specification recommends a 50-kHz sampling rate. Another disadvantage is that running a short test does not lend itself to running a long-term benchmark-type test utilizing a series of different operating conditions.

Further, measuring current is more difficult than measuring voltage, and errors are easily introduced.

An Ideal System

Traditional methods for measuring battery life have limitations and cannot supply the information necessary to provide the required insight to optimize designs. An ideal system for performing battery drain measurement and analysis would:

- properly source power to the DUT
- log battery rundown voltage for validating operating time
- accurately measure current from milliamps to ampere levels
- be able to log the current drain and other data for durations from minutes to days, to address the variety of test scenarios required
- provide a post-test summary of basic test results such as run time, average current, average voltage, and amp-hours and watt-hours consumed
- provide data analysis for understanding how operational anomalies affect battery life, and to enable design optimization

Based on these requirements, a generic system for battery drain measurement and analysis would have the elements shown in **figure 2**. Traditional solutions and new, better approaches for each of these elements are described below.

First, a means for placing the DUT into the appropriate operating mode for the desired testing is needed (DUT stimulus). For mobile phones, a base-station emulator is usually used to interact with

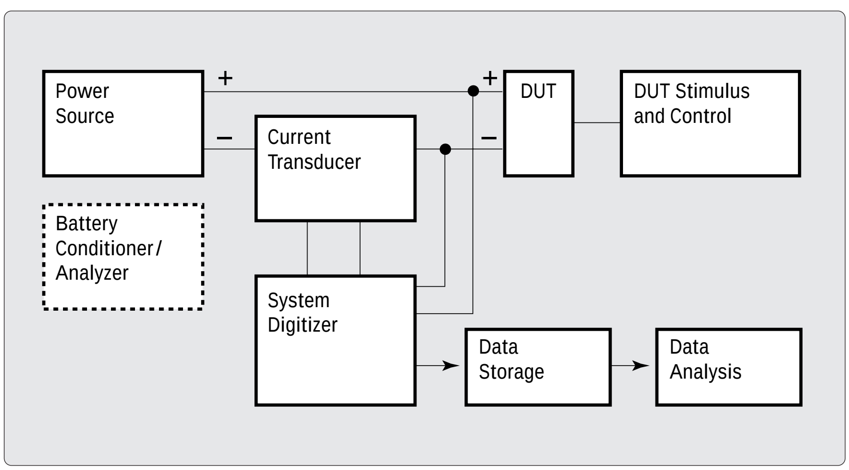


Figure 2. A generic system for battery current-drain measurement and analysis

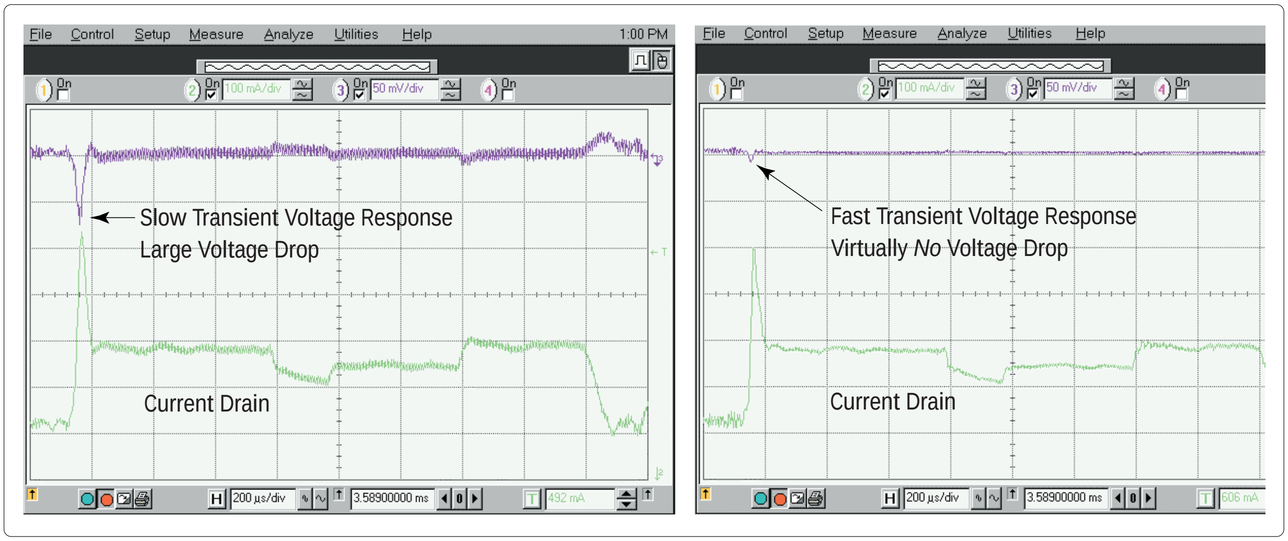


Figure 3. Transient voltage response of two power sources when powering a *Bluetooth*-enabled headset: a general-purpose power supply (left), and a specially designed power source (right)

and provide the necessary protocol for DUT operation. Second, a means of properly powering the DUT is required, using either a battery or a power supply. A power supply is useful for testing the DUT independent of its battery. Likewise, a battery conditioner/analyzer is helpful for evaluating the battery independent of its DUT. Other important system elements are a transducer for measuring the current without introducing error, equipment to digitize and log the voltage and current signals over long periods of time, and a system for storing the digitized test results and providing post-test analysis.

Power Source Options

The power source provides controlled power to the DUT. The battery is a traditional source of power for conducting run-time validation testing, and it makes sense to use the actual battery, where the battery and DUT are to be tested in combination. However, a battery is not a controlled source and its voltage continually changes with use, temperature, and charge. Other testing is better served with a controlled voltage source.

A power supply can provide a controlled voltage that doesn't vary with time. Remote voltage sensing allows the user to control the voltage right at the input of the DUT. However, a problem with using a general-purpose power supply is that its voltage response is different than that of a battery, due to its slow transient response and zero output resistance. The ideal power source would be a specialized power supply with fast transient response and settable output resistance, so that it emulates the response of a battery.

It is vitally important to minimize any voltage drops when powering digital wireless devices running off of only 1 to 4 volts of bias. A general-purpose power supply is designed to provide stable DC power for a wide variety of loads and conditions. It typically has a large output capacitor to reduce output ripple voltage, but this leads to its slow transient voltage response. **Figure 3 (left)** shows that a general-purpose power supply has about 80 mV of transient voltage drop in response to the pulse loading of a *Bluetooth*™–enabled headset. This was with a relatively short (1 meter) length of wiring, typical of a bench setup.

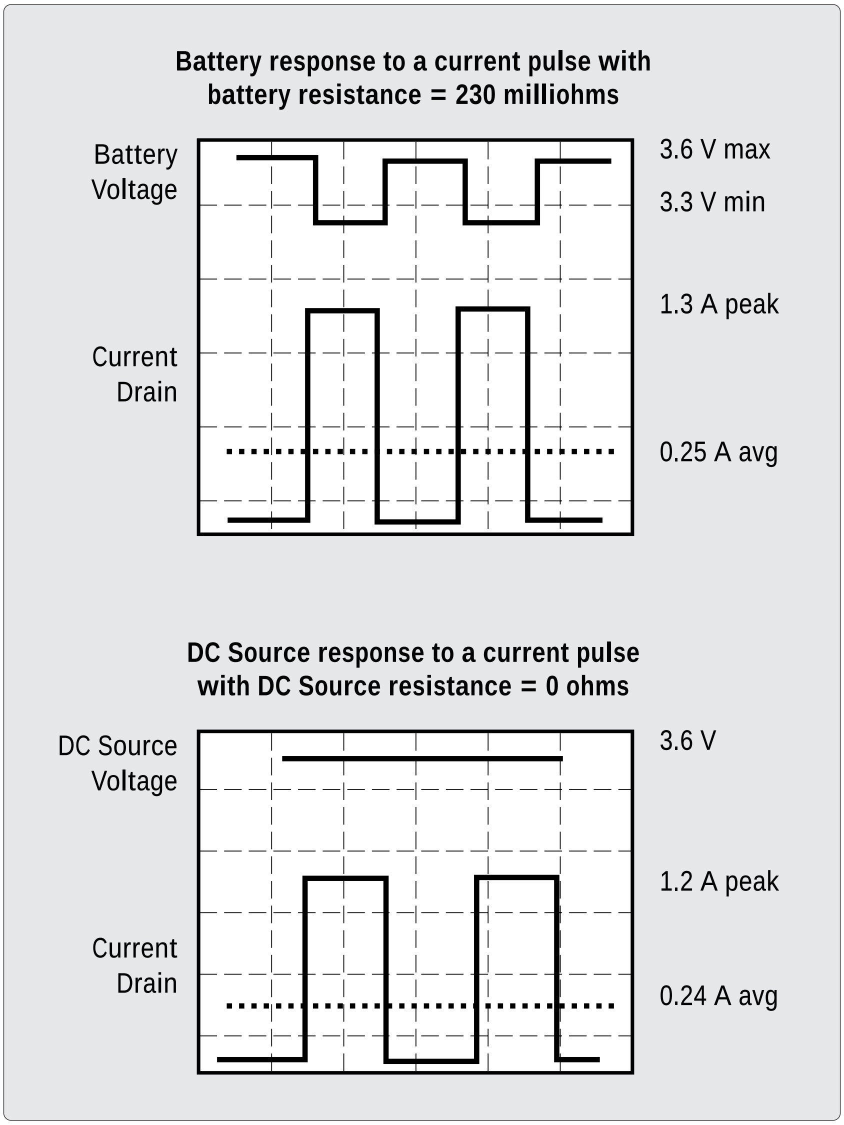


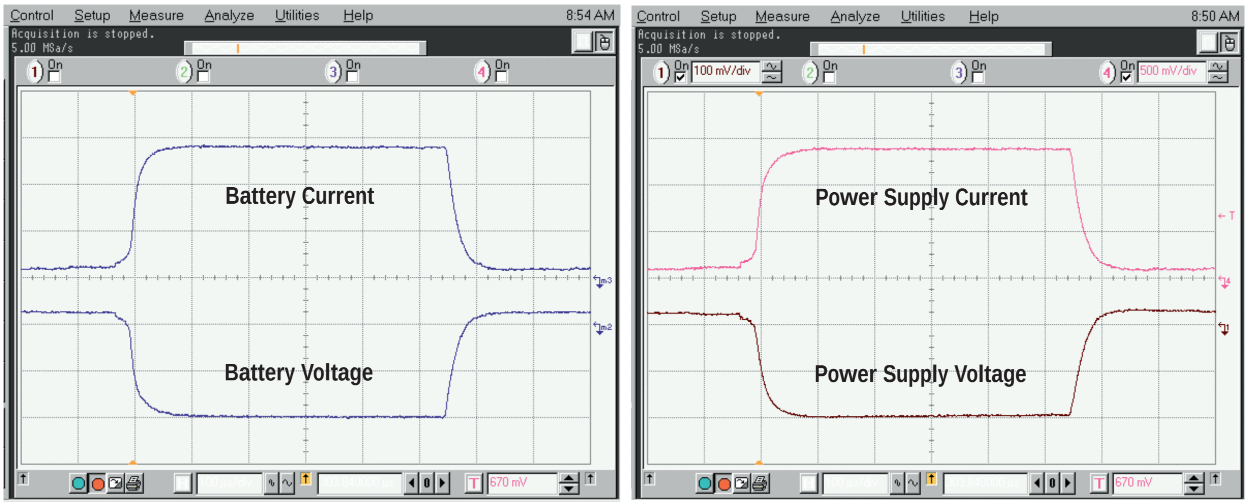
Figure 4. A GSM mobile phone performs differently when powered by a power supply with zero output resistance than when powered by an actual battery, making battery operating time appear longer than it would under realistic conditions.

In comparison, when a power supply with fast transient voltage response (specifically designed for powering digital wireless devices) is used, the transient voltage drop is greatly reduced. **Figure 3 (right)** shows that the transient voltage drop is reduced to about 12 mV when the headset is powered by the Agilent Mobile Communications dc Source, a power source designed for use when testing mobile communications devices.

Battery resistance also affects a device's run time. **Figure 4** shows the loading characteristics of a GSM mobile phone, comparing its performance when powered by an actual battery versus a power supply. Many mobile devices draw higher peak and average current to offset the lower operating voltage due to the resistance voltage drop.

In the upper graph (testing with an actual battery), the battery voltage drops by almost 300 mV in response to the GSM phone transmit burst current, due to the battery resistance. This response increases the current drain by about 5 percent. Another impact is that the peak voltage drop will cause the mobile phone to reach its low-voltage shutdown earlier.

In the lower graph (testing with a power supply with zero output resistance), the current drain is about 5 percent lower than what would be experienced in actual use with a battery. The exact difference depends on the design of the particular mobile phone. As a result, the estimated operating time, based on current measurements using a power supply with zero output resistance, can be higher than when using an actual battery.



Battery R = 0.170 ohm

Power Supply Resistance programmed to 0.170 ohm

Figure 5. When the output resistance of the Agilent Mobile Communications dc Source is correctly programmed (right), its voltage response performance is the same as a battery's (left).

Again, a battery is not an ideal voltage source. **Figure 5 (left)** shows how a battery's output voltage drops in response to its load current, due to the battery's internal resistance. In addition to having fast transient voltage response, a power supply should have programmable output resistance to emulate the internal resistance and voltage response of a battery.

Figure 5 (right) shows the voltage response of the Agilent Mobile Communications dc Source with its output resistance programmed to match the battery's internal resistance of 170 milliohms. Its voltage response performance is the same as that of the battery.

The specialized power supply is better than the actual battery for current-drain analysis in many ways, as its output voltage and output resistance are controllable and time invariant. Keeping the source fixed over time removes power from the list of variables when conducting controlled trials and comparing different devices and design changes.

Ways to Measure Current Drain

The next element for a battery drain analysis system is a current transducer to measure current drain. The wide dynamic range of current drain dictates two measurement ranges for testing the two primary operating modes: standby and active. The nature of pulsed current drain with high peak but relatively low DC average requires relatively high measurement ranges with very good full-scale accuracy in order to ensure adequate accuracy at the lower average value. Typically a 1-A range is needed for standby and a 5-A range is needed for active operation, with a basic accuracy of 0.2 percent of full scale.

One traditional solution is a current shunt. The DC voltage drop is also a problem with shunts. The GSM TW.09 specification calls for 0.5 Ω and 0.1 Ω for standby- and active-mode testing. Depending on peak currents and operating voltage, this could present a challenge, especially for lower battery voltages. Assuming the peaks are as high as 1 A and 5 A respectively, the shunt voltage drop would be 0.5 V peak. This would not be well suited for battery voltages under 4 V.

Other problems with using shunts are that thermal EMF voltages can introduce large offset errors, and grounding and common-mode signals need to be addressed or can likewise introduce errors.

This combination of limiting the maximum resistance and voltage drop at the high end of the measurement range, and error signals at the low end of the measurement range, makes it challenging to cover the dynamic range needed when using a current shunt.

A second traditional solution is a clamp-on DC current probe. This method has negligible voltage drop but requires periodic recalibration for offset drift. The ability to zero-out the offset and control its drift likewise limits the dynamic range of measurement with a current probe.

A specialized power source that incorporates current measurement internally resolves many of the challenges of using an external current transducer.

Digitizing Methods

The next element, a system digitizer, measures the current-shunt voltage and bias voltage to the DUT and converts them to digital data for storage and post-processing. A sample rate of 50 kHz or faster is required to accurately capture the sub-millisecond pulses and anomalies characteristic of digital wireless devices.

Traditional solutions include high-speed analog-to-digital converters (ADCs), sampling DVMs, and digital oscilloscopes, all with deep-buffer memory for caching the high-speed data. There are dedicated high-speed data logging and storage systems available, but these can be fairly expensive. Lower-end solutions may require considerable effort to custom configure them for a particular application. Also, high-speed data transfer can be a problem when testing runs for an extended period of time.

A power supply integrated with a high-speed digitizing measurement system is a specialized solution for digitizing the measurements while powering the DUT. The Agilent Mobile Communications dc Source uses a high-speed DSP-based digitizing measurement system, much like that of a digital oscilloscope. It has three DC current ranges to provide accurate current measurements in active, standby, and off modes, specially tailored for digital wireless device testing.

Data Storage and Analysis

The final elements for a battery drain analysis system are data storage and analysis. Data storage requirements include the ability to record and store the high-speed digitized data for tests of durations from minutes to days. Analysis requirements include a run-time summary and post-test processing of basic results. Run-time results include average current and voltage, and amp-hours and watt-hours consumed.

The analysis software should be able to identify anomalies in the data. The most common anomalies for digital wireless devices include unusually high or long pulses of significant occurrence to affect drain, as well as the infrequent, random overload spikes that can cause premature device shutdown due to battery voltage droop.

Traditional solutions for storage include PC and disk drive, or a high-end data logger. Commercial spreadsheet software packages are typically used for analysis, and custom-programmed routines are required to search for anomalies.

A commercial data-logger system with storage can be fairly expensive. Tests that run for hours to days create massive amounts, up to gigabytes, of data, and files this size become impractical. Consequently, tests employing high-speed data capture are run for only minutes in actual practice.

An ideal system would first process and reduce the data, and then provide storage and analysis capabilities. The Agilent 14565A Device Characterization Software is an easy-to-use graphical front panel for the Agilent Mobile Communications dc Source. It runs on a PC and features three modes of operation to provide source control, measurement, and analysis without requiring any programming.

The Waveform Capture and Analysis operating mode provides an effective means of capturing and displaying an oscilloscope-like view of the battery current drain over a short period of time. Built-in measurement functions include average, and pulse minimum, low, high, and maximum values. These capabilities permit making basic estimates and analysis on battery current drain and operating time.

The Data Logging and Analysis operating mode allows data logging from 10 seconds to 1000 hours. Over this duration the Agilent Mobile Communications dc Source continuously samples the current at a 64-kHz rate to capture high-speed details and random overloads. Voltage can also be sampled at a low rate to support average voltage and watt-hour measurements.

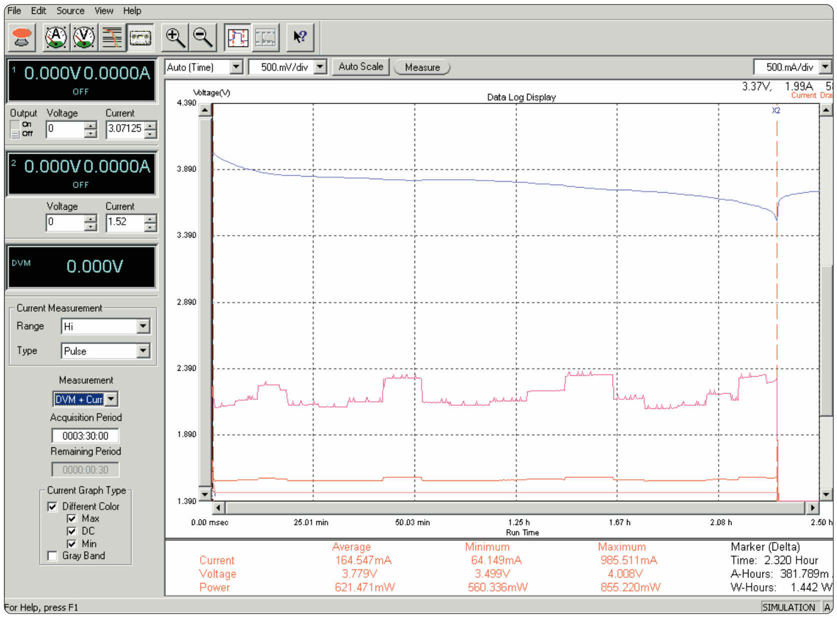


Figure 6. Device Characterization Software screen capture displaying minimum, maximum, and average currents, and average voltage waveforms over time.

Figure 6 is a screen capture showing the display of minimum, maximum, and average currents, and average voltage waveforms and numerical values over time. This is illustrating running the DUT with dynamic sequence, changing its active output transmit power level over time. A special integrating feature resolves the data overload problem of traditional solutions.

The integrating feature reduces the data to meaningful and manageable results as it is captured in real time. In a traditional approach, sampling at a 64-kHz rate results in 64,000 data points at the end of a 1-second period. In comparison, with the integrating method used in the Device Characterization Software, each integration period (up to 1 second long) provides a minimum, maximum, and average value for each period of the 64-kHz-sampled data. This effectively provides data reduction up to 64,000 times taking place in real time in the instrument.

The reduced data is more meaningful as it captures the relevant average and peak values. Tracking the peak provides a way of identifying infrequent, random (thus hard to capture) overloads that could cause early low-voltage shutdown. The reduced data is now more manageable for storage, post-test analysis, and export, requiring about 5 MB for less than 100 hours, and another 5 MB for each subsequent 100 hours. The system logs the data to the disk drive to prevent loss of data in the event that the test is inadvertently interrupted. There is no need for high-speed data streaming to a PC.

CCDF Makes Complex Analysis Easier

Newer digital communications systems such as 3G use complex modulation formats with high levels of amplitude modulation for transmitting higher data rates. The resulting current-drain waveforms are complex and random when viewed in the time domain.

Figure 7 shows current drain versus time for an RF power amplifier of a cdma2000 handset transmitting with three data channels.

The current drain similarly gets more complex and unpredictable when run over long periods typical of a battery operating time test. As a result it becomes difficult to predict average and peak values for estimating battery operating time or to easily observe the effects of design changes on current drain for optimizing battery operating time. A better way to visualize and analyze complex current-drain patterns is to examine their statistical distribution, such as with a complimentary cumulative distribution function (CCDF) graph.

A CCDF graph is an alternative, cumulative form of a histogram or probability distribution function. It is a display of the current or voltage on the x-axis versus its cumulative percent of occurrence on the y-axis. The 14565A Device Characterization Software includes a CCDF Capture and Analysis mode for long-term current-drain measurement **(figure 8)**. It can be used to quantify and analyze the DC current

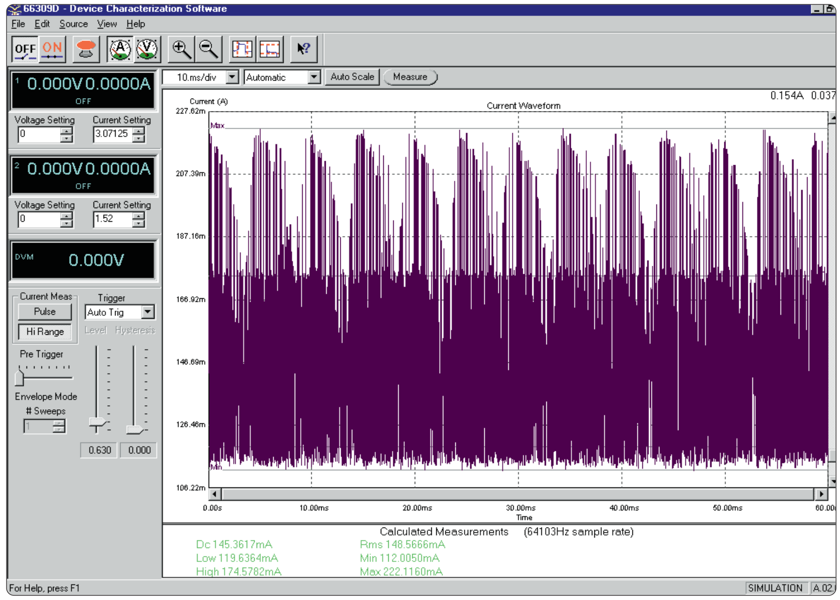


Figure 7. The current-drain waveform of the RF power amplifier of a cdma2000 handset is complex and unpredictable when viewed in the time domain.

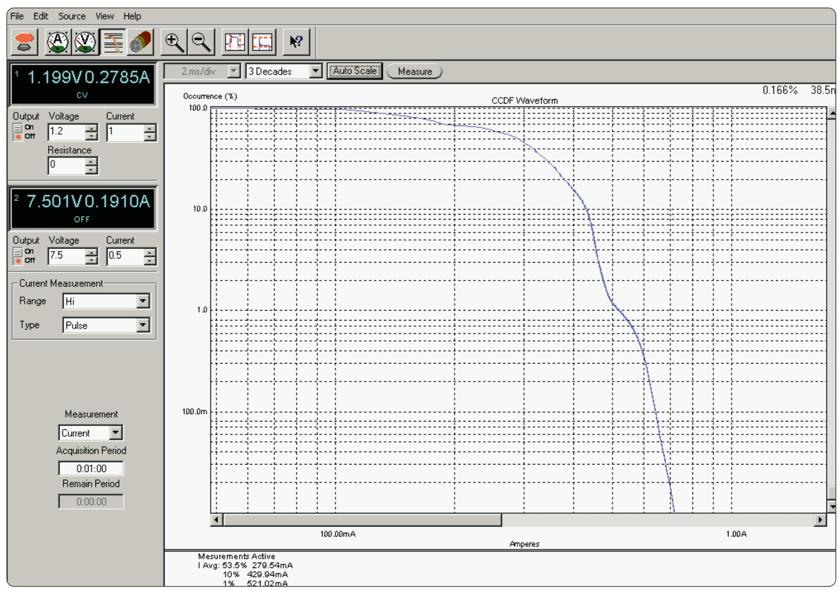


Figure 8. Vertical and horizontal shifts in a CCDF graph quantify current-drain differences due to design changes.

drain of a digital wireless device for the purpose of optimizing its operation to extend battery life. One advantage of a CCDF graph is it expands the scale at higher amplitude current, which is an area of interest.

In CCDF mode, the Device Characterization Software can continuously accumulate current or voltage over a period of 10 seconds to 1,000 hours. During this period the data is sampled at 64 kHz to capture and characterize high-speed details of the signal. It accumulates and builds the CCDF internally, so there is no need for high-speed data streaming or storage of large data files.

Numerical results include average value versus percent occurrence, peak value, and intermediate values at each decade of percent occurrence. Built-in tools for save, recall, and compare quantify changes between different CCDF graphs. These are useful capabilities to analyze subtle effects of design changes for device optimization.

Vertical and horizontal shifts in the CCDF graph quantify differences due to design changes, and are key to analyzing behavior and optimizing battery life. Vertical shifts indicate time-related changes. Some causes of vertical shifts are pulse widths of a particular amplitude that are different than expected, or that are occurring at a different rate than expected. Horizontal shifts indicate amplitude-related changes. One cause of horizontal shifts is a certain pulse drawing a different amount of current than expected, perhaps due to incorrect calibration of the RF output power control.

Specialized Tools Facilitate Design Optimization

Employing battery drain analysis tools and techniques in your battery-life testing allows you to analyze and optimize designs for maximum battery run time. A specialized solution such as the Agilent Mobile Communications dc Source makes current-drain measurement faster and more accurate. Fast response sourcing with programmable resistance simulates the performance of a battery. An integrated high-speed digitizing measurement system resolves the challenges of using conventional current shunts, probes, and digitizers. Data logging and analysis functions such as those provided by the Device Characterization Software improve design analysis and optimization by providing effective data reduction and visualization of long-term current drain. These tools are a useful complement to an overall test portfolio for mobile wireless device product development.

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