APPLICATION NOTE

Battery Drain Analysis for Low-Power IoT Devices

The Challenge

Low-power devices associated with the Internet of Things (IoT) consume power at highly variable rates, from microseconds to seconds, and from picoamperes to amperes. Accurate battery drain measurements are critical to achieving the long battery life customers expect, and Keysight's broad range of solutions enables engineers to get convenient, fast, and accurate results that properly characterize battery drain on IoT devices.

The spectrum of design and testing needs

It is no longer sufficient for an IoT device to last a few years between battery replacements. Customers often expect 10-year battery life in many applications, and some vendors even advertise "leave for life" or "set and forget" devices that last for the application lifetime, often well beyond a decade.

To meet these expectations, chipset designers create integrated circuits with deep sleep modes that consume very little current. These devices have operation modes with slow clock speeds, reduced instruction sets, low battery voltages, and low current consumption. These applications require testing at three to six orders of magnitude of current levels for events lasting microseconds or milliseconds.

To reduce the relatively large power consumption associated with wireless communications, standards groups are defining new low-energy operating modes that combine low radio-frequency (RF) power levels and simple connection protocols that limit active operation time. Wireless module manufacturers extend battery life by designing and testing programs for embedded processors to shorten power-hungry states.

KEYSIGHT TECHNOLOGIES

The product designer who integrates sensing, processing, control, and communication components into a final product must know how peripherals behave and consume power. This designer has additional software or firmware control over power supplies, analog and mixed-signal components, and digital and RF subsystems. As the product goes into production, a simpler set of tests and test equipment can verify proper device operation quickly and inexpensively.

These different needs challenge the engineer to make measurements with widely varying levels of detail at each step of the development process. The chip designer and module designer need very fast evaluation of power consumption in various device operating states. The module designer needs similarly fast measurement over many orders of magnitude on any of several chips, correlated to module firmware operations. The product designer may need slightly less precise time resolution but must know accurate overall power consumption throughout the hardware and software development process. Finally, the manufacturing test department needs to know the device operates correctly, perhaps using a simpler set of test equipment.

Wearable IoT devices

Users wear some IoT devices, such as hearing aids, digital eyewear, and fitness trackers. Because these devices are often in operational (nonsleep) modes, they tend to have shorter battery lives. Figure 1 shows a typical block diagram for a wearable fitness tracker.

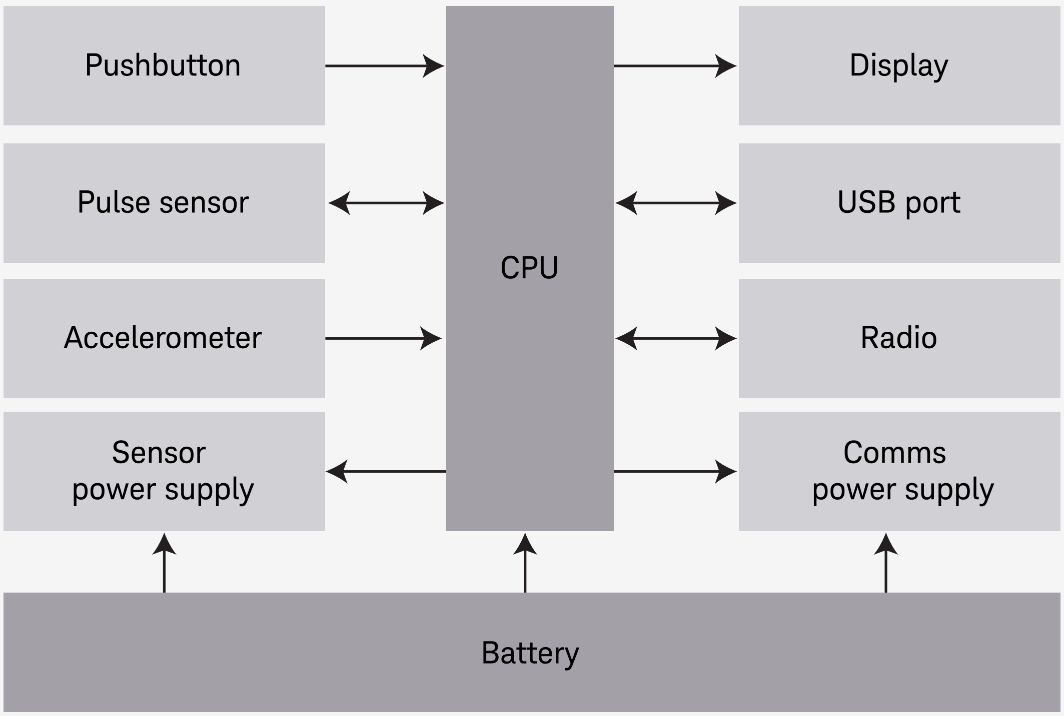


Figure 1. Block diagram for a wearable fitness tracker

Wearable fitness devices have sensors and RF components that intermittently measure, store, and send data. To optimize the power budget and usability, the design engineer may use a variety of instruments and software to characterize energy measurements and then tune the CPU firmware to optimize the energy used during each operation. The rest of this document describes five such devices, summarized below.

Table 1. Key specifications of Keysight's battery life solutions

					CX3300 [3] Series device current waveform analyzer	
	34470A DMM	**N2820A scope probe**	**B2900 [2] SMU**	**N6705C / N6781A DC power analyzer and SMU**	**Normal**	**Hi res**
Display size (diagonal)	4.3"	Scope dependent	4.3"	5.9"	14.1"	
Bandwidth, sample rate	17 kHz, 50 kSa/s	500 kHz, 5 GSa/s	10 kHz, 100 kSa/s	29 kHz, 200 kSa/s	140 MHz, 1 GSa/s	15 MHz, 75 MSa/s
Meas. resolution	14 bits	14 bits	20 bits	18 bits	14 bits	16 bits
Min measurable pulse width	100 µs	2 µs	100 µs	25 µs	5 ns	50 ns
Min measurable static current [4]	10 pA	500 nA	1 pA	800 nA	150 pA	
Min measurable dynamic current (10 kHz BW)	10 nA	500 nA	10 fA	2.4 µA	150 pA	
Max measurable current	10 A	5 A	3 A	3 A	50 A	
Min/max source current	(none)	(none)	3 A	3 A	(none)	
Burden voltage [5]	27 mV	1 mV	0 mV	0 mV	4 mV	
Price	+	++	++	++	++++	
Typical use	R&D / Mfg	R&D	R&D	R&D / Mfg [1]	R&D	

1. Using N6700 frame with N6781A SMU in mfg and N6705A frame with N6781A SMU in R&D.
2. 1 pA is RMS noise (NBW = 0.1 Hz to 10 Hz).
3. 150 pA is RMS noise (NBW = 10 Hz to 20 MHz).
4. Accounts for typical noise with 1% error and quasi-DC current measurement.
5. When measuring 10 mA on appropriate range; the N6781A and B2900 Series both source current, so always 0 mV burden voltage.

Table 2. Key benefits and tips of Keysight's battery life solutions

	Benefits	Tips
34470A DMM	• Low-cost, readily available tool • High precision up to 7.5 digits • Measures static, low- or high-level currents • Digitize mode useful for capturing waveforms up to 10 kHz at 4.5 digits • Small form factor fits easily into rack	• Avoid fast-changing signals • Use fixed range to avoid measurement discontinuities
N2820A current probe	• High sensitivity • High dynamic range • Excellent bandwidth for fast-changing signals up to 3 MHz • Works with many readily available oscilloscopes • Very flexible triggering model	• Amplitude resolution depends on oscilloscope • Keep leads short for optimal bandwidth

B2900 series SMU	• Lowest range has resolution down to 10 fA; highest range measures up to 10 A
	• Built in source means:
	  ◦ Zero burden voltage
	  ◦ No droop
	  ◦ Simplified wiring
	• Small form factor fits easily into rack
	• Quick I/V Measurement Software provides measurement insights
		• Avoid fast-changing signals
		• Use fixed range to avoid measurement discontinuities
		• Capital purchase

N6705C DC power analyzer + N6781A SMU	• Seamless ranging; can measure nA to A in a single pass
	• Built in source means:
	  ◦ Zero burden voltage
	  ◦ No droop
	  ◦ Simplified wiring
	• Can simulate battery behavior
	• Plug in modules allow customization for multiple applications
	• Can re-use modules and programs in manufacturing with N6700 mainframe
	• Optional 14585 software shows CCDF and other information to enhance insights
		• Larger form factor requires more rack space
		• Capital purchase

	Benefits	Tips
CX3300 series device current waveform analyzer	• Purpose-built for measuring dynamic current signals up to 140 MHz (includes probe BW), 14 or 16 bits • Displays waveform features that were never visible before • Unmatched performance—measures fast signals, low to high currents • Integrated measurement categories: time, current levels, area, CCDF, and much more • Automatic current and power profiler provides detailed power budget information	• Huge display gives excellent usability, but requires more rack space • Capital purchase • Keep leads short for optimal bandwidth

Truevolt 34470A DMM

Figure 2. Keysight Truevolt 34470A DMM

The product designer may be able to perform basic current measurements with an instrument already on the bench: a digital multimeter (DMM). For example, the Keysight 34470A DMM can measure current with precision (down to 10 pA accuracy) and digitize at high rates (up to 50,000 readings per second, or 20 µs per reading). As an integrating DMM, it can measure current consumption precisely over various time spans. With the device under test (DUT) in a steady-state condition, the DMM can measure the current (or voltage) in a circuit with high resolution using normal modes and selectable integration times, yielding seven orders of magnitude resolution from ranges down to 1 µA full scale.

In digitizing mode, the 34470A can sample current at high rates and generate numerical or graphical results for analysis of waveform features. The 34470A can manage high common mode voltages and brief, high-current transients. This allows the user to measure circuits without ground reference and to zoom in on low current states and still make accurate sleep-mode measurements.

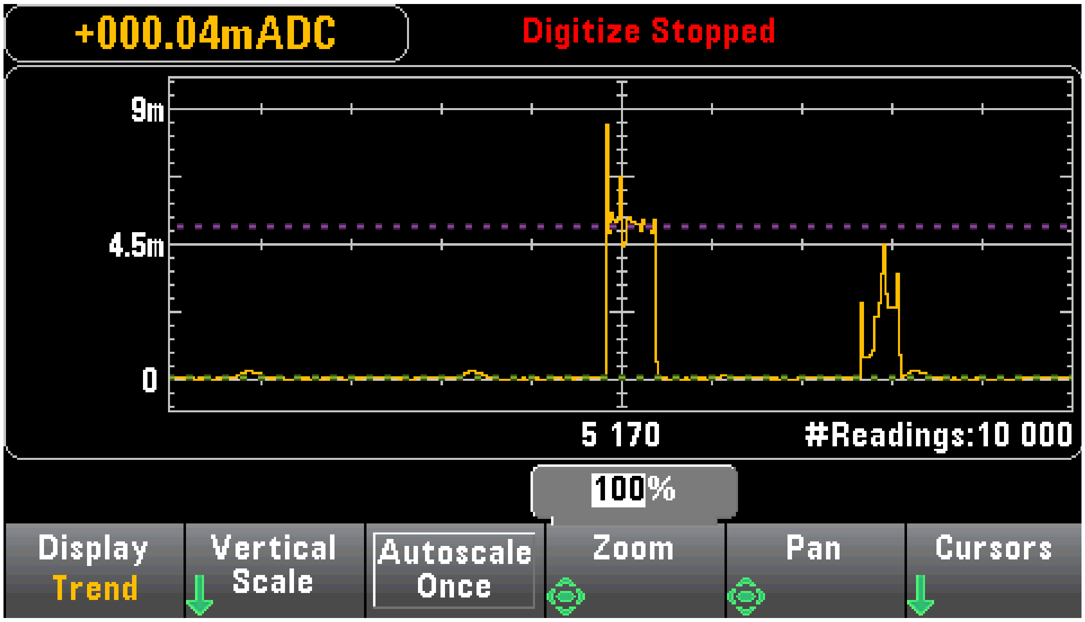


Figure 3. Digitized current waveform of wearable fitness monitor shown on the display of the Keysight 34470A DMM

InfiniiVision X-Series Oscilloscopes

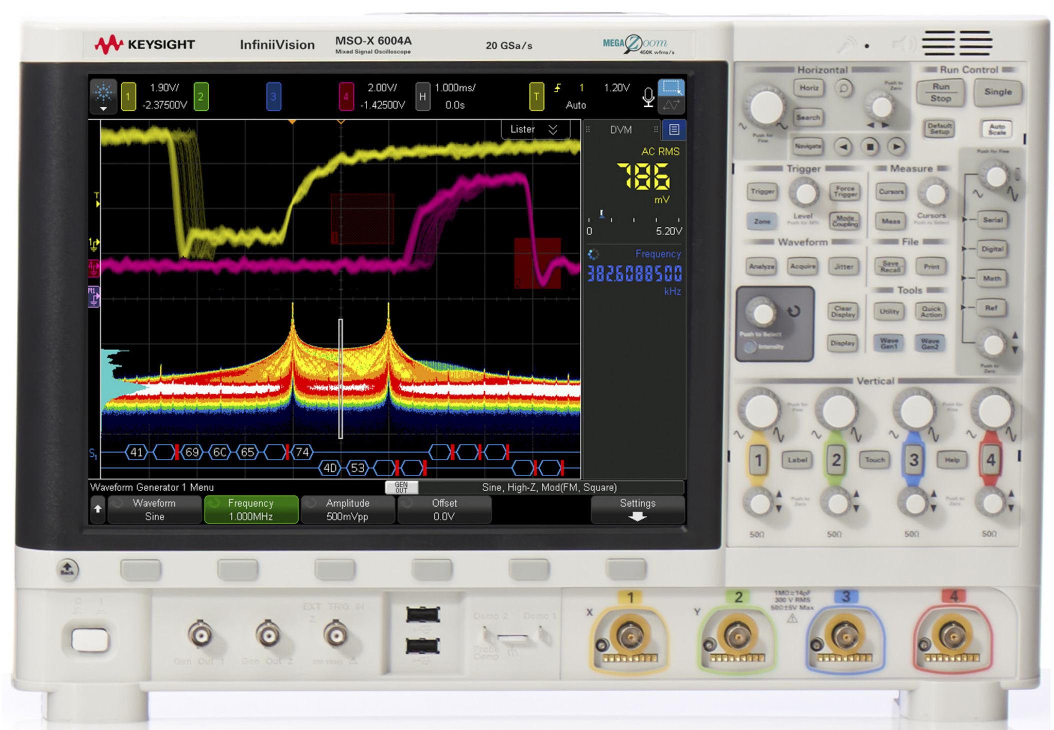


Figure 4. Keysight InfiniiVision MSO-X 6004A mixed-signal oscilloscope

Another instrument already on the bench of most designers is the oscilloscope. With decades of measurement evolution and user interface development, the oscilloscope can rapidly adapt for battery-drain analysis with a Keysight N2820 Series current probe as an input to one of its channels. While this solution is not as accurate as some others, it includes flexible triggering capabilities. Its familiar use model allows the user to evaluate signals quickly.

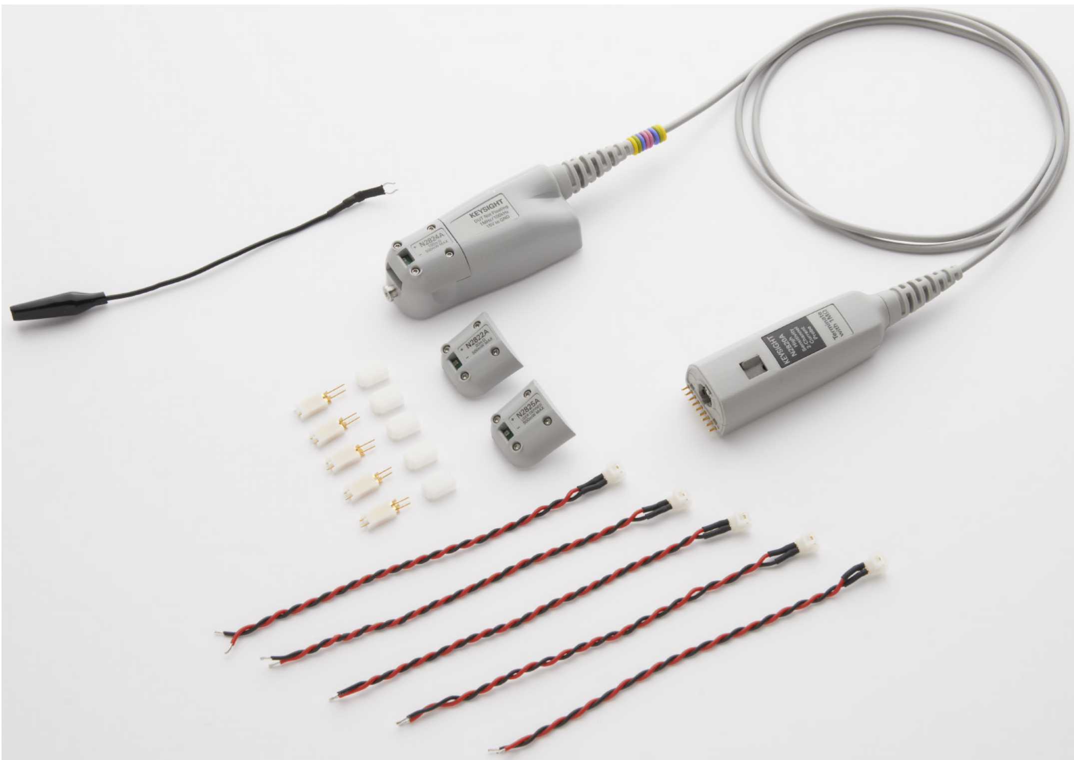


Figure 5. Keysight N2820 Series current probe

Keysight N2820A high-sensitivity current probes can measure current consumption of battery-powered devices or individual circuits. Oscilloscopes using the N2820A offer higher bandwidth than many other instruments — in this case, 500 kHz to 3 MHz of bandwidth — at 20,000:1 dynamic range. The N2820A’s special “make before break” connectors allow the user to rapidly move around the circuit while it is active, characterizing the behavior of various circuit nodes.

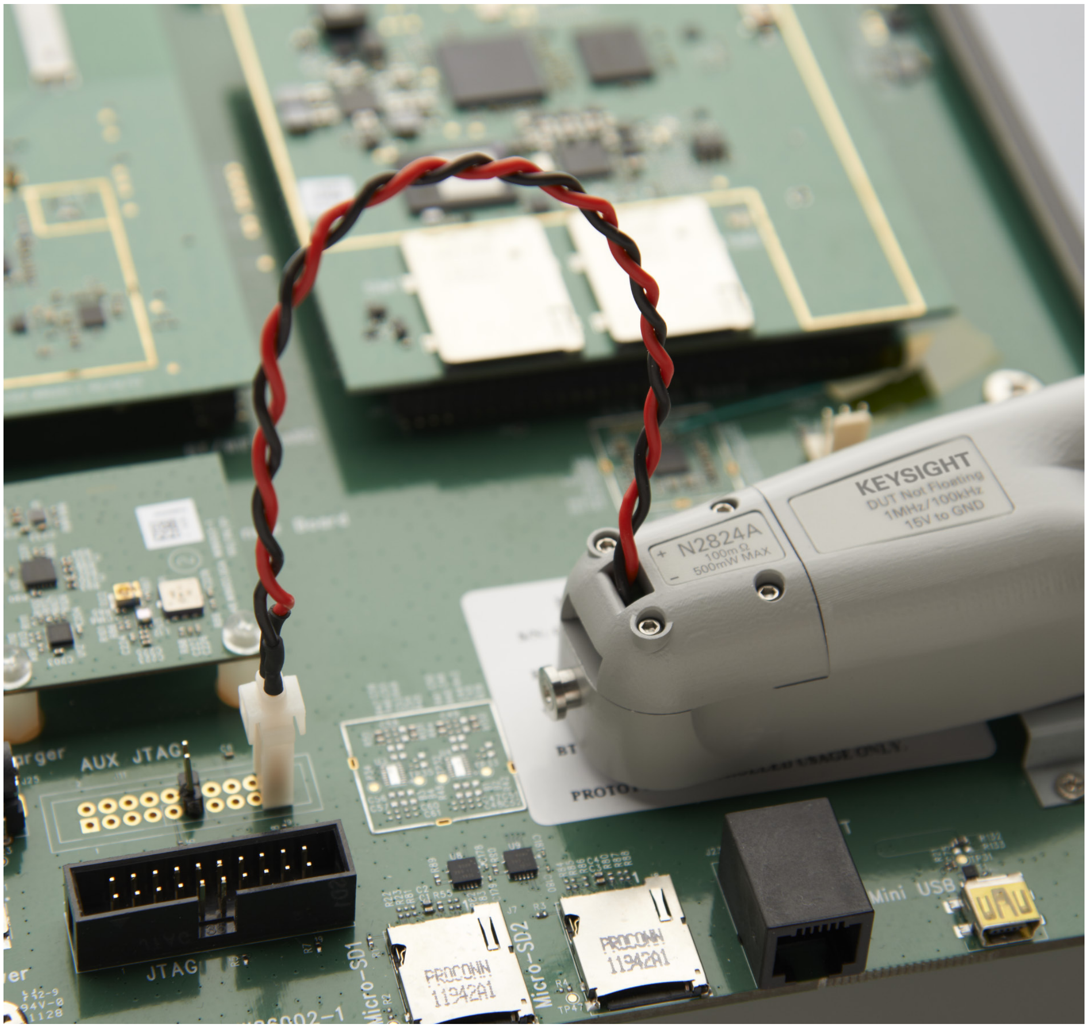


Figure 6. N2824A connected to a printed circuit board assembly

If you use the probes on mixed signal oscilloscopes (MSOs) with digital pattern inputs, circuit behavior can quickly be correlated to control states and the processor instructions that cause the circuit behaviors. This allows product firmware engineers to directly measure the effects of software or firmware changes on power consumption.

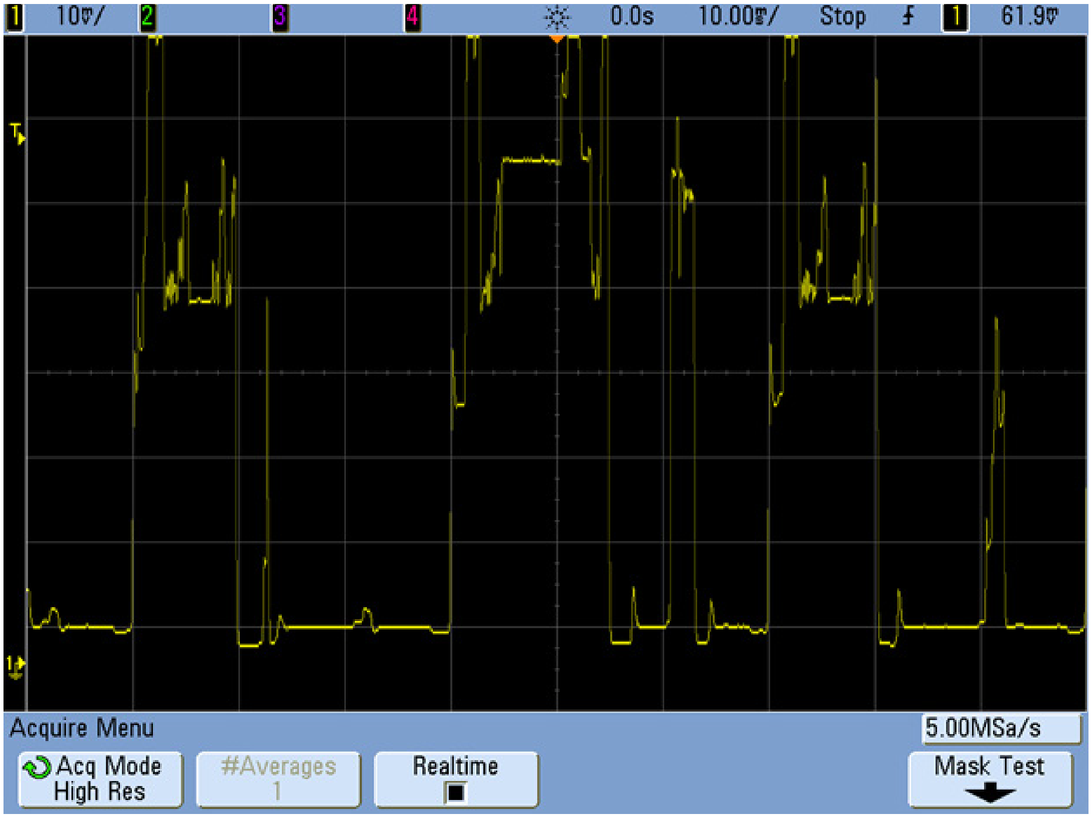


Figure 7. Oscilloscope trace of IoT device charge behavior. Note the presence of high and low currents with high rates of change.

N6705C DC Power Analyzer and N6781A SMU

Figure 8. Keysight N6705C DC power analyzer

The source / measure unit (SMU) is an intelligent power supply that can deliver power to the DUT while measuring current consumption and evaluating the results, including battery drain analysis. The Keysight N6705C with the N6781A SMU module is such a device. The power supply can simulate dynamic conditions, including power sequencing, battery droop, and various supply variations. Because it supplies the power, it can measure it accurately (0.025% up to 18 bits) and quickly (100 kHz). The N6705C can behave like an oscilloscope so the designer has a familiar operating model to rapidly explore circuit behavior. It can also behave like a data logger to record long-term circuit power consumption.

The N6781A SMU has glitch-free sourcing and measurement thanks to its seamless ranging across four current measurement ranges. It can perform as a voltage or current source or as a constant voltage or constant current electronic load with excellent transient response that delivers stable output during high-speed load changes.

Software packages, such as the Keysight 14585A Control and Analysis Software, can add capabilities to the designer's toolkit, allowing fast connection setup and measurement of the device's most important characteristics. For example, the 14585A software can perform a complementary cumulative distribution function (CCDF) analysis, which concisely displays short- and long-term battery drain measurement.

Following design verification, you can move the SMU module and its SCPI programs into the factory to become part of the manufacturing test setup.

B2900 Series Precision SMUs

Figure 9. Keysight B2912A precision SMU

The Keysight B2900 Series precision SMUs combine cost-effective precision measurement with a best-in-class graphical user interface to give designers deep insight into their applications. A two-channel B2900 reduces wiring complexity, as it replaces two DC voltage sources and two DMMs.

These SMUs have excellent precision (minimum 10 fA / 100 nV sourcing and measuring resolution), and the color LCD features several task-based viewing modes that dramatically improve productivity for test, debug, and characterization. The design or validation engineer can also develop tests using the SCPI programming language, which can then be reused if the B2900 SMU is integrated into production test systems. A limit test feature lets the instrument make automatic pass / fail judgments in production test without the need to write a PC-based test program.

Beyond SCPI, the B2900 Series has several remote control options available at little or no cost: BenchVue, B2900A graphical web interface, B2900A Quick IV measurement software, and EasyEXPERT group+. The B2900A lets you quickly configure and perform IV measurements and display the results in tables and graphs without programming.

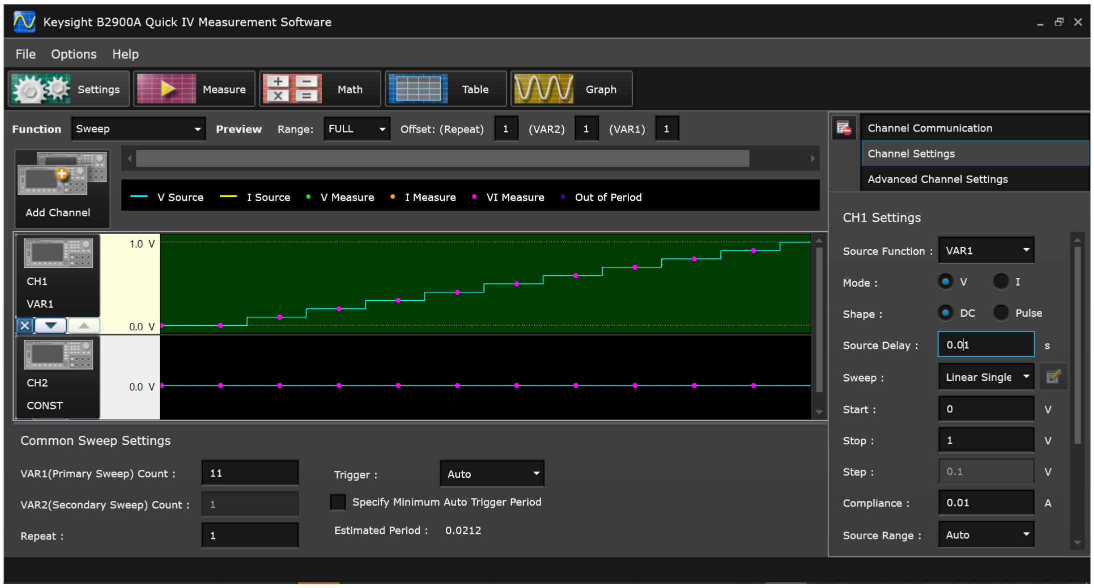


Figure 10. Keysight B2900A Quick IV measurement software

CX3300 Series

Figure 11. Keysight CX3324A device current waveform analyzer

A device current waveform analyzer is a new class of instrument that is especially useful to low-power IoT device designers. The Keysight CX3300 Series provides the most detailed views, in both amplitude (100 nA to 10 A) and time (140-MHz bandwidth and up to 1-GHz sampling rate), of any current measurement instrument on the market. These detailed views let you precisely view low-level current waveforms that were previously undetectable.

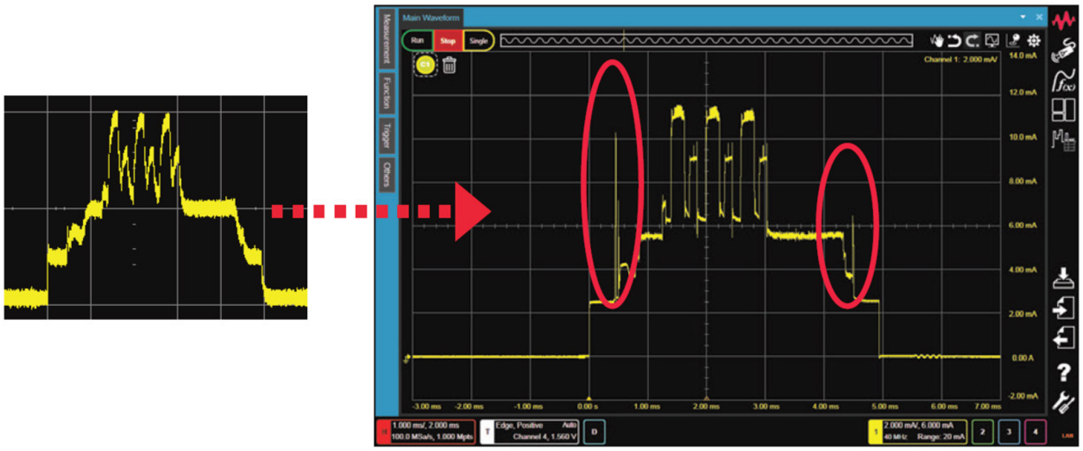


Figure 12. See waveform details that were previously hidden

The CX3300's large display and multitouch oscilloscope use model make it easy to capture, examine, and measure high-resolution current waveforms at the circuit, subcircuit, or chip level. The instrument's "Anywhere" zoom function lets you quickly expand any current waveform segment in both X and Y to see greater detail.

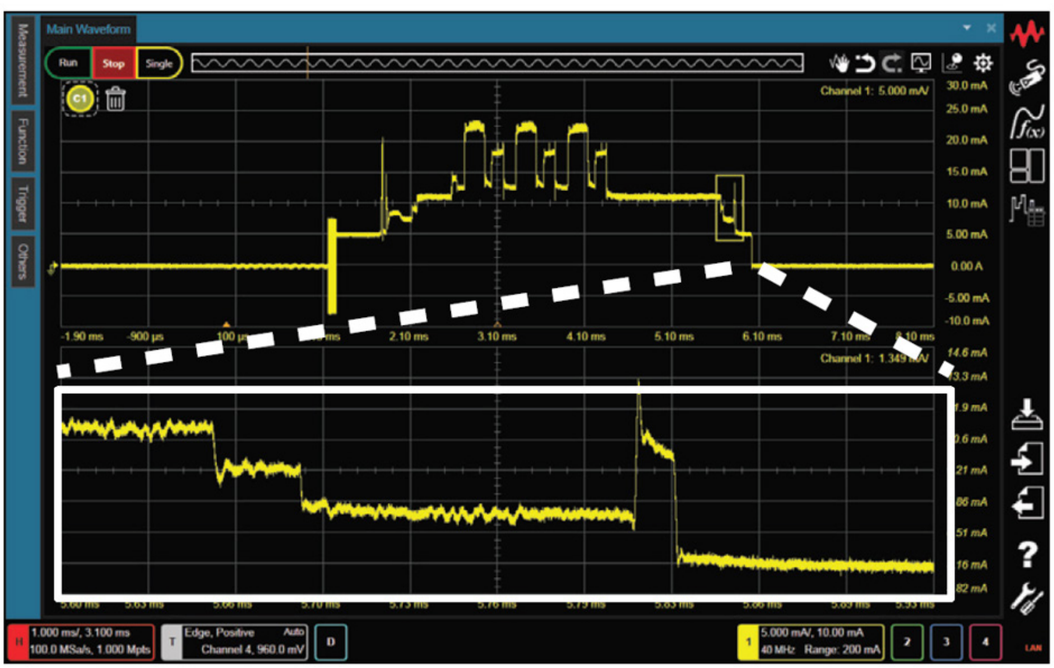
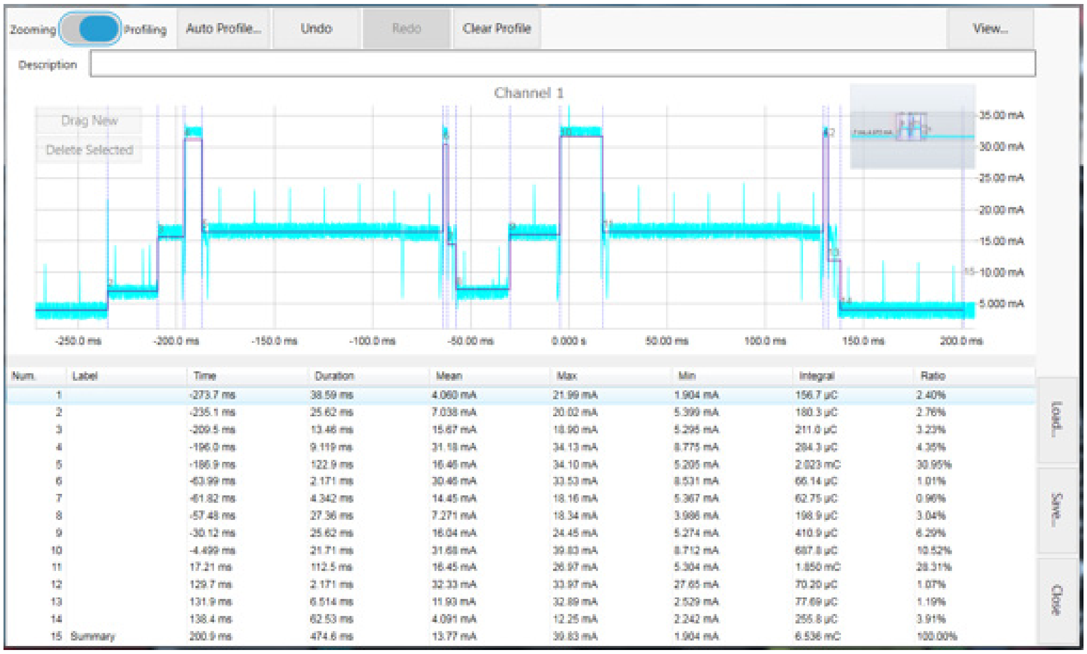


Figure 13. The Anywhere zoom function expands the area within the yellow rectangle in both X and Y, showing detailed waveform information

Powerful analysis functions in the CX3300's Automatic Current and Power Profiler display the measurements in time and current, as well as total charge consumed in microcoulombs (μC).



Num.	Label	Time	Duration	Mean	Max	Min	Integral	Ratio
1		-273.7 ms	38.59 ms	4.060 mA	21.99 mA	1.904 mA	156.7 μC	2.40%
2		-235.1 ms	25.62 ms	7.038 mA	20.02 mA	5.399 mA	180.3 μC	2.76%
3		-209.5 ms	13.46 ms	15.67 mA	18.90 mA	5.295 mA	211.0 μC	3.23%
4		-196.0 ms	9.119 ms	31.18 mA	34.13 mA	8.775 mA	284.3 μC	4.35%
5		-186.9 ms	122.9 ms	16.46 mA	34.10 mA	5.205 mA	2.023 mC	30.95%
6		-63.99 ms	2.171 ms	30.46 mA	33.53 mA	8.531 mA	66.14 μC	1.01%
7		-61.82 ms	4.342 ms	14.45 mA	18.16 mA	5.367 mA	62.75 μC	0.96%
8		-57.48 ms	27.36 ms	7.271 mA	18.34 mA	3.986 mA	198.9 μC	3.04%
9		-30.12 ms	25.62 ms	16.04 mA	24.45 mA	5.274 mA	410.9 μC	6.29%
10		-4.499 ms	21.71 ms	31.68 mA	39.83 mA	8.712 mA	687.8 μC	10.52%
11		17.21 ms	112.5 ms	16.45 mA	26.97 mA	5.304 mA	1.850 mC	28.31%
12		129.7 ms	2.171 ms	32.33 mA	33.97 mA	27.65 mA	70.20 μC	1.07%
13		131.9 ms	6.514 ms	11.93 mA	32.89 mA	2.529 mA	77.69 μC	1.19%
14		138.4 ms	62.53 ms	4.091 mA	12.25 mA	2.242 mA	255.8 μC	3.91%
15	Summary	200.9 ms	474.6 ms	13.77 mA	39.83 mA	1.904 mA	6.536 mC	100.00%

Figure 14. The Automatic Current and Power Profiler breaks up a waveform into segments and provides detailed analysis of current and power consumption for each segment

The CX3300's optional digital input channels (CX1152A) allow a chip programmer to immediately see the effects of device programming changes on battery power. These digital channels are useful when you need to sync current measurements with digital signals, such as the IoT device's controller input / output or data bus.

The digital channel runs at up to 0.5 GSa/s and supports a maximum record length of 512 Mpts. Unlike conventional digital probes, each CX1152A probe has 10 MΩ input resistance, which minimizes load current to enable accurate low- power measurements.

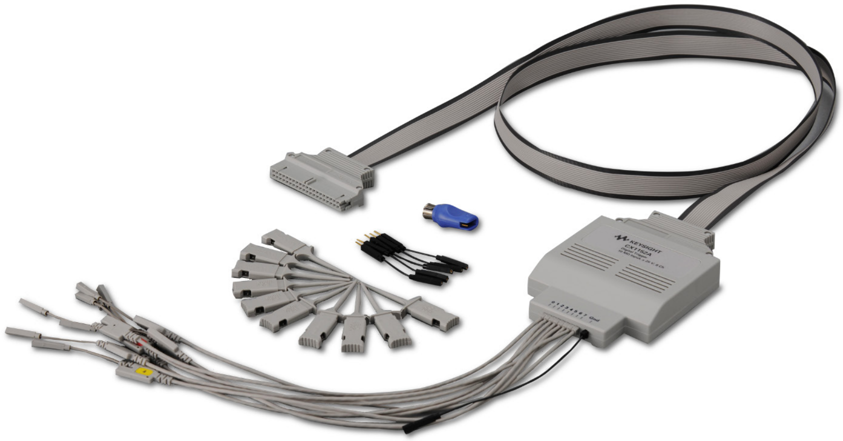


Figure 15. Optional CX1152A digital input channels for Keysight CX3300

This combination of high-precision measurements with ease of use speeds time to market for products with optimal battery life, even when measuring the timescale in nanoseconds.

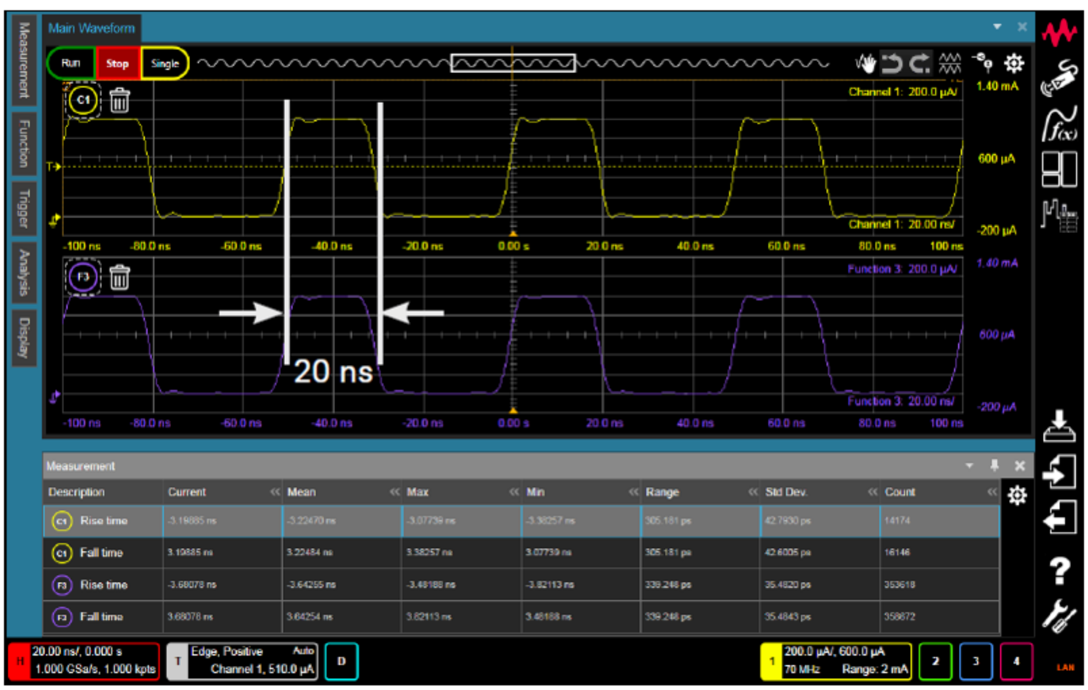


Figure 16. A 20-ns pulse, clearly visible on the CX3300 display

Conclusion

The devices that will fuel the rapid growth of IoT over the next few years are on the drawing boards now. As consumer, industrial, and medical customers demand ever-longer battery life from IoT devices, designers and manufacturers need insight into their devices' complex battery consumption waveforms to innovate ways to extend battery life. Only Keysight offers this broad variety of instruments and software to meet the needs of IoT designers, from chip design and test, RF module performance evaluation and test, to final product manufacturing test.

Learn more at: www.keysight.com

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