Maximizing IoT Device Battery Life

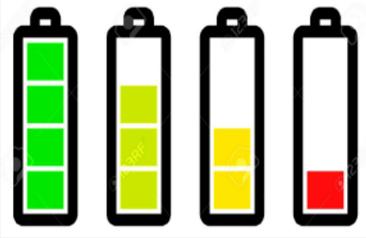
Solution Engineer / Keysight Technologies

Bu-Geun Mun

Top Challenges for IoT Devices

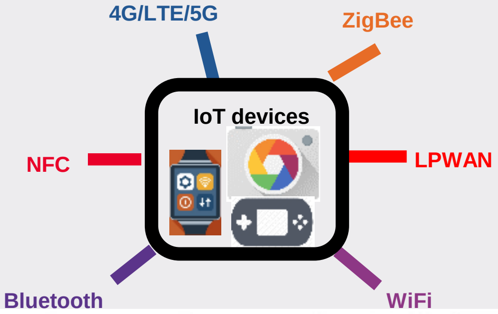
THE CHALLENGES FROM R&D, MANUFACTURING TO DEPLOYMENT

Energy Efficiency



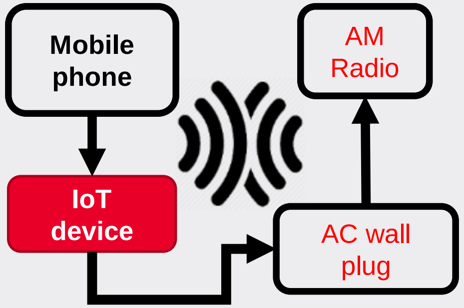
- Maximize battery run time
- Design trade off:
  - Battery type & capacity
  - Processing power
  - Component size & quality
  - Cost
  - Firmware behaviour

Multi-Technologies & Standards



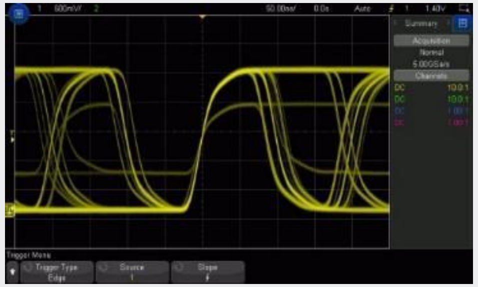
- Complex testing
- Fast evolving standards
- Device interoperability
- Inter and intra-device interference
- Wireless coexistence

Interference, Compliance, Regulatory test



- Radiated emission
- Radiated immunity
- Conducted emission
- Conducted immunity
- Spectrum regulatory

Signal and Power Integrity



- Reflections / crosstalk
- Impedance mismatch
- Excessive losses and noise
- Unwanted transients
- Voltage drops
- Overheating
- Jitter, clock and data error

Agenda

- IoT Device Operation Basics
- IoT Power Measurement Challenges
- IoT Sourcing Requirements
- Gaining Insights for Optimizing Battery Run-Time
- Analyzing & Optimizing Power Savings
- Keysight Solutions for IoT Power Measurements

Wireless Revolution = Battery Powered Device

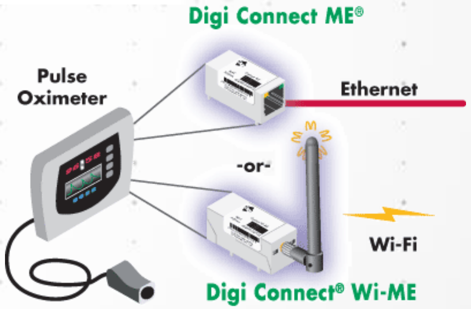
Mobile devices

Digital Camera's

Portable Medical/Fitness

Zigbee, WLAN, BT, GPS

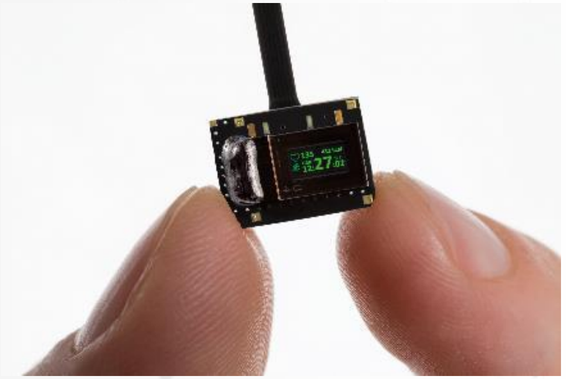
IoT



Battery life is one of the main consumer concerns when choosing a handset

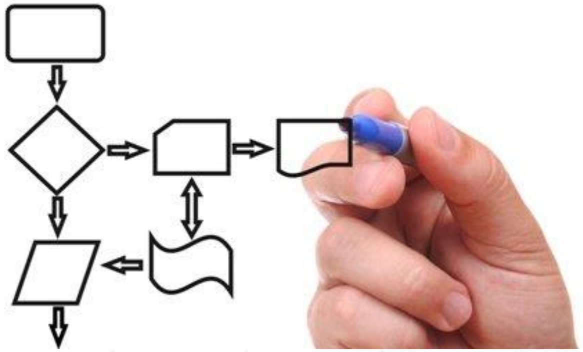
A Growing Need for Battery Current Drain Testing for All Phases of IoT Product Development

- In hardware development



- Optimize energy efficiency

- In software development validate new code builds



- Run application code regression test suites, assess impact on battery drain

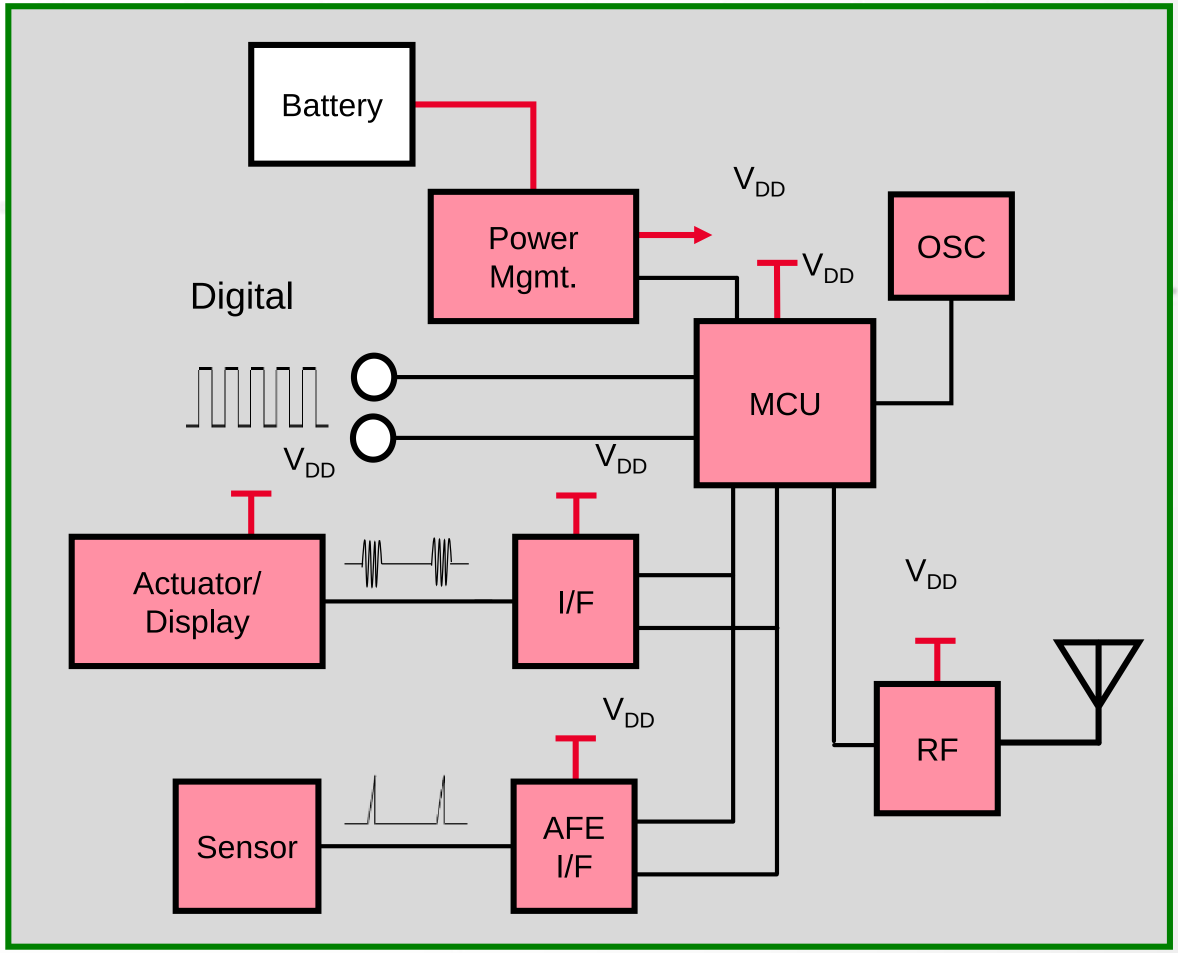
- In integration and validation run suites of benchmark tests

- run suites of benchmark tests
  - Validate battery drain for all required operational modes
  - Validate operating time with product’s battery (battery run-down test)

Benefits:

- Bring smaller, longer running, more competitive products to market
- Faster time-to-market and at lower expense by reducing development time

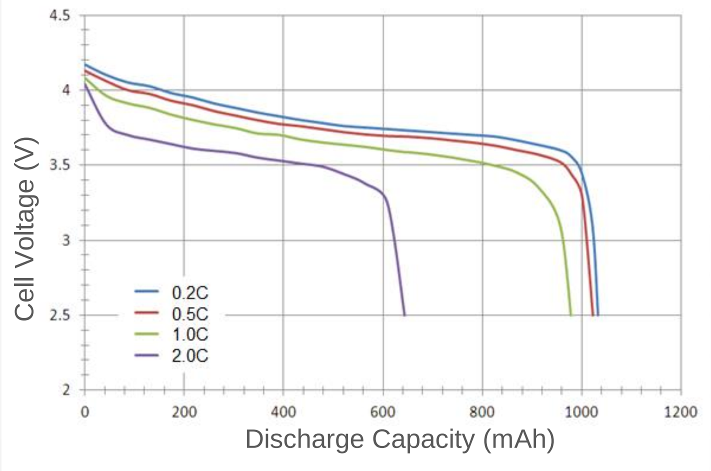
Typical IoT Device Structure



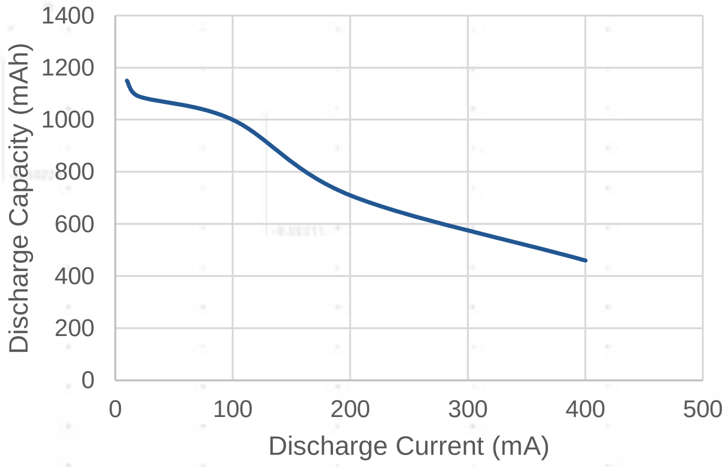
How Battery Life is Calculated?

$$Battery\ \ life\,(hours) = \frac{Battery\ \ capacity\,(Ah)}{Average\ \ current\ \ drain\,(A)}$$

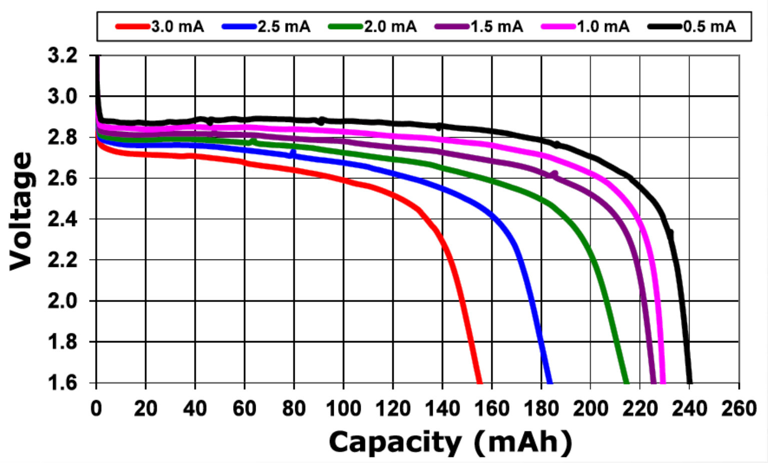
- System designers calculate battery life based on: **active**, **sleep** and **hibernate currents**
- In real devices, however, the battery life is typically shorter than calculated
- Battery capacity is not fixed. It changes depending on the average discharge current and usage pattern



1,000 mAh Li-ion cell, 3V Cut-off Voltage



1,100 mAh Alkaline Cell, 0.9V Cut-off Voltage



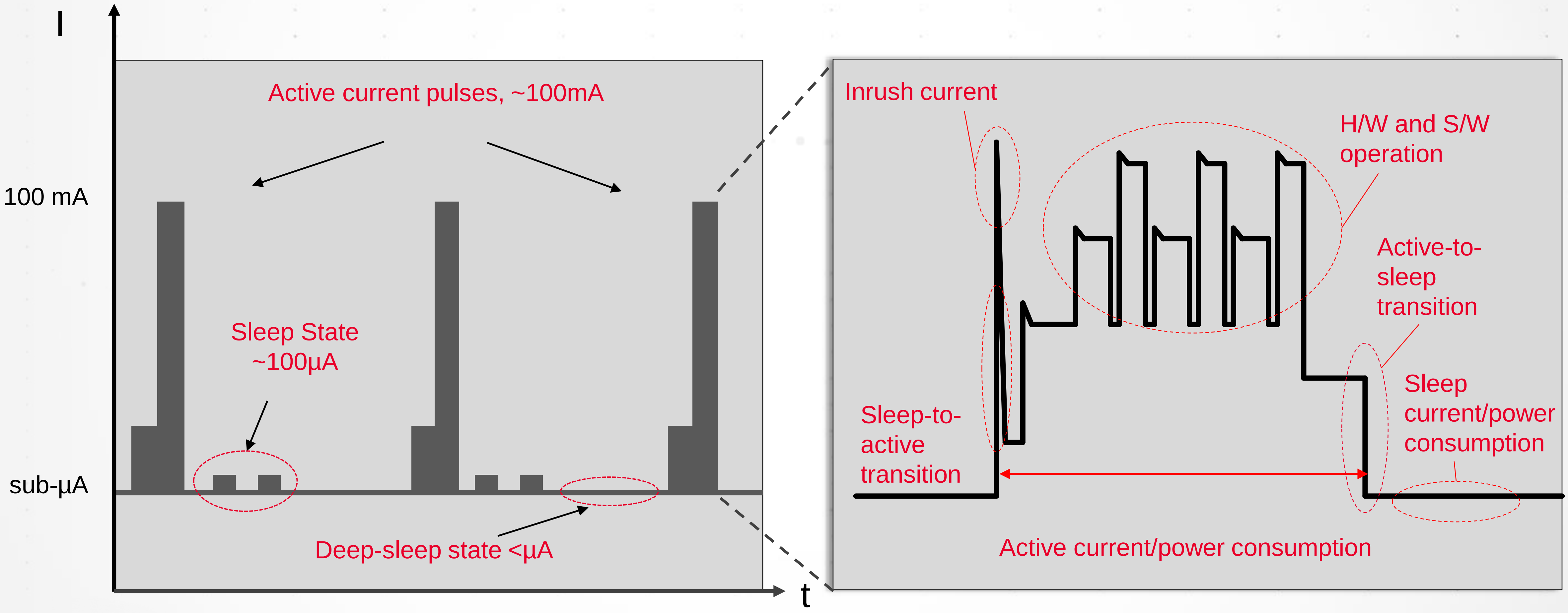
240 mAH CR2032 Lithium coin, 2V Cut-off Voltage

Discharge current profile highly affects battery capacity and lifetime

KEYSIGHT TECHNOLOGIES

Basic IoT Device Operation

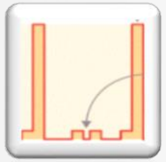
INTERMITTENT TRANSITIONS BETWEEN ACTIVE AND SLEEP STATES



KEYSIGHT TECHNOLOGIES

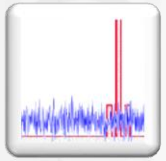
IoT Power Measurement Challenges

WHAT IS NEEDED TO OBTAIN AN ACCURATE CURRENT PROFILE?

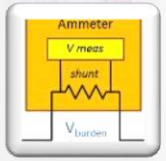


- High dynamic range & current resolution

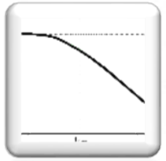
- DC measurement accuracy



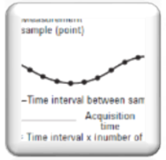
- Low noise floor



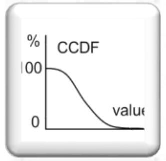
- Minimal effect from the test system / zero burden voltage



- Bandwidth

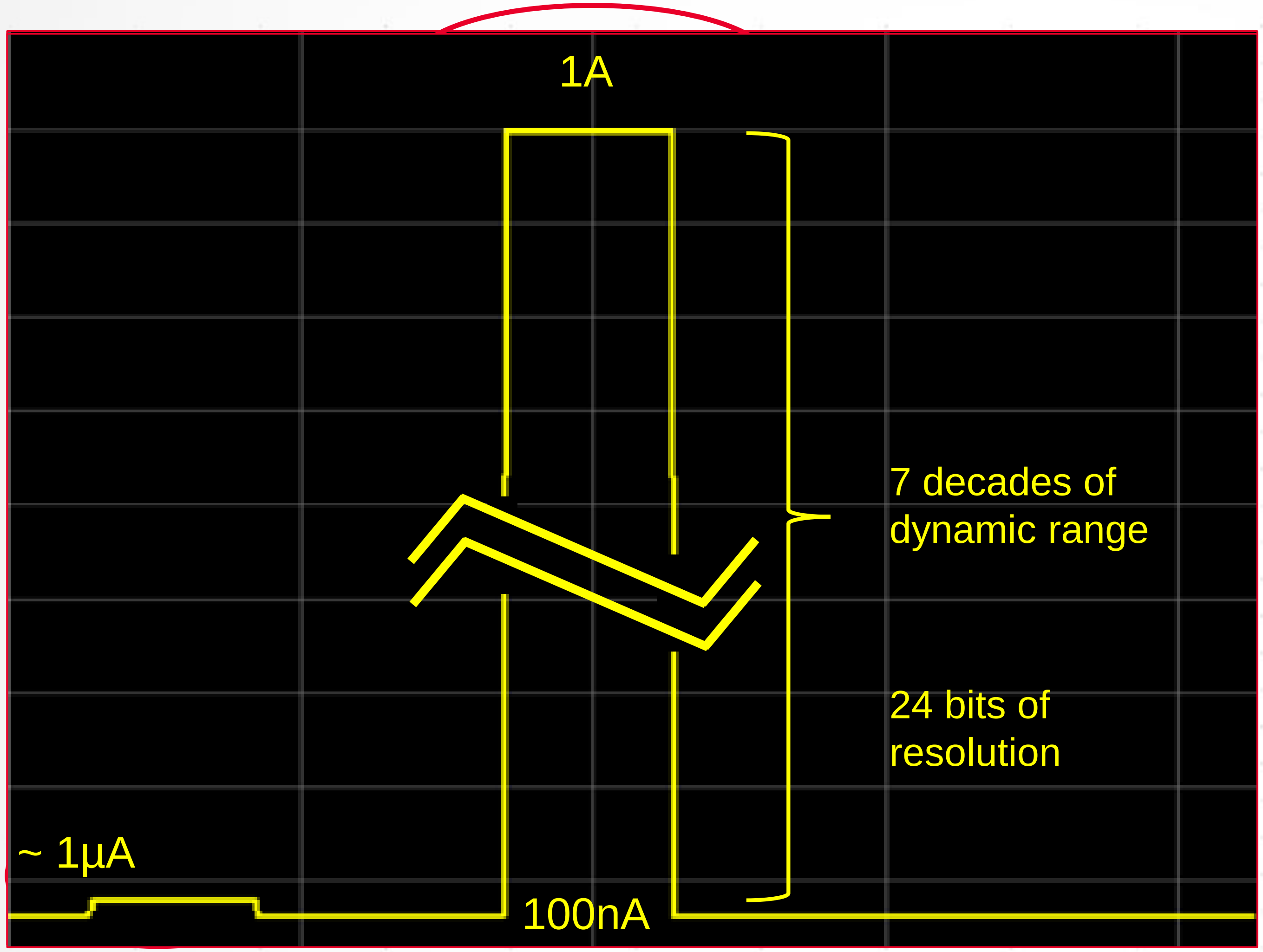


- Waveform digitizing and datalogging



- Measurement functions & analysis

Current Dynamic Range Challenge



DMM best case 16 bits

1A range → 16µA current resolution $(\frac{1}{2^{16}})$

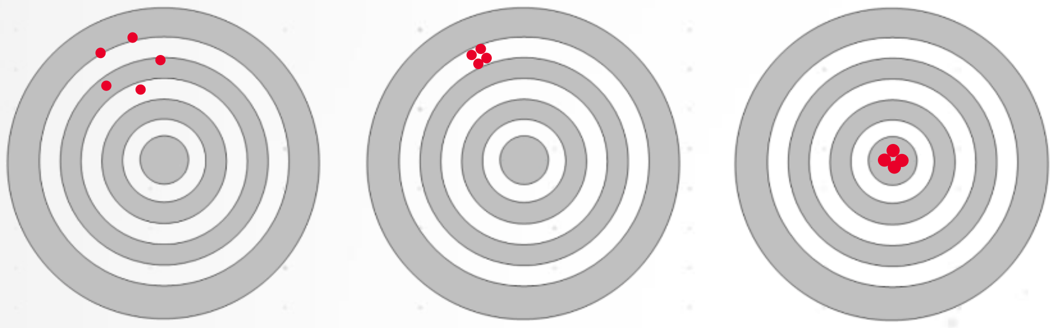
7 decades of dynamic Range

24 bits of ADC Resolution, $Log_2 10^7 = 24$

Both sleep current and active current evaluation are important for power consumption reduction.

DC Measurement Accuracy

DC ACCURACY, CONVENTIONAL FIXED RANGE MEASUREMENTS



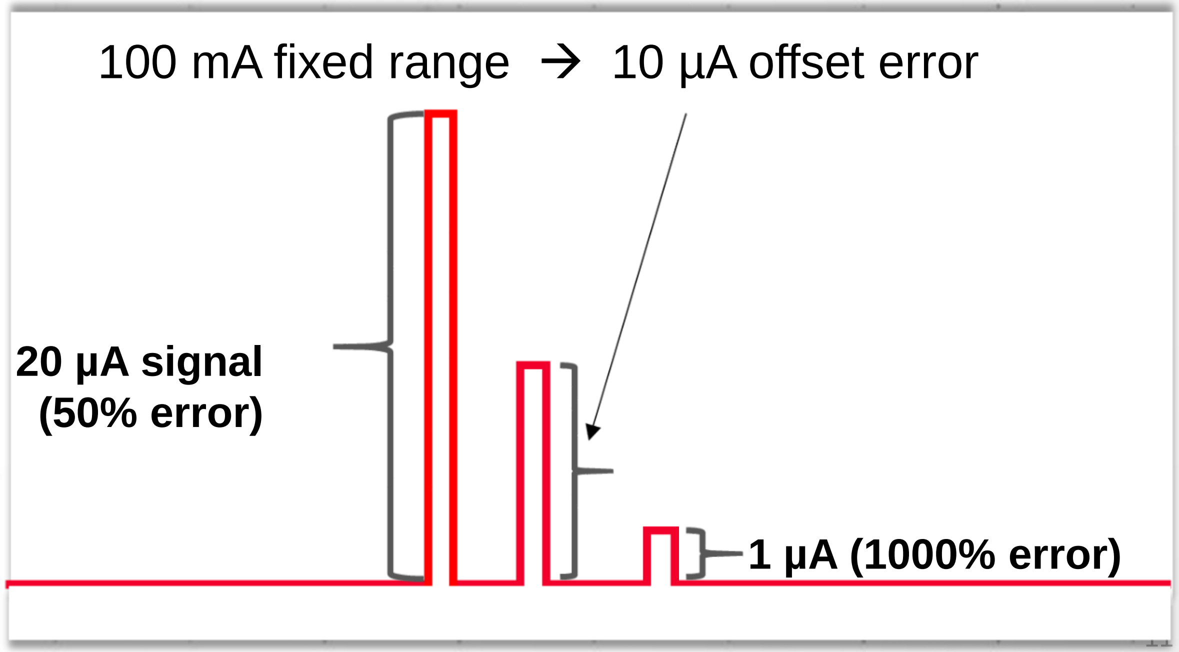
Low accuracy,
Low precision

Low accuracy,
High precision

High accuracy,
High precision

Range	Measurement Accuracy @23°C ±5°C	Measurement Resolution (18 bits)
3A	0.03% + 250µA	25µA
100mA	**0.025% + 10µA**	1µA
1mA	0.025% + 100nA	10nA
10uA	0.025% + 8nA	0.1nA

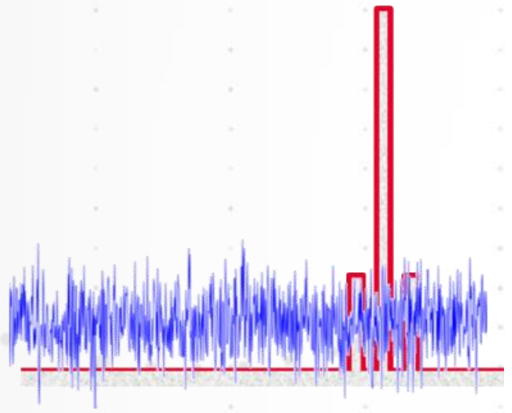
- **Accuracy** – designates how close a measured value is to the true quantity of what is being measured
- **Resolution** – is the smallest increment the system can display or measure
- **Precision** – The degree to which repeated measurements or calculations show the same or similar results



KEYSIGHT TECHNOLOGIES

AC Noise Floor & Waveform Digitization

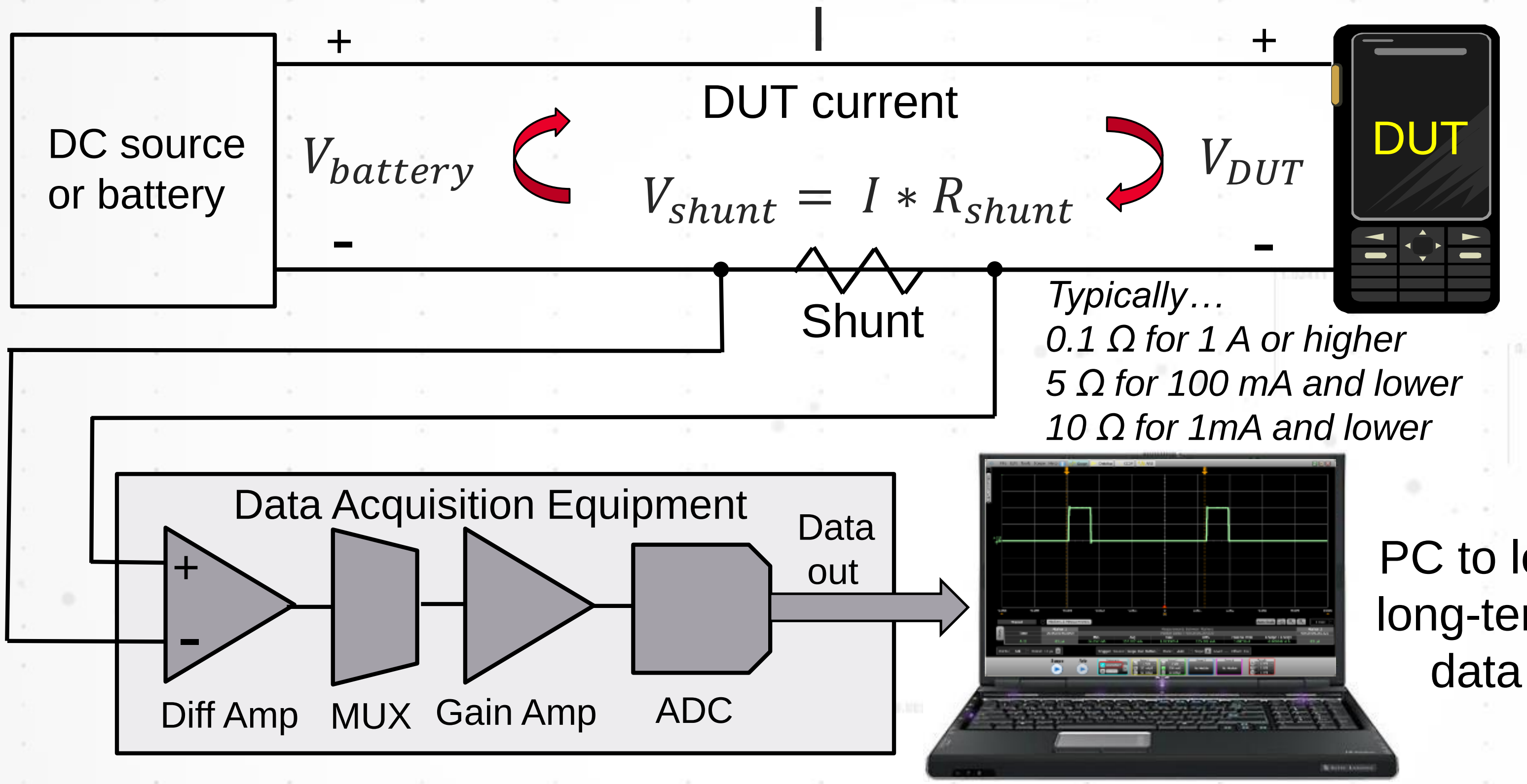
- Main noise sources
  - DUT AC impedance and fixture capacitance
  - Noise floor of the instrument



Range	Measurement Noise	Measurement Resolution (18bits)
3A	400uA	25µA
100mA	20uA	1µA
1mA	2µA	10nA
10uA	20nA	0.1nA

Example of signal buried in noise

Minimal Effect from the Test System / Zero Burden Voltage



PC to log long-term data

$$V_{DUT} = V_{battery} - I * R_{shunt}$$

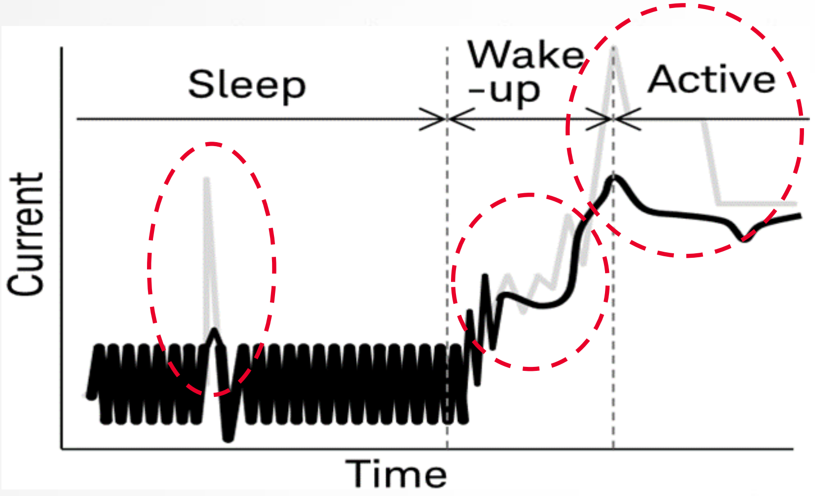
- Complexity
- Multiple shunts needed
- Limited dynamic range

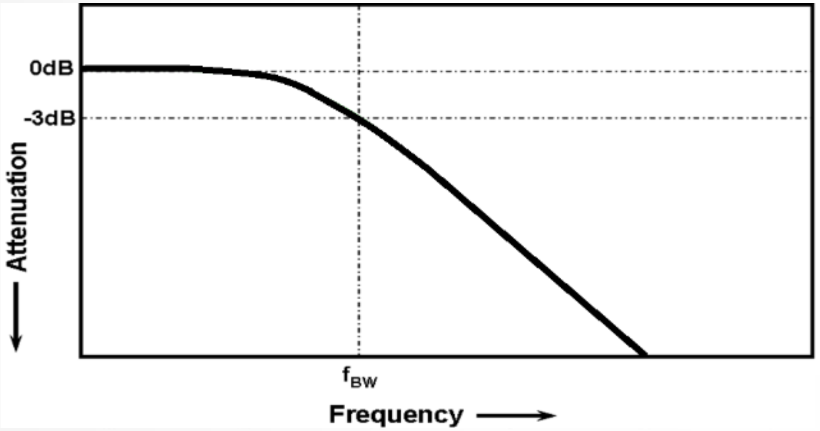
Excessive peak voltage drop on shunt risk to power off your device

$$V_{burden} = 100\ mA * 10\ \Omega = 1V$$

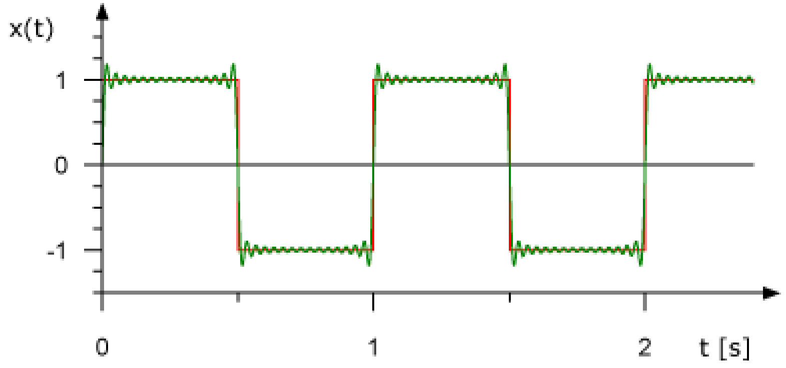
$$V_{DUT} = 4V - 1V = 3V$$

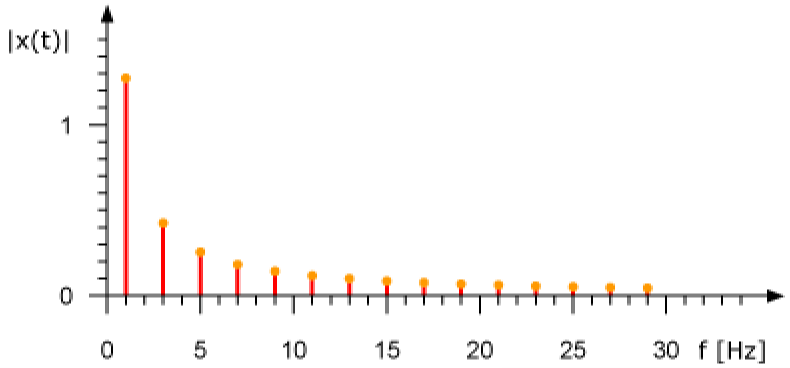
Required Measurement Bandwidth





The frequency where a sine wave is attenuated by 3 dB, ~30% amplitude error





Maximum frequency defined by the fastest edge speeds.

Step 1: Determine fastest edge speeds

Step 2: Calculate f_{knee}

f_{knee} = 0.5 / RT (10% - 90%)

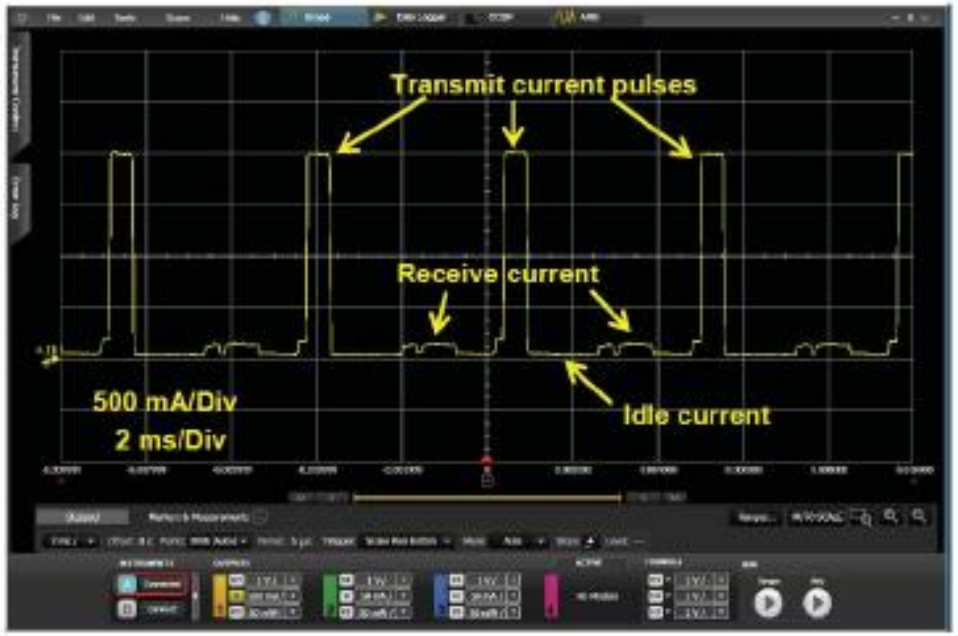
f_{knee} = 0.4 / RT (20% - 80%)

Step 3: Calculate bandwidth

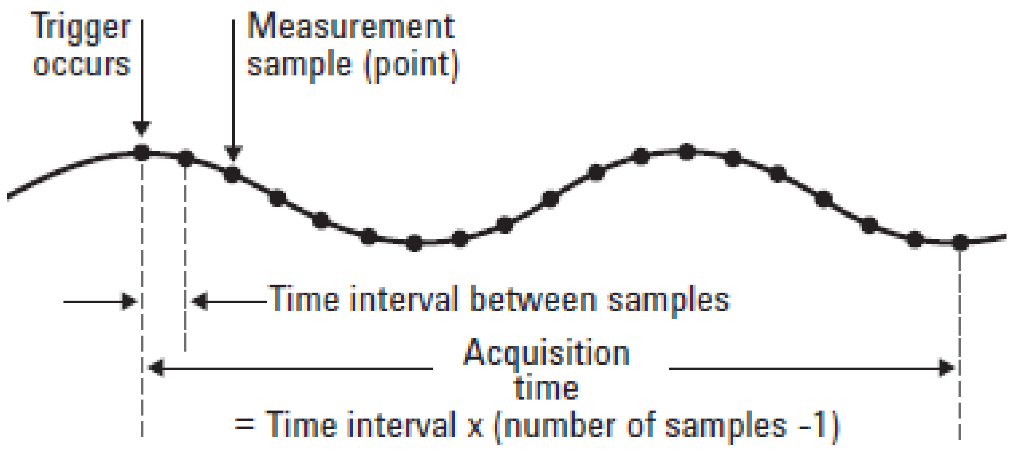
Required accuracy	**Gaussian response**
20%	$f_{BW} = 1.0 \times f_{knee}$
10%	$f_{BW} = 1.3 \times f_{knee}$
3%	$f_{BW} = 1.9 \times f_{knee}$

Logging Dynamic Waveforms Over Time

MEASURING CURRENT DRAIN WITH BUILT-IN DIGITIZERS



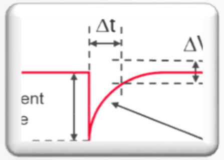
- Datalogging Capabilities
  - Log data over hours, days or weeks
- High Sampling Rate
- Sufficient Memory

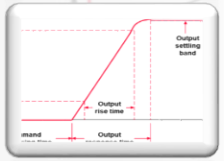


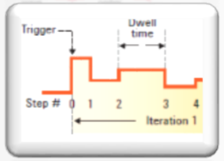
N = Sample rate x Acquisition time

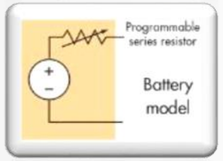
Example: 1 hour of data acqusition at 50kSa/s
50kSa/s x 3600s = **180M points**

IoT Sourcing Challenges



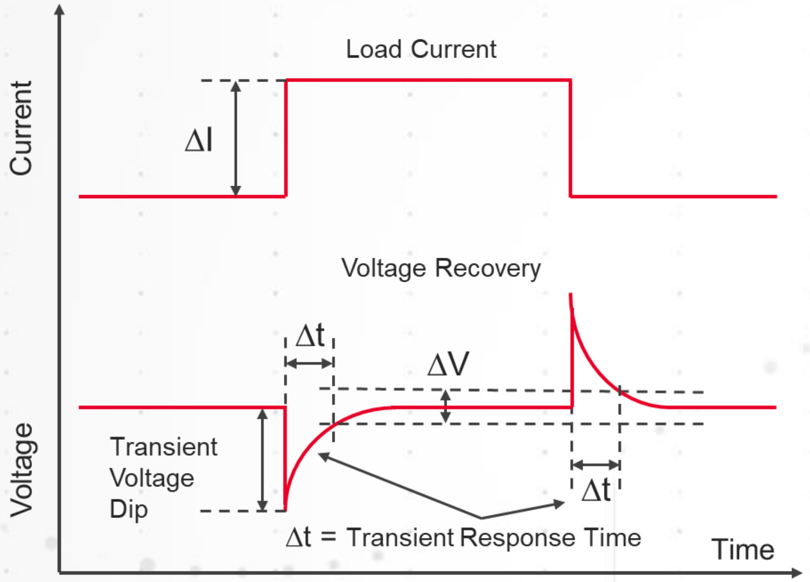




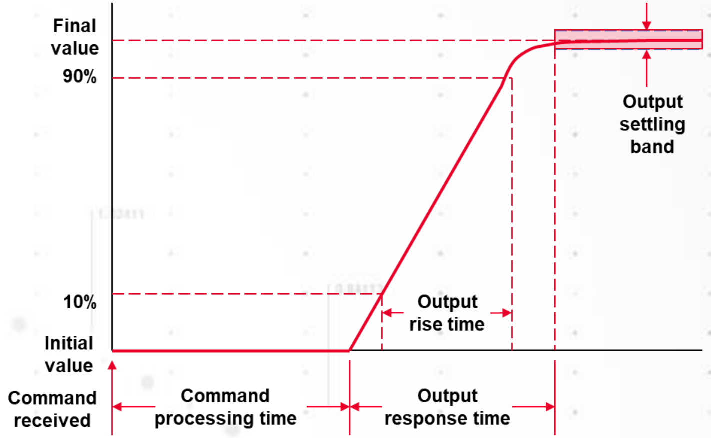


- Load transient response time / Transient recovery time
- Fast up/down-programming capability
- Arbitrary waveform sourcing & sinking capabilities
- Battery emulator mode

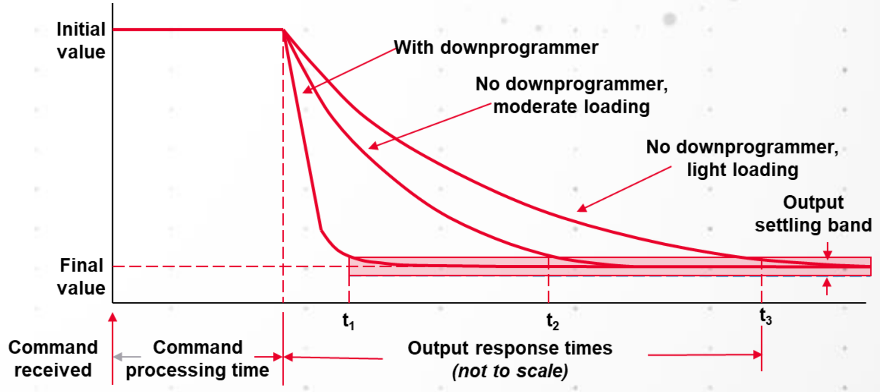
Power-Supply Transient Recovery Time



Transient response / load transient recovery time



Up-programming response time

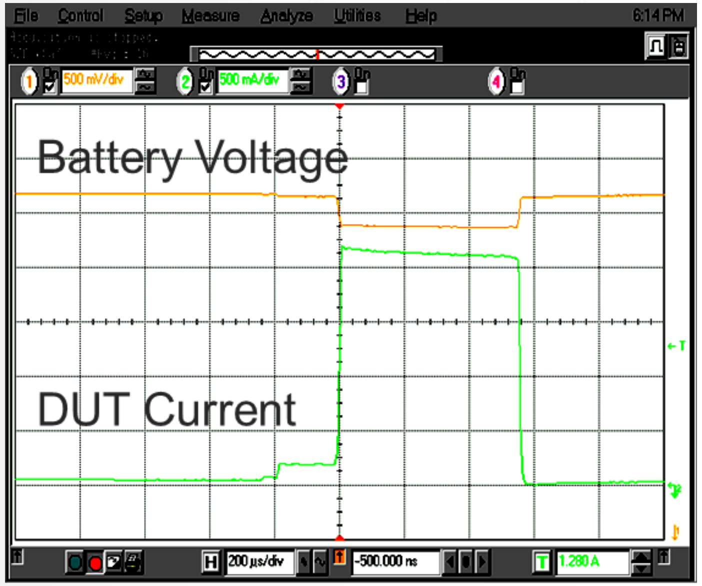


Down-programming response time

- Undervoltage can **shut down** your device
- Overvoltage/over current can **kill** your device

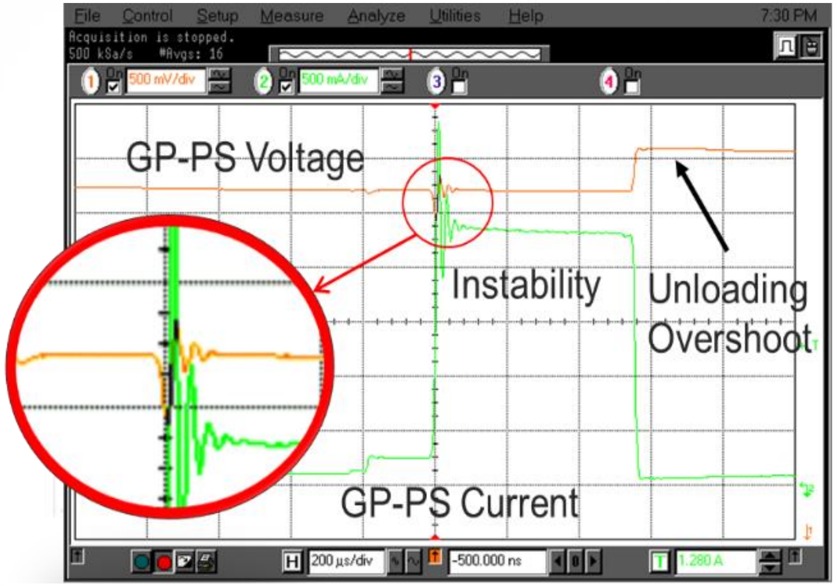
Properly Powering a Mobile Device

COMPARING A BATTERY, POWER SUPPLY & A BATTERY EMULATOR SMU



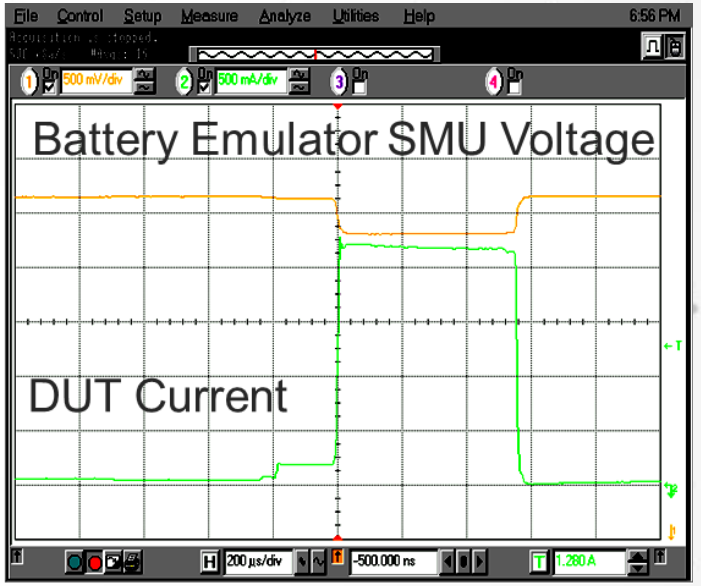
Actual battery response to a GSM current pulse load

- Battery voltage drops proportionally with current
- Battery resistance is 150 mΩ



General purpose power supply response to a GSM current pulse load

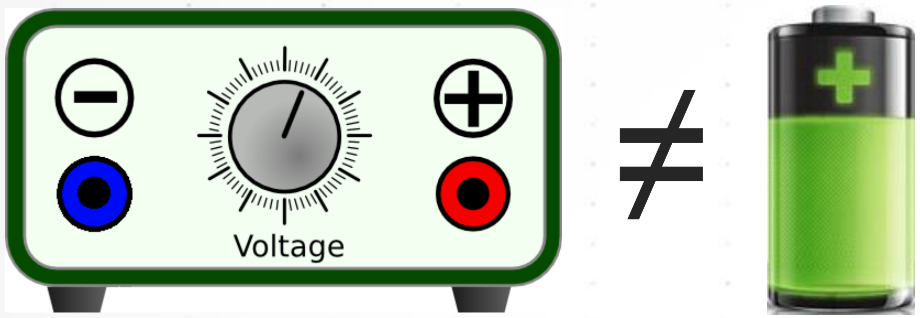
- Voltage response and current drain does not match battery
- Instability & overshoot
- 10% higher drain experienced

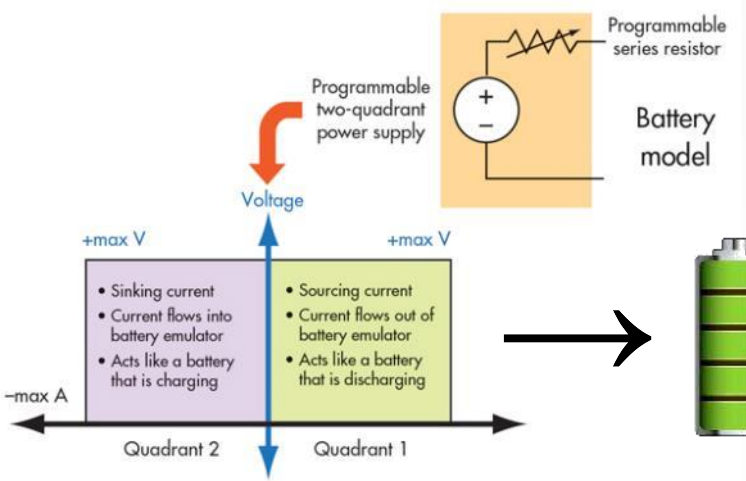


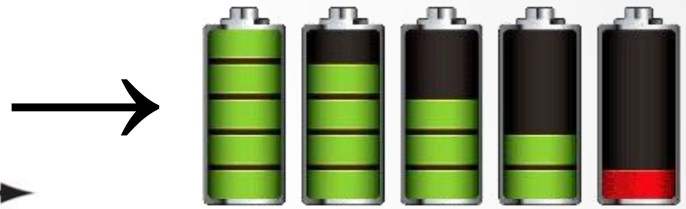
N6781A Battery emulator SMU response to a GSM pulse load

- Voltage response and current drain comparable to the battery
- Battery emulator SMU set to 150 mΩ

Power Supply vs Battery Emulator







Power supply is not equivalent to a battery

Battery emulator can simulate a real battery

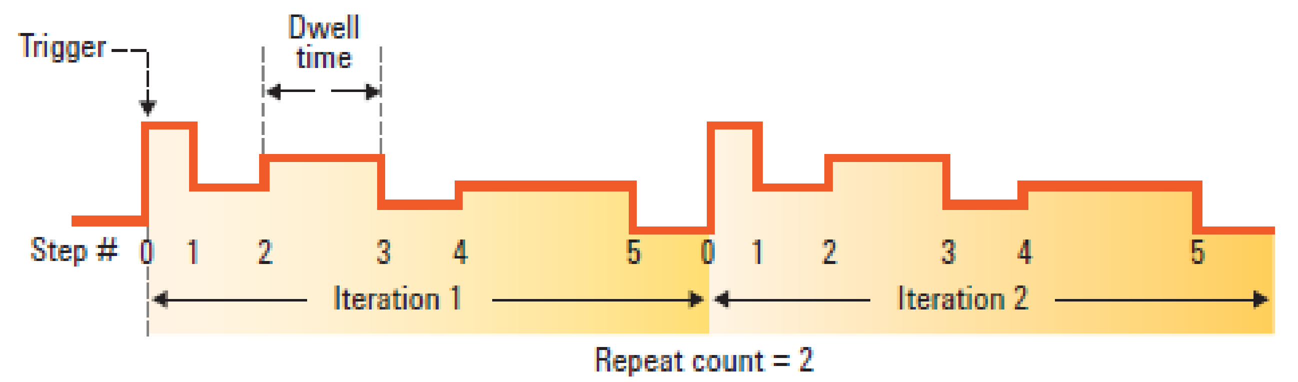
- Power supply tends to maintain very low and constant output impedance
- Power supply never runs down
- Power supply is a power source, but a battery can both source power (as it discharges) and absorb/sink power (as it charges)

- Output voltage and resistance are reprogrammed to simulate the effects of state-of-charge and battery aging
- Battery emulator SMU can simulate battery run-down
- SMU can both source and sink power

Benefits:
- Reduces test setup time
- Creates a safer test environment
- Provides more repeatable results vs using a real battery during test

Create Time-Varying Voltages/Current Using Power Supply List Mode

- Arbitrary waveform creation
- Record & play back
- List mode
  - **One or more voltage or current steps** – defined voltage or current values
  - **Dwell times** – duration associated with each voltage or current step
  - **Repeat count** – the number of times you want the list to repeat
- Example:
  - Test an IoT device under different current



Innovations for Battery Drain Characterization

GAIN INSIGHTS IN MINUTES, NOT DAYS!

+

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N6705C DC Power Analyzer Mainframe

N6781A/N6785A 2-Quadrant SMUs

14585 Software

- Integrates multiple instrument functions into a single box:
  - 1 to 4 advanced power supplies;
  - Digital voltmeter and ammeter
  - Arbitrary waveform generator
  - Oscilloscope
  - Long term data logger
  - Full functionality from front panel

- Specialized for battery drain testing:
  - N6781A: 20V, +/3A, +/-20W
  - N6785A: 20V, +/-8A, +/-80W
  - **Innovation:** Seamless ranging spans over 7 decades of measurement from nA to A
  - Up to 200 KSa/sec digitizing rate
  - Battery emulation DC source
  - Zero-burden current measurement operation for testing with the battery
  - For use in the N6705 mainframe

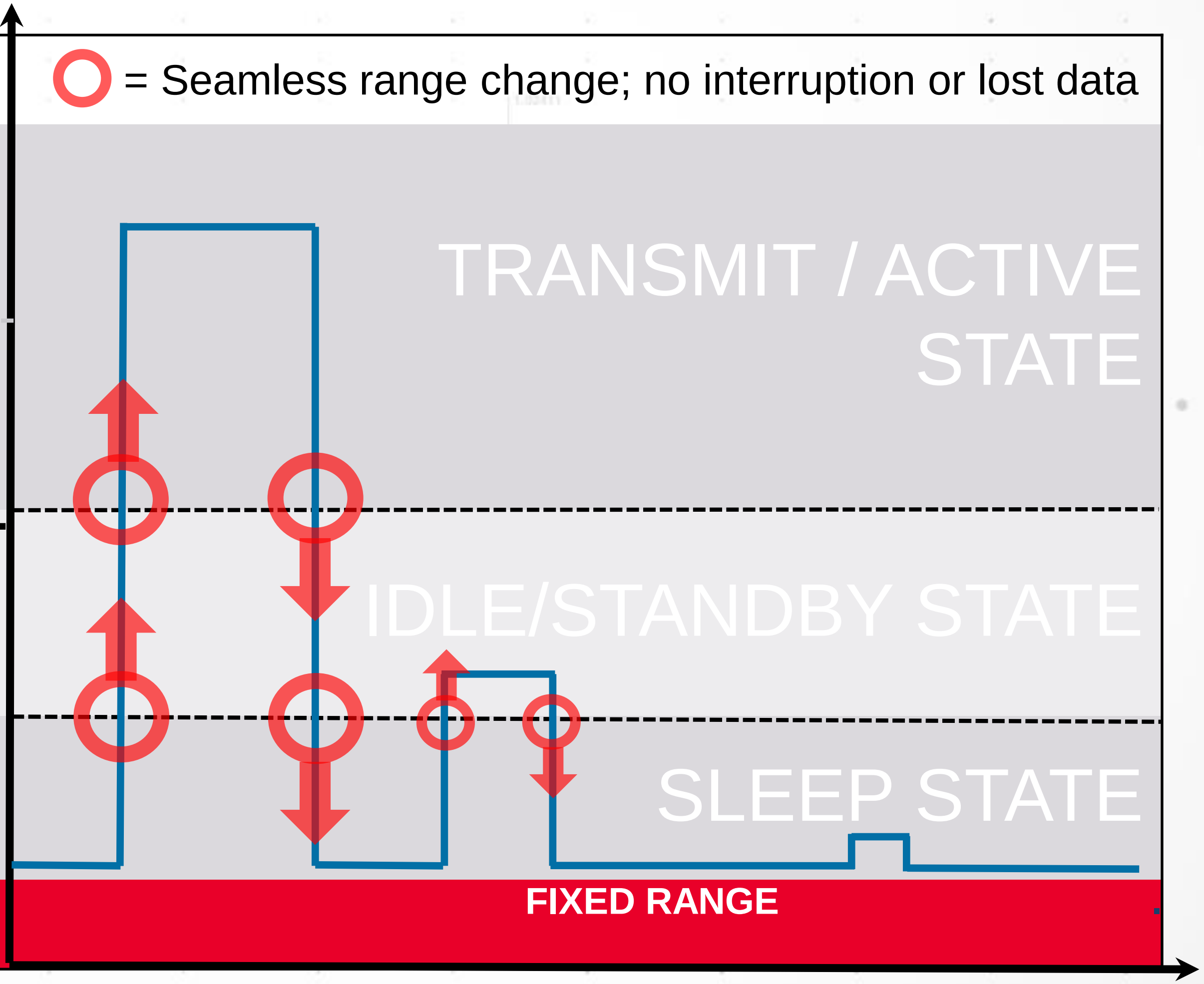
N678xA Seamless Measurement Ranging

ADDRESSING DYNAMIC RANGE CHALLENGE

Unique Keysight Patented Solution

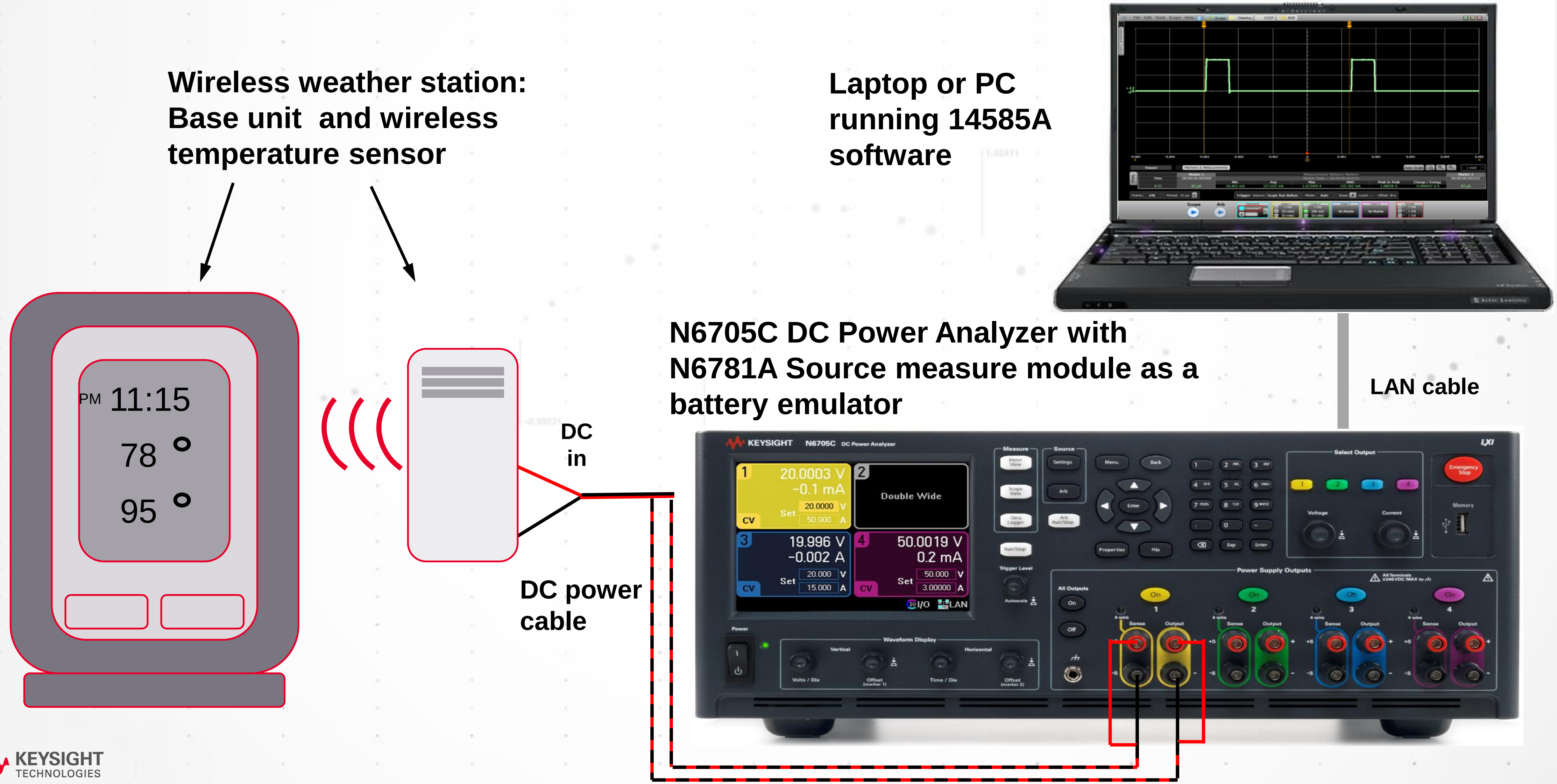
Seamless Range Changes

Range	Measurement Accuracy
8 A	±(0.04% + 1.5 mA) N6785A, N6786A ONLY
3 A	±(0.03% + 250 µA) N6781A, N6782A ONLY
100 mA	±(0.025% + 10 µA)
1 mA	±(0.025% + 100 nA)
10 µA	±(0.025% + 8 nA) N6781A, N6782A ONLY



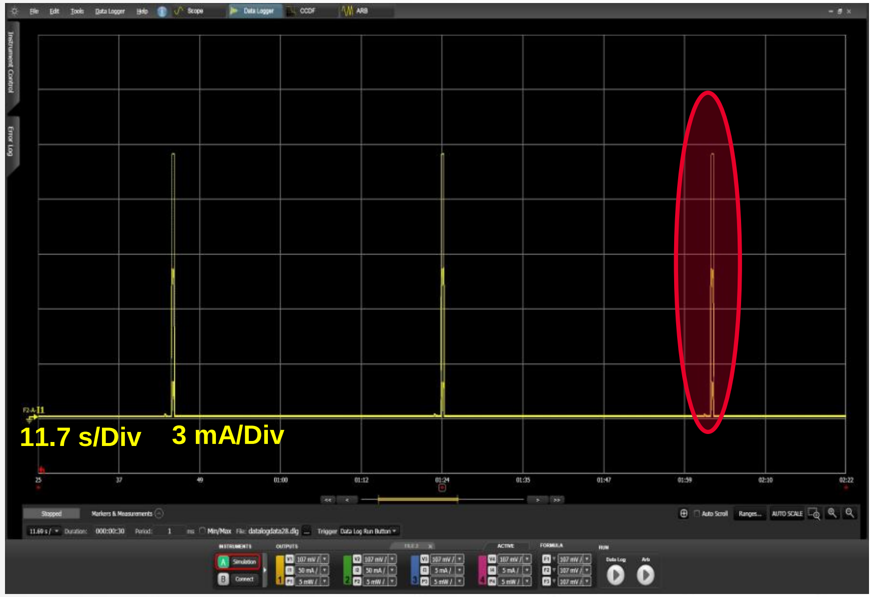
Power-savings Current Drain Measurement

WIRELESS SENSOR EXAMPLE: TEST SETUP

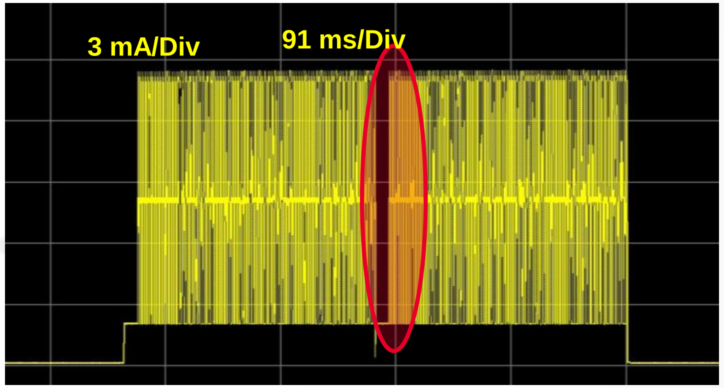


Greater Time Resolution Yields Detailed Insights

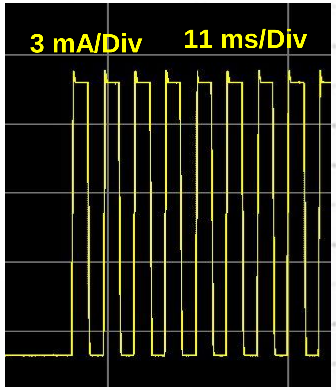
TEMPERATURE-HUMIDITY SENSOR EXAMPLE



Wireless Temp / Humidity Sensor, 38 sec-long, 7.54 µA sleep periods



Dual Transmit Burst
- 1-temp, 1-humidity
- 0.19 sec-long each
- 8.6 mA average during burst



Transmit Burst Pulses
- **14.4 mA pulse plateau**
- 2 ms pulse duration
- 2.01 mA idle current

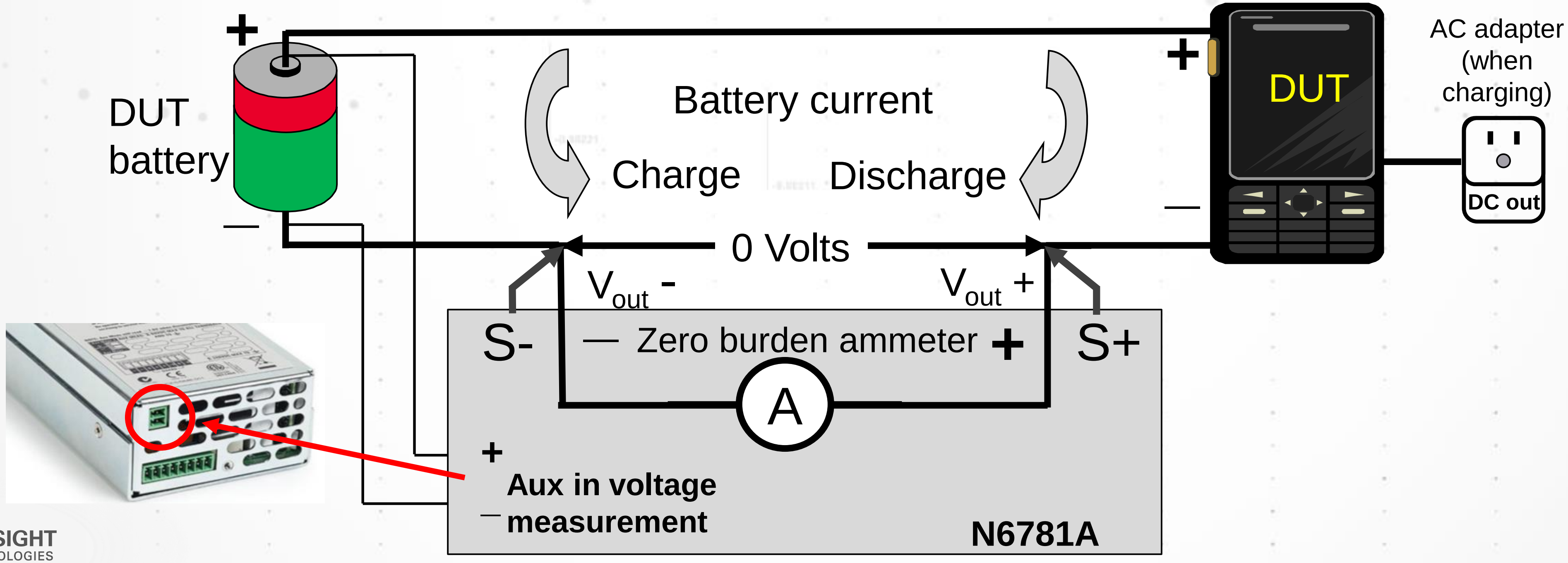
- 200 µsec resolution provides insights. 600 K-points for 120 sec capture
- 99% of the time is sleep; **7.46 µA average** (**7.54 µA * 99%**)
- 1% of the time is transmit; **86 µA average** (**8.6 mA * 1%**)
- 12,900 Hrs (1.5 yrs) with 1.2A-Hr battery (**93.5 µA total drain**)
- 14.4 mA pulsed, for determining RF PA Power Added Efficiency (PAE)

KEYSIGHT TECHNOLOGIES

Detailed Run-down (and Charge) Testing with Battery

MOBILE PHONE EXAMPLE: TEST SETUP

- N6781A or /5A regulates zero volts while measuring current, i.e. zero burden shunt
  - Eliminates voltage drop and impedance problems that a shunt causes
- Built-in auxiliary DVM input simultaneously measures battery voltage
- High speed simultaneous voltage and current logging yields key insights on battery capacity and discharge and charge management



Detailed Battery Run-down Testing

MOBILE PHONE EXAMPLE: TEST RESULTS

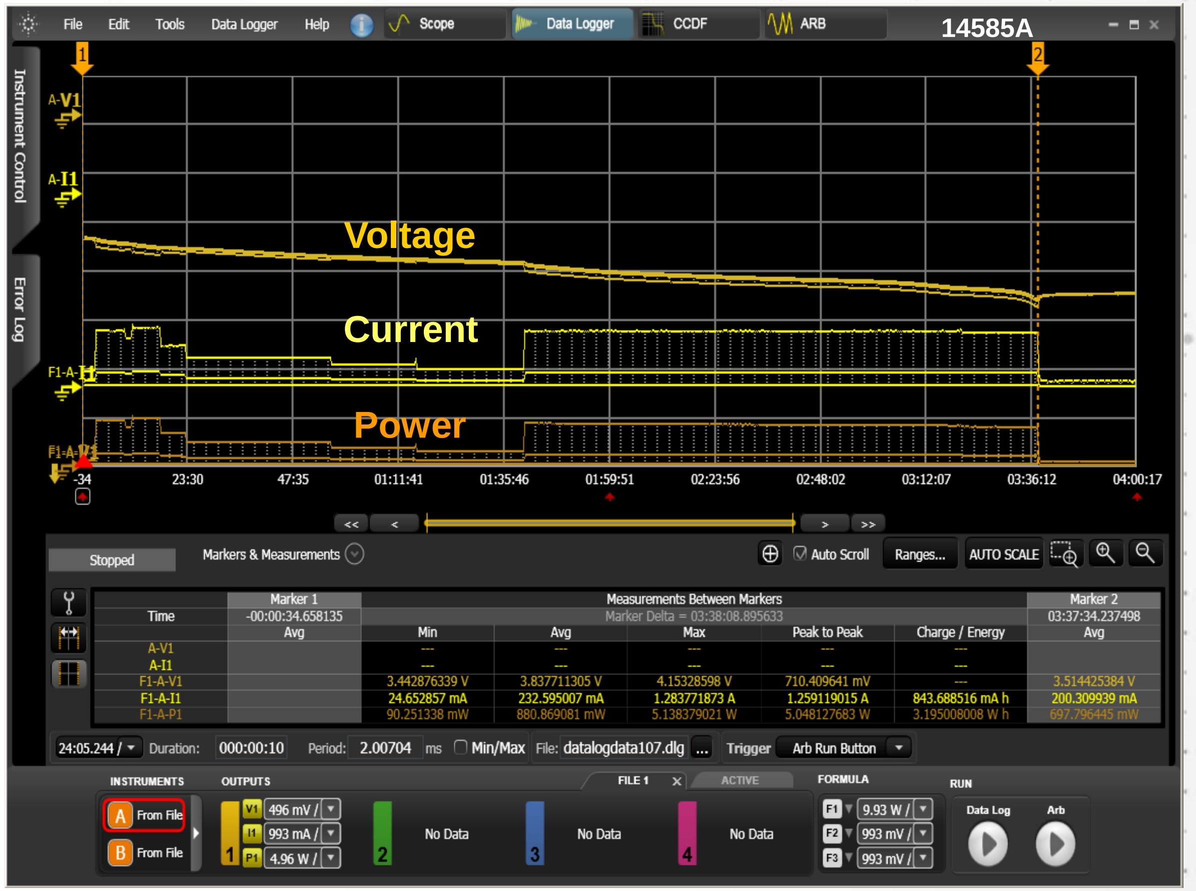
Logged min, avg & max volts, amps, & watts

Markers at start and shutdown determine:

- I avg = 233 mA
- V avg voltage = 3.82 V
- Charge = 843 mAh
- Energy = 3.19 Wh
- Run time = 3 hr 38 min
- V shutdown = 3.44 V

Insights:

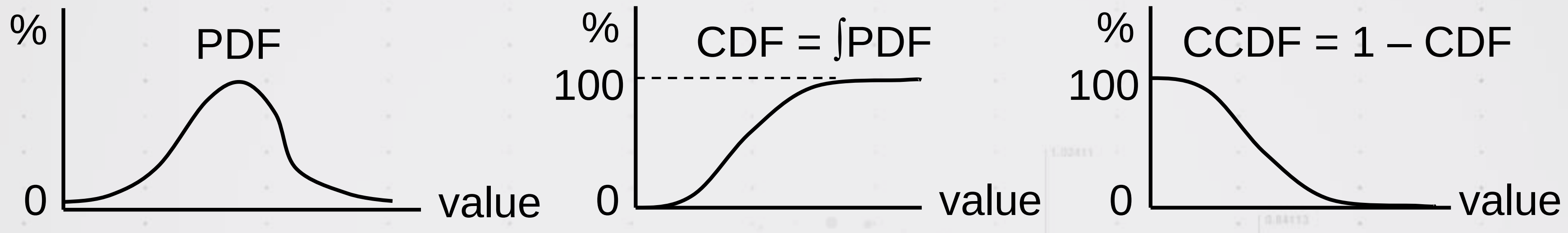
- Charge used (843 mAh) was less than spec'd (900 mAh)
- Energy used (3.19 Wh) was less than spec'd (3.42 Wh)
- 3.44V shutdown level high (target 3V)



N6781A SMU and 14585A software measuring battery run-down on a mobile phone

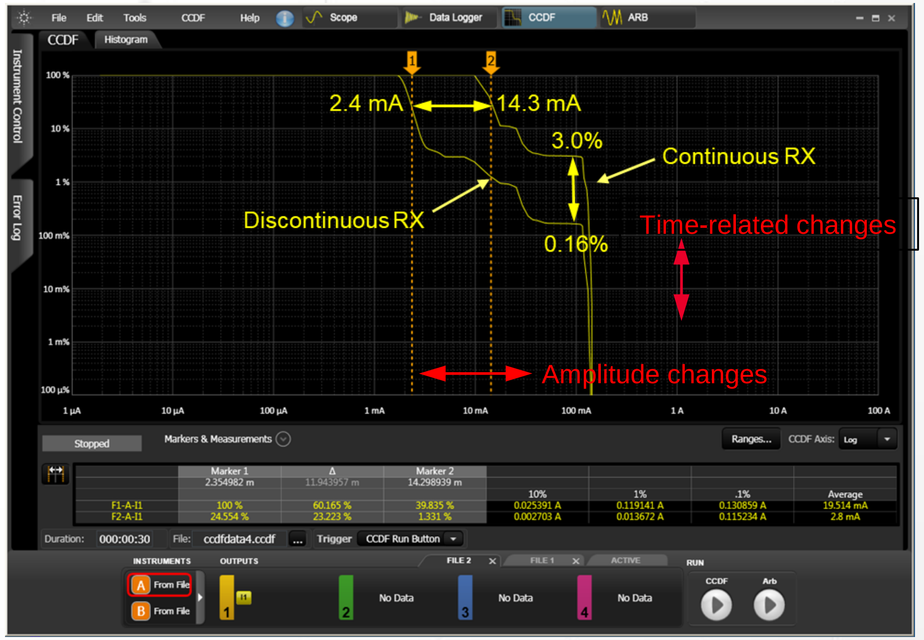
Analyzing & Optimizing Power Savings

COMPLEMENTARY CUMULATIVE DISTRIBUTION FUNCTION (CCDF)



What is a CCDF?

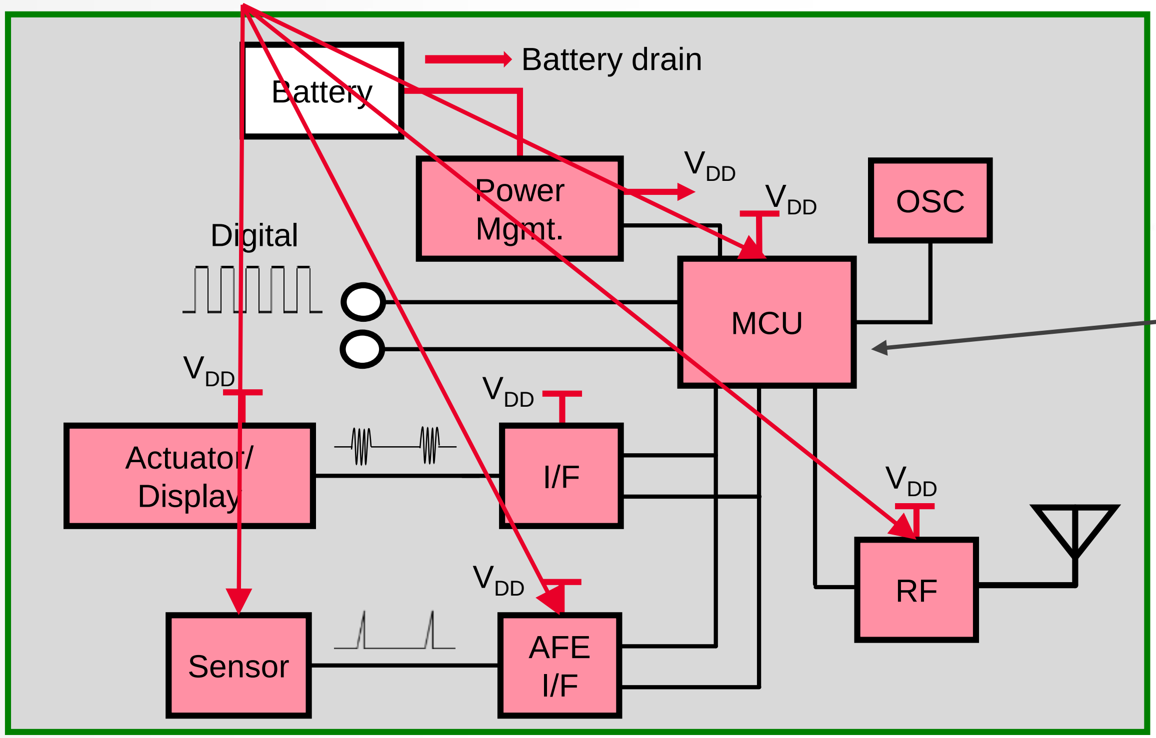
- CCDF effective for complex current drain signals
- Vertical axis is % occurrence, time-related changes
- Horizontal axis is amplitude, amplitude-related changes
- A (vertical) change of 2.8% of RX at 128 mA
  18% of the power savings
- A (horizontal) change of 11.9 mA of the idle current activity (~ 90%)
  55% of the power savings



Comparing CCDF profiles of standby current drain, continuous RX vs. discontinuous RX

What if I Need to Measure even Smaller High BW Currents?

- nA current levels
- 10 – 100MHz



Example

Si10xx Sub-GHz Wireless MCUs

- Ultra low power wireless/communication
- MCU/ SoC/IP core/Sensors

- 10 mA Rx, 18 mA Tx
- 10 nA sleep with brownout detectors disabled
- 50 nA sleep with brownout detectors enabled
- 650 nA sleep with internal RTC

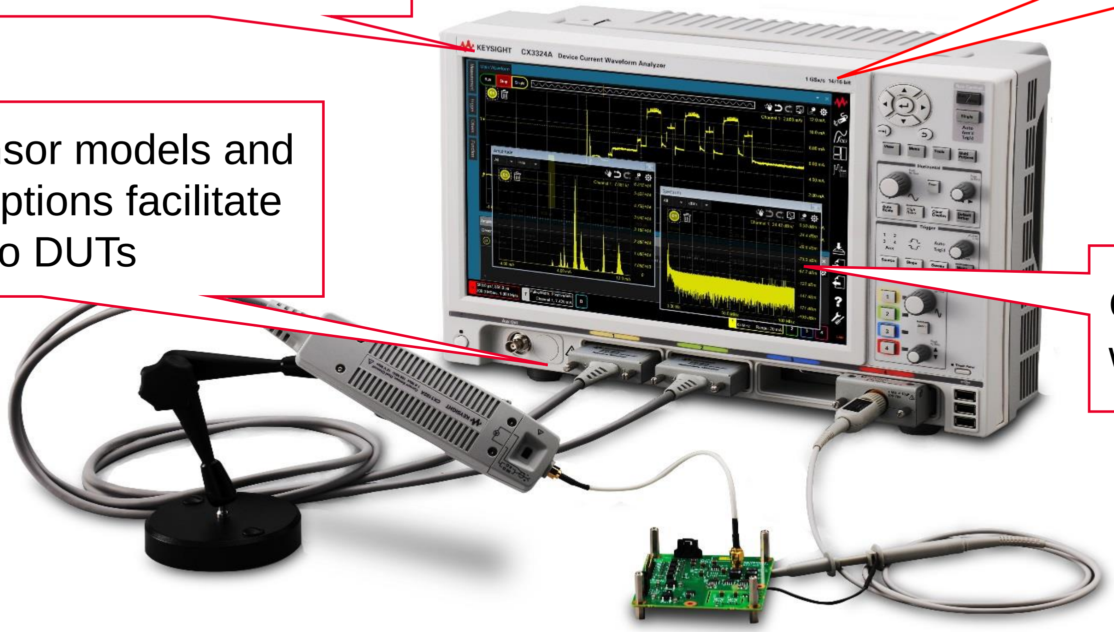
CX3300 Device Current Waveform Analyzer

EXTEND YOUR ADVANTAGE IN LOW POWER

Measure currents from 150 pA to 100 A with up to 16 bit resolution

Max 200 MHz wide dynamic range with 1 GSa/s fast sampling

Three current sensor models and six sensor head options facilitate easy connection to DUTs

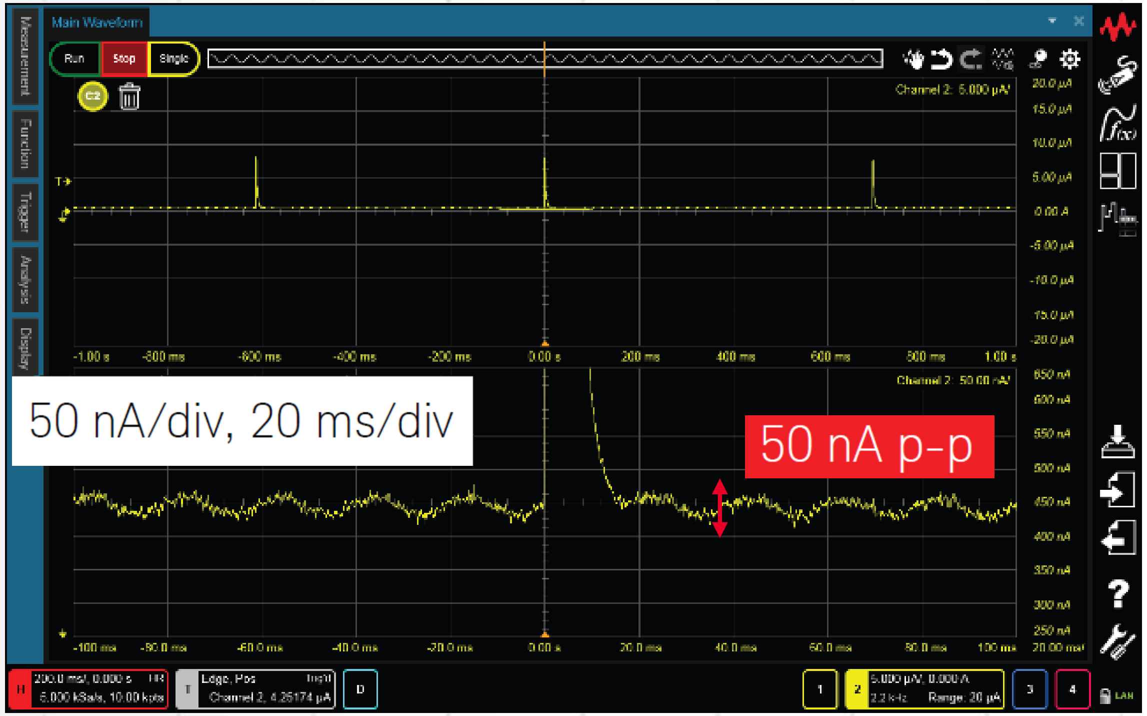


Convenient current waveform analysis functions

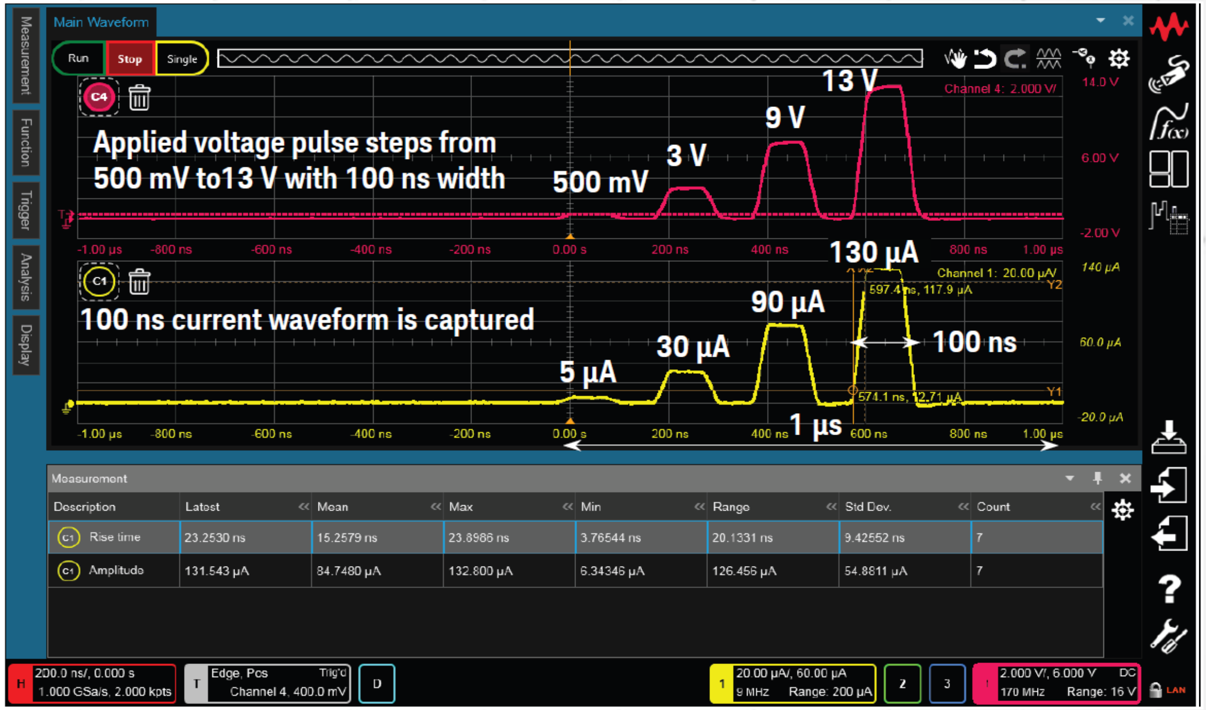
- Convenient current waveform analysis capabilities: automatic current profiler, cumulative current distribution function (CCDF) and fast Fourier transform (FFT)

Capture Signals That Were Previously Undetectable

EVALUATE FAST INRUSH CURRENTS, SPIKES & SMALL SIGNALS

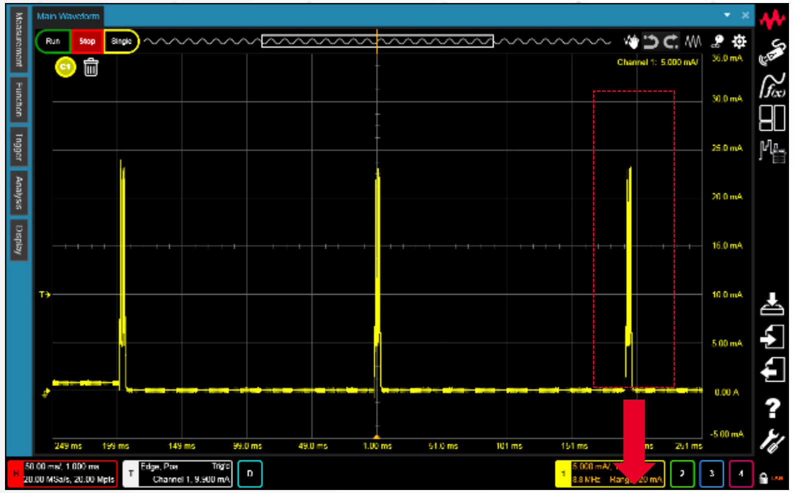


Ultra low noise current measurements



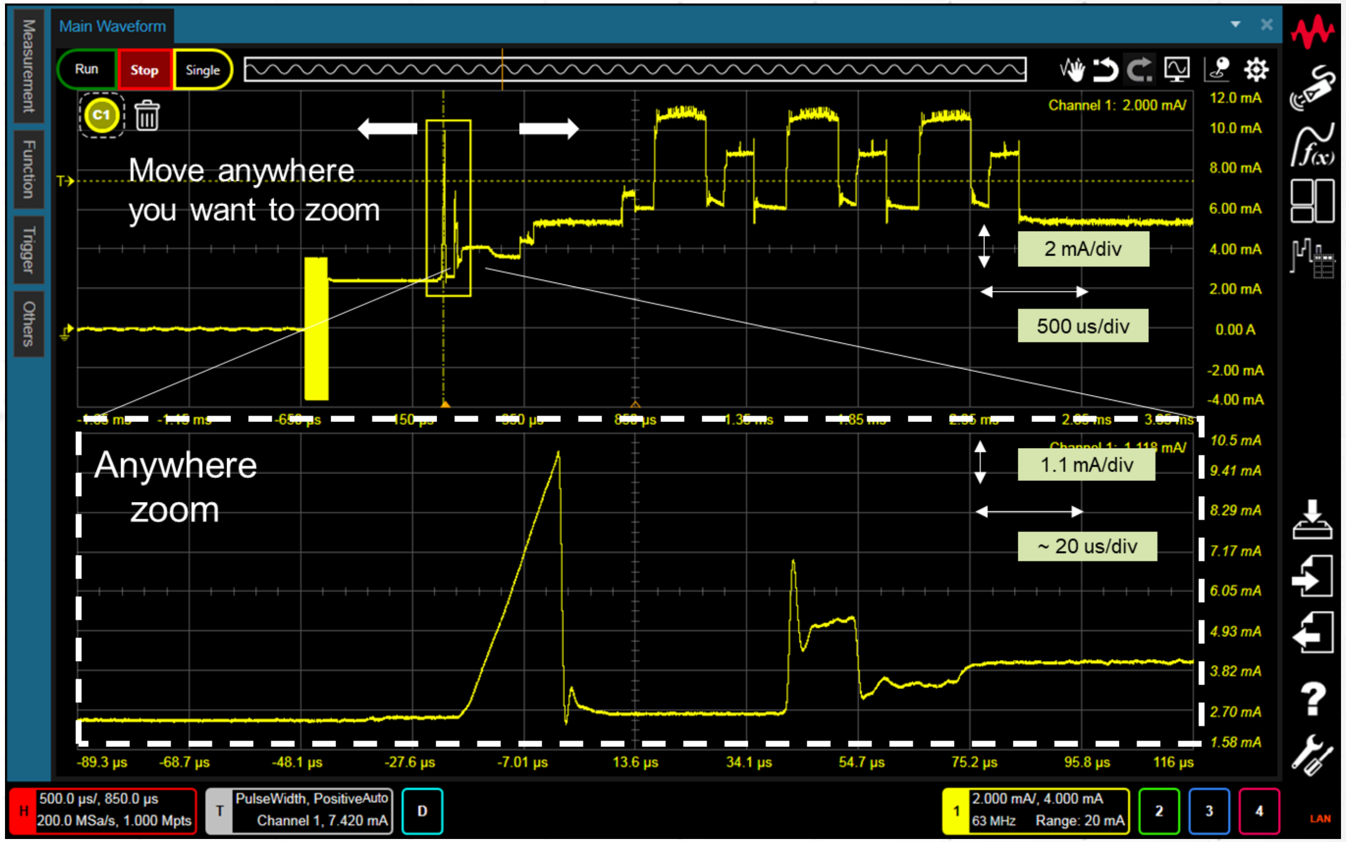
Measuring high bandiwth components

Detailed Current Profile Analysis



Macro view of IoT device with intermittent states

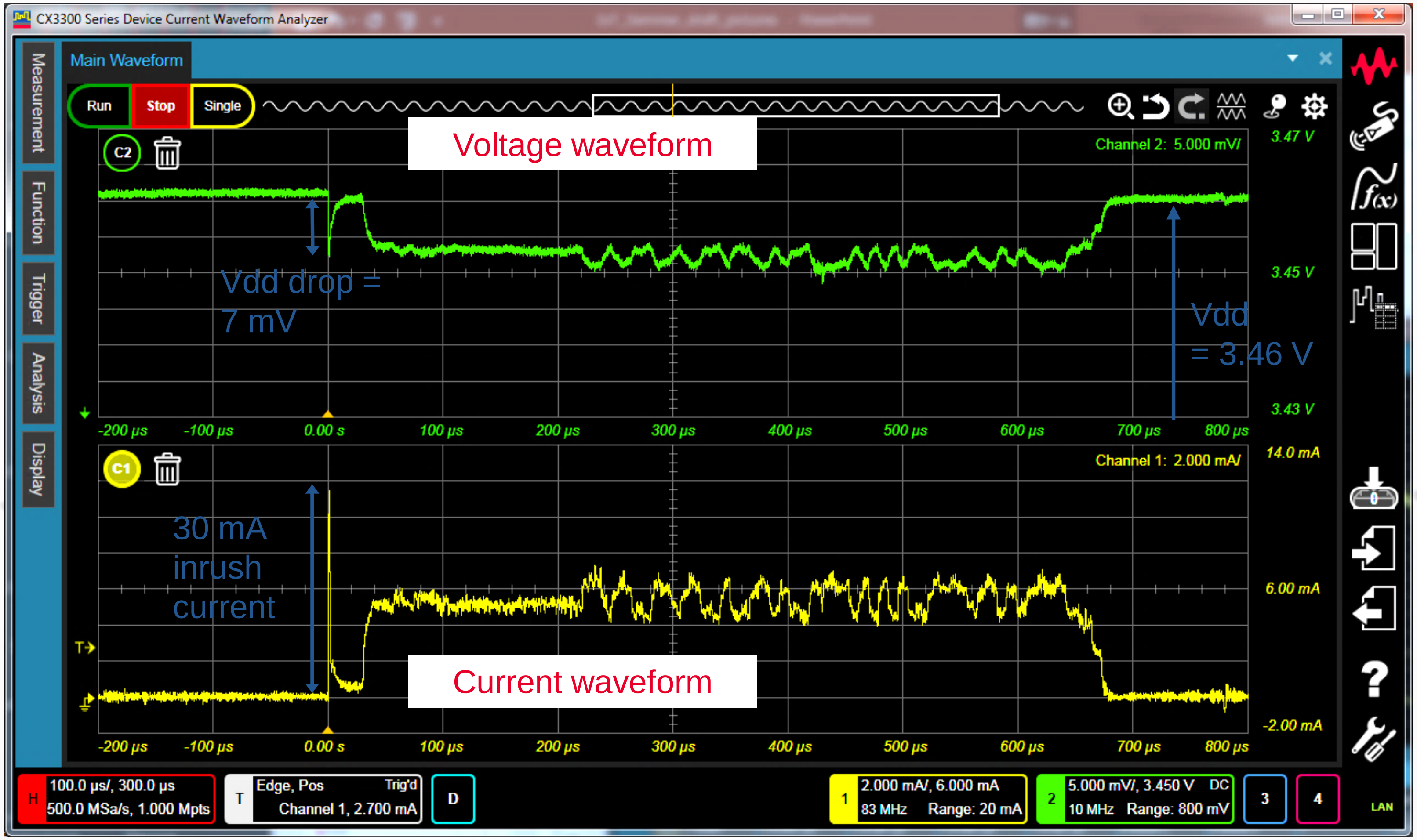
Detailed view of active state waveform



Upon further expansion of the waveform, more details of the state transition can be examined.

Detailed Voltage & Current Profile Analysis

THE RELATIONSHIP BETWEEN VOLTAGE AND CURRENT

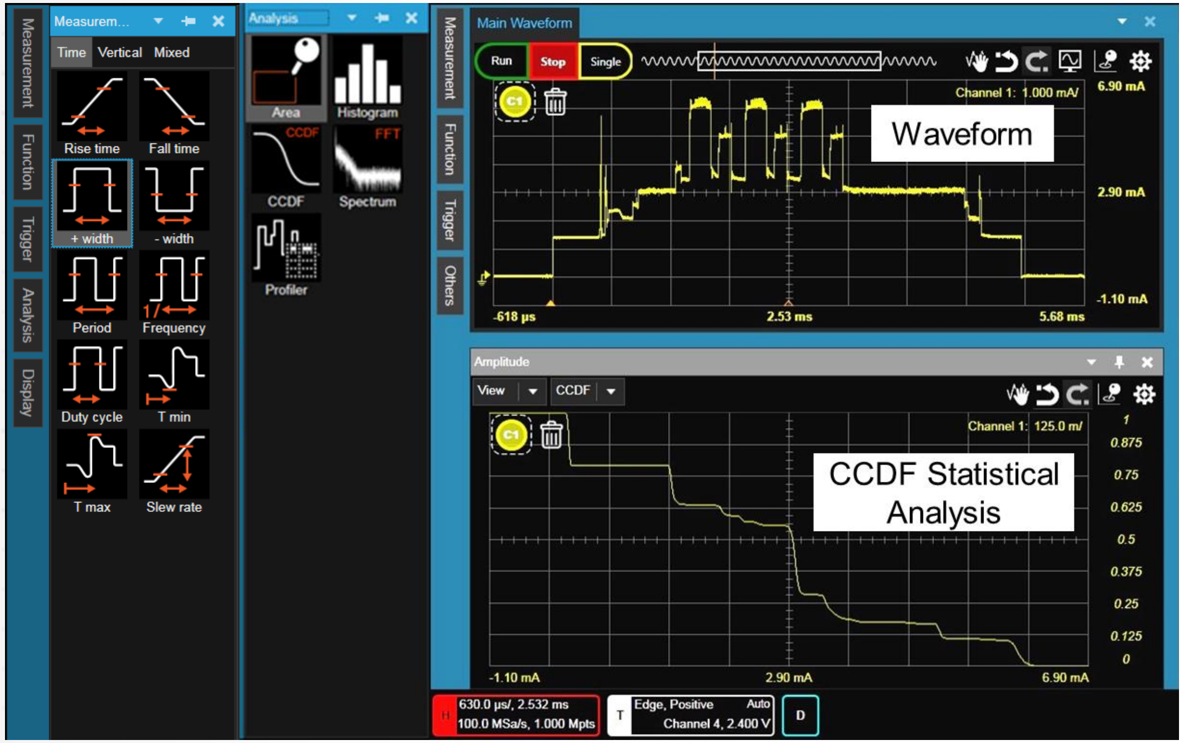


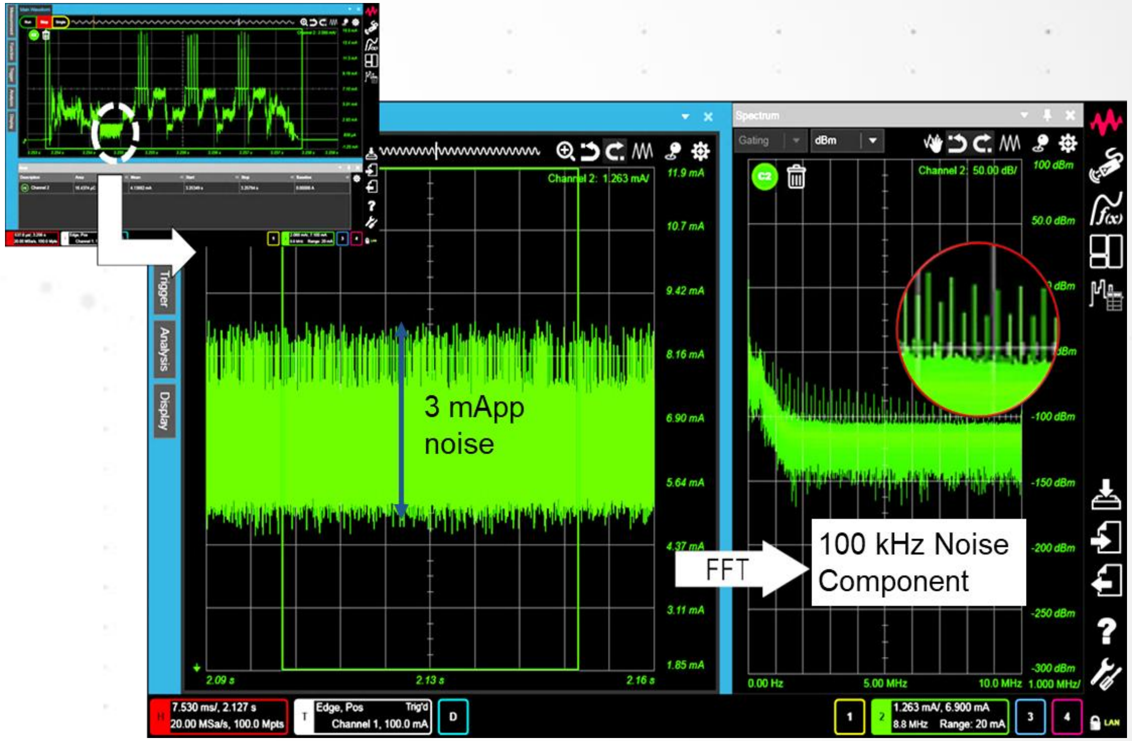
By understanding the relationship between the voltage and current waveforms, you can optimize parameters such as the voltage drop caused by the inrush current

KEYSIGHT TECHNOLOGIES

Analysis Functions for Dynamic Current Waveform

DRAG & DROP INTUITIVE MEASUREMENTS





- Measurement & analysis functions
  - Vertical and time measurements
  - Histogram, Spectrum, CCDF & Current Profiler a

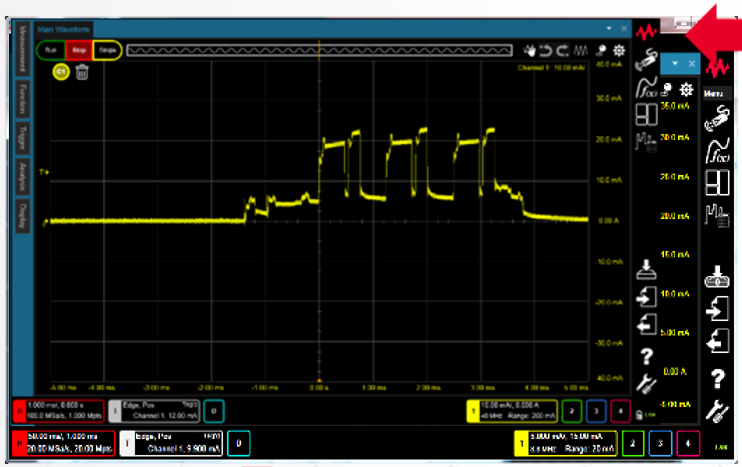
Determine the root cause of unexpected noise and signals via FFT

Fast Current Profile Analysis

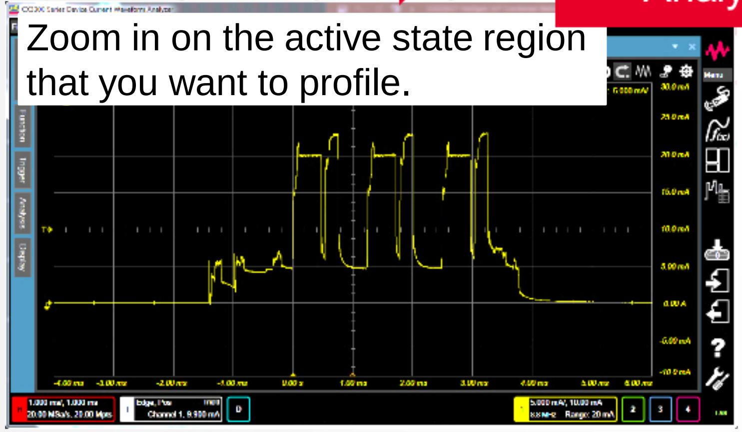
AUTOMATIC CURRENT PROFILING TOOL

Generate and analyze the current profile immediately after acquiring the waveform

Optimize the device operation

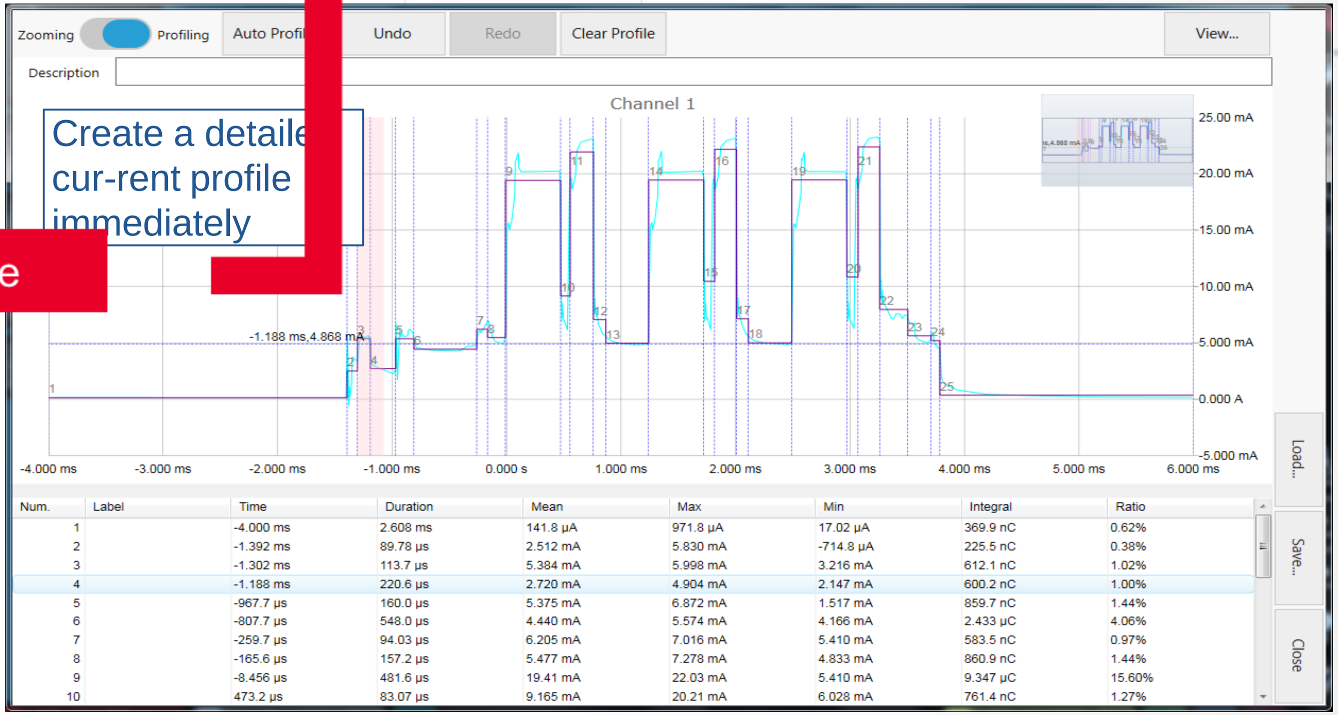


Zoom in on the active state region that you want to profile.



Analyze current profile

Create a detailed cur-rent profile immediately



Num.	Label	Time	Duration	Mean	Max	Min	Integral	Ratio
1		-4.000 ms	2.608 ms	141.8 μA	971.8 μA	17.02 μA	369.9 nC	0.62%
2		-1.392 ms	89.78 μs	2.512 mA	5.830 mA	-714.8 μA	225.5 nC	0.38%
3		-1.302 ms	113.7 μs	5.384 mA	5.998 mA	3.216 mA	612.1 nC	1.02%
4		-1.188 ms	220.6 μs	2.720 mA	4.904 mA	2.147 mA	600.2 nC	1.00%
5		-967.7 μs	160.0 μs	5.375 mA	6.872 mA	1.517 mA	859.7 nC	1.44%
6		-807.7 μs	548.0 μs	4.440 mA	5.574 mA	4.166 mA	2.433 μC	4.06%
7		-259.7 μs	94.03 μs	6.205 mA	7.016 mA	5.410 mA	583.5 nC	0.97%
8		-165.6 μs	157.2 μs	5.477 mA	7.278 mA	4.833 mA	860.9 nC	1.44%
9		-8.456 μs	481.6 μs	19.41 mA	22.03 mA	5.410 mA	9.347 μC	15.60%
10		473.2 μs	83.07 μs	9.165 mA	20.21 mA	6.028 mA	761.4 nC	1.27%

Battery Life is a Key Concern

WHEN DESIGNING PORTABLE IOT DEVICES

Industrial sensors/ gateways

Consumer devices

Medical devices

	SIGFOX	LoRaWAN	NB-IoT	Cat M	EC-GPRS
Release	Now	Now	H2 2016	H2 2016	H2 2016
Link budget	~162dB	~157dB	~164dB	~156dB	~164dB
Battery life	>10 years	>10 years	>10 years	>10 years	>10 years
Spectrum	un & lightly-license bands e.g. 868, 915 MHz	un & lightly-license bands e.g. 169, 433, 470, 868, 915 MHz	GSM & LTE Licensed bands	LTE Licensed bands	GSM Licensed bands
Rates and modulation	Uplink: 100bps BPSK 100Hz BW Downlink: 500bps GFSK 600Hz BW	GFSK, CSS (Chirp Spread Spectrum) ~0.3 to 50kbps 125kHz BW	Up to ~250kbps Uplink π/4-QPSK, rotated π/2 BPSK, 8PSK, opt 16QAM Downlink BSK-16QAM 180kHz BW	1Mbps QPSK, 16 or 64QAM 1.4MHz BW	~10 to ~240kbps GMSK, opt 8PSK, 200kHz BW
Silicon	Multi-vendor	Semtech (2nd vendor announced)	Multi-vendor	Multi-vendor	TBC
Protocol	SIGFOX	Semtech (2nd vendor announced)	3GPP Multi-vendor	3GPP Multi-vendor	3GPP Multi-vendor
Certification	SIGFOX	LoRa Alliance	GCF/PTCRB TBC	GCF/PTCRB TBC	GCF/PTCRB TBC

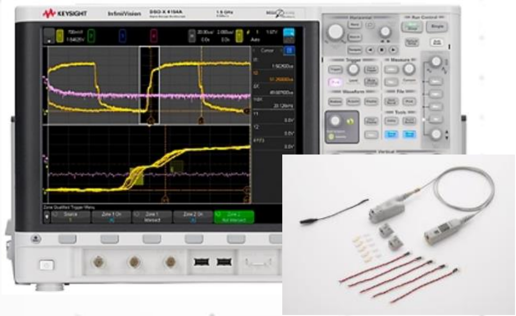
Challenges:

1. How to define the battery life?
2. What are the critical events that contribute to the power consumption and how frequently do those events happen?
3. What design changes or tradeoffs should I make to optimize battery life?

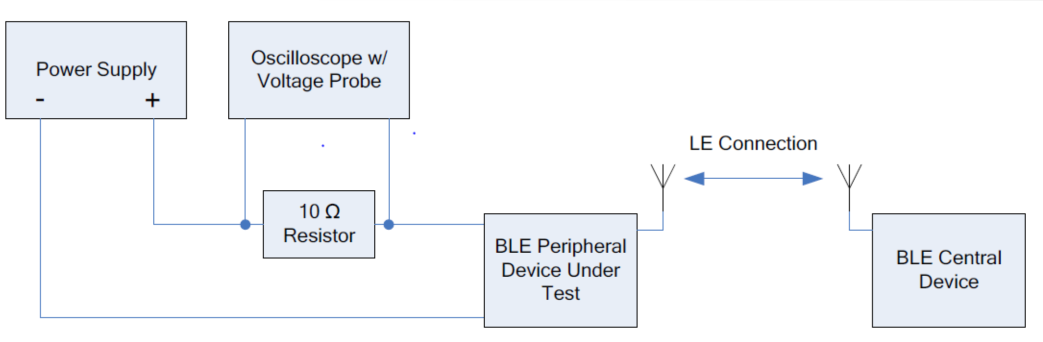
How Do You Measure Battery Life?

Digital Multimeter

Power supply



Scope & Probe

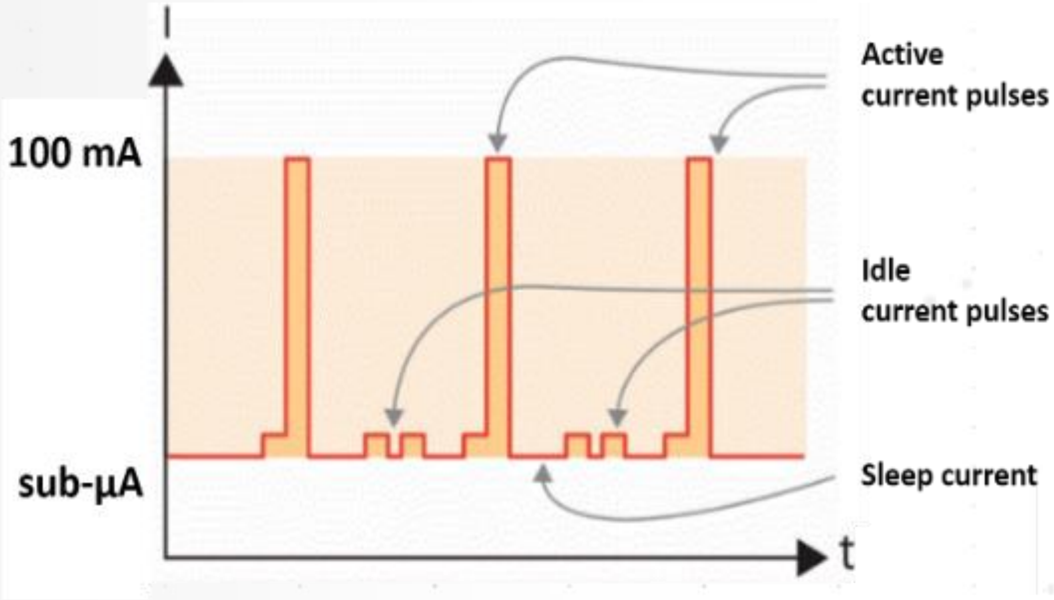


Easily available, easy to use, flexible and low cost

KEYSIGHT TECHNOLOGIES

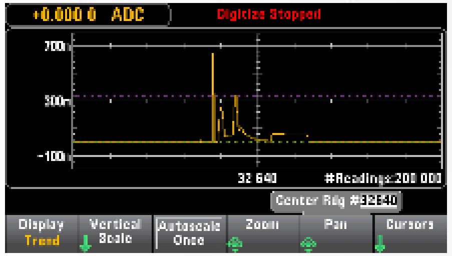
Have You Considered These Issues?

THERE MAY BE PROBLEMS YOU HAVE UNDERESTIMATED

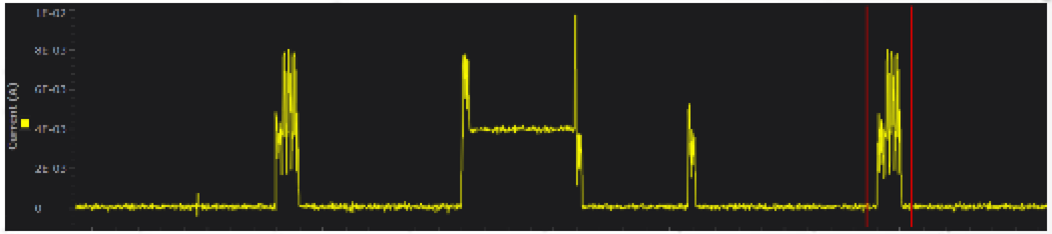


Typical current drain profile of IoT device – fast changing and wide range!

Inaccurate & poor visibility



Limited dynamic range and resolution



Lack of insights

(What is causing the current spikes? How much current is consumed during TX mode or idle mode? How or what to improve?)

These challenges waste your time and effort, and result in fragmented, inaccurate view of the IoT device's battery life.

The New Way to Perform Battery Drain Analysis

Ideally, what they need is a solution that can help them to……

Significantly *increase test capability*

Reduce *their test development and testing time*

Get ***Accurate*** *views of your device's battery life*

X8712A IoT Device Battery Life Optimization Solution

KEY BENEFITS

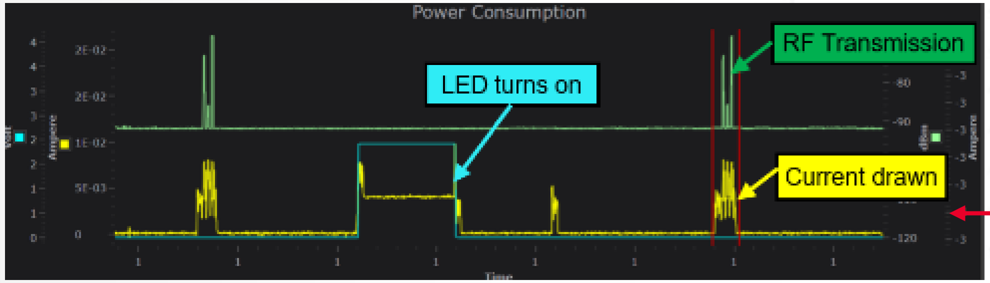
TAP-based SW
(KS833A1A)

Shield box
(not from Keysight)

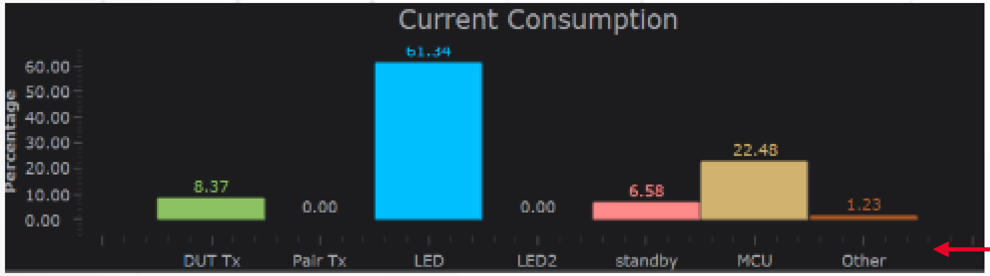
N6705C DC Power Analyzer with
N6781A SMU module

X8712AD RF Event Detector

Detect design weakness with quick and effortless event-based power consumption analysis



Correlate current waveform with other RF/DC events



Break down current consumption% by event

Accurately predict the battery life of your IoT device

Battery (Ah)	0.2

Battery capacity

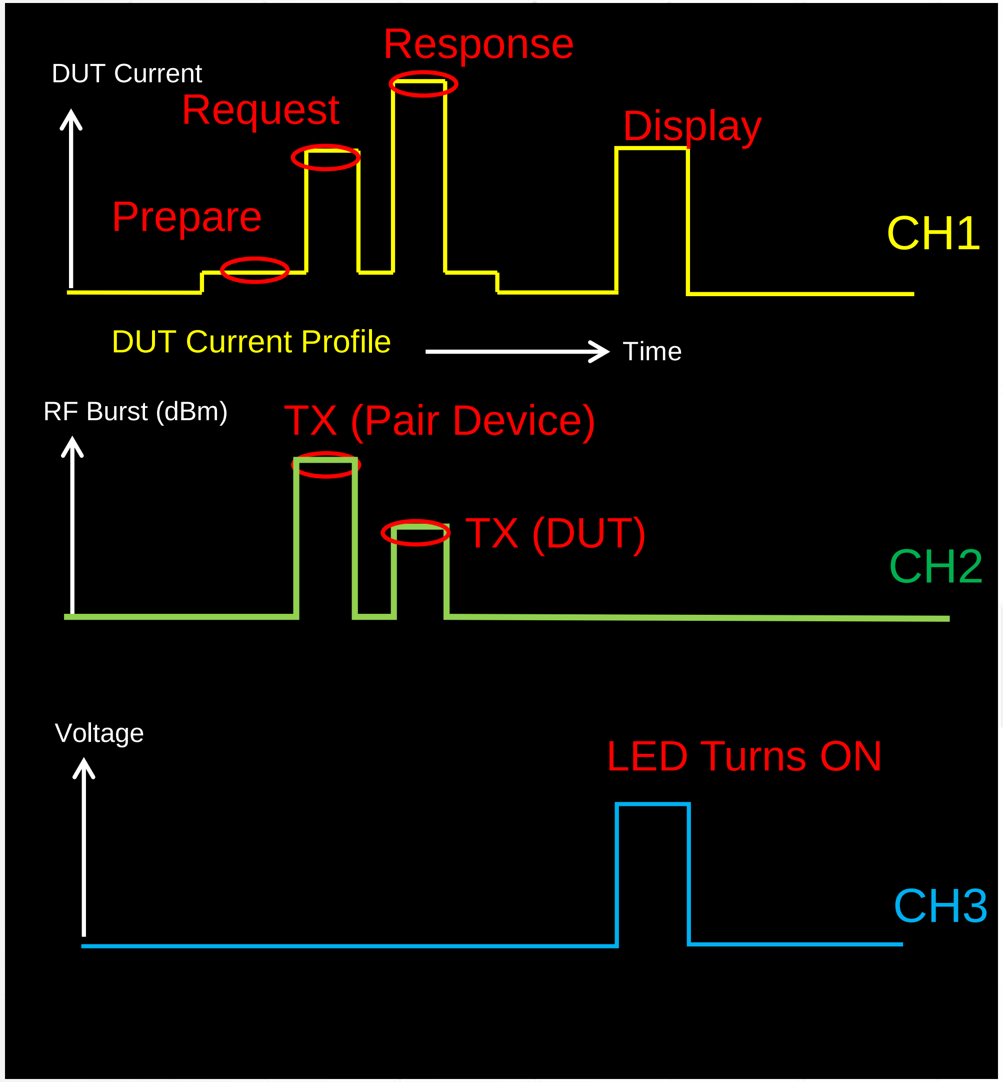
Max Current	11.04 mA
Cycle Time	6.02 ms
Charge Energy	5.24 nAh
Battery Life	63.84 h

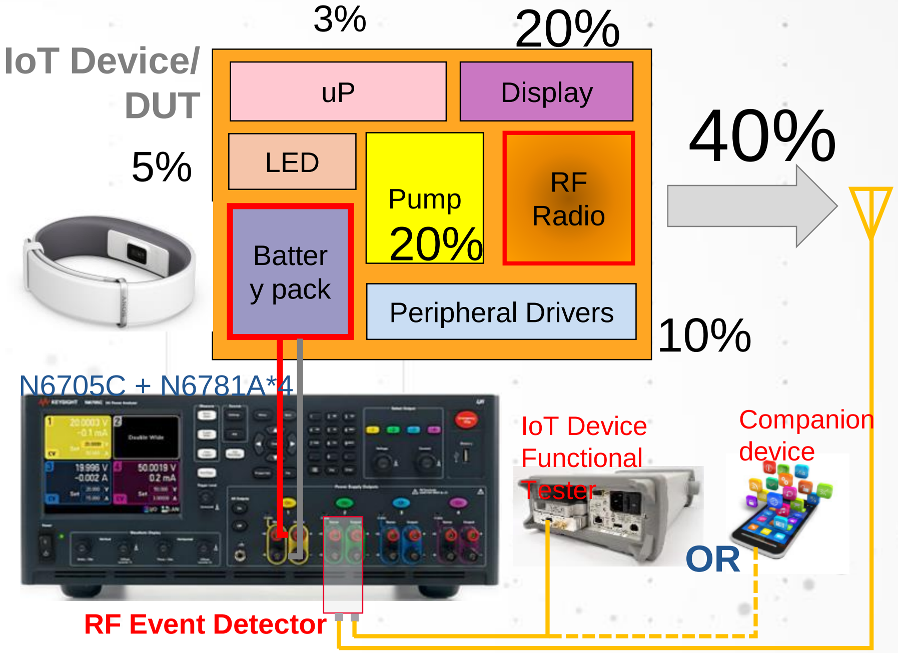
Max current

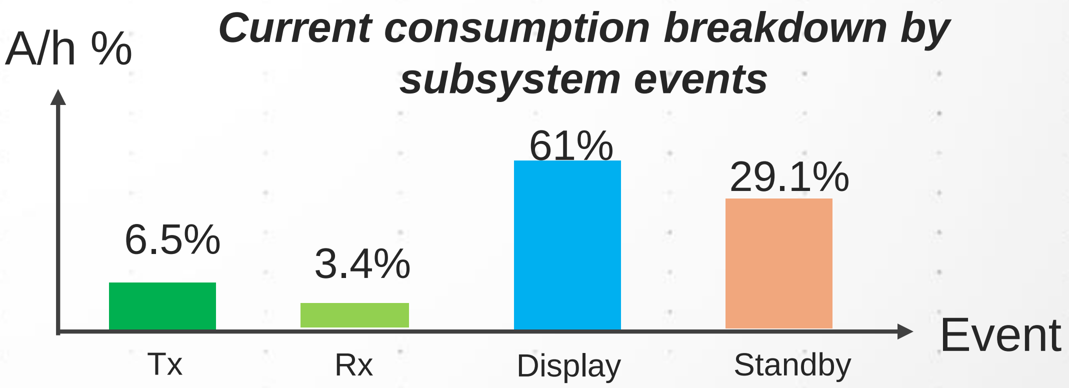
Charge consumed

Battery life

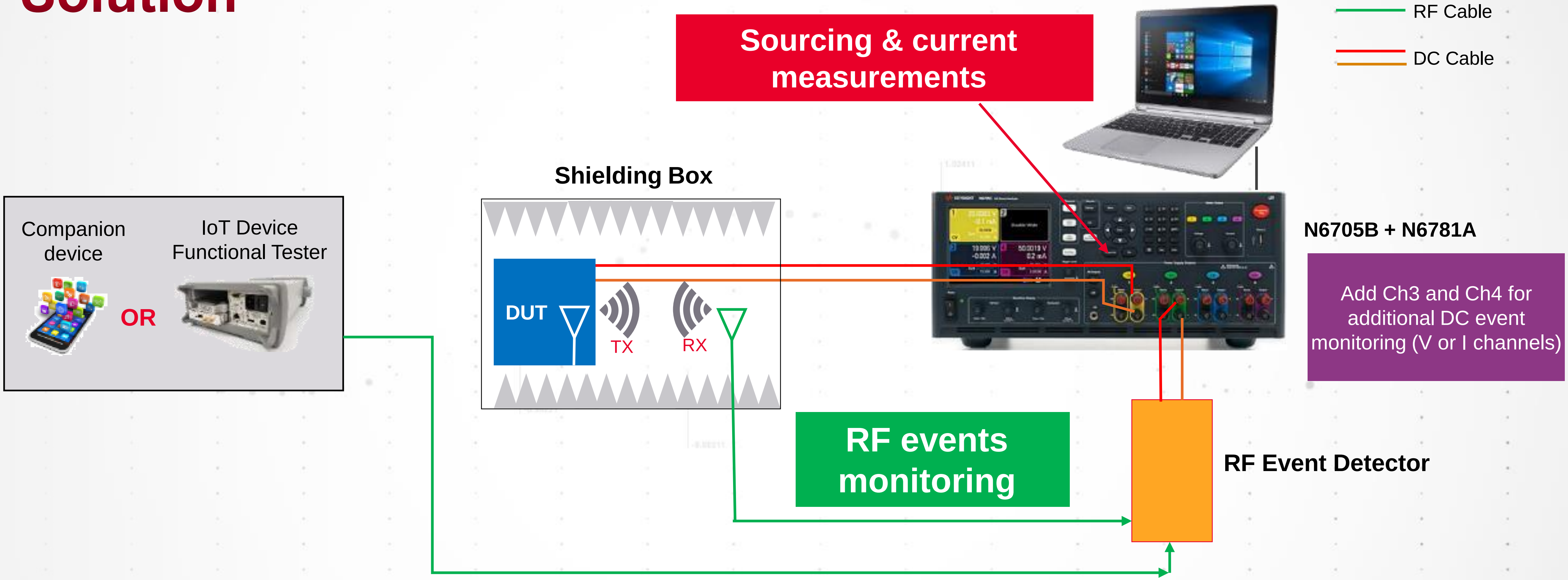
4 Channel Current Consumption Analysis Concept





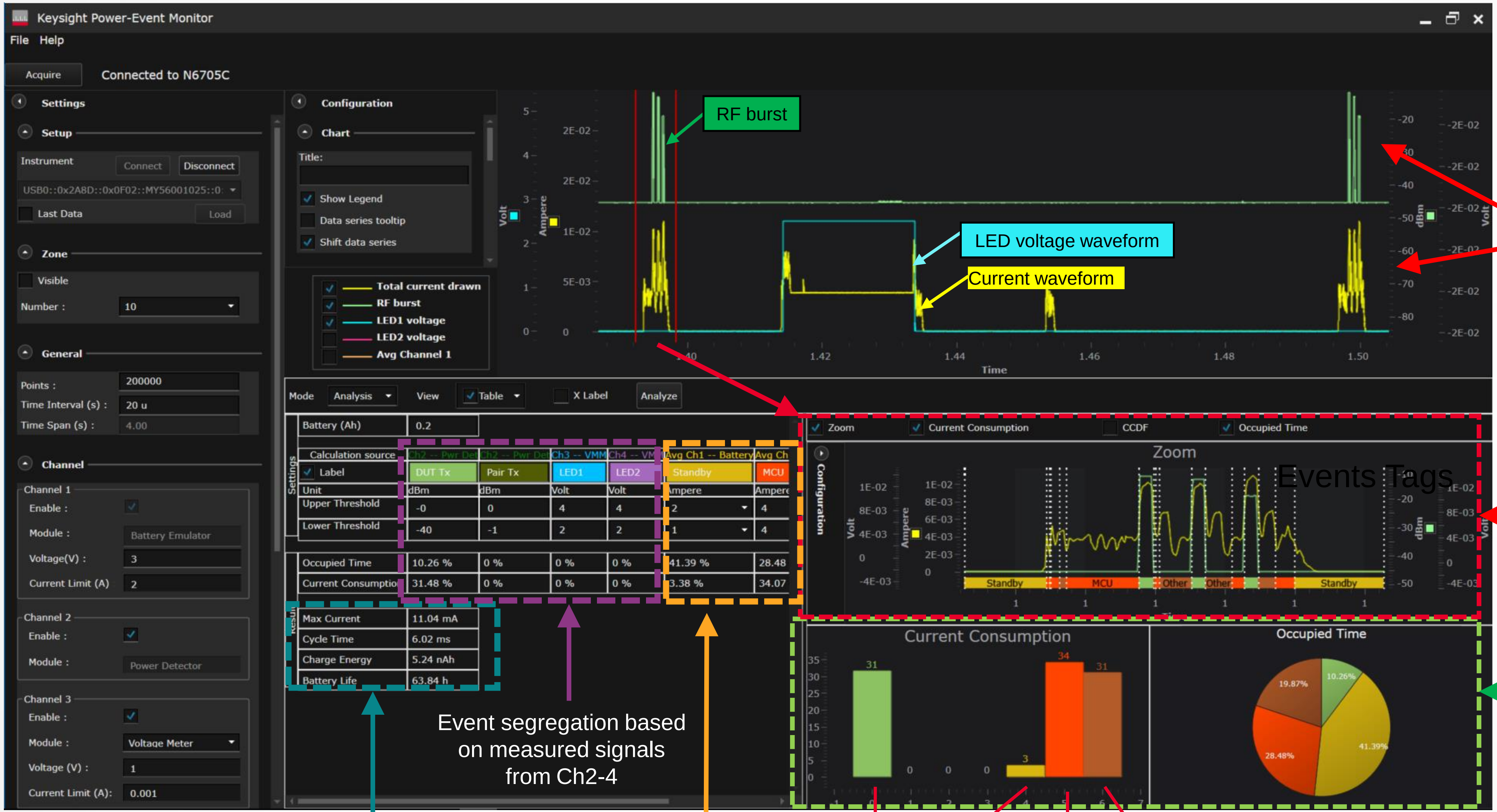


Keysight X8712A IoT Device Battery Life Optimization Solution



Synchronize and correlate current consumption with RF and DC events.
Identify critical events that contribute to the most power consumption.

KS833A1A Event-Based Power Analysis Software



Synchronous capture of current consumption waveform and RF/DC events

Waveform Zoom & Analysis

Event based analysis (event current consumption and occupied time in %)

Event segregation based on measured signals from Ch2-4

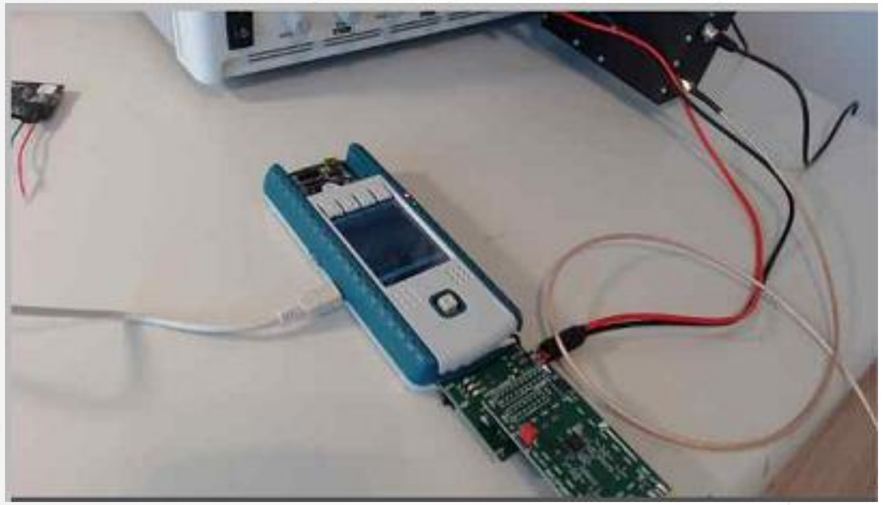
Battery life analysis

Event segregation using current zones

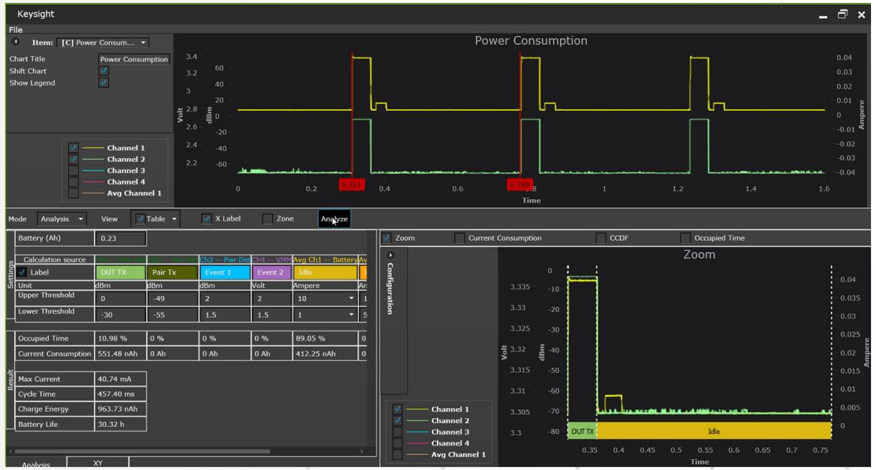
TX standby MCU Others

Application Examples

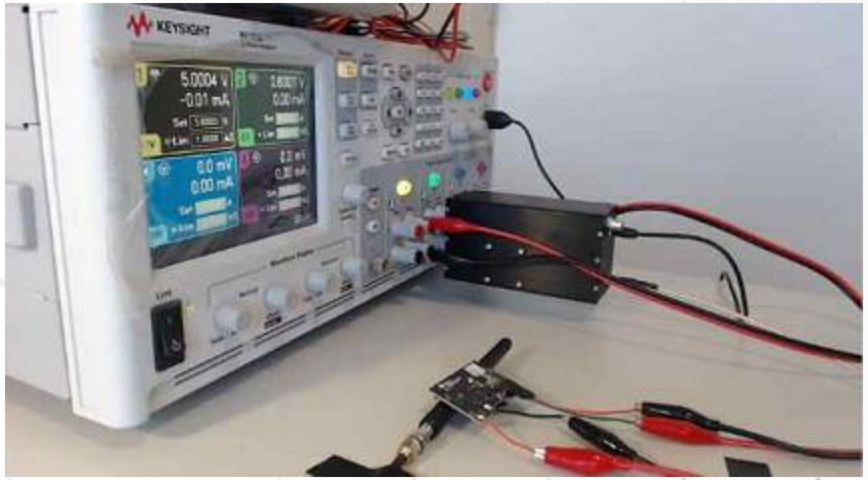
2 channel operations for LoRa module



Ch1 – Sourcing & Current
Ch2 – RF

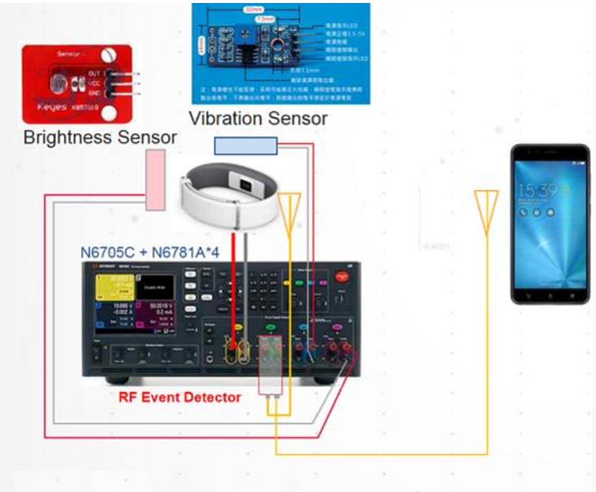


3 channel operations for Sensor Tag



Ch1 – Sourcing & current
Ch2 – RF
Ch3 – LED voltage

4 channel operations for Smart Watch

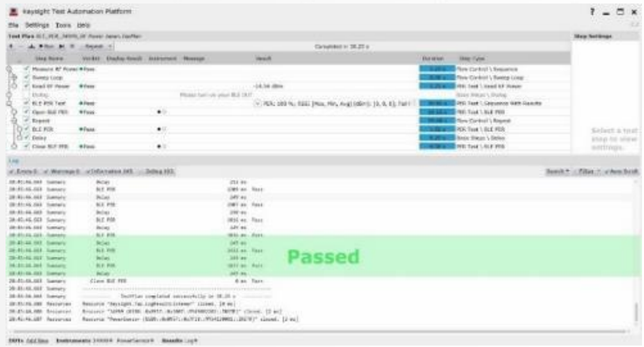


Ch1 – Sourcing & Current
Ch2 – RF
Ch3 – Vibration sensor
Ch4 – Brightness sensor

KEYSIGHT TECHNOLOGIES

IoT Device Functional Test + Power Consumption Analysis

EXAMPLE CONFIGURATIONS FOR BLE DEVICE



BLE Signaling Measurement Suite

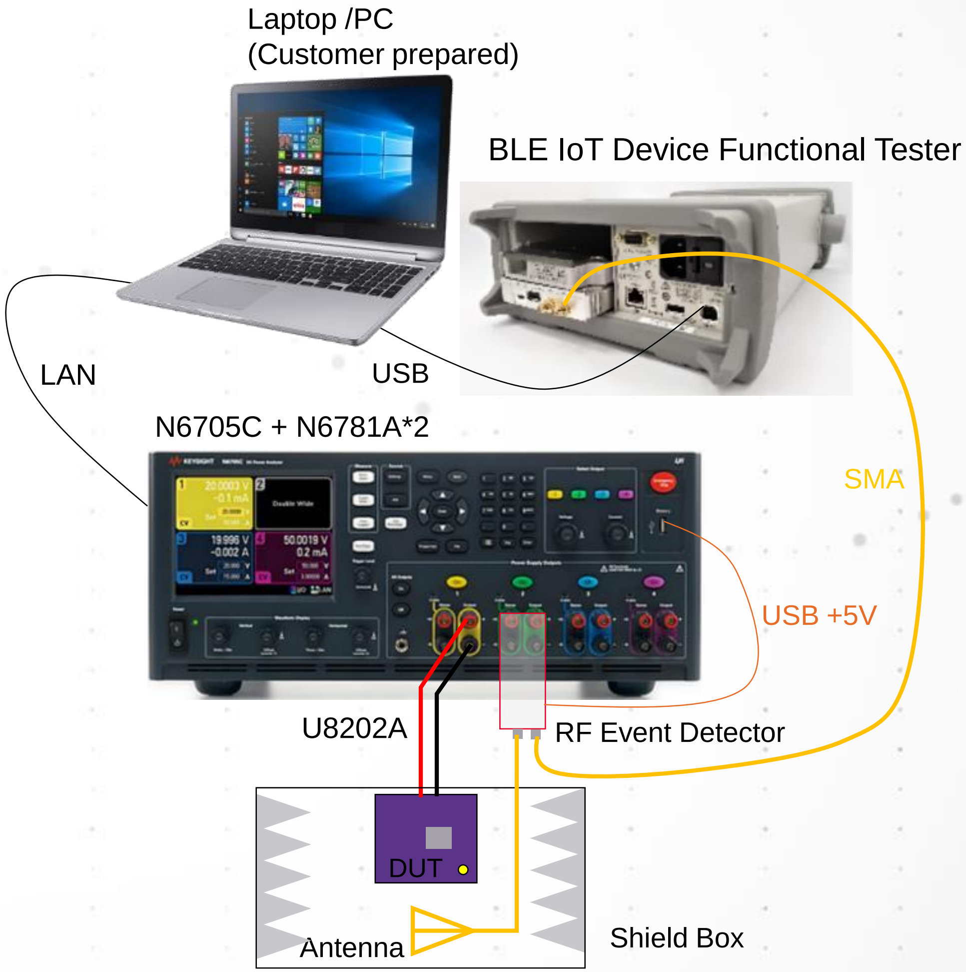
- Tx Power
- PER
- Sensitivity

Event-Based Power Consumption analysis Suite

- Events + current monitoring
- Advanced current consumption over events analysis & battery life estimation

14585A (N6705C opt 056)

- Scope & Data Logging of voltage & current
- Arbitrary waveforms creation



Battery Drain Analysis Solutions from Keysight

N6705C and N6781A SMU module

- *Patented seamless ranging*
- *Measure wide range of current from nA to A in one pass*
- *Accurately emulate a battery*
- *Log data for seconds, hours or days*

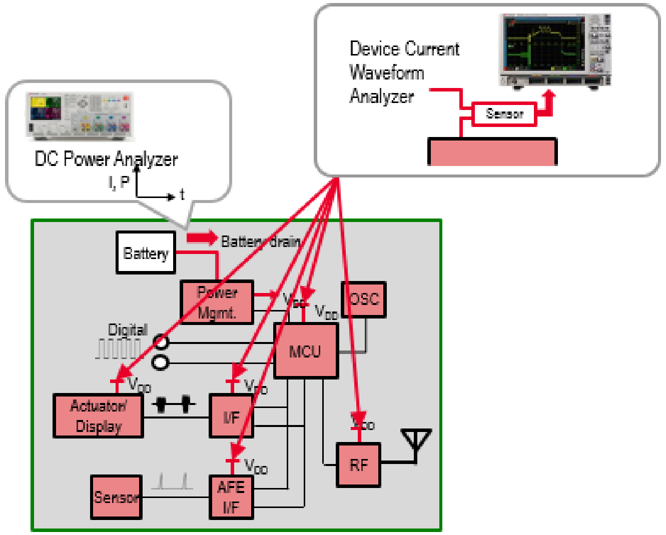
CX3300 Device current waveform analyzer

- *Highest bandwidth choice*
- *Show low-level current waveforms that were previously undetectable*
- *Up to 200MHz and 14/16 bits resolution*

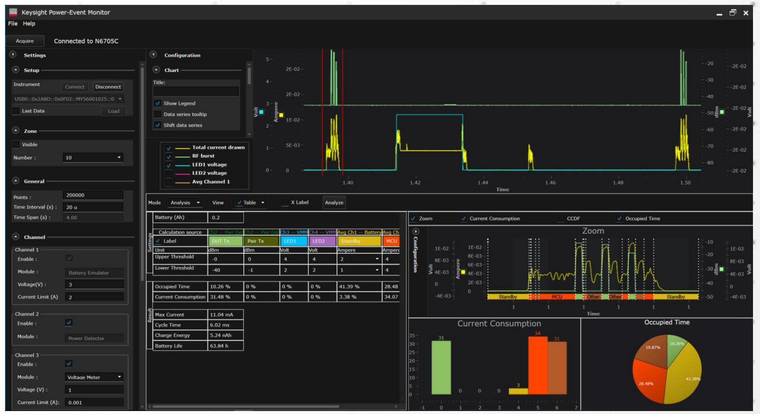
X8712A IoT device battery life optimization solution

- *Detect design weakness with quick and effortless event-based power consumption analysis*
- *Synchronize and correlate current consumption with RF and DC events.*
- *Accurately predict the battery life of your IoT device*

- *Best for battery drain analysis of IoT device*
- *Built-in power supply to simulate battery and measure battery current drain*



- *Best for current profile measurements of sub-circuit, IC or power lines inside an IoT device*
- *Wide bandwidth to characterize in-rush current of IC*



Questions?

KEYSIGHT TECHNOLOGIES

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