70th Anniversary

展望太克 榮耀70

2016太克科技

春季創新論壇

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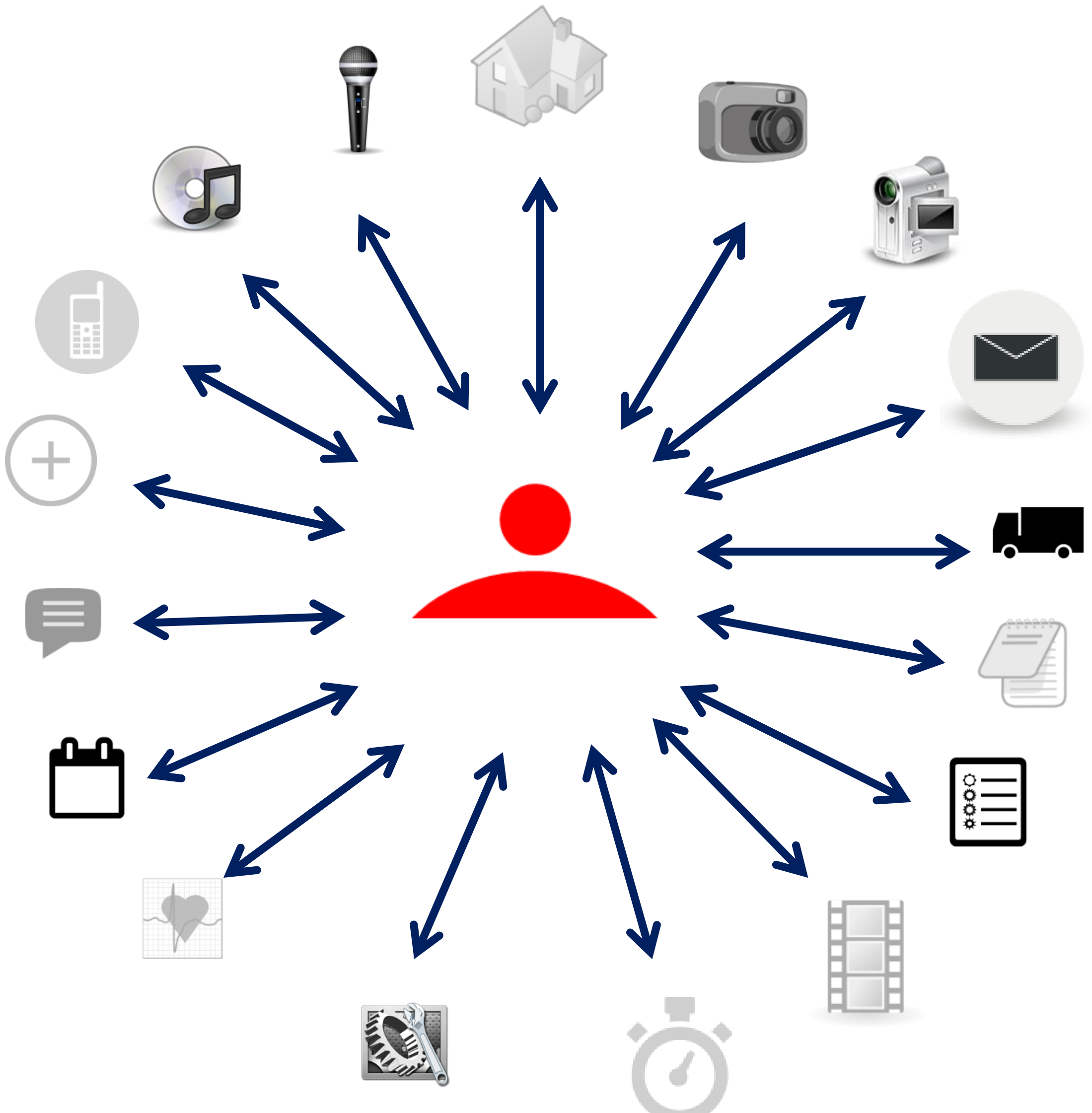
Tektronix 70th Anniversary 展望太克 榮耀70

Power Consumption Measurement Techniques

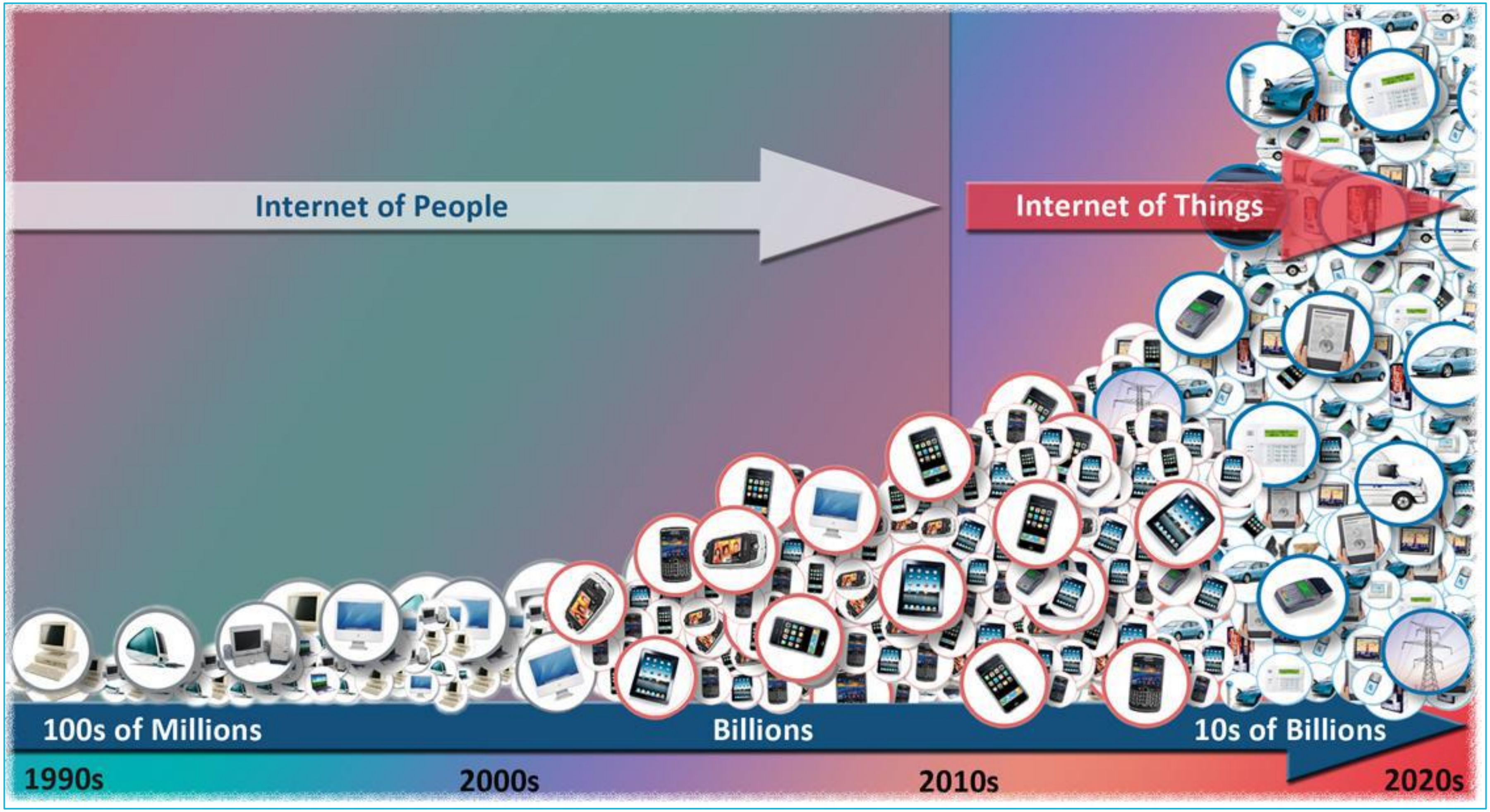
Maximize the Battery Life of Your Internet of Things Device

Jonathan Chang

Internet of Things



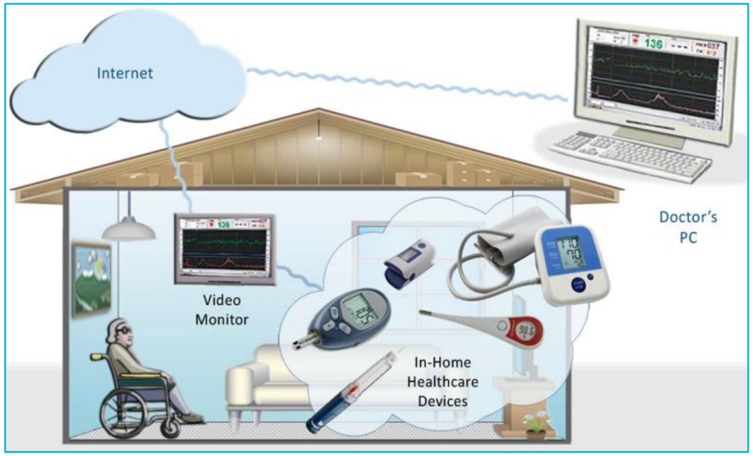
IoT : Internet of Things : Disruption & Potential for high growth



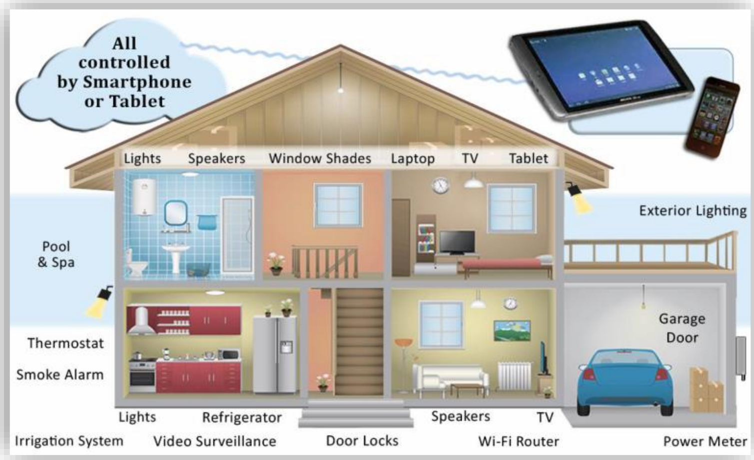
Source: Raymond James research

IoT applications

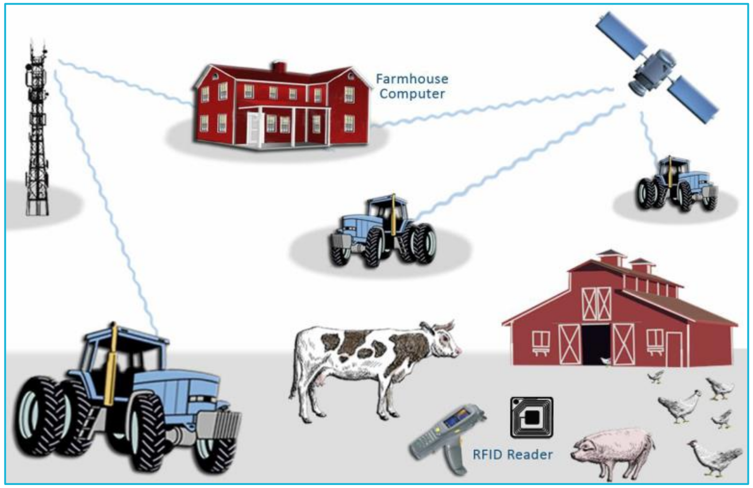
Health



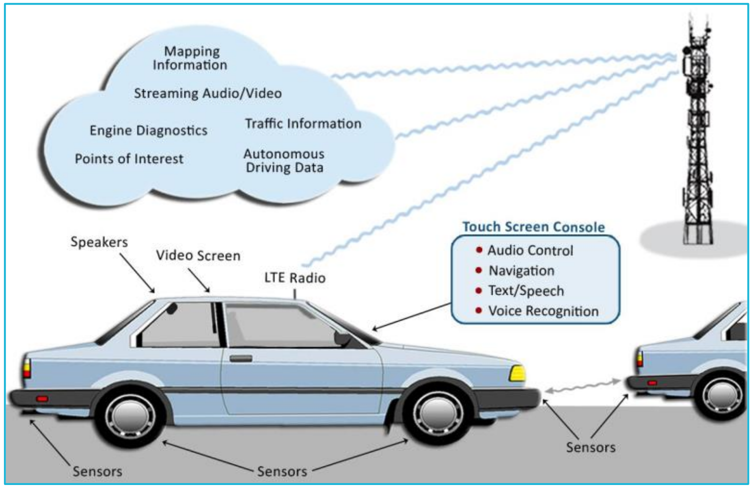
Home automation



Farming / Smart metering / …



Automotive

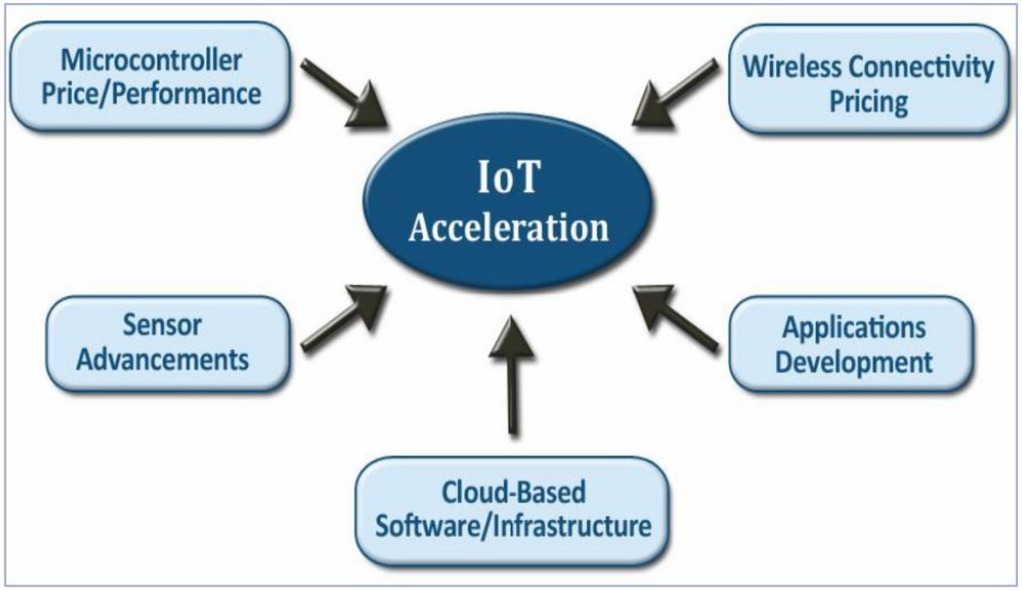


Source: Raymond James research

M2M World of Connected Services

The Internet of Things

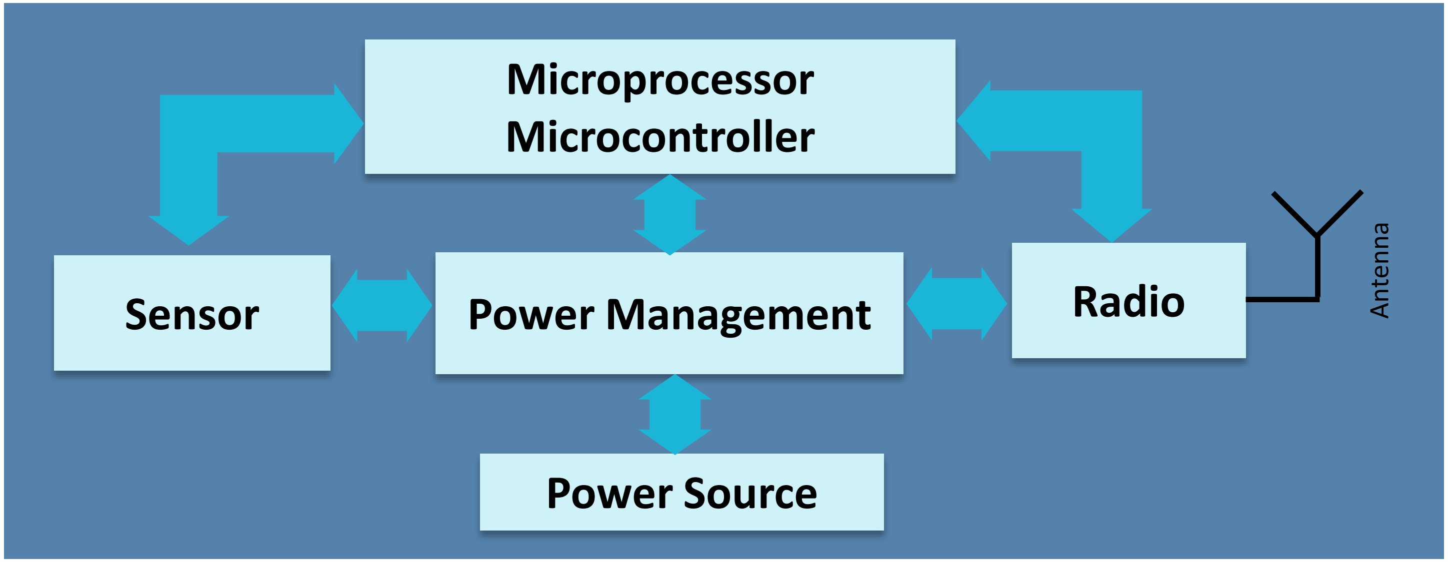
Device development is accelerated by new low cost IoT modules (sensors, RF modules, MCUs)



Source: Raymond James research

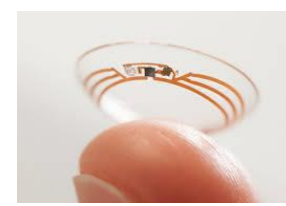
- Explosion of sensor systems and components. Several physical/chemical parameters can be sensed (temperature, pressure, movements, etc.)
- Wireless connectivity made simpler with wider offering of high performance RF modules
- MCUs offering higher performances (low power, computation speed, DSP, etc.)

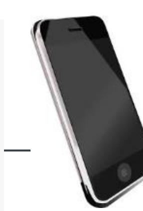
IoT wireless, portable device architecture and Power Budget



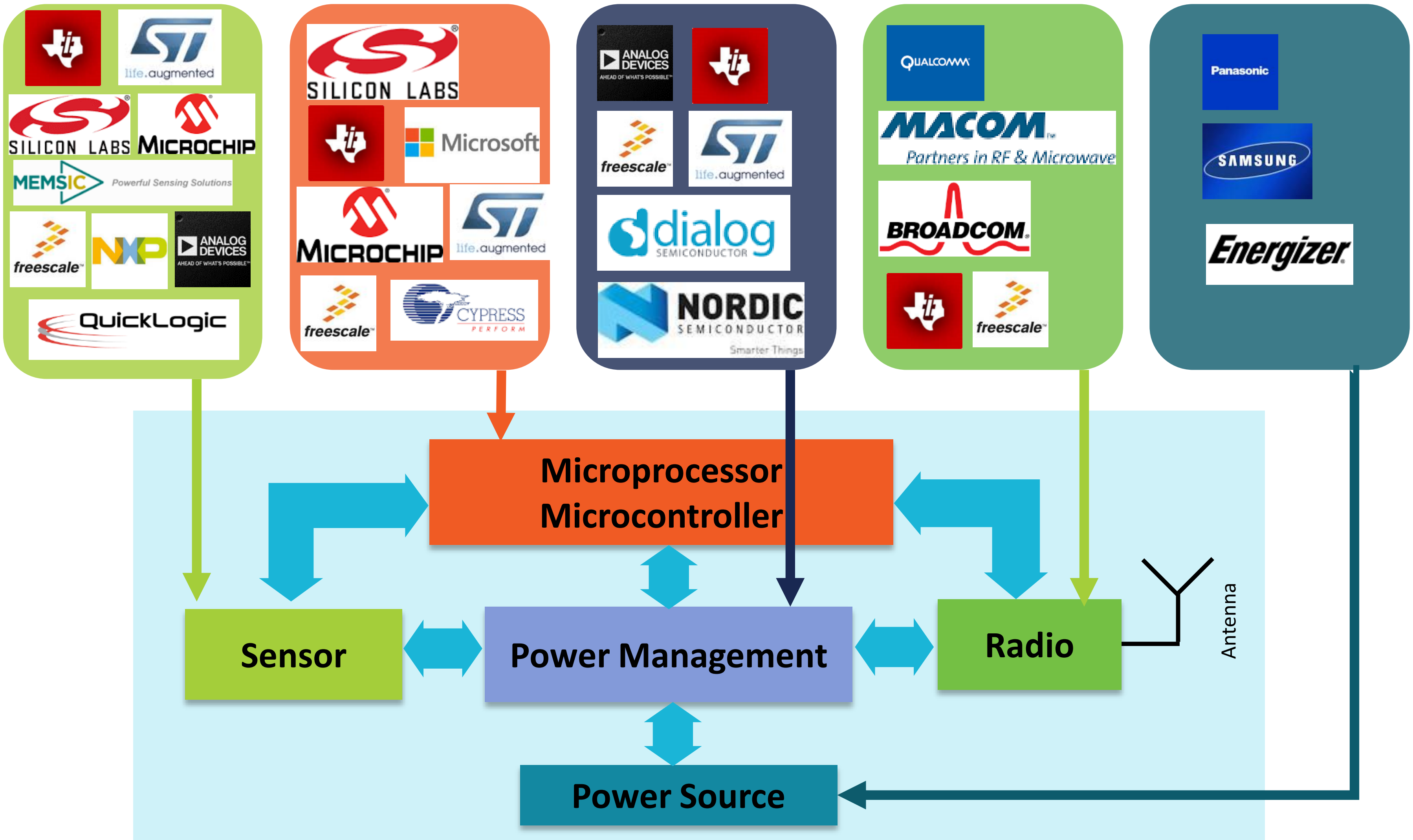
Power Budget:*<u>80uW</u>* (6months)

Accelerometer 14uW
Bluetooth SMART Tx/Rx 12uW
Power Management Unit 20uW
Processing 34uW
(MCU 100uA/MHz + memory + peripheral + oscillator)



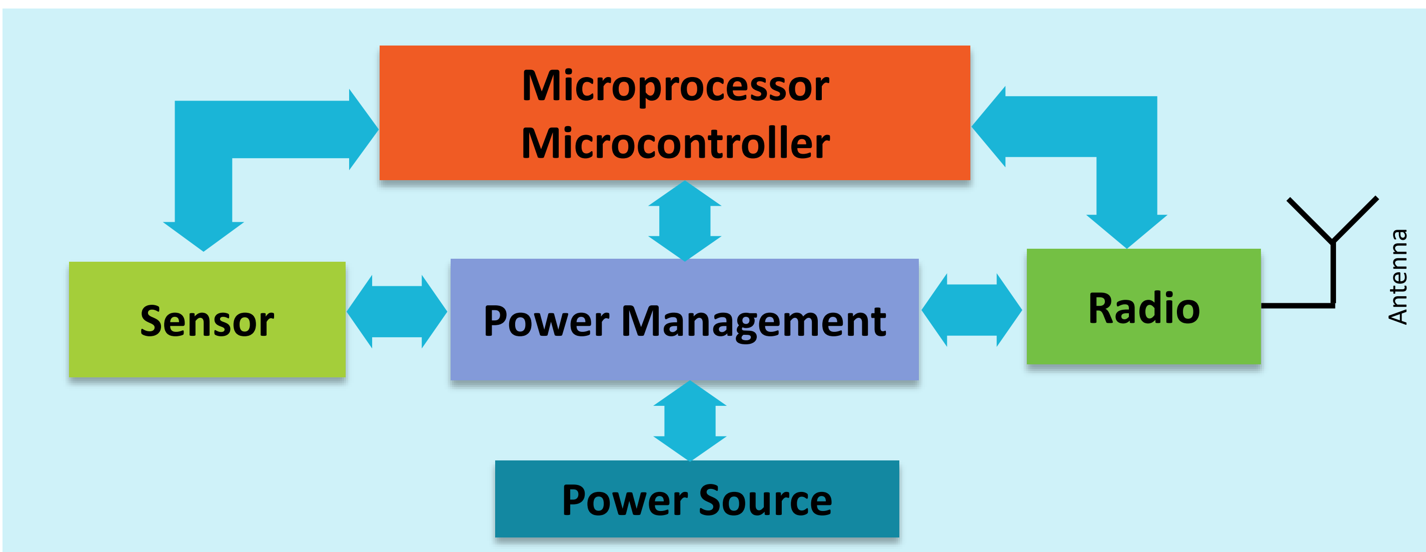


Low Power Modules & Components

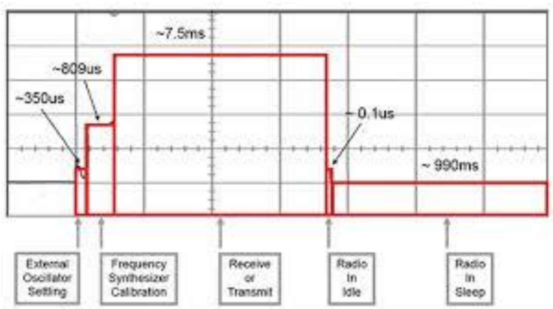


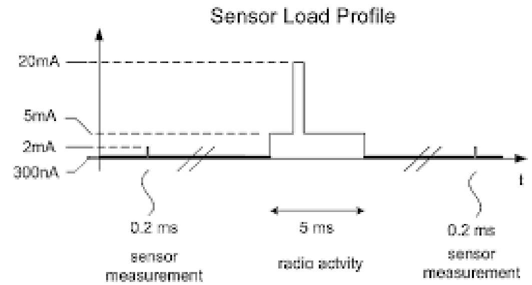
Low Power Devices & End Products

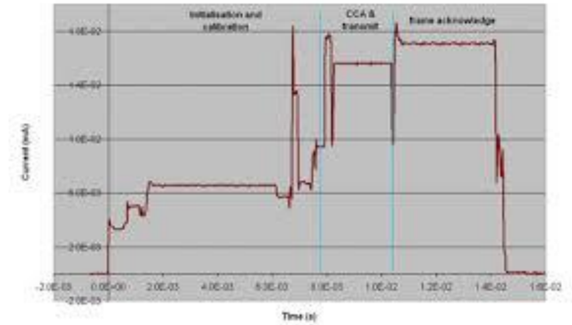
Enables statistical data analysis

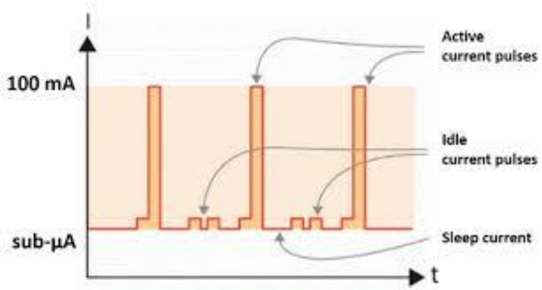


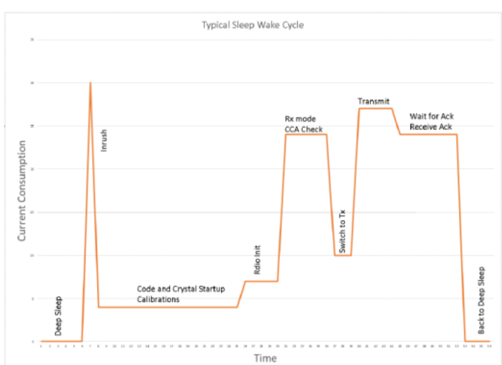
Typical IoT device power profile





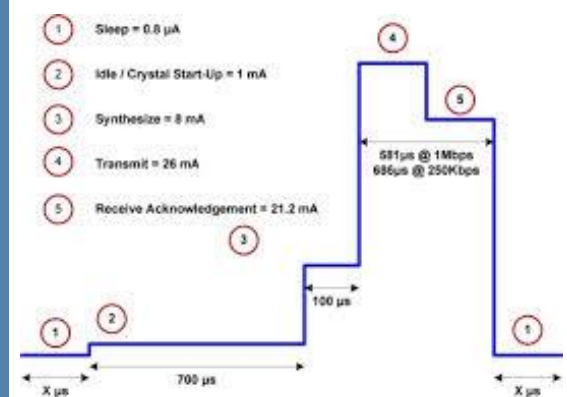


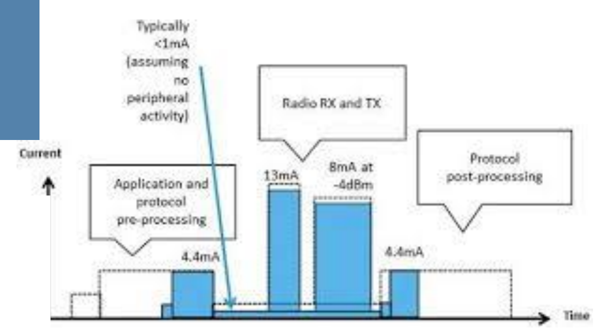


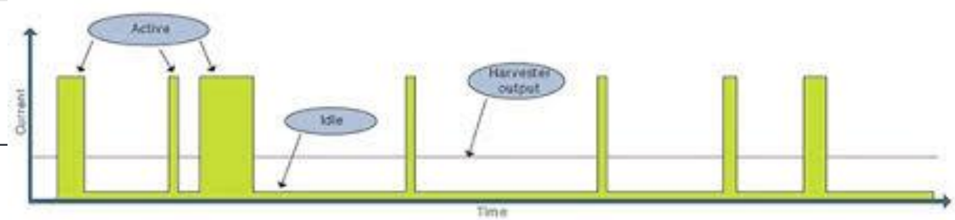


Common Characteristics

- A wide dynamic range of current
- High current > 1A
- Low current < 1uA
- Complex multilevel current load profile
- Fast transients from 100us to 100ms
- Long periods of operation







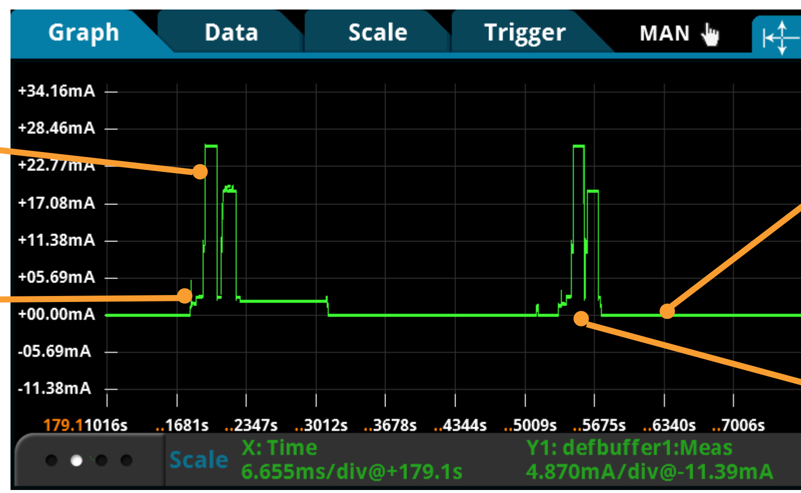
Characterizing low power consumption is not a trivial matter

Test Challenges

- Accurately capturing a wide dynamic range of current, over 8 decades
  - Sleep mode load currents down to 10^{-9}A
  - Transmit mode currents from 10^{-3}A to 1A
- Capturing complex and fast transmit mode load current waveforms
  - Ensuring sufficient sampling rate, bandwidth, and record length
  - Triggering on a short duration, fast rise time waveform
  - Analyzing power consumption from complex waveforms
- Ensuring stable, clean, and accurate power to the device-under-test (DUT)

Peak power consumption
Data Transmission
~29mA

Active mode consumption
Data acquisition
~2mA

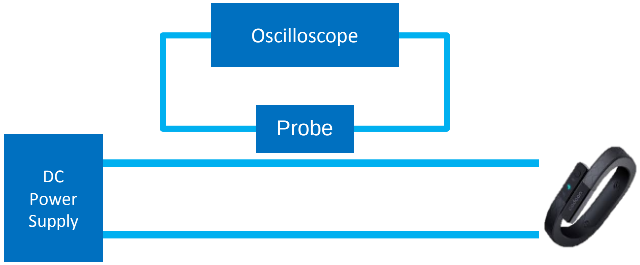


Ultra Low Power Consumption
Sleep Mode
~70nA

Fast Transient Event Capture
Pulse Width
~4ms

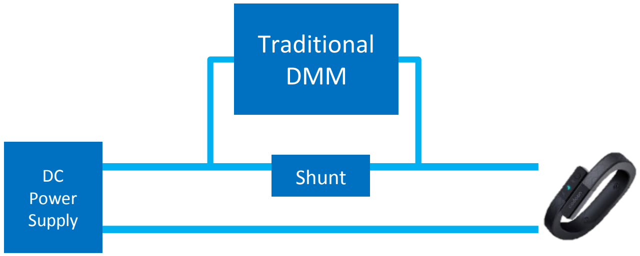
Long datalogging
Device operation > 10s, >10 million data points need to be saved

Traditional Test Solutions



Scope + Current Probe + Regular Power Supply

- High Sampling Rage
- Low Accuracy – High Noise, Hard to capture signal
- Few to support long term recording



Regular DMM + Regular Power Supply

- Hi Accuracy
- Low Sampling Rate – High Noise, Hard to capture signal
- High Burden Voltage
- No high level trigger function
- Slow transient response
- Poor Source Accuracy

Measuring power relies on accurate current measurement

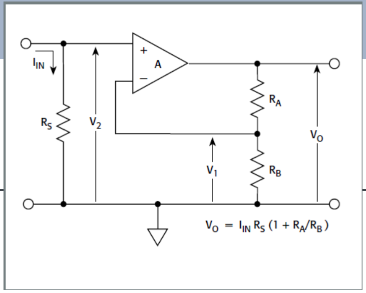
- Auto-range on most ammeters and DMMs may introduce latency and glitch
  - produce an inaccurate or even incorrect result
- Almost all ammeters and DMMs use either the shunt ammeter or the feedback ammeter technique

Shunt Ammeter

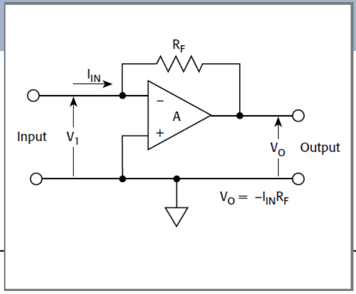
- Built-in current sensing resistor
- Higher voltage burden reducing the actual voltage applied to the device
- Lower sensitivity
- Smaller resistor means smaller voltage burden and
  - faster instrument response time
  - degrade the signal-to-noise
  - significantly impacts the accuracy and sensitivity

Feedback Ammeter

- Virtually no voltage burden
- Higher sensitivity
- Large signal to noise ratio
- Bandwidth limited
  - More sensitive to capacitance and susceptible to oscillation and unstable readings.



Shunt Ammeter



Feedback Ammeter

Effect of shunt/sense resistor and other sources of error on low sleep mode current

- Burden voltage from the internal series resistance that can be as high as 500mV
  - Effectively reducing 3 V power source to 2.5 V
- Reduced signal to noise ratio (SNR)
  - Need sensitivity ≤100pA to measure 10's of nA
- Measurement accuracy
- Connections between the device and the instrument
- Ammeter input bias current
- Source resistance of the device under test
- Leakage current from cables and fixtures
- Currents generated by triboelectric or piezoelectric effects

Much more difficult task!

		Scope +current probe	Scope +sense resistor	Pico ammeter	Broad Purpose DMM	DMM7510
Sensitivity		LOW	LOW	LOW	LOW	**HIGH (1pA)**
Voltage Burden	Technique	Hall effect	Sense resistor	Shunt	Shunt	**Hybrid (Feedback + Shunt)**
	Magnitude	0V	HIGH	LOW	HIGH	**15mV all ranges ≤1mA**
Accuracy		LOW	LOW	HIGH	LOW	**HIGH**

DMM7510 Example ~70nA

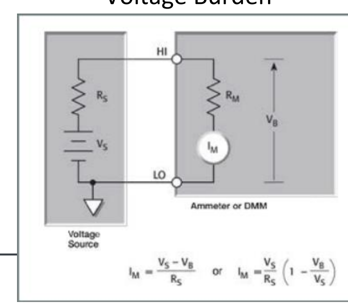
DC Current

ENHANCED ACCURACY (within 30 days of autocalibration, T_{OPER} ±5°C from T_{ACAL})

Range [38]	Resolution	Maximum Burden Voltage	Accuracy ±(ppm of reading + ppm of range): 24 Hour T_{CAL} ±1°C [39]	90 Day T_{CAL} ±5°C	1 Year T_{CAL} ±5°C	2 Year T_{CAL} ±5°C
10.000000 µA	1 pA	15 mV	30 + 30	75 + 30	75 + 30	75 + 30
100.00000 µA	10 pA	15 mV	20 + 5	60 + 9	60 + 9	60 + 9
1.0000000 mA	100 pA	15 mV	30 + 5	60 + 9	60 + 9	60 + 9
10.000000 mA	1 nA	20 mV	40 + 5	60 + 9	60 + 9	60 + 9
100.00000 mA	10 nA	200 mV	50 + 18	150 + 30	150 + 30	150 + 30
1.0000000 A	100 nA	400 mV	150 + 50	400 + 50	400 + 50	400 + 50
3.000000 A	1 µA	1300 mV	200 + 40	400 + 40	400 + 40	400 + 40
10.000000 A [41]	1 µA	650 mV	700 + 275	800 + 275	1500 + 275	2000 + 275

< 15mV @ all ranges ≤ 1mA

Voltage Burden

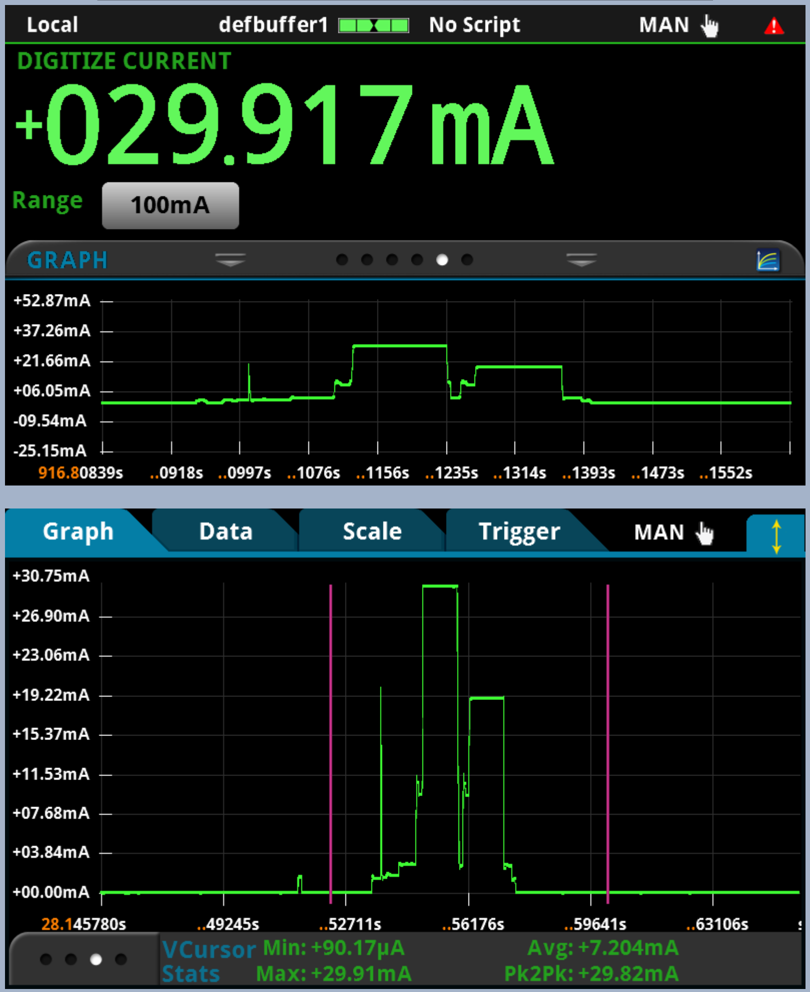


Effect of shunt/sense resistor on high transmit/receive current

- Burden voltage from the internal series resistance that can be as high as 500mV
  - Effectively reducing 3 V power source to 2.5 V
- Can choose smaller resistance value with smaller burden voltage and faster response time and better accuracy because of the large test signal

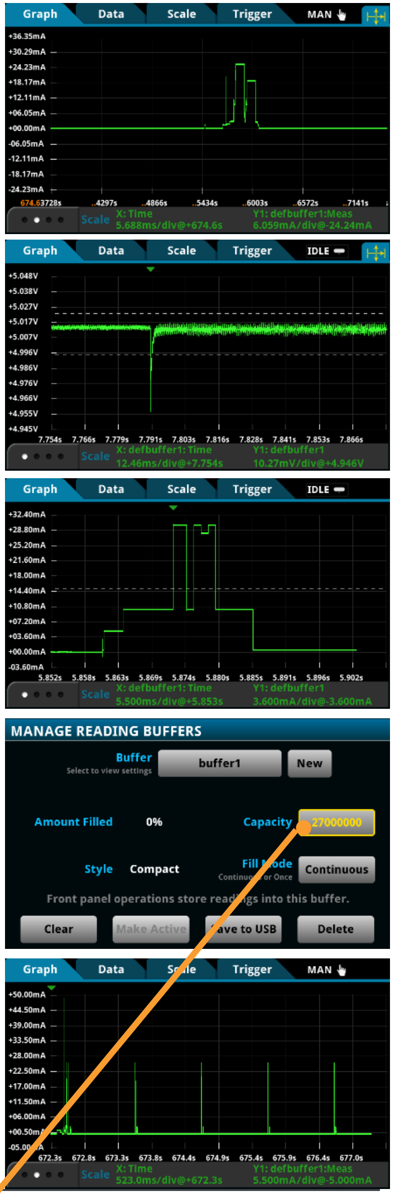
Much easier measurement to make!

DMM7510 Example ~ 30mA



Capturing complex transient current waveform is a significant undertaking

- Slow reading rates (nplc) and large processing overhead on conventional ammeters and DMMs
- Oscilloscopes are perfect for capturing fast transients, but lacks the sensitivity for low level measurement
  - Small signal is lost in scope and probe noise
- Analog bandwidth combined with sample rate determines the smallest fast transient
  - Higher sample rate can better reconstruct the original waveform
  - Small bandwidth will not resolve high-frequency changes such as a "wave-up" profile. Amplitude will be distorted. Edges will slow down.
  - Details lost due to the 10kHz bandwidth are not recoverable at 200kSamples/s sample rate
  - High speed DMM7510 has sufficient performance and sensitivity for IoT device operation
- Monitoring power consumption over an extended period
  - Small internal data storage on conventional DMMs and other instruments makes trending impossible
  - Scopes are not ideal for trending data over time
  - Streaming data or transferring to an external storage device is a huge benefit



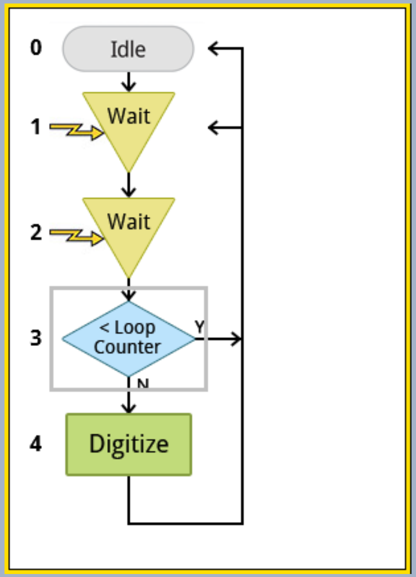
DMM7510 Internal Data Buffer Capacity > 27 million

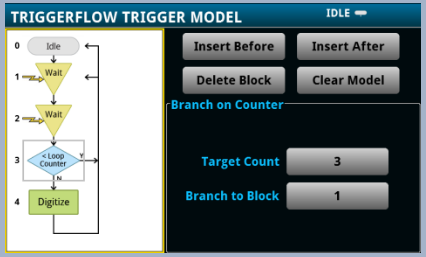
Built-in triggering simplifies the task to locate the waveform of interest

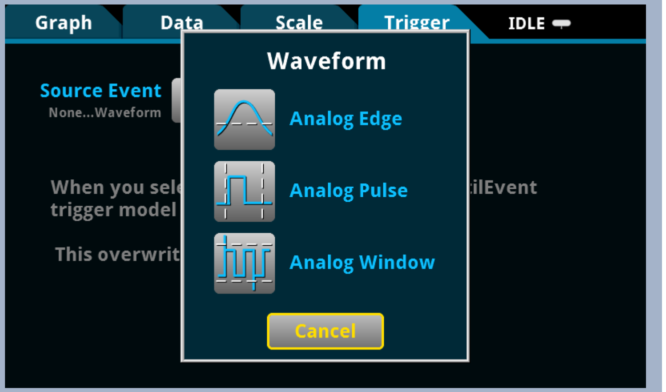
- No trigger capability on conventional current measuring instruments
- Low current (microampere) edge trigger accuracy relies on the sensitivity the trigger acquisition system in the instrument.
- Advanced triggering, such as pulse width, logic trigger, A-B sequence trigger, and synchronous external trigger are ideal for challenging waveforms.

A variety of triggering available on DMM7510

✓ Edge, Pulse, Timeout, Logic, Time, Sequence (A->B Event), Boolean Logic/State, Pattern, Window

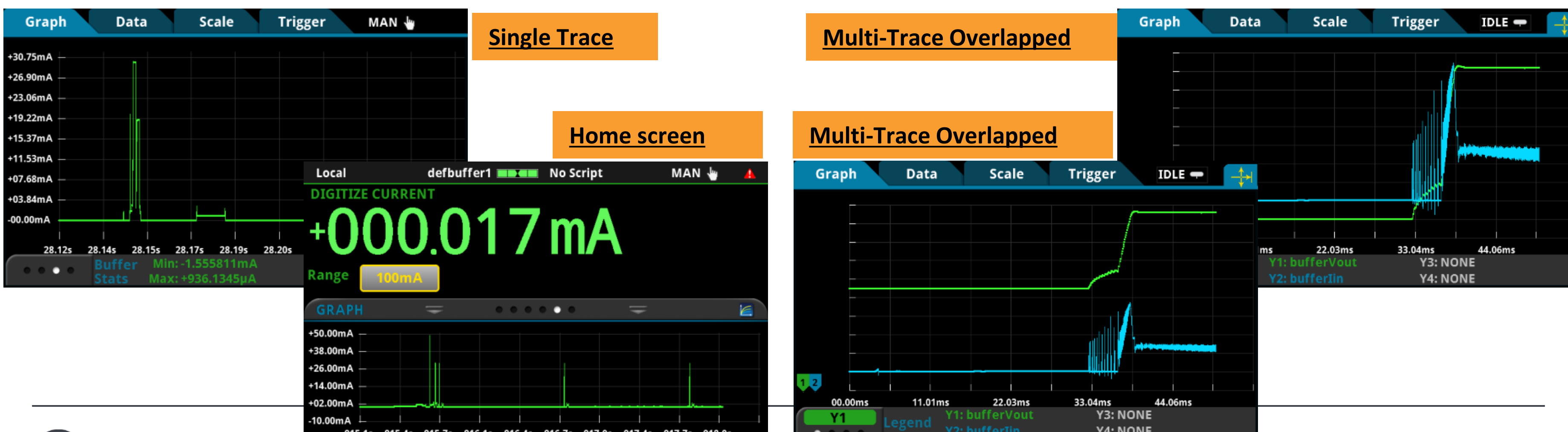






Graphical display for quicker insight into power profile

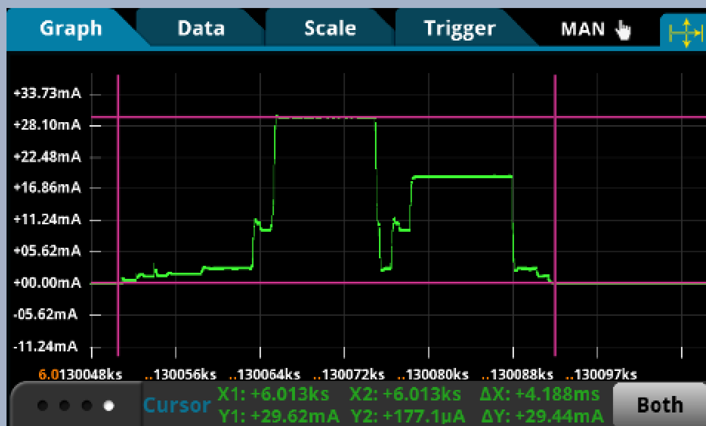
- Instruments with a graphical display are ideal for capturing IoT device operation and let user immediately “see” device operation
  - Conventional instruments can only acquire current readings
  - Some specialized instruments provide basic statistics such as min, max, and average.
  - Oscilloscope offers more sophisticated numerical calculation tools such as RMS calculations, duty cycle, and other math operations
- Pinch-and-zoom touchscreen interface allow for quick analysis of waveforms
- Measurement “gating” using cursors enable quicker and deeper insight into device operation
- Intuitive UI design is a large part of the ‘time-to-answer’ calculation



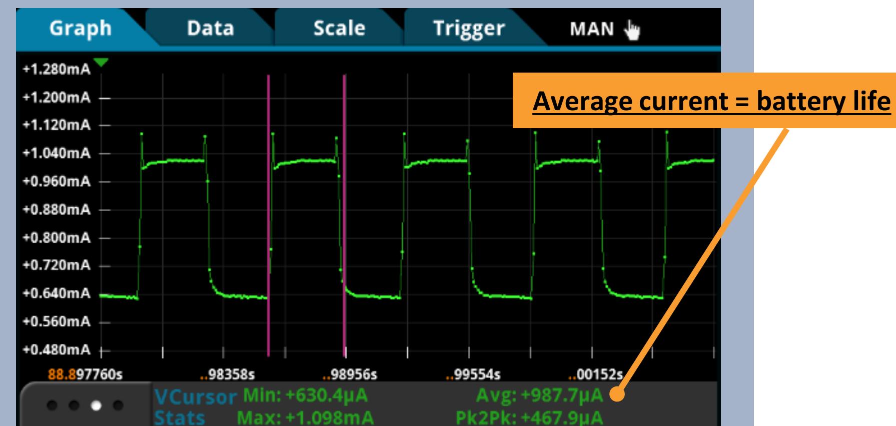
Automated tools for analyzing power consumption from complex waveforms

DMM7510's Touchscreen Graphical User Interface

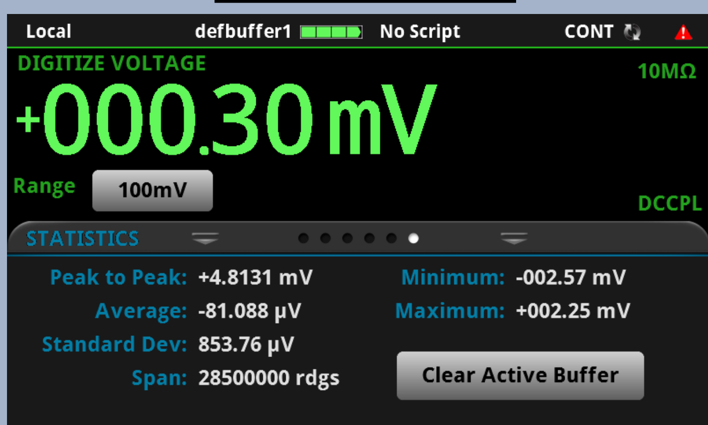
Cursor Analysis



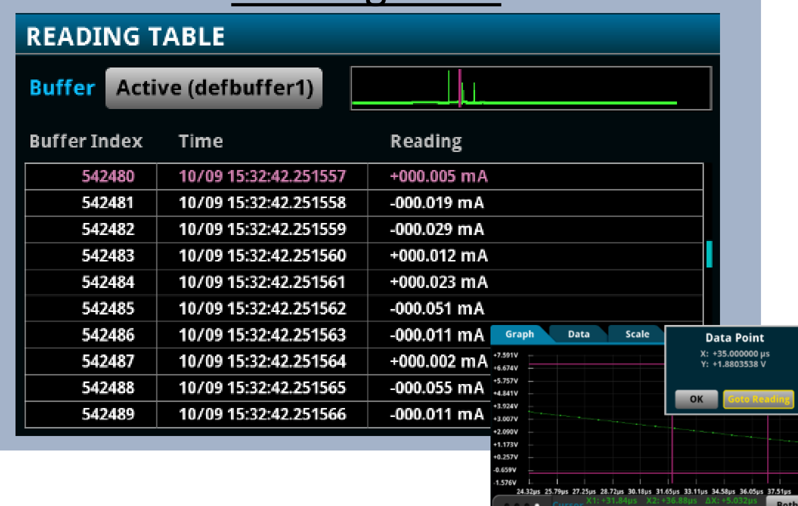
"Gated" Cursor Statistics



Buffer Statistics



Reading Table


READING TABLE

Buffer: Active (defbuffer1)

Buffer Index	Time	Reading
542480	10/09 15:32:42.251557	+000.005 mA
542481	10/09 15:32:42.251558	-000.019 mA
542482	10/09 15:32:42.251559	-000.029 mA
542483	10/09 15:32:42.251560	+000.012 mA
542484	10/09 15:32:42.251561	+000.023 mA
542485	10/09 15:32:42.251562	-000.051 mA
542486	10/09 15:32:42.251563	-000.011 mA
542487	10/09 15:32:42.251564	+000.002 mA
542488	10/09 15:32:42.251565	-000.055 mA
542489	10/09 15:32:42.251566	-000.011 mA

DMM7510 meets the low current and the waveform capture needs in a single box solution

Common current measurement solutions today

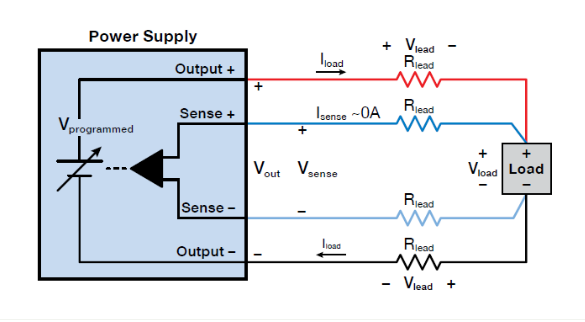
	Scope + Voltage Probe + Sense Resistor 	Scope + Current Probe 	Picoammeter 	Broad Purpose DMM 	DMM7510 Graphical Sampling DMM 
Dynamic Range	✗	✗	✗	✓	✓
Low Current	✗	✗	✓	✓	✓
High Current	✓	✓	✗	✓	✓
Sample Rate	✓	✓	✗	✗	✓
BW	✓	✓	✗	✗	✓
Trigger	✓	✓	✗	✗	✓
Internal Memory	✗	✗	✗	✗	✓
Graphical Display	✓	✓	✗	✗	✓

DMM7510 Summary

- **High sensitivity**
- **Minimal voltage burden**
- **Fast waveform capture**
- **Long Data Memory**
- **Solution oriented waveform analysis**
- **Ease to use UI**

Use a high quality supply to provide clean, stable and accurate DC power

- Look for good setting and readback accuracy when powering IOT devices that operate on low voltages
  - Ensures accurate determination of shut-off threshold voltage

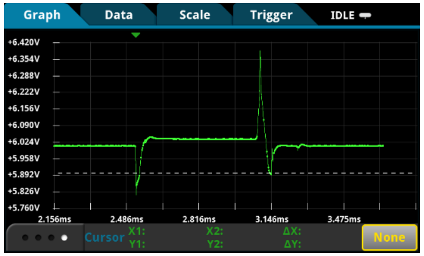


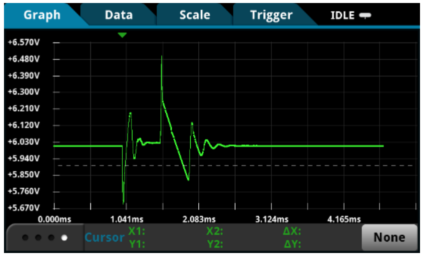
- Use a supply with remote sensing to ensure the voltage is accurately applied to the load

- Use a low noise output supply to minimize disturbance to the DUT

- Use a power supply with a fast response to maintain a stable output during large load current transitions
  - Transitions from sleep mode/standby mode to a transmitting mode can be from milliamps to amps, in microseconds

fast response to load change

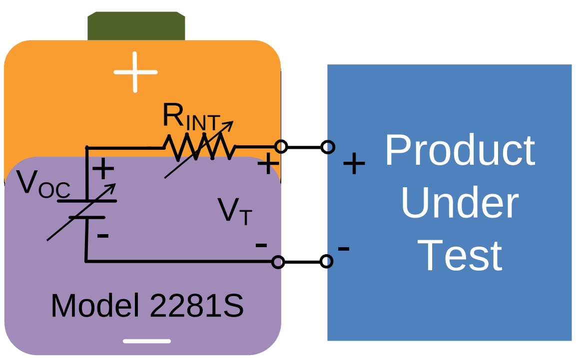




Poor response to load change

Enhancement to the Power Consumption Analysis Solution – Dynamically Simulate the Battery

- Test the DUT under the most realistic sourcing conditions
- Simulate different types of batteries based on battery models
- Simulate different battery conditions
  - Avoid waiting for a battery to reach a specific condition
  - Precisely replicate a test condition

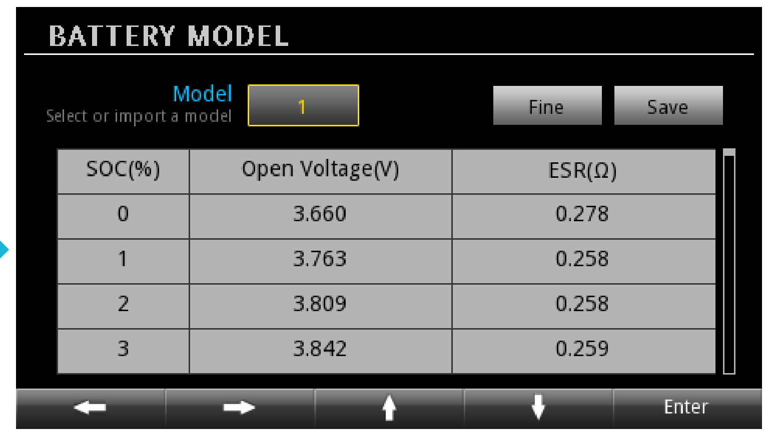


2281S Builds Up a Battery Model based on Charging Cycle Data

After a full charge cycle, the 2281S builds up a battery model automatically and can simulate the battery based on that model

Battery testing → **Build battery model** → **Battery simulation**

Points	Voc	Current	ESR	A-H
163	+11.177 V	+0.500 A	0.341 Ω	+0.001405 Ah
164	+11.177 V	+0.500 A	0.341 Ω	+0.001414 Ah
165	+11.177 V	+0.500 A	0.341 Ω	+0.001423 Ah
166	+11.177 V	+0.500 A	0.341 Ω	+0.001431 Ah
167	+11.177 V	+0.500 A	0.341 Ω	+0.001440 Ah
168	+11.178 V	+0.500 A	0.341 Ω	+0.001448 Ah
169	+11.178 V	+0.500 A	0.341 Ω	+0.001457 Ah
170	+11.178 V	+0.500 A	0.341 Ω	+0.001466 Ah



SOC(%)	Open Voltage(V)	ESR(Ω)
0	3.660	0.278
1	3.763	0.258
2	3.809	0.258
3	3.842	0.259

Battery charging data → → → Generate battery model

Battery model includes the parameters: State of Charge (SOC), Open Circuit Voltage (Voc) and Equivalent Series Resistance (ESR)

Power Sourcing for Battery-Powered Devices and Products

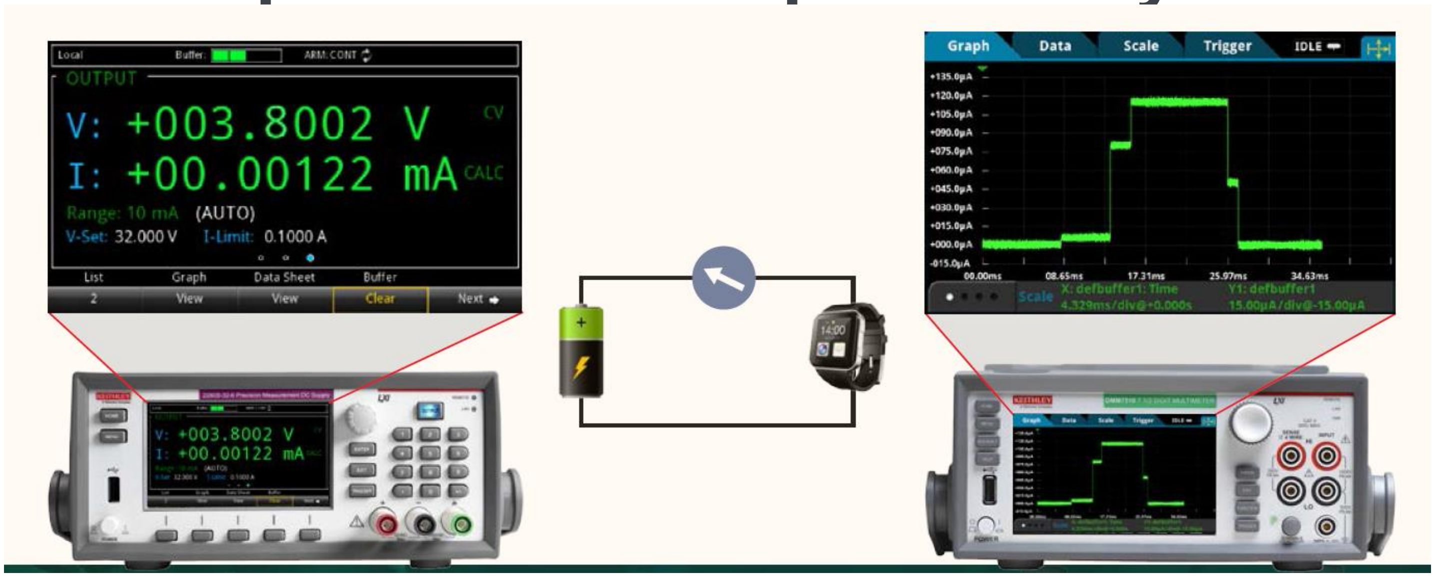
- Parameters automatically adjust based on the model and power consumed by the device
- Customize battery “State of Charge” and “Open Voltage” point

Select a model

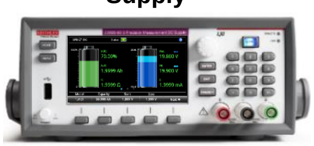
Test at any battery voltage

Test at any capacity

IoT device power consumption analysis solution



2280S Precision Measurement DC Power Supply



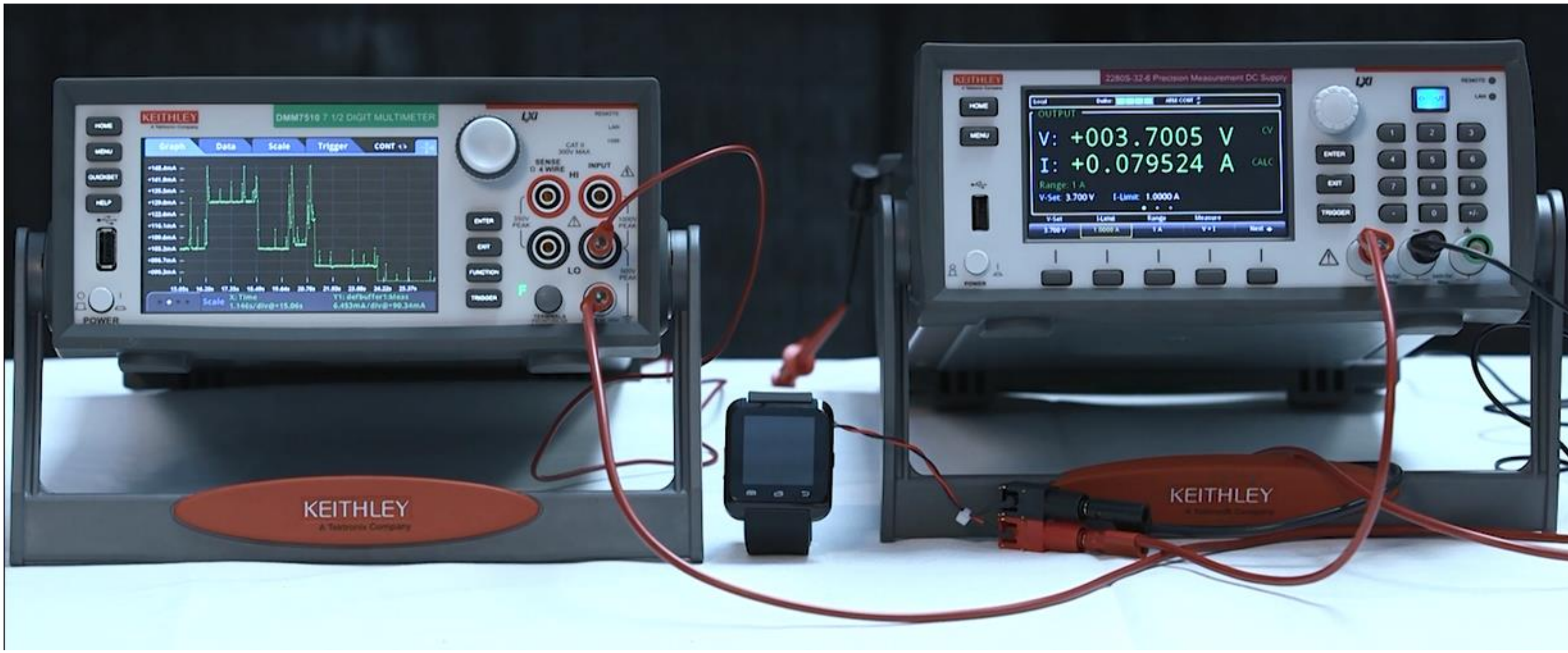
2281S Battery Simulator

- Voltage setting and measurement accuracy of 0.02% of reading +3mV - superior to most power supplies
- Low noise; it is a linear supply: < 1mVrms output ripple and noise
- 4-wire remote sensing to ensure that the programmed value is accurately delivered to the load
- High resolution TFT display and soft-key/icon-based user interface simplify power operation

DMM7510 7½-Digit Graphical Sampling Multimeter

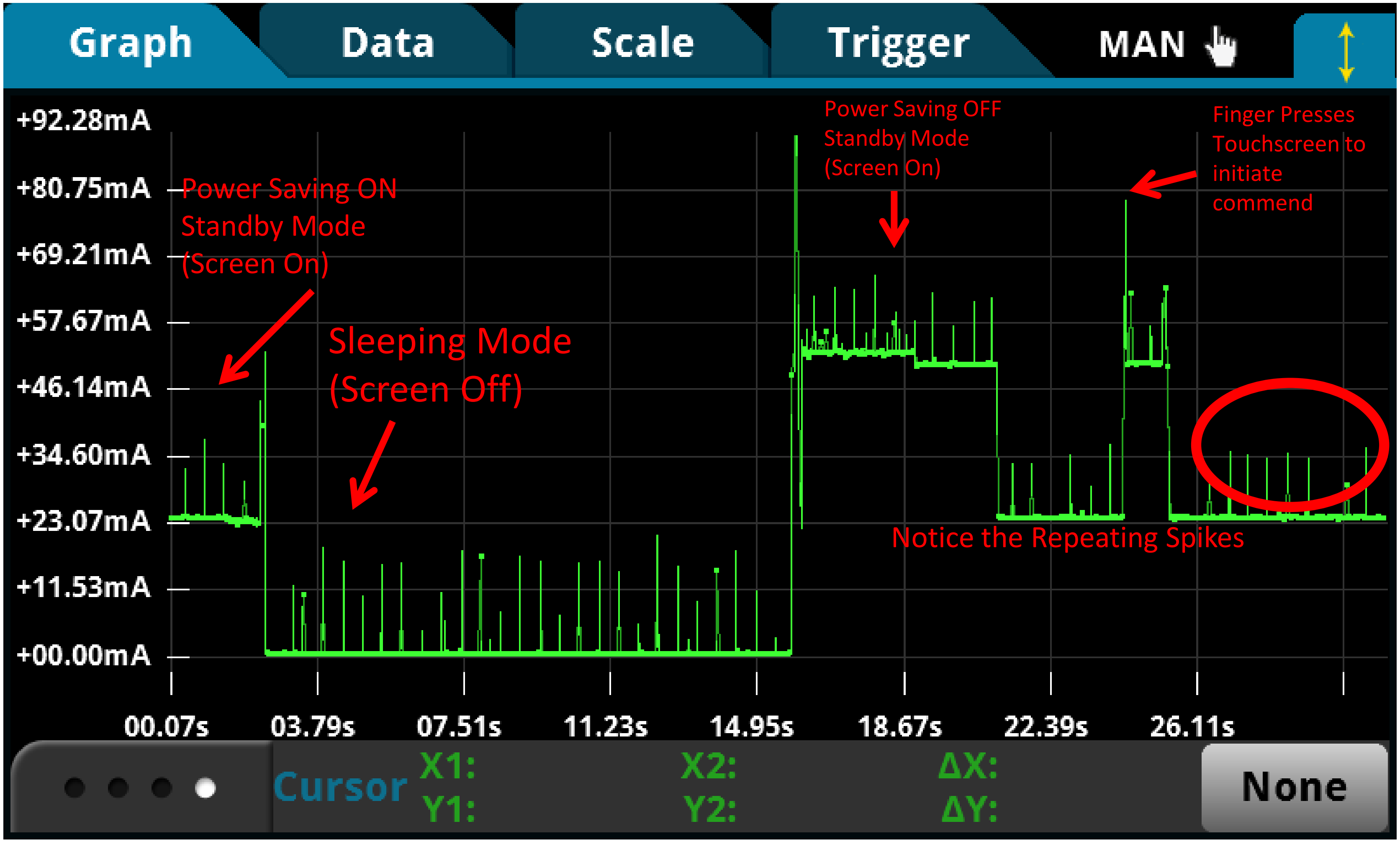
- 1pA resolution, 0.006% basic 1 year DC current accuracy
- 15mV burden voltage
- Precisely analyze current and voltage waveforms and transients with 1MS/sec, 18-bit digitizer
- Capture signal with advanced analog triggering features
- Large reading memory (27.5 million compact and 11 million standard) to capture more of your signal
- Display more with five-inch, high resolution touchscreen interface

Example
Smartwatch Power Consumption



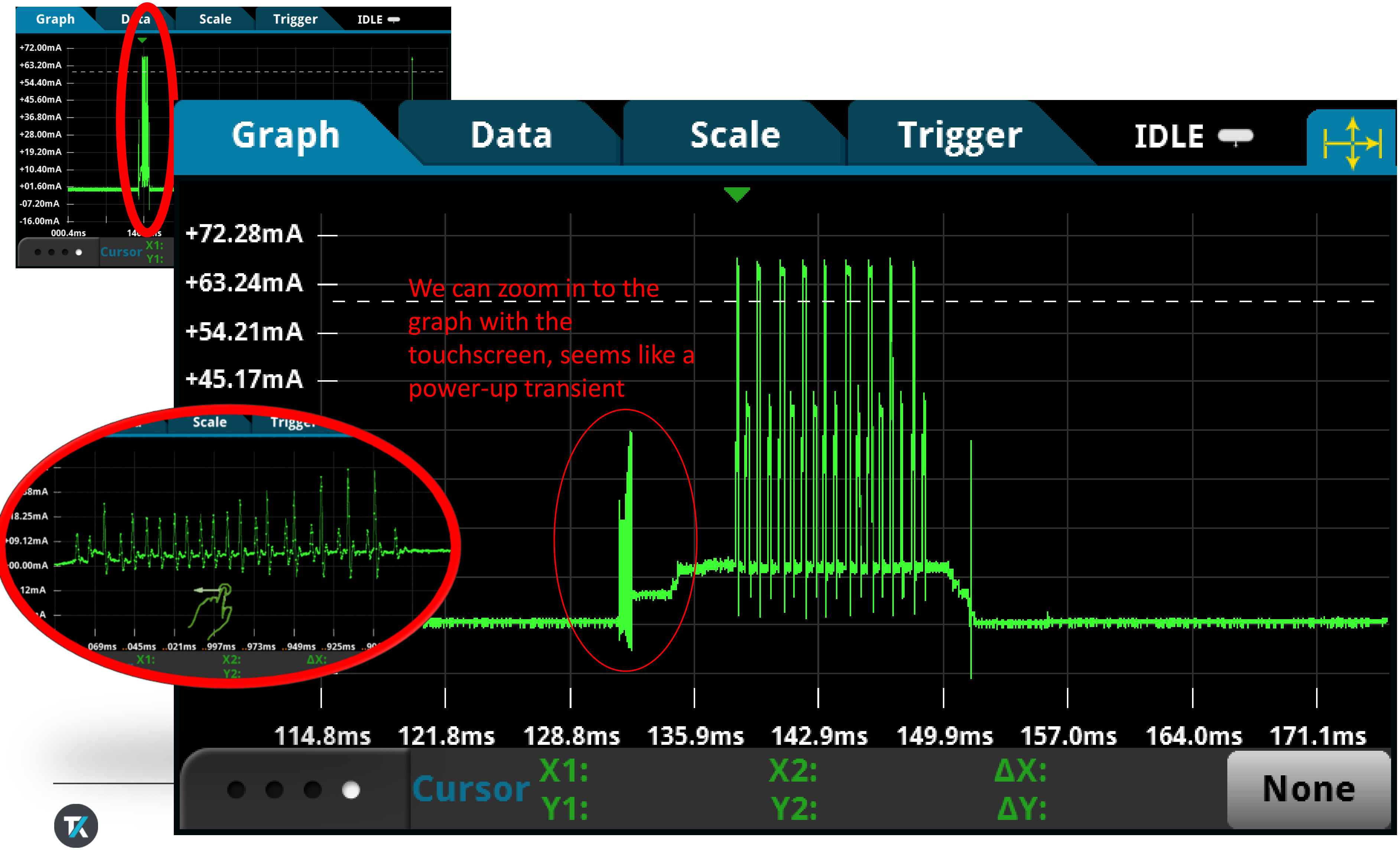
Example

Analyzing Smart Watch Overall Power Consumption



Example

Analyzing Smart Watch Overall Power Consumption

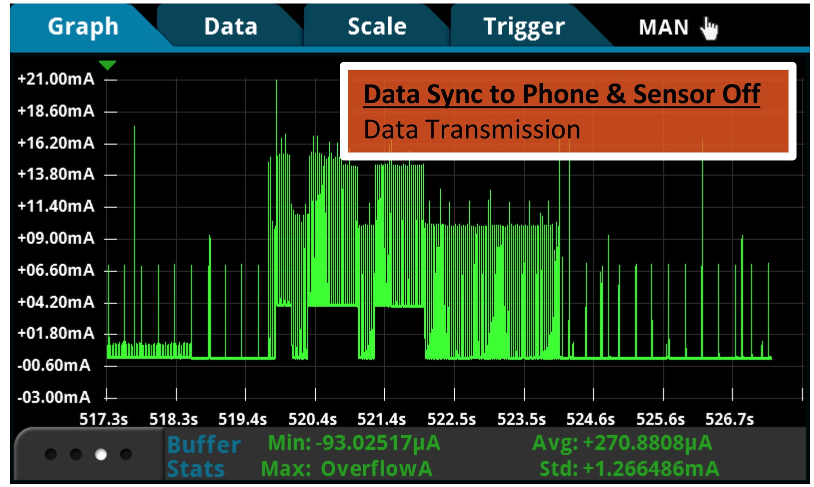


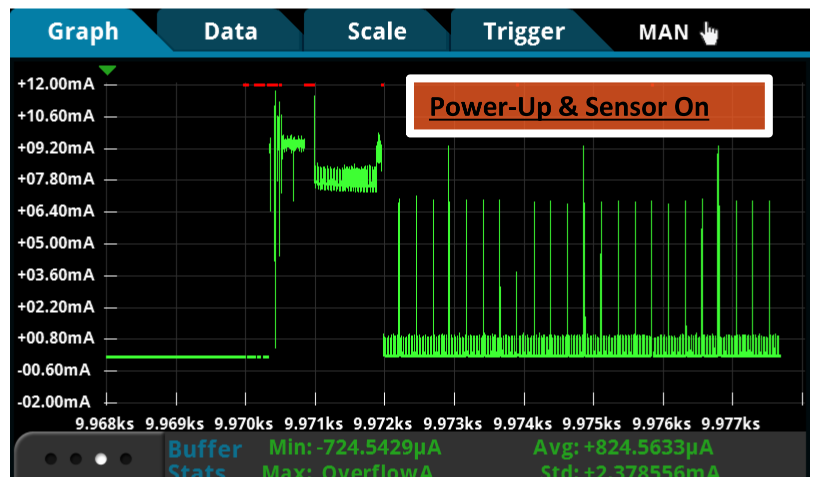
Example

Graph
Data
Scale
Trigger
IDLE
+72.28mA
+63.24mA
+54.21mA
+45.17mA
+36.14mA
+27.10mA
+18.07mA
+09.03mA
+00.00mA
-09.03mA
114.8ms 121.8ms 128.8ms 135.9ms 142.9ms 149.9ms 157.0ms
Cursor X1: Y1: X2: Y2: ΔX: ΔY:
Zoom In
+73.54mA
+61.28mA
+49.02mA
+36.77mA
+24.51mA
+12.25mA
+00.00mA
-12.25mA
-24.51mA
136.8ms 138.2ms 139.7ms 141.1ms 142.5ms 143.9ms 145.4ms 146.8ms 148.2ms
Zoom In
+67.23mA
+66.21mA
+65.19mA
+64.17mA
+63.15mA
143.28752ms ..42ms ..32ms ..22ms ..12ms ..02ms ..92ms ..82ms ..72ms
Set Cursor
Cursor X1: +143.3ms X2: +143.4ms ΔX: +127.3µs
Y1: +66.66mA Y2: +64.75mA ΔY: +1.908mA
Both
+73.54mA
+61.28mA
+36.77mA
+24.51mA
+12.25mA
Zoom In
143.12651ms ..76ms ..02ms ..28ms ..54ms ..80ms
Cursor X1: Y1: X2: Y2: ΔX: ΔY:
None

Demo - BLE Pedometer

CR2032 BATTERY OPERATED

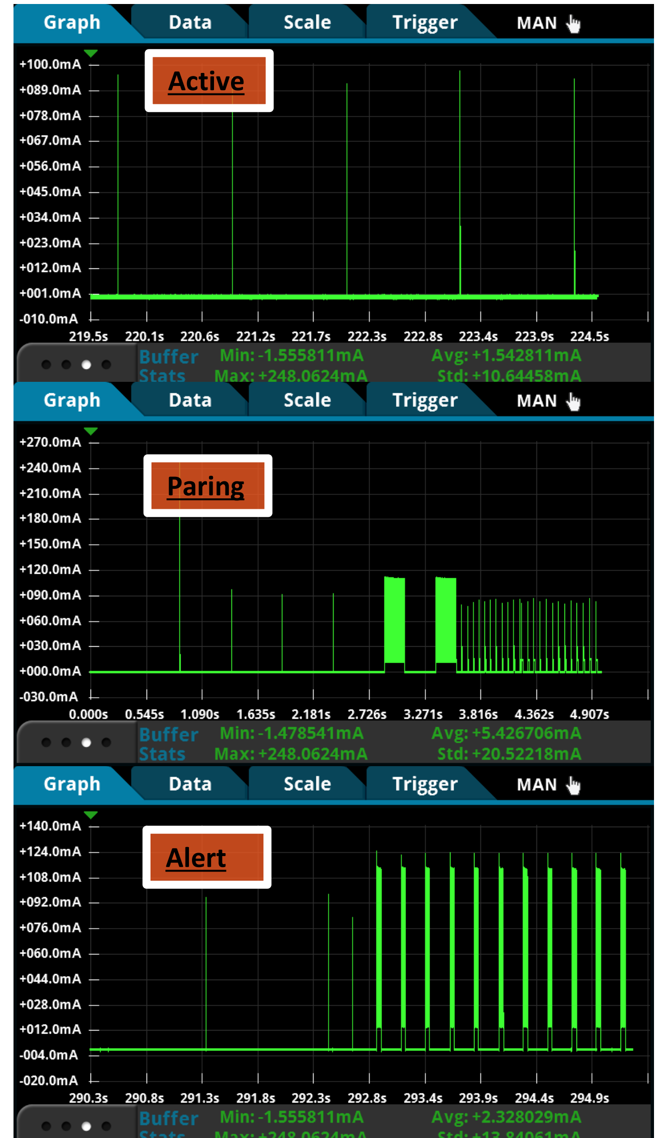




Demo – BLE Anti-loss Tracker

FOLLOW-ALONG

Find each other (iTag and smart phones) within range



What is SourceMeter ?

Well, it works.

It works well.

Functions of a Source Measure Unit (SMU)

A fully-integrated combination of multiple instruments

- A *Source Measure Unit* instrument can simultaneously source or sink voltage while measuring current, and source or sink current while measuring voltage.

Precision DMM

Source Measure Unit (**SMU)**

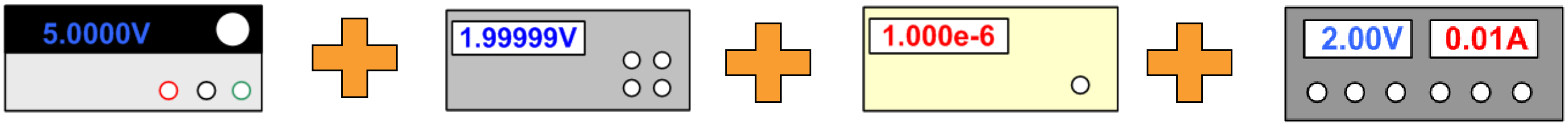
Precision Power Supply

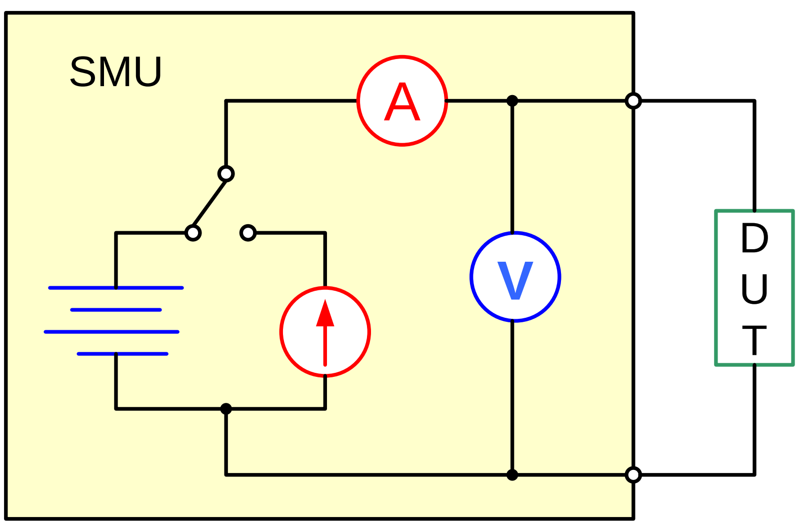
True Current Source

Electronic Load

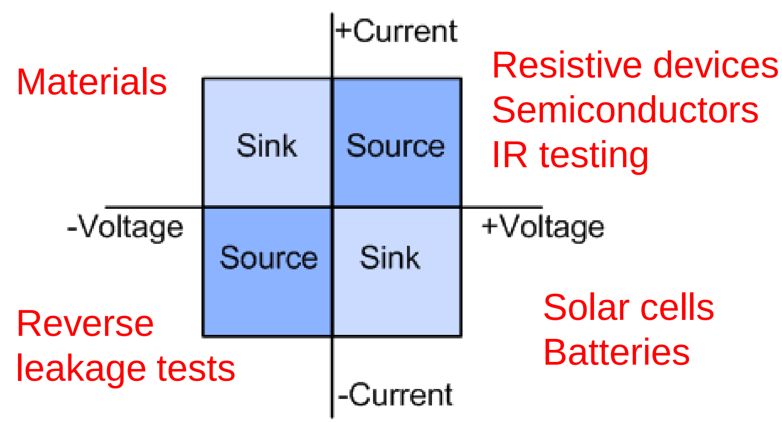
SourceMeter make your test much easier!

Precision Power Supply | DMM (measure I, V, and R) | Current Source | Electronic Load





SMU
4 Quadrant – Source and Sink

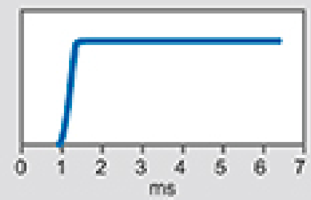
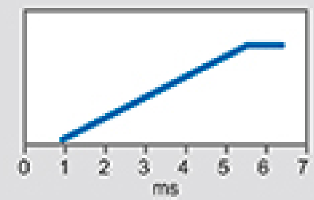
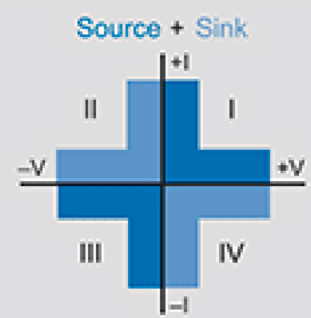
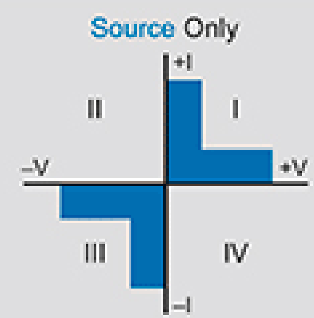


SMU Compared to Power Supply: What are the differences?

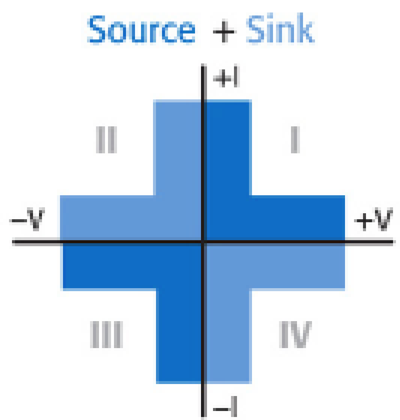
Power Supply

Versus

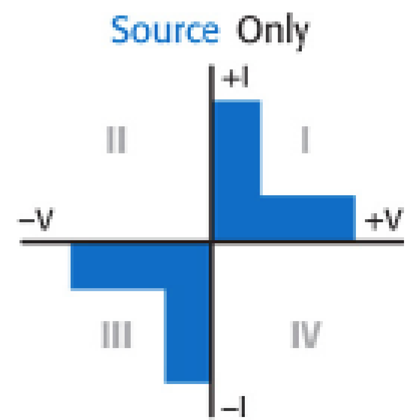
Source Measure Unit (**SMU**)

	SMU Instrument	Typical Power Supply
Speed		
Source/ Measure Precision	10µA measurement uncertainty = 5nA	10µA measurement uncertainty = 2500nA
Voltage and Current Resolution (Typical)	Voltage: 1µV – 200V Current: 1pA – 3A	Voltage: 1µV, 1mV – 200V Current: 1pA, 1mA – 3A
4 Quadrant Operation		

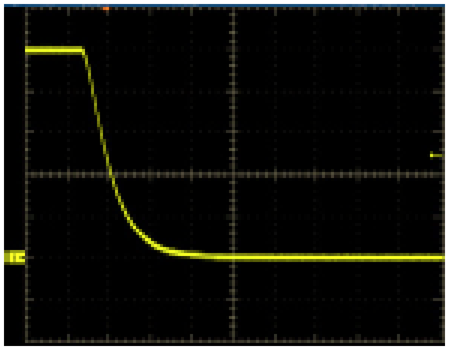
Advantage of 4 Quadrant Operation – Fast Discharge



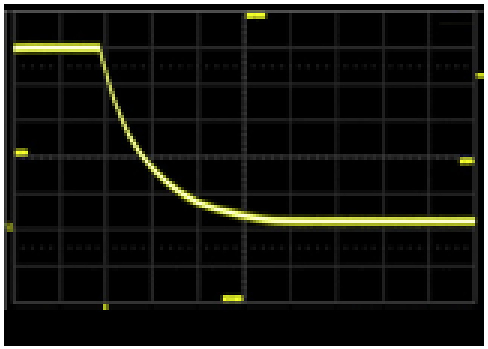
4 Quadrant SMU



2 Quadrant Power Supply

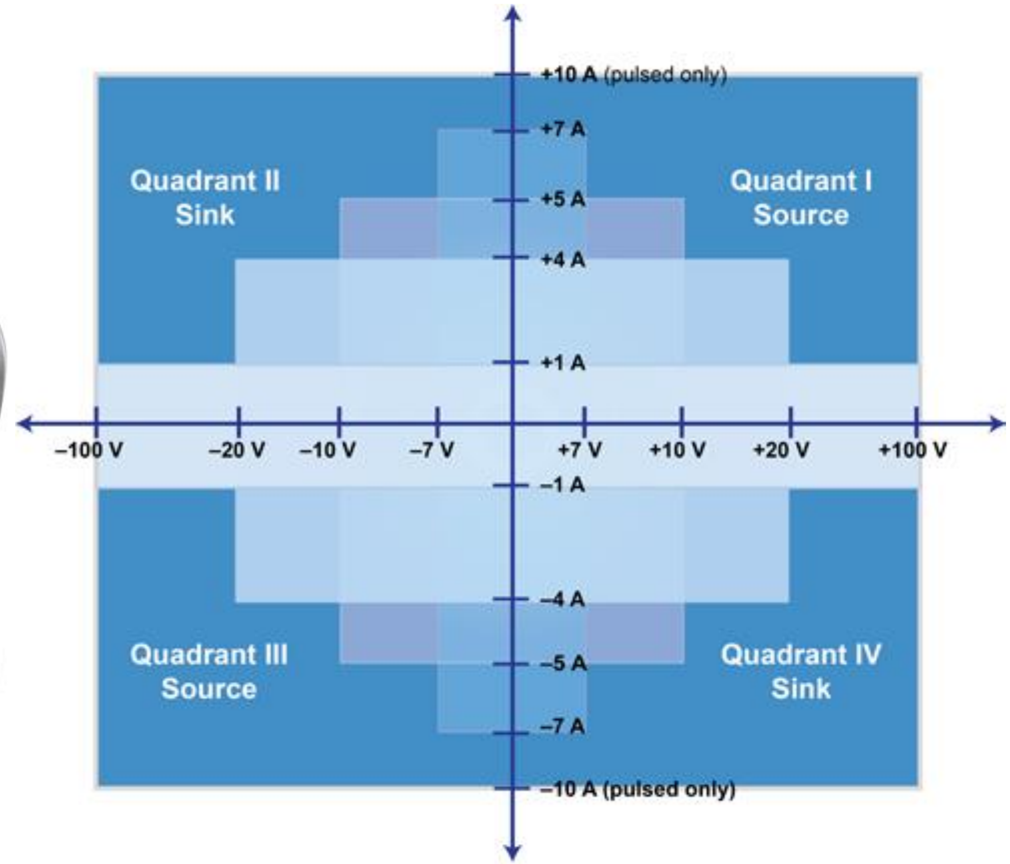


Using a Model 2657A
Time Scale = 2 msec/div
Total discharge time ~ 5 msec



Using a Power Supply
Time Scale = 2 sec/div
Total discharge time > 6 sec

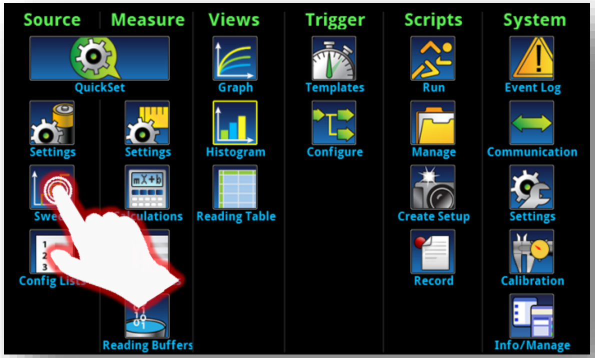
Keithley 2461 -1000 Watts, 10 Amps Pulse, 7 Amps DC



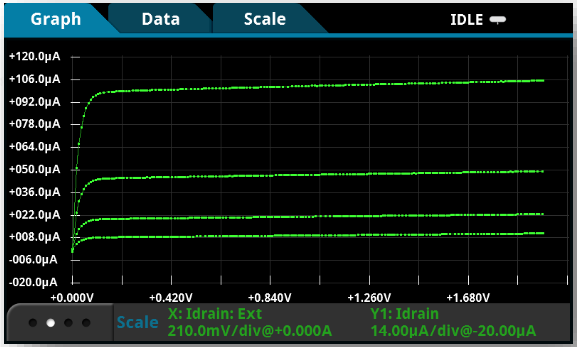
Maximum voltage and current		
	Voltage	Current
DC or pulsed	100 V	1 A
	20 V	4 A
	10 V	5 A
	7 V	7 A
Pulsed	100 V	10 A

= Limited operating area, pulsed only

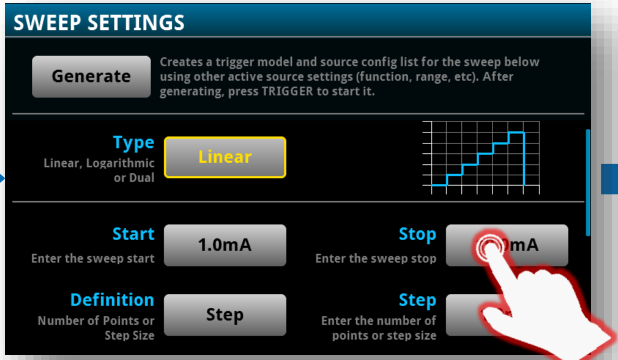
IV Characterization with Interactive SMUs



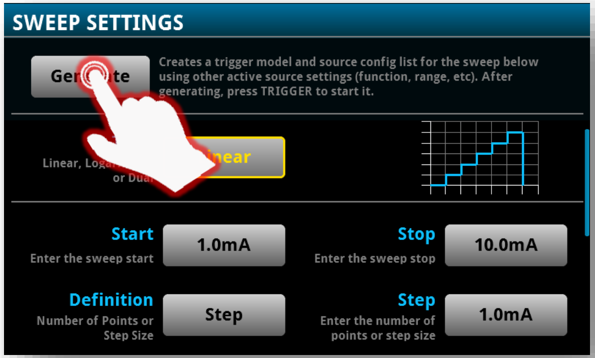
Go to the Main menu and tap the Sweep icon under Source



Analyze your results

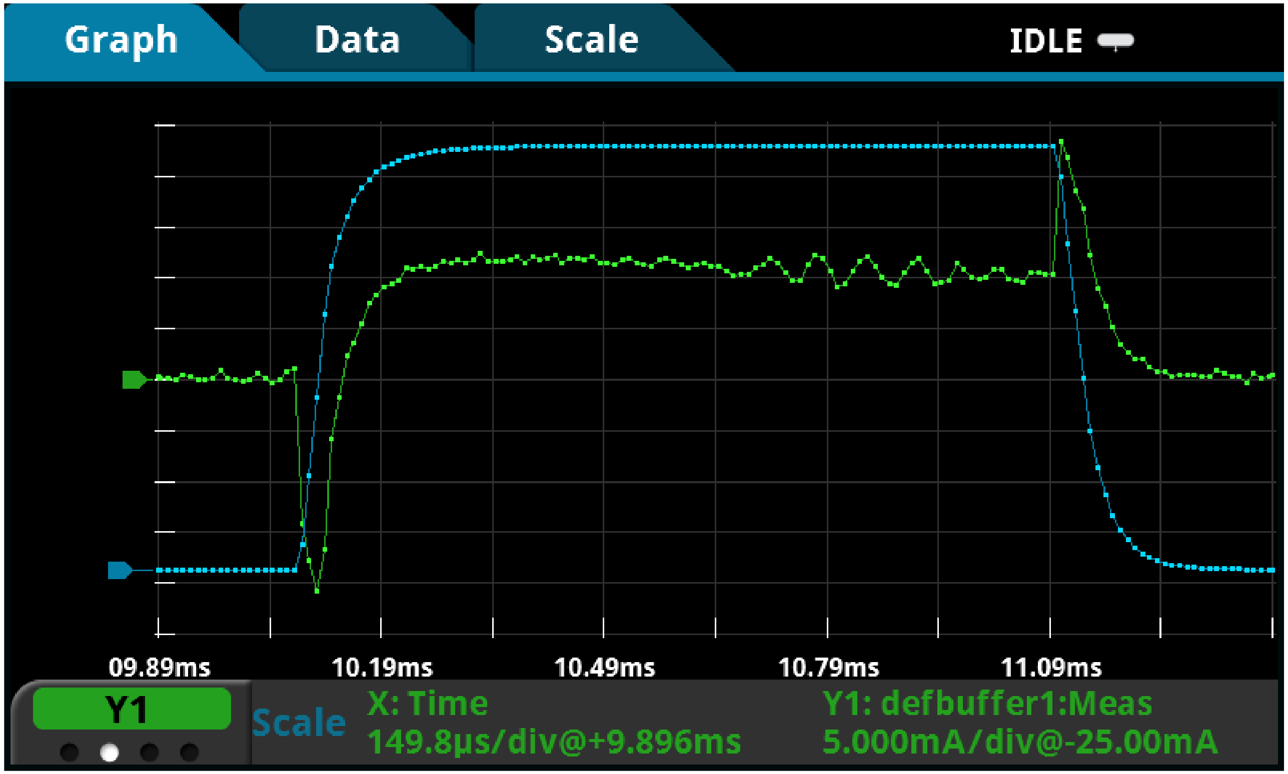


Configure the Sweep Settings



Tap the Generate button to configure the SMU

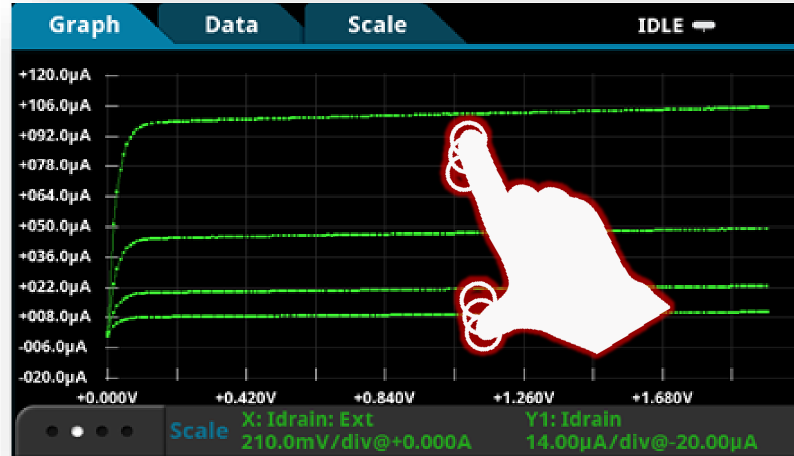
Viewing the source and digitize waveforms simultaneously on the front panel (2461 only)



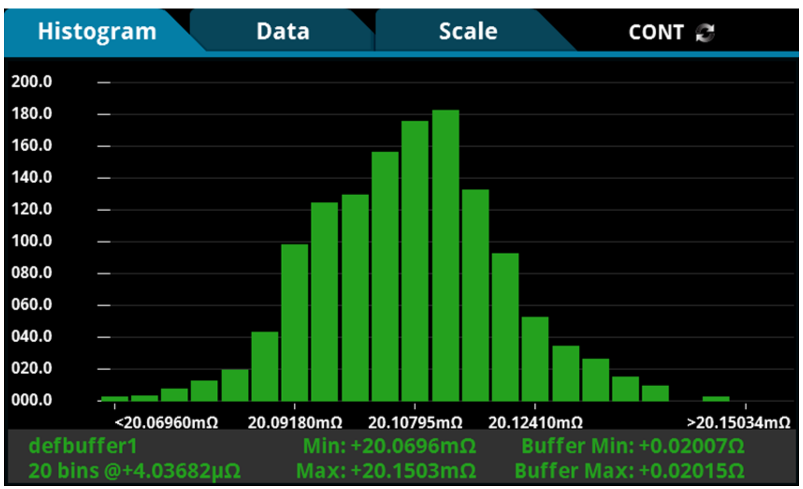
Source readback to capture the current source waveform and the voltage digitize waveform. Plot the two waveforms together on the same graph to examine time dependencies between the two waveforms.

Visualizing IV Data

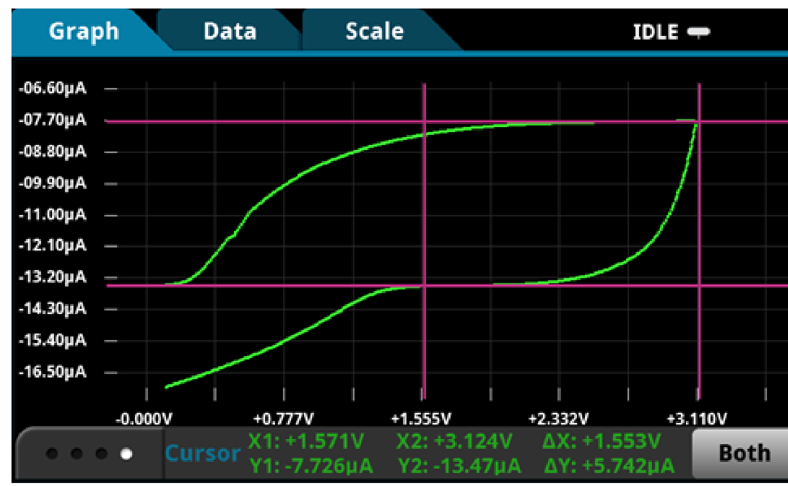
Go to the main menu and tap the Graph or Histogram icon under Views



Data is plotted on the graph as it is collected.
Use pinch-and-zoom gestures to zoom in on the data.



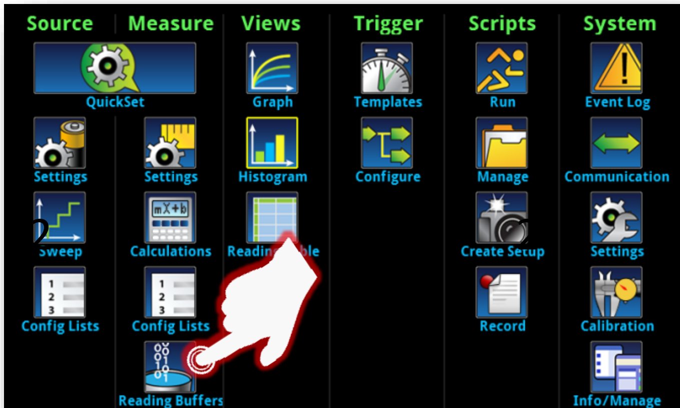
View real time statistical data



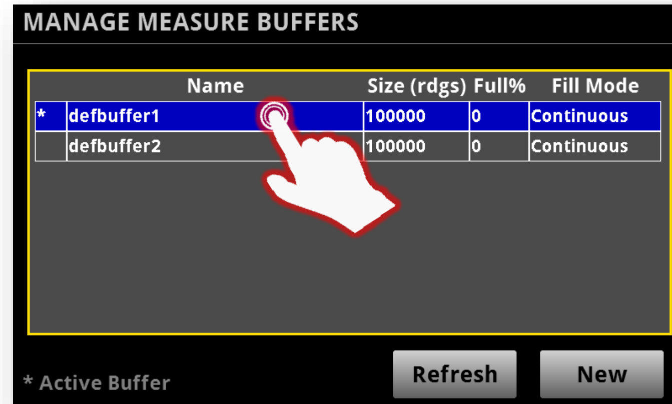
Analyze with scope-like cursors

Saving the Data

1.

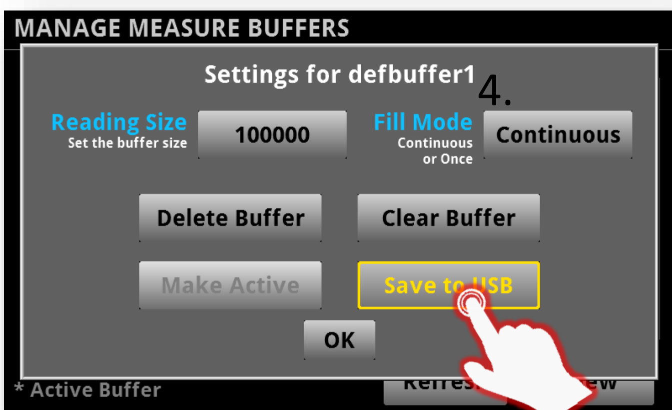


Go to the Main menu and tap the Data Buffers icon under Measure



Tap the name of the buffer where the sweep data was collected, defbuffer1

3.



Tap the Save to USB button

Give the file a name then tap OK

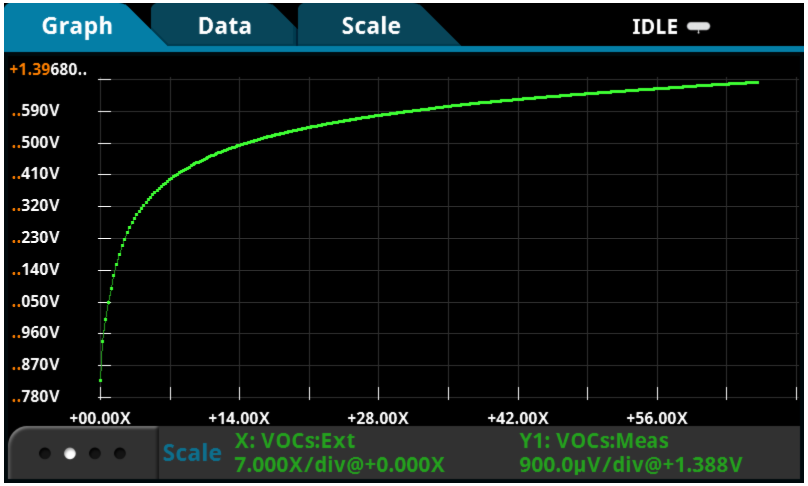
TSP® -Link for Test System Scaling

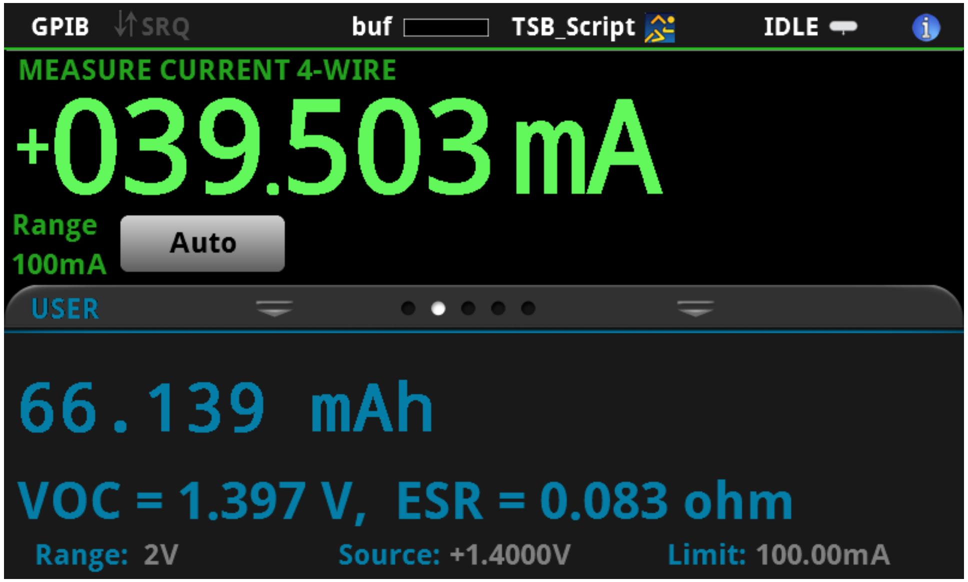
Channel expansion without needing a mainframe

- Connect up to 32 Model 2450's for multi-point or multi-channel parallel testing
- Unlike mainframe-based systems, there are no power or channel limitations
- Only requires one GPIB, USB, or LAN/LXI connection

Battery Test with a SourceMeter (TSP enabled)

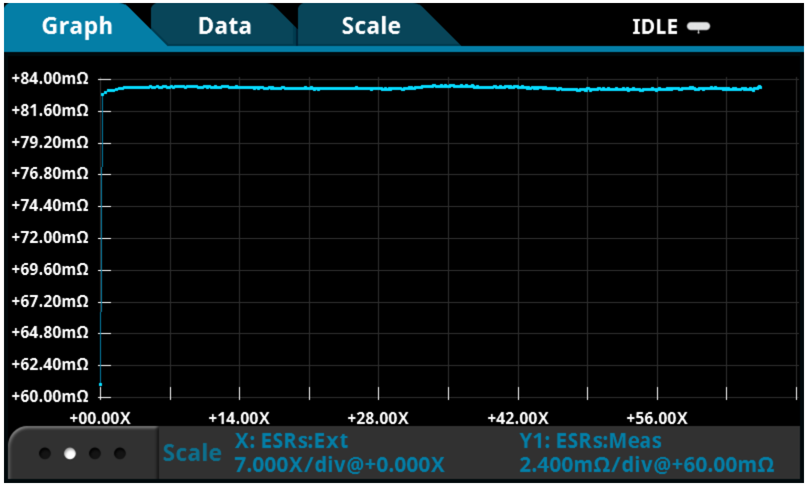
VOC



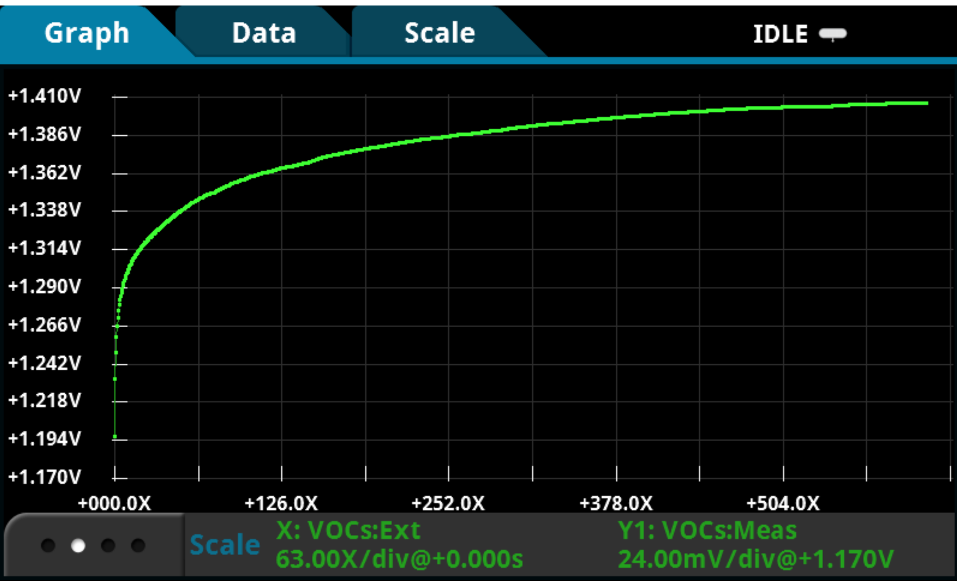


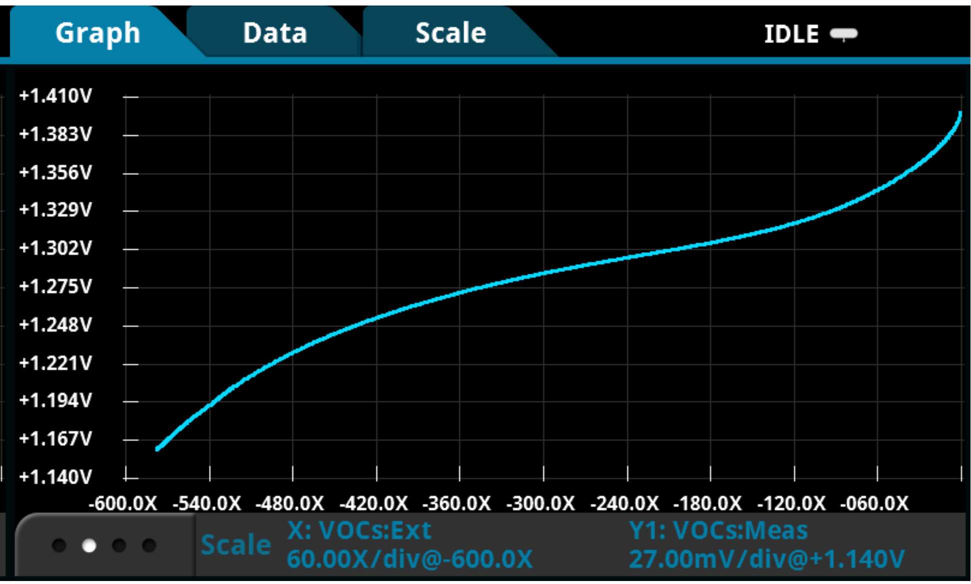
Battery Capacity / SOC

ESR



Charging or Discharging Curves





Thank You !