

Keithley New Battery Simulator 2281S

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Agenda:

- Why need battery simulator
- Keithley new battery simulator spec
- Battery simulator function
 - High precision power source
 - Battery test
 - Battery simulation
- Battery simulator application
 - Power management unit test
 - Remaining power calibration
 - Battery test and verification
- Demo

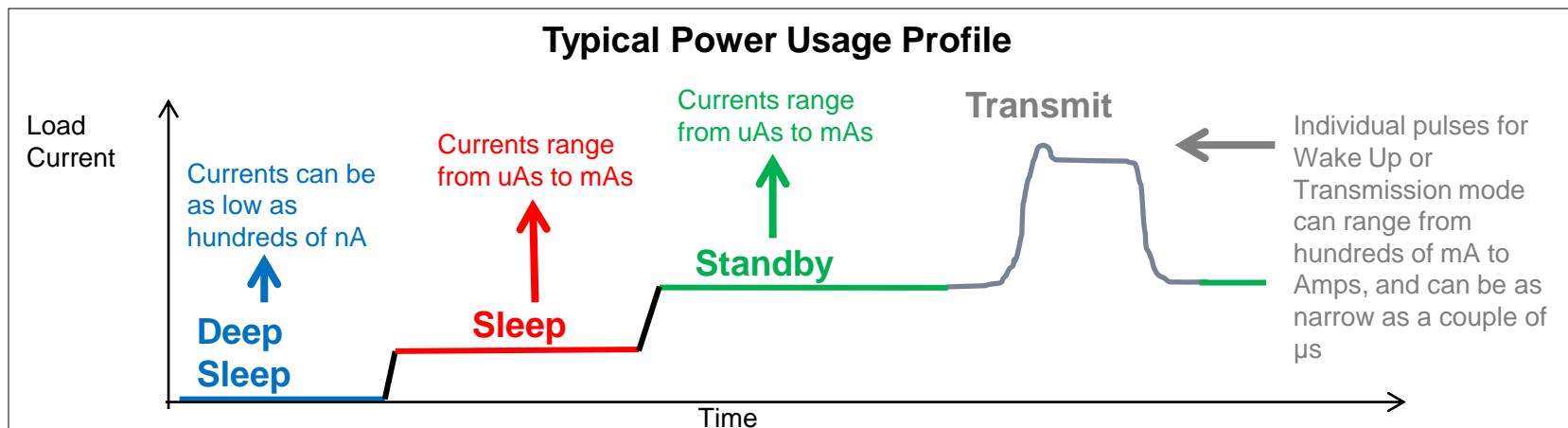
Variety of battery powered devices in market

Wireless communication devices and wearable devices



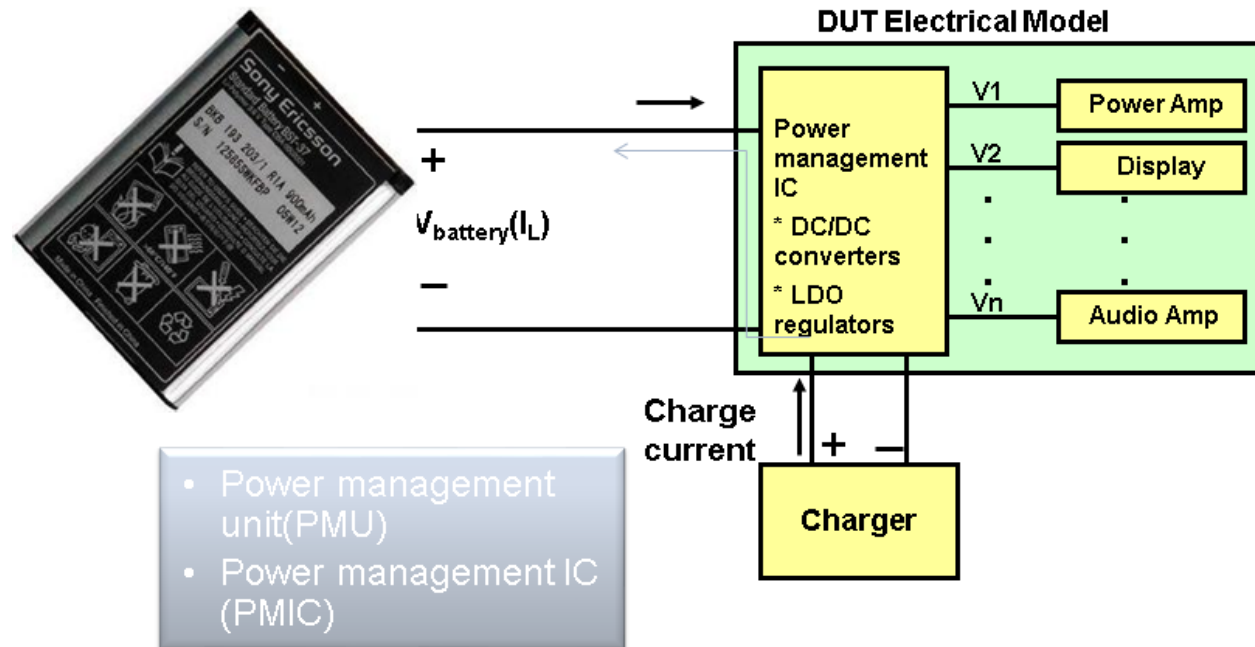
Low Power Consumption Analysis for IoT/Wearable Devices

- Flourishing application requirements
 - Caused by intensifying wearable/IoT device market
- Wide range of customers across many industries
 - RF module – Bluetooth/Wi-Fi
 - Sensors
 - Device design – Wearables, IoT, portable devices
 - IC design – Microcontroller/microprocessor, power management IC



- Current solutions are deficient
 - Oscilloscope: Low sensitivity; high noise; no long-term monitoring capability
 - Digital Multimeter: Low sample rate; no advanced triggering
 - DC Power Analyzer: Low accuracy

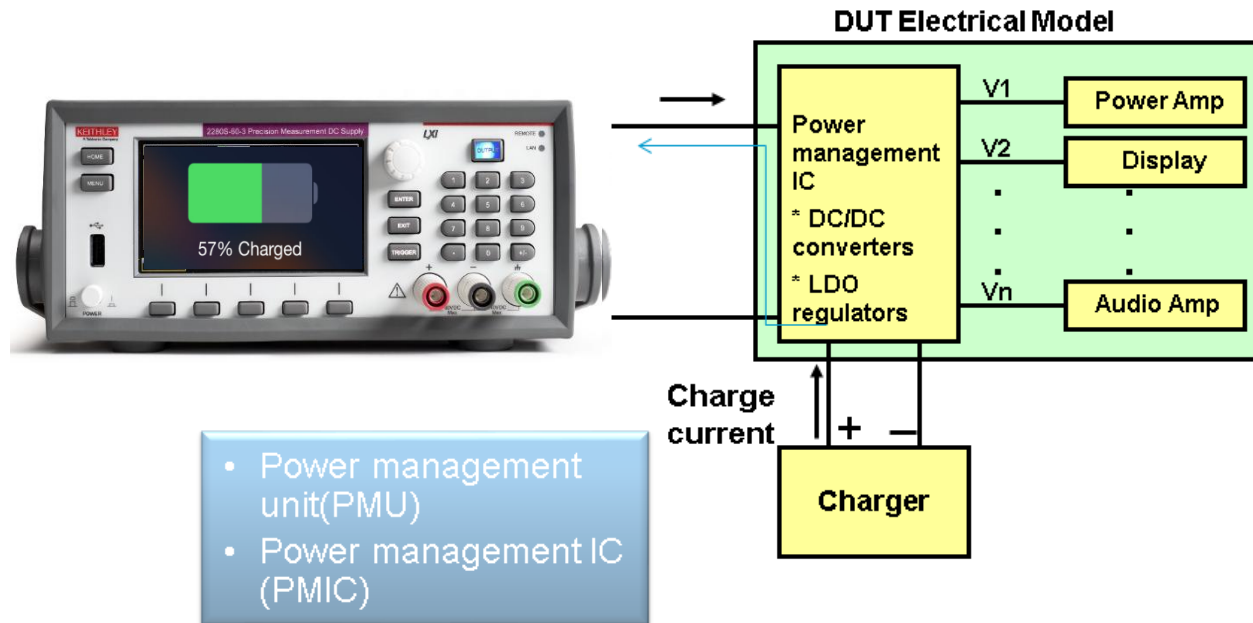
Testing issue with PMU/PMIC circuit



Use real battery test PMU/PMIC under different battery condition

General PMU test with battery is very complex, and need very long testing time on charging and discharging to get to certain battery condition, which lead to low test efficiency

Customer needs: Battery simulator to test PMU/PMIC



Battery simulator is used to replace real battery, simulate battery charging/discharging characteristic, and could be arbitrarily change the SOC, Voc, ESR, battery capacity to test DUT's action under different battery condition. Greatly help R&D customer increase test efficiency and saving test time

Different kinds of batteries from different vendors



Li-Ion Battery

NI-MH battery

Nicd battery,
Pe, Fe,
Lead-acid (Pb)

- How to characterize battery performance?
 - Capacity (Amp-Hour), impedance, aging effect, Charging/discharging curve

Customer needs: Single tools to test battery performance:



1. Battery charge/discharge test
2. Make accurate measurement on battery capacity (Amp-Hour)
3. Other measurement: battery impedance (ESR), open circuit voltage...
4. Generate battery model based on test result
5. Test script for complex sequencing test (charge/discharge cycling test)

The first 'Real' battery simulator in the industry

2281S-20-6 battery simulator



Simulate real battery output performance based on customized battery model

Battery simulator key spec:

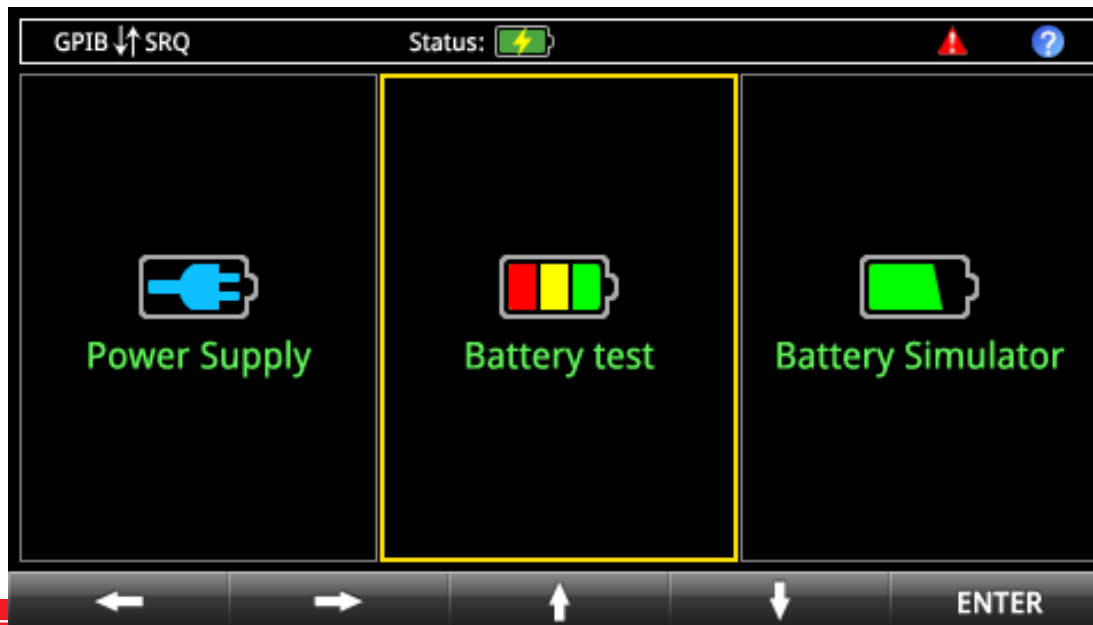
- Output range
 - 20V, -1A~+6A (Maximum sinking: 1A, Maximum sourcing: 6A)
- Accuracy/Resolution
 - Current measurement accuracy <10uA
 - Current measurement resolution 10nA
- Ripple & noise
 - Peak to peak <10mV
- Transient response
 - 50uS
- Battery resistance simulation
 - $-0.1\ \Omega \sim +10\Omega$
- Battery states:
 - SOC: 0%~100%
- Battery model:
 - Preset battery model or user defined battery model
 - Fine model includes 100 points
 - Coarse model includes 10 points, easy for customer to create or modify



Share same hardware platform with 2280S precision DC power supply

Basic function of battery simulator

- High precision power supply
 - Power up DUT with clean & stable output, capture uA to Amp level current drain in waveform of raw data form
- Battery test
 - General charging/discharging test, battery capacity test and battery ESR (equivalent series resistance) test
- Battery simulation
 - Simulate battery output according to user defined battery model



Why power supply mode?

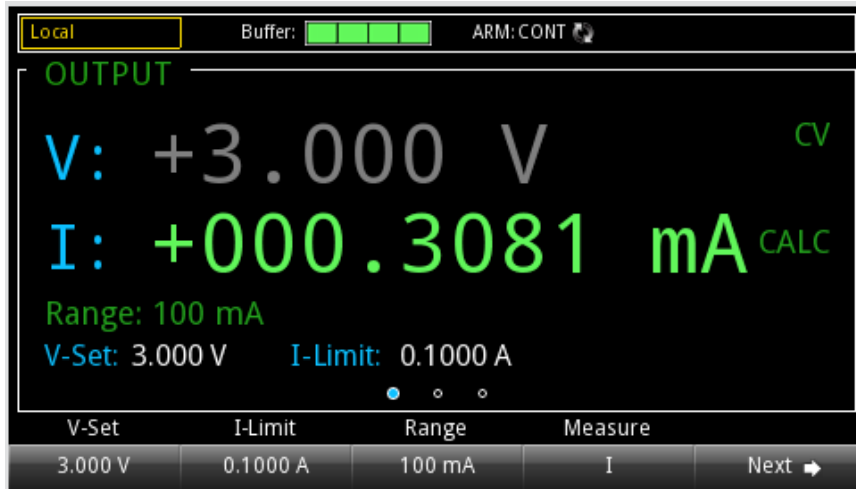
- Using high precision power supply to measure DUT DC current consumption



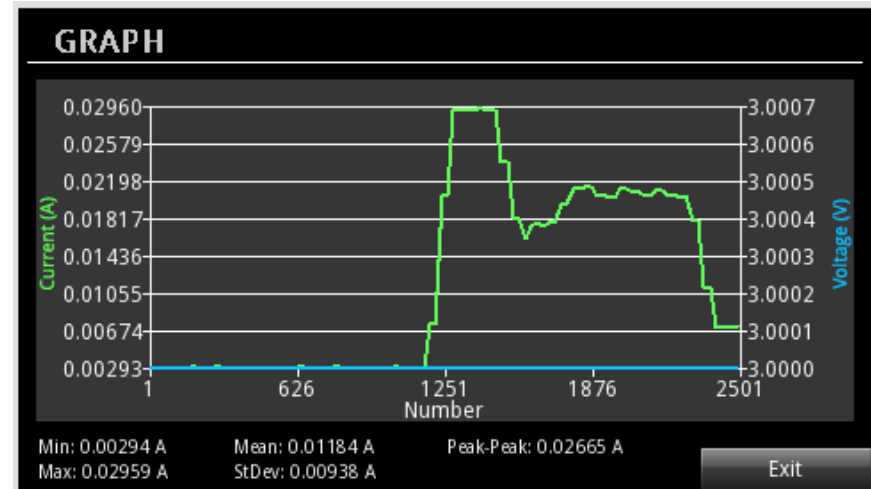
- High measurement accuracy, up to 10uA under 10mA range
- High sampling speed, up to 3000 sample per second
- Show current/voltage waveform
- Data logging mode with maximum sampling rate, streaming data back to PC via LXI interface

High precision power supply

2281S power supply mode provide 3 way to display measurement result



Meter mode



Waveform mode

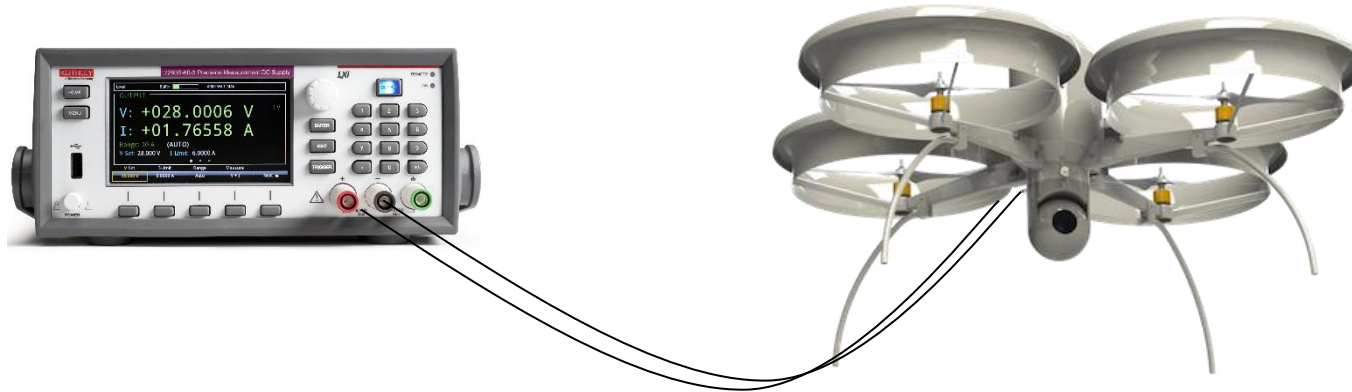
DATA SHEET

Points	Time	Voltage	Current
1	05/05 14:53	+003.0000 V	+000.7054 mA
2	14:53:27.49	+003.0000 V	+000.8593 mA
3	14:53:27.49	+003.0000 V	+000.8942 mA
4	14:53:27.49	+003.0000 V	+000.8965 mA
5	14:53:27.49	+003.0000 V	+000.8965 mA
6	14:53:27.49	+003.0000 V	+000.8965 mA
7	14:53:27.49	+003.0000 V	+000.8970 mA
8	14:53:27.49	+003.0000 V	+000.8971 mA

← → ↑ ↓ Exit

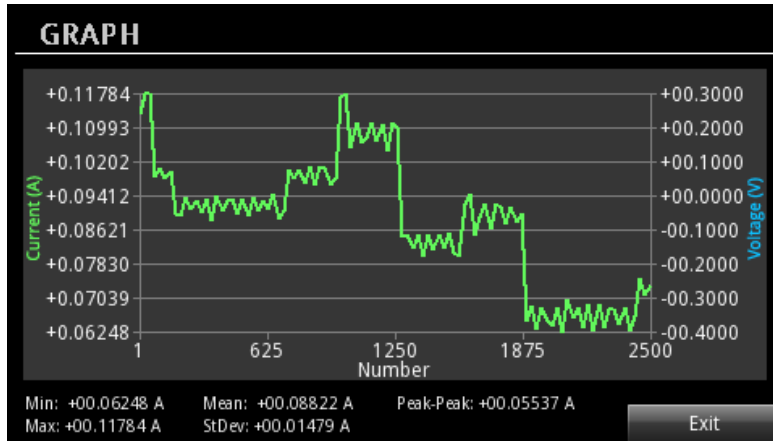
Data sheet mode

Using power supply to power a drone

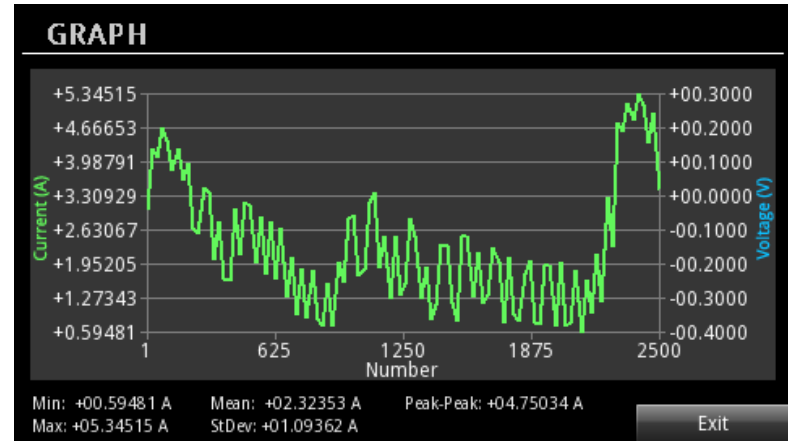


- Replace battery with 2281S under power supply mode
- Setup output to 4.2V, 6A
- Setup current measurement to its maximum sampling rate to view DC current waveform:

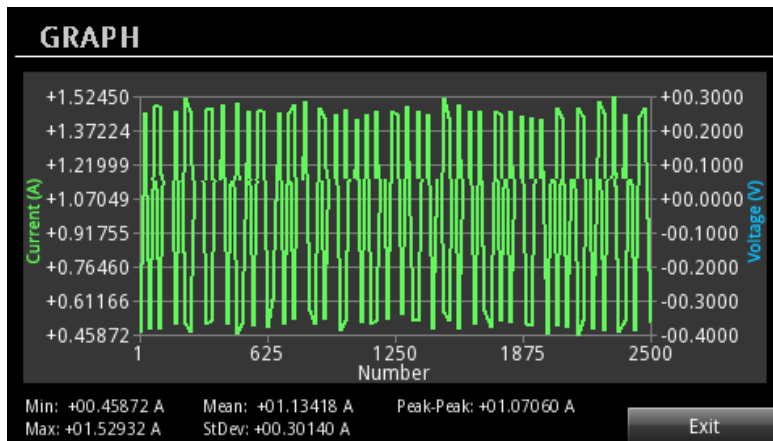
Measure current consumption under different working mode



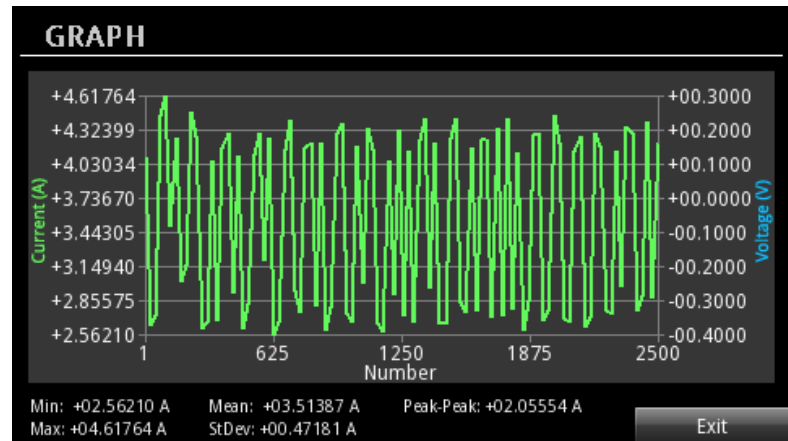
Idle mode



Flight Attitude Control

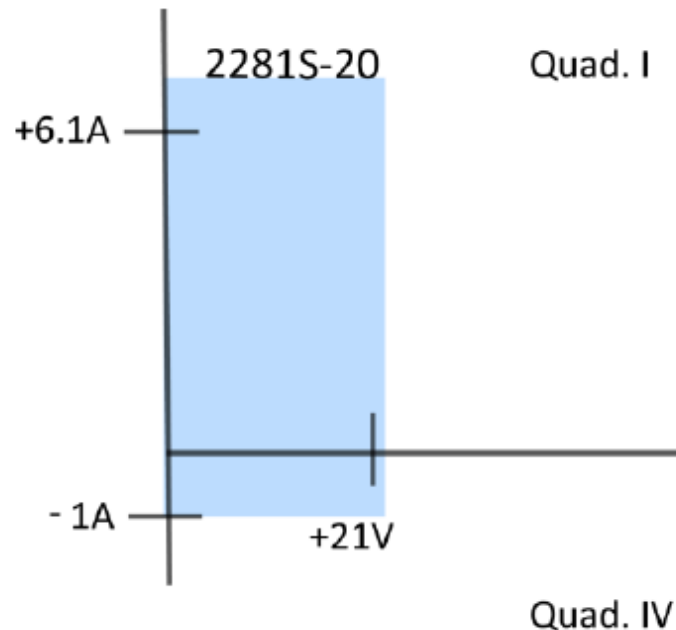


Standby mode



Rising

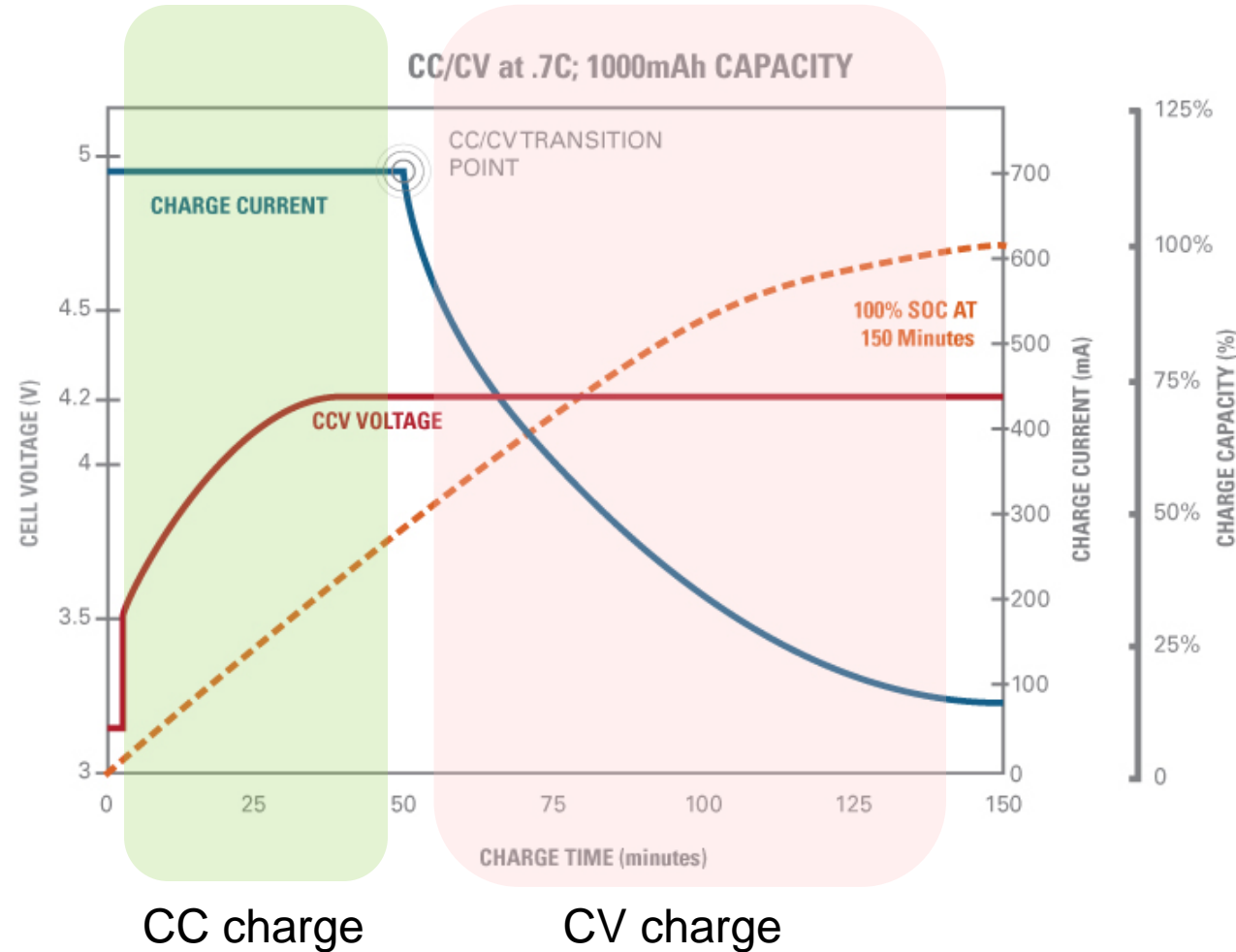
Battery test (charging/discharging test) of rechargeable battery



2281S could be used to either charge or discharge a battery because of 1.5 quadrants output

Charge: Source up to 6A
Discharge: Sink up to 1A

Typical battery charging curve



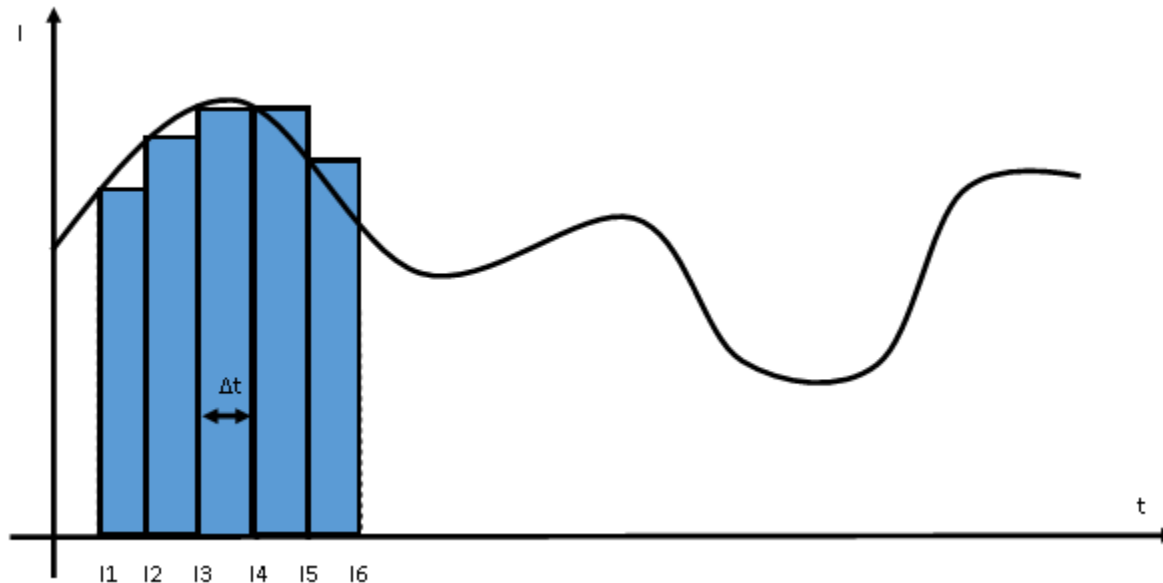
Recording voltage, current, Amp-hour and ESR* measurement result in whole charging process.

The charging process from SOC 0%~100% will be used to build up battery model for battery simulation use

Amp-hour measurement under battery test mode

- Measuring current at fixed sampling rate, calculate Amp-Hour by:

$$A-H = \sum I(n) * \Delta t :$$

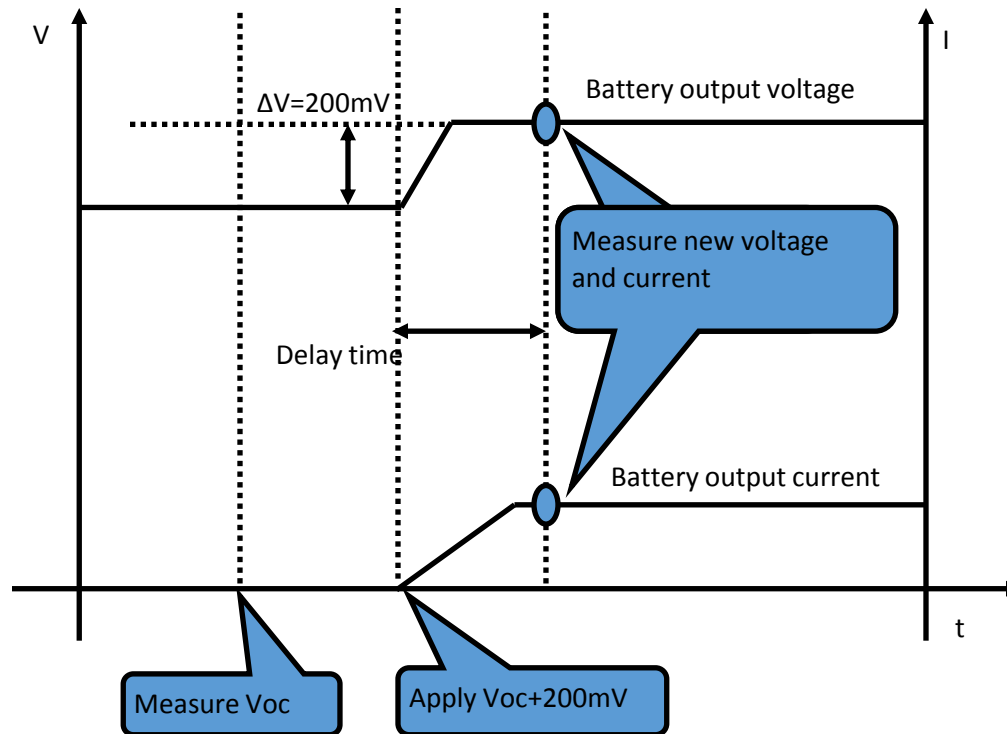


- Build-in 6 ½ digit DMM make accurate measurement on current
- Amp-hour measurement is very accurate when the current changes slowly (especially under charging/discharging mode)

Battery DC impedance measurement

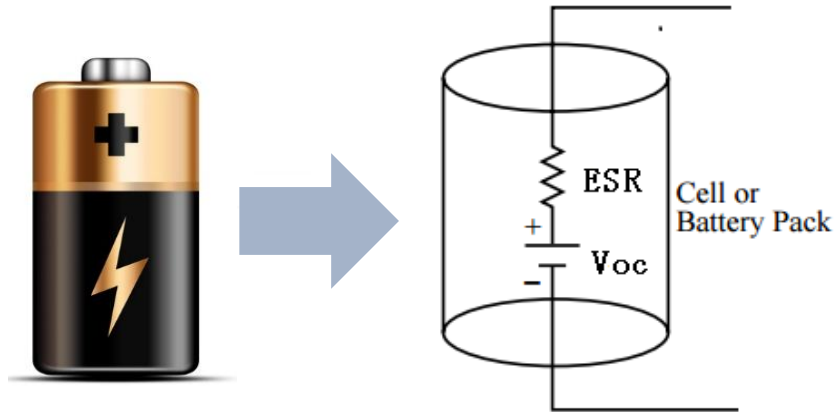
- Measure battery impedance based on following equation:

$$ESR = \Delta V / \Delta I$$



Battery model:

- We simplify a battery as following shows:



ESR is the battery impedance
Voc is the open-circuit voltage

- 2281S could charge a battery from Empty to Full state, log voltage, current, impedance, and Amp-Hour information during the charge process

DATA SHEET				
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

Build up battery model based on test result

- After a full **charge** cycle of the battery, the instrument build up battery model automatically and could simulate battery based on that model



DATA SHEET				
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



BATTERY MODEL		
Model <input type="text" value="1"/>		<input type="button" value="Fine"/> <input type="button" value="Save"/>
Select or import a model		
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

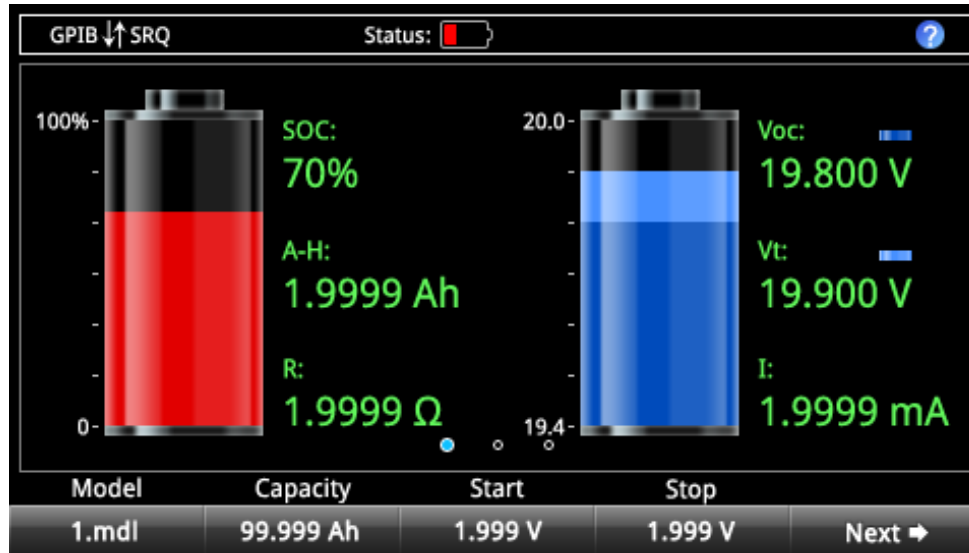
Battery charging data $\rightarrow \rightarrow \rightarrow$ Generate battery model

Battery model includes relationship among SOC, Voc and ESR

Build up battery model based on test result

- Two kinds of battery models: Fine and Coarse
 - Fine model includes 101 points, from SOC 0% to SOC 100%, each point take 1%
 - Coarse model includes 11 points, from SOC 0% to SOC 100%, each point take 10%
 - Between each two points, 2281S use linear interpolation to make the curve smooth
 - Customer could manually create or edit the battery model, customer could export or import battery model through USB port
 - Each model have its own name and description
 - Store up to 10 different battery model in memory

Battery simulation



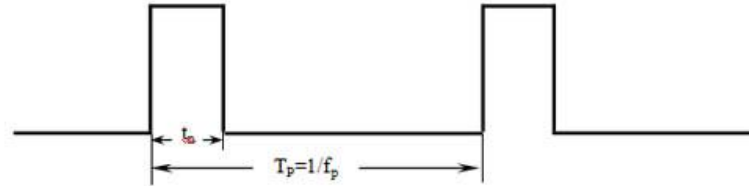
- Choose your own battery model
- Free to set battery initial state with different Voc of SOC level
- Adjust battery capacity, accelerate battery charging/discharging process
- Customer could add offset to battery impedance to reduce the effect of wire or test fixture impedance

Battery simulation

- Using color bar to show battery states:
 - Left bar shows SOC, right bar shows battery voltage
- Select simulation mode between static and dynamic
 - Dynamic: battery Voc changes with charging/discharging
 - Static: Battery Voc not changing
- Adjusting battery output terminal voltage (V_t) according to battery resistance (ESR) and current level, simulate real battery output characteristic
 - R: battery impedance (ESR), I: Charging/Discharging current
 - V_t : Battery terminal voltage, V_{oc} : Battery open circuit voltage
 - $V_t = V_{oc} - R * I$ (I is negative when charging, positive when discharging)

Battery impedance simulation

- Battery impedance simulation under pulse load



- Wireless device usually generate pulse load which will lead the battery output voltage slightly change because of the impedance of battery

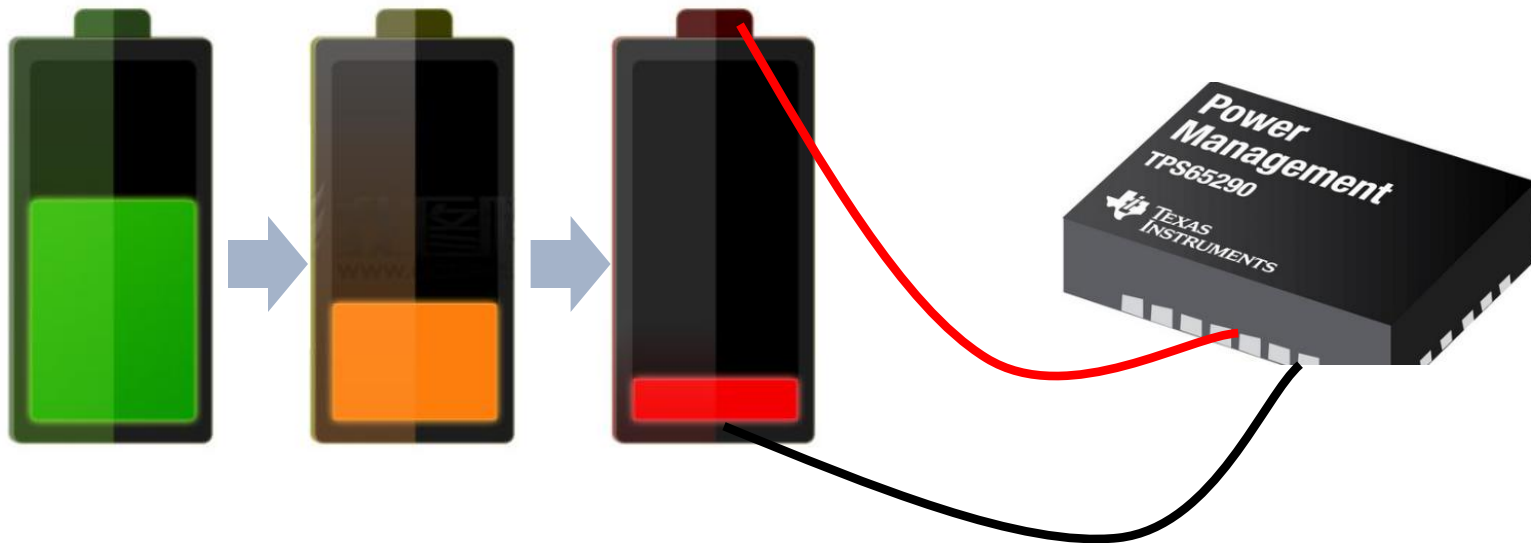
Battery output voltage response

Load current pulse



Application (1)

- Testing power control unit/IC function under different battery states



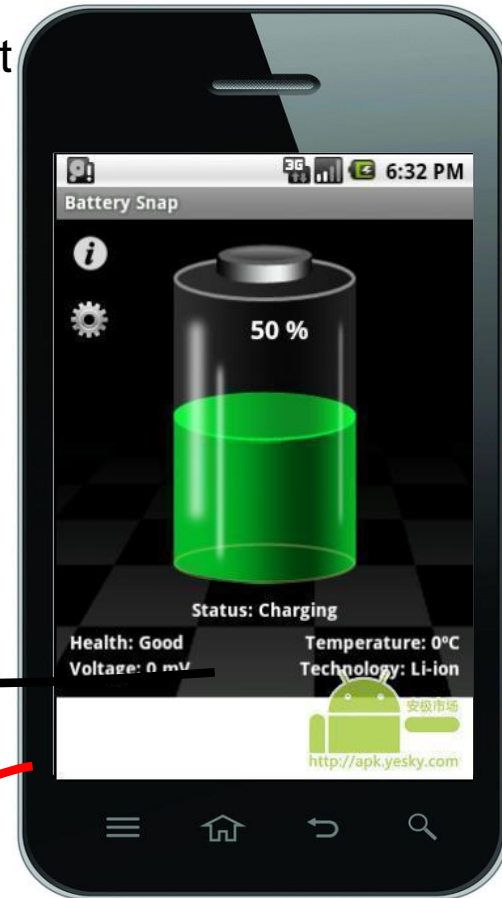
1. Test basic function of PMU module under different battery states
2. Verify DUT working voltage range, find shut down voltage points
3. Verify battery charge regulator function, make sure battery works under right voltage range
4. Test PMU module control mechanism in dynamic, verify PMU function in charging/discharging process

Setup battery with arbitrary states (Voc, Soc, ESR and capacity)

Saving test time and increase test efficiency

Application (2)

- Verify battery remaining display algorithm
 - Check if battery remaining display is correct
 - Calibrate battery remaining algorithm



Replace real battery, adjust battery states arbitrarily

See difference between DUT display and battery states setting

Saving test time, increase test efficiency

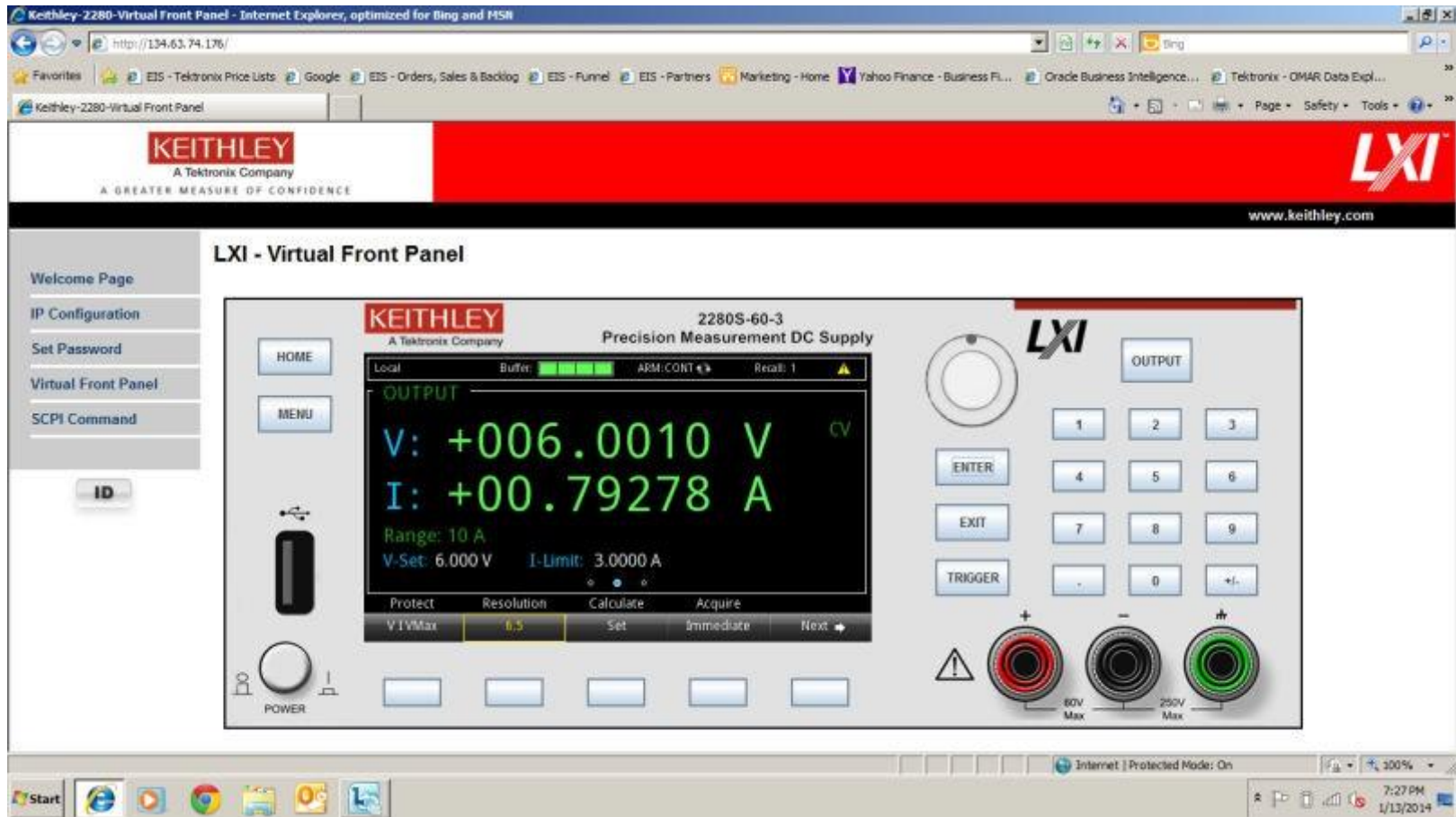
Application (3)

- Test battery performance, build up battery model
 - General charging/discharging test, recycling charging/discharging test, understand battery aging effect
 - Test battery capacity, ESR, OVP, OCP function
 - Build up battery model, compare different battery type performance



Remote control over LXI interface

- Control or monitor the supply using its web browser over the LAN LXI interface



Remote control over LXI interface

LXI - Data Logging

Navigation Menu:

- Welcome Page
- IP Configuration
- Set Password
- Virtual Front Panel
- SCPI Command
- Data Logging**

Table:

Points	Mode	Voltage	Unit	Current	Unit	Math	Relative	OXF	Overflow	Time
14796	CV			1.4238647E-4	A	0	0	0	0	2014-11-12 16:31:28.8768
14797	CV			1.4137456E-4	A	0	0	0	0	2014-11-12 16:31:28.8772
14798	CV			1.2956894E-4	A	0	0	0	0	2014-11-12 16:31:28.8775
14799	CV			2.1119638E-4	A	0	0	0	0	2014-11-12 16:31:28.8779
14800	CV			1.261959E-4	A	0	0	0	0	2014-11-12 16:31:28.8782
14801	CV			1.353031E-4	A	0	0	0	0	2014-11-12 16:31:28.8786
14802	CV			1.2855702E-4	A	0	0	0	0	2014-11-12 16:31:28.8790
14803	CV			1.2788242E-4	A	0	0	0	0	2014-11-12 16:31:28.8793
14804	CV			1.6667231E-4	A	0	0	0	0	2014-11-12 16:31:28.8797

MODE: Manual

Stop

- 24-hour uninterrupted data logging for several days (Sampling rate 3K/s)
- Real-time statistics update, including Max, Min, Average and Electric charge

Table:

11364	CV	12.600316	V	1.8817985	A	0	0	0	0	2014-11-07 15:32:43.1013
11365	CV	12.600321	V	1.8817737	A	0	0	0	0	2014-11-07 15:32:43.1431
11366	CV	12.600314	V	1.8817452	A	0	0	0	0	2014-11-07 15:32:43.1848
11367	CV	12.600297	V	1.8817166	A	0	0	0	0	2014-11-07 15:32:43.2266
11368	CV	12.600277	V	1.8816862	A	0	0	0	0	2014-11-07 15:32:43.2684

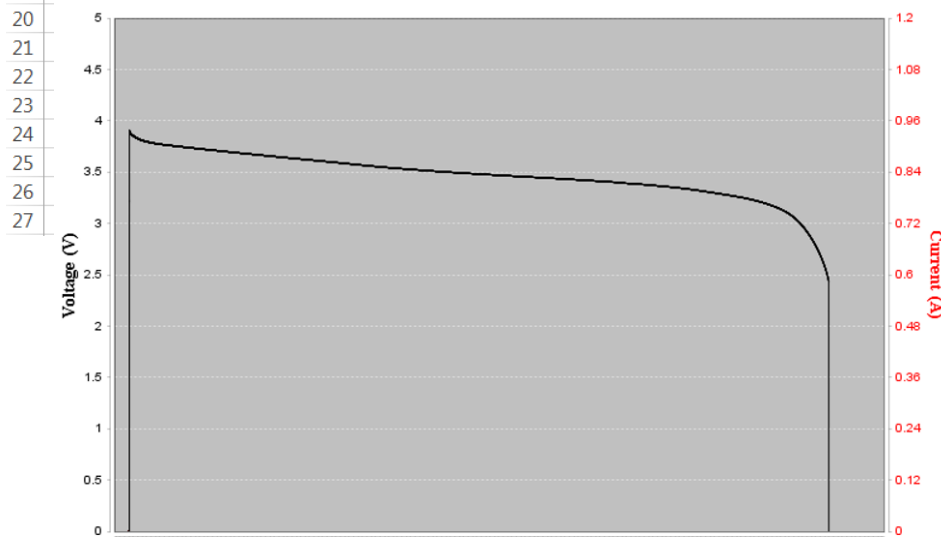
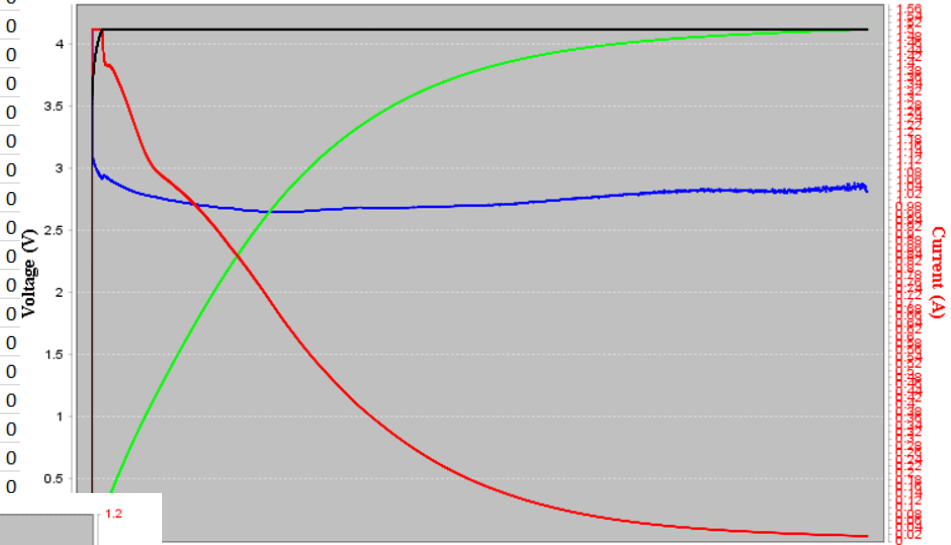
Statistics:

Vmax	12.600394	V	Imax	1.9998226	A
Vmin	11.89879	V	Imin	0.9998445	A
Vavg	12.543977	V	Iavg	1.918472	A

Electric Charge: 253.00612 mAh

Remote control over LXI interface

1	Points	Mode	Voltage(V)	Current(A)	ESR	A-H	OXF	Overflow	Date	Time	Millisecond	Relative Time
2	1	CC	3.52284	1.499878	0.350837	0	0	0				
3	2	CC	3.561029	1.499874	0.350837	2.08E-04	0	0				
4	3	CC	3.583603	1.499877	0.350837	5.21E-04	0	0				
5	4	CC	3.600567	1.499869	0.350837	8.34E-04	0	0				
6	5	CC	3.61442	1.499886	0.350837	0.001146	0	0				
7	6	CC	3.626285	1.499879	0.350837	0.001459	0	0				
8	7	CC	3.636766	1.499885	0.350837	0.001772	0	0				
9	8	CC	3.646252	1.499881	0.350837	0.002084	0	0				
10	9	CC	3.654964	1.499883	0.350837	0.002397	0	0				
11	10	CC	3.663131	1.499878	0.350837	0.002709	0	0				
12	11	CC	3.670815	1.499878	0.350837	0.003022	0	0				
13	12	CC	3.678119	1.499886	0.350837	0.003335	0	0				
14	13	CC	3.685099	1.499872	0.350837	0.003647	0	0				
15	14	CC	3.691811	1.499875	0.350837	0.00396	0	0				
16	15	CC	3.691811	1.499875	0.262216	0.00396	0	0				
17	16	CC	3.701021	1.499879	0.262216	0.004627	0	0				
18	17	CC	3.707734	1.499881	0.262216	0.00494	0	0				
19	18	CC	3.71392	1.499888	0.262216	0.005252	0	0				



Time	Voltage	Current	ESR
6:46:56	258.5	16358.5	
6:46:57	8.9	17108.9	
6:46:57	759.2	17859.2	
6:46:58	509.7	18609.7	

— Voltage — Current — AH — ESR

DEMO