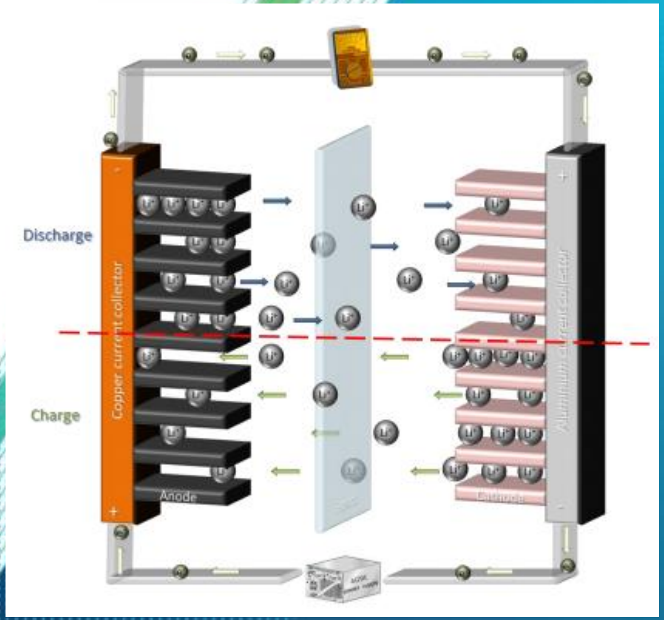
Tektronix

KEITHLEY
A Tektronix Company

Energy Storage Cells Test Solution



13 FEBRUARY 2019
ANDREA VINCI – EMEA AUTOMOTIVE AND POWER BDM

ENERGY STORAGE EVENT

12 februari 2019 | NH Conference Centre Koningshof

WE'RE FOR THE ENGINEER

From Inspiration to Realization

Reducing the distance between inspiration and realization.

Tektronix is the measurement insight company committed to performance, and compelled by possibilities. Tektronix designs and manufactures test and measurement solutions to break through the walls of complexity, and accelerate global innovation. Together we empower engineers to create and realize technological advances with ever greater ease, speed and accuracy. Tektronix solutions have supported many of humankind's greatest advances of the past 70 years. Health. Communication. Mobility. Space. With offices in 21 countries, we are committed to the scientists, engineers and technicians around the world who will define the future.

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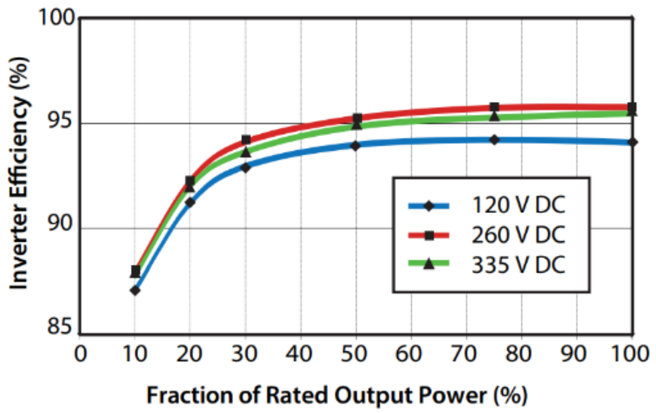
Some Intersection with Energy Storage Markets

Applications problems

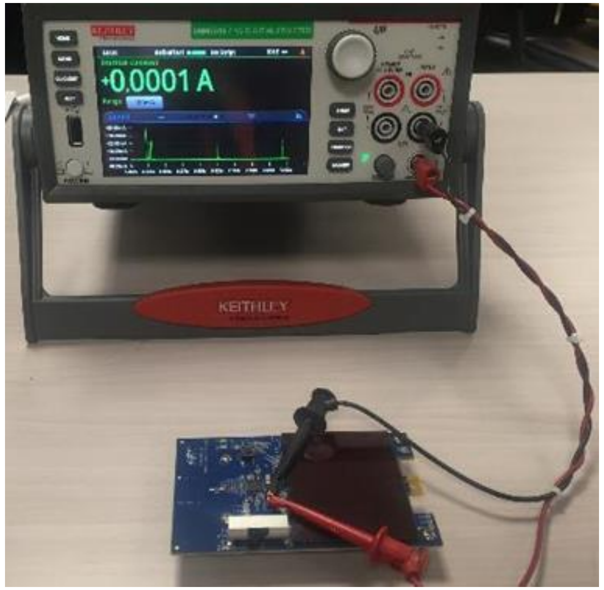
$$P_d = P_L + P_{\text{switch}} + P_{\text{other}}.$$

$$\eta = \frac{P_o}{P_o + P_d},$$



PV market

- Power quality
- Efficiency of DC-DC and DC-AC converters



Low Voltage IoT market

- Energy supply of small smart device

Energy Harvesting

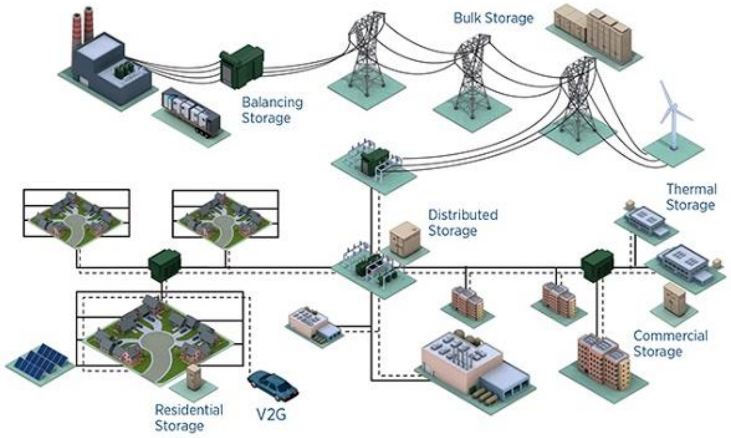
What we may target (to be)

Fast growing markets

- Electro-mobility
- Back-up power / renewables grid integration

What is the problem you are trying to solve?

- Requirements?
- Test problems?
- Custom Specific Needs?
- Software integration?



Example of system we designed for IoT

Demand markets

Smartphones
Electric Vehicles
Renewable Energies

Trends

Higher Voltages
Smaller Size
More Energy per size

Research

Improve Li-Ion
Electrodes -> Cathode materials
Membrane/Liquids

Metrics

Cost
Efficiency
Size
Lifetime
Safety

IoT space
Integration in IoT for Vehicles
Vehicle trackers GPS
(3.7V backup, battery charging ICs)
Power Backup
(4.2V cell/1.5A, 2.5A output current)

Ranges

DC voltage ranges 40/60V
DC current ranges 100’s/1000’sA

Batteries: Characteristics and Suitability

Applications

Consumer Electronics,
Electric mobility,
Energy Storage

Requirements

Short Bursts of high current
Low current for long periods
…

Lithium Ion Batteries

High Energy
High Power Density

To evaluate Battery Characteristics and Suitability per Application you need to check:

- Energy/Power (Ragone plot)
- Cell Impedance vs Temperature
- Cell Impedance vs Load
- Charge/Discharge Characteristics

- Composition of a solution system kit:
- Power supply (AC/DC, DC/AC)
- Electronic load
- Voltmeter/ammeter (digitizer, datalogger)
- Thermal chamber
- Switches for series tests
- Control software

How to test battery cell

CHARACTERIZE BATTERY CELL PERFORMANCE

- Short term performance
  - Battery function test: charge/discharge/protection
  - Battery capacity
  - Battery impedance (AC impedance)
- Long term performance
  - Aging performance
  - Self-discharge
  - Battery cell uniformity

- Research needs vs Industry needs

Keithley in Research

Predict battery life by Columbic Efficiency

- CE = Qd/Qc (discharge capacity/charge capacity)

$$Q = \int I(t) * dt = \frac{1}{R} \int V(t) * dt$$

  - If CE = 1,   battery has eternal life
  - For real battery CE < 1,   but very close
  - CE is an constant throughout battery life
  - CE could be used to predict battery long term performance

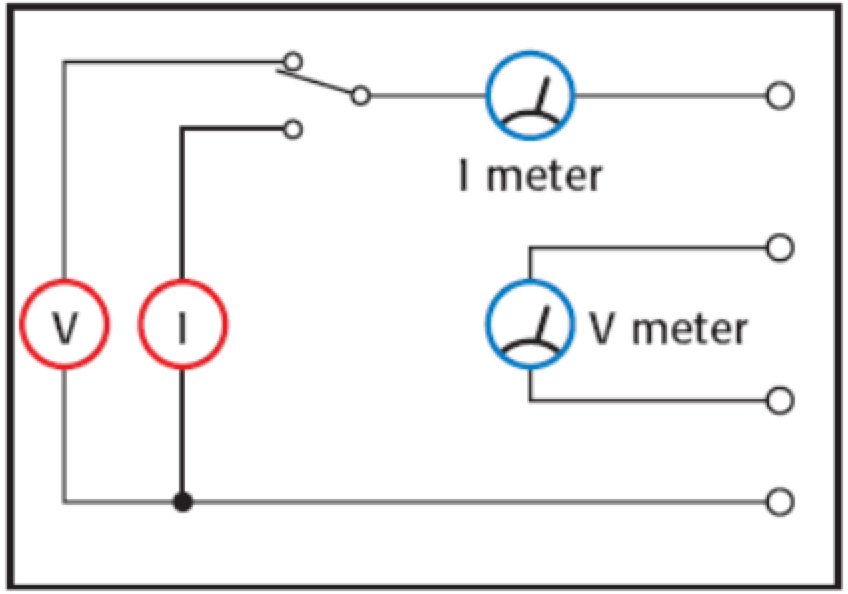
Traditional battery tester could not be used to measure CE because of the accuracy

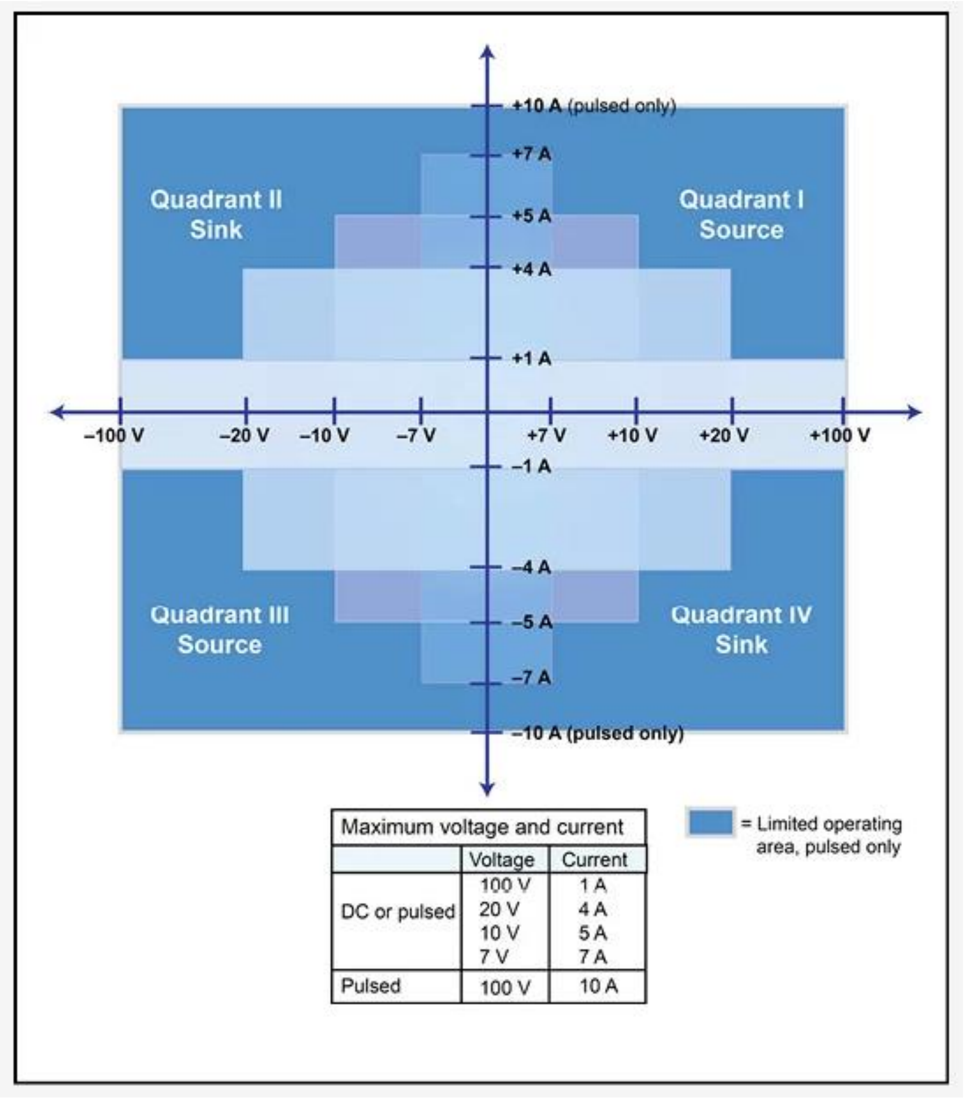
If CE = 0.9998, 1000 cycles lead to 81.87% capacity left

Pioneering Li-Ion capacity test

Bring solutions to Industry

What is a Keithley SMU?



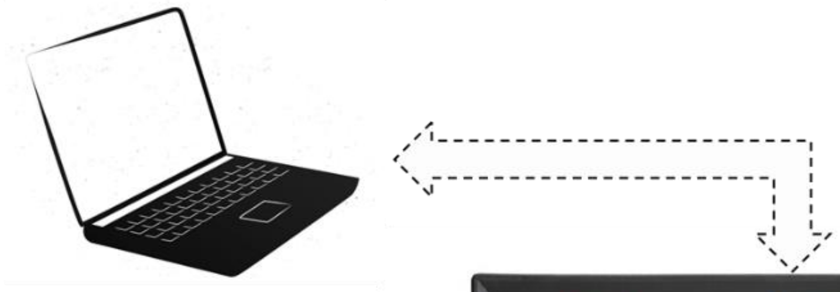


What is Keithley TSP infrastructure?

- Embedded Test Script Processor turns an instrument into a Smart Instrument
- Flexibility of Automated Test Programmer
- Much less GPIB transactions when a test sequence is executed rather than common SCPI command execution approach

```
--Take a reading and get the current, voltage and time
curr = smu.measure.read(defbuffer1)
volt = defbuffer1.sourcevalues[iteration]
time = defbuffer1.relativetimestamps[iteration]
hours = time/3600

--Print the # of completed cycles, the voltage and the time for
--the iteration.  Display information on front panel
print("Completed Cycles: ", iteration, "Voltage: ", volt, "Time: ", time)

display.settext(display.TEXT1, string.format("Voltage = %.4fV", volt))
display.settext(display.TEXT2, string.format("Current = %.2fA, Time = %.2fHrs", curr, hours))

--Increment the number of iterations and wait 10 seconds
--Compare the measured voltage to the voltage limit
--Exit the loop if it is
if volt <= voltLimit then
        break
end

iteration = iteration + 1
delay(10)
```

Program resides completely in the instrument



Preload script(s) into the instrument then disconnect from PC. Can store scripts in nonvolatile memory.

WARNING

The script presently does not include any built-in safeguards to prevent the user from discharging a LITHIUM ION battery beyond safe limits. It is the user's responsibility to follow all manufacturer's guidelines when setting the discharge current and cut-off voltage for a LITHIUM ION battery to ensure safe operation of the test setup and program.

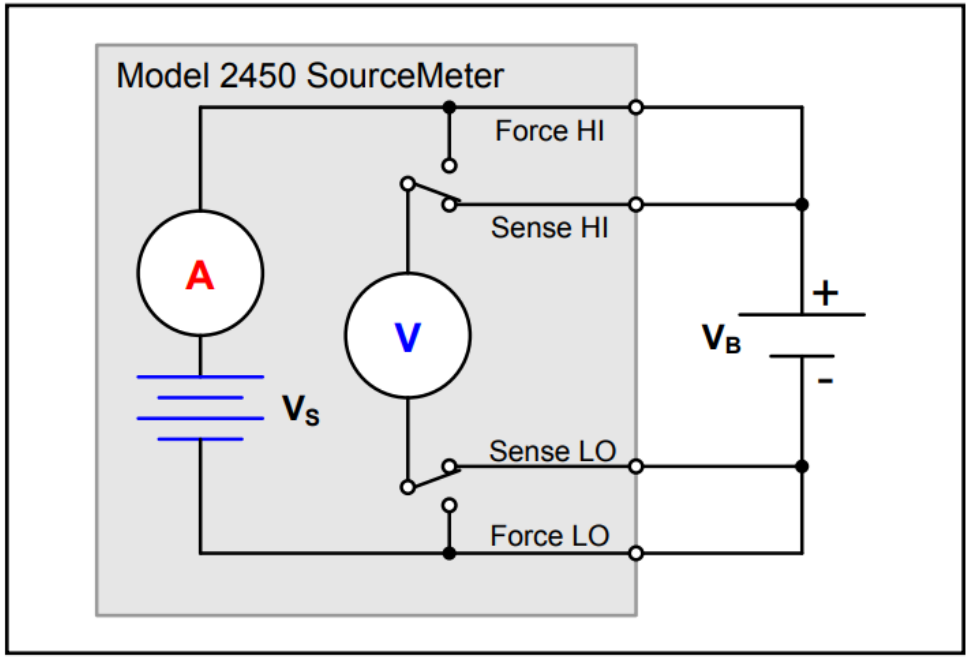
CAUTION

Do not connect the battery to the SourceMeter instrument until prompted by the script do so. Connecting the battery earlier may cause it to start discharging prematurely.

Record a macro (settings only). Manage and run like other scripts.

Modeling the battery: cycle tests example

- Use a Keithley 2461 SourceMeter® to simulate a battery.
- Get a battery model (with 101 points) generated by a separate TSP script
- Open circuit voltage and internal resistance as a function of the battery's state of charge



Technical Background

- The battery model used to create the simulation includes:
  - The battery's capacity, in Amp-Hours
  - The State of Charge (SoC) from 0 to 100%
  - The Open Circuit Voltage at each SoC, in Volts
  - The Internal Series Resistance at each SoC, in Ohms

- The Model 2461 measures current at 1MSample/sec and outputs voltage according to the formula:

$$V_{output} = V_{open} - (I_{measured} * ESR)$$

- The voltage output has a response time of ~200µs
  - i.e. it takes 200µs for V_{output} to change after the current through the SMU changes

Technical Background

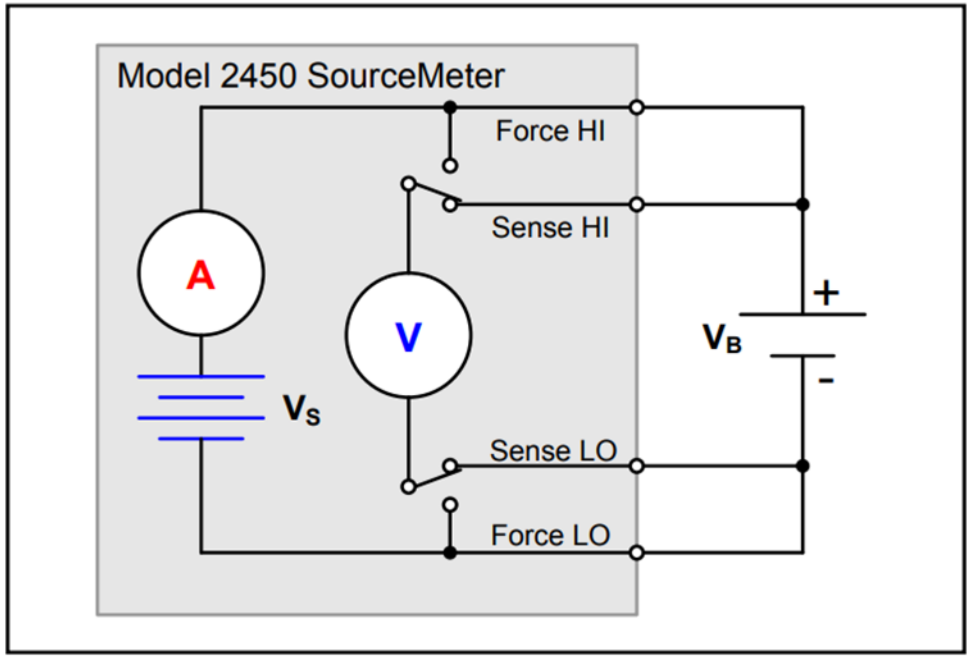
- The simulation calculates the Amp-Hours output by/sunk by the SMU using the trapezoidal integration method from the measured current and the SMU's internal clock.
    - **The simulation can handle both charging and discharging of the model symmetrically**
- Voc, ESR, SoC, and Capacity are interpolated (linearly) between the 101 points of the model
- This specific SMU has a current limit of 7A and an output limit of 7V. These limits may be reduced in the script if these high levels are not needed to increase responsiveness at lower current levels.

Connections to your Device

- The script requires a **4 wire connection** to your device, leaving the sense leads disconnected may cause erratic behavior and damage to your device.

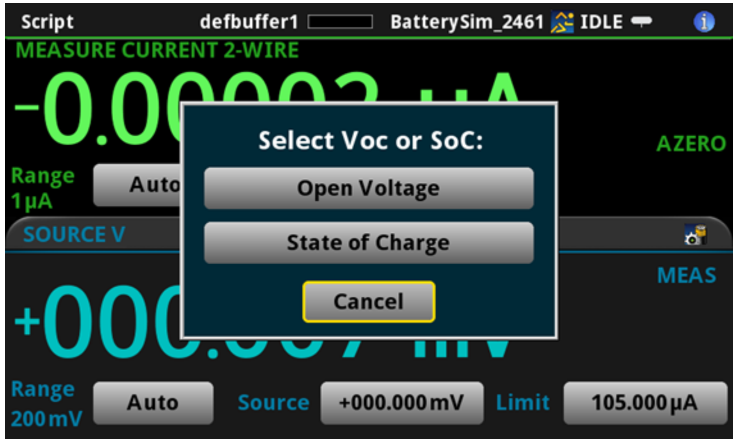
- Force Hi/Sense Hi should be connected to the device terminal expecting a positive voltage
  - Likewise, Force Lo/Sense Lo should be connected to the device terminal expecting a battery's negative terminal.

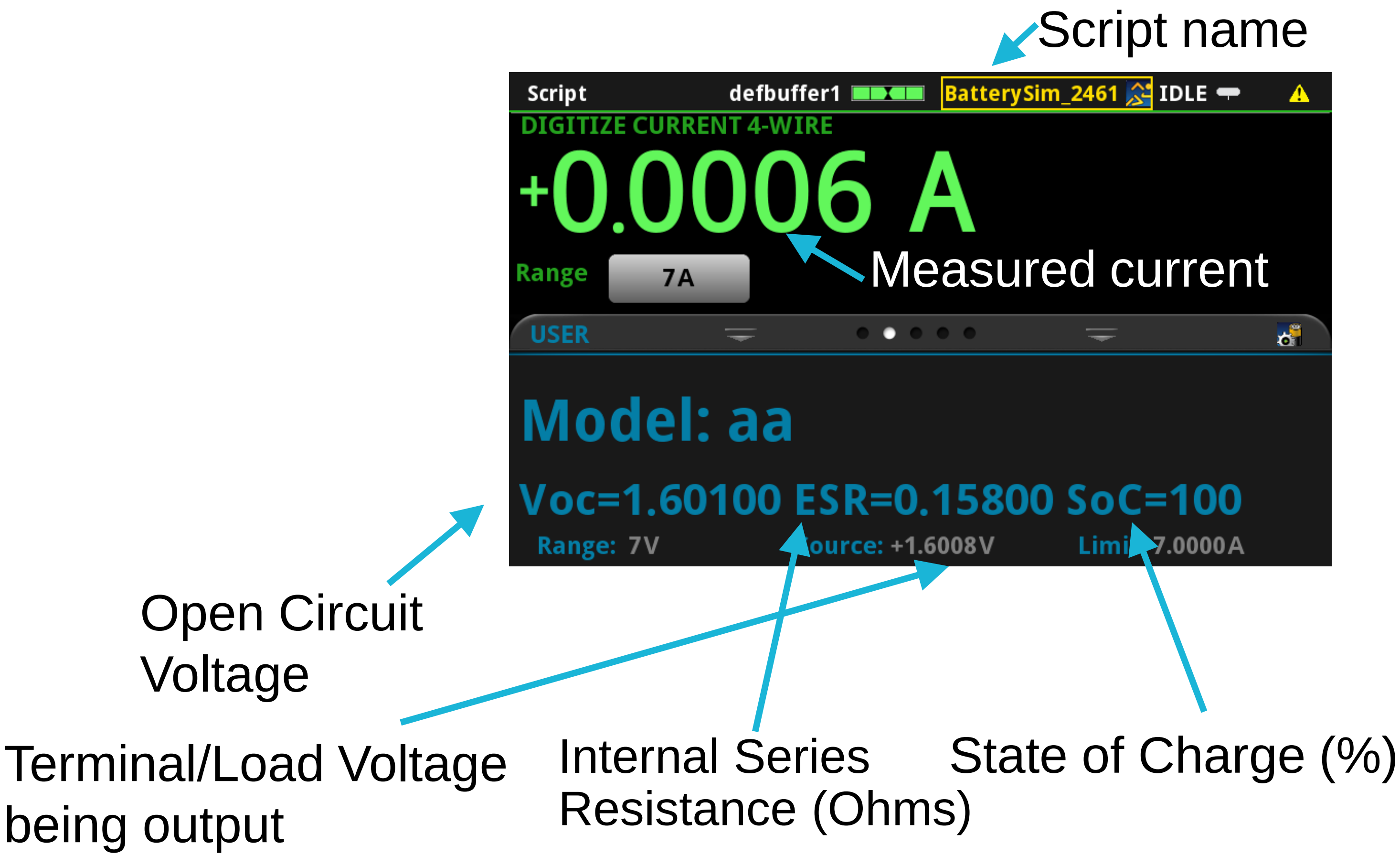
- For highly sensitive devices, it is recommended to only make connections after the simulation starts.



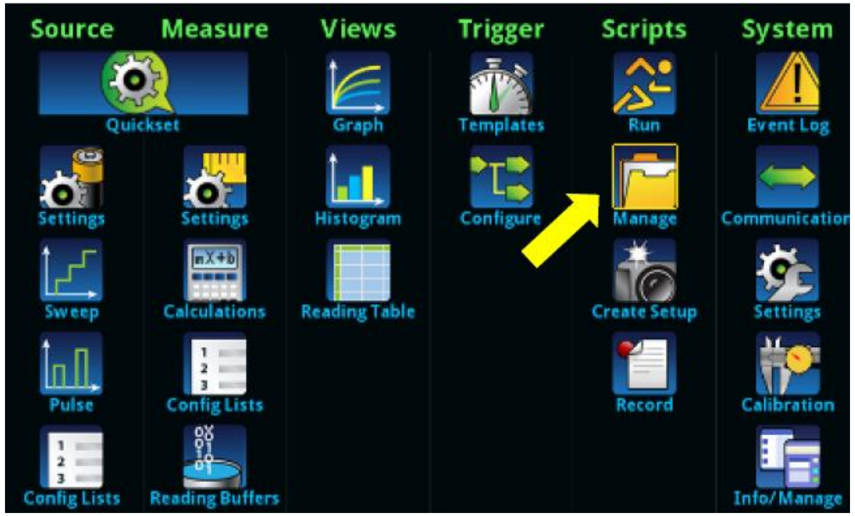
Ways to Run the Script

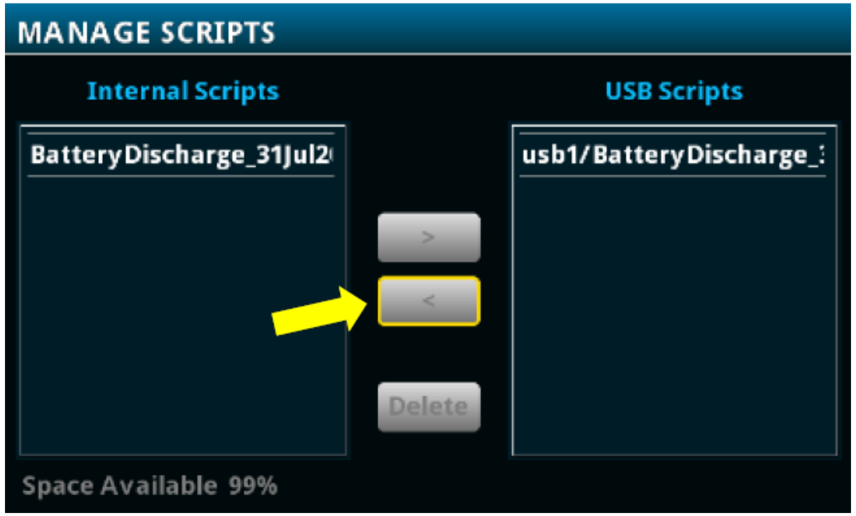
- The script can be loaded and run either from the front panel of the instrument or from an external computer using Keithley's Test Script Builder (TSB) application.

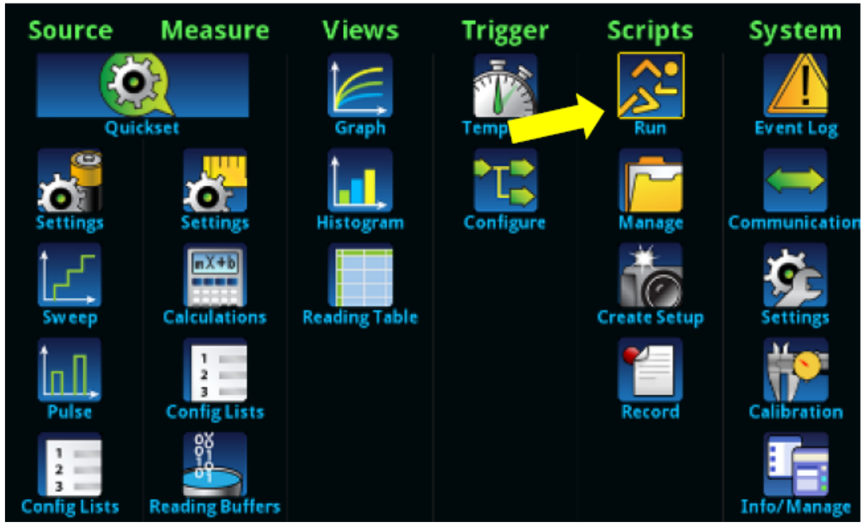


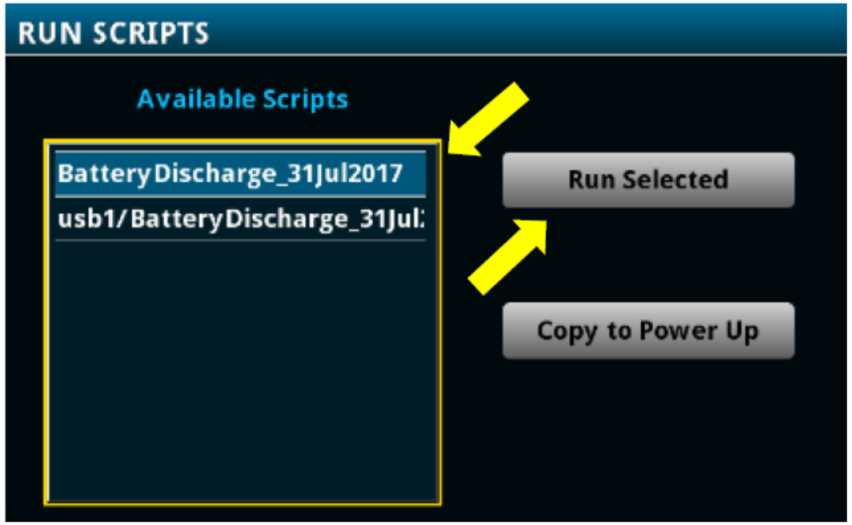


Script


Source
Measure
Views
Trigger
Scripts
System
Quickset
Graph
Templates
Run
Event Log
Settings
Settings
Histogram
Configure
Manage
Communication
Sweep
Calculations
Reading Table
Create Setup
Settings
Pulse
Config Lists
Record
Calibration
Config Lists
Reading Buffers
Info/Manage

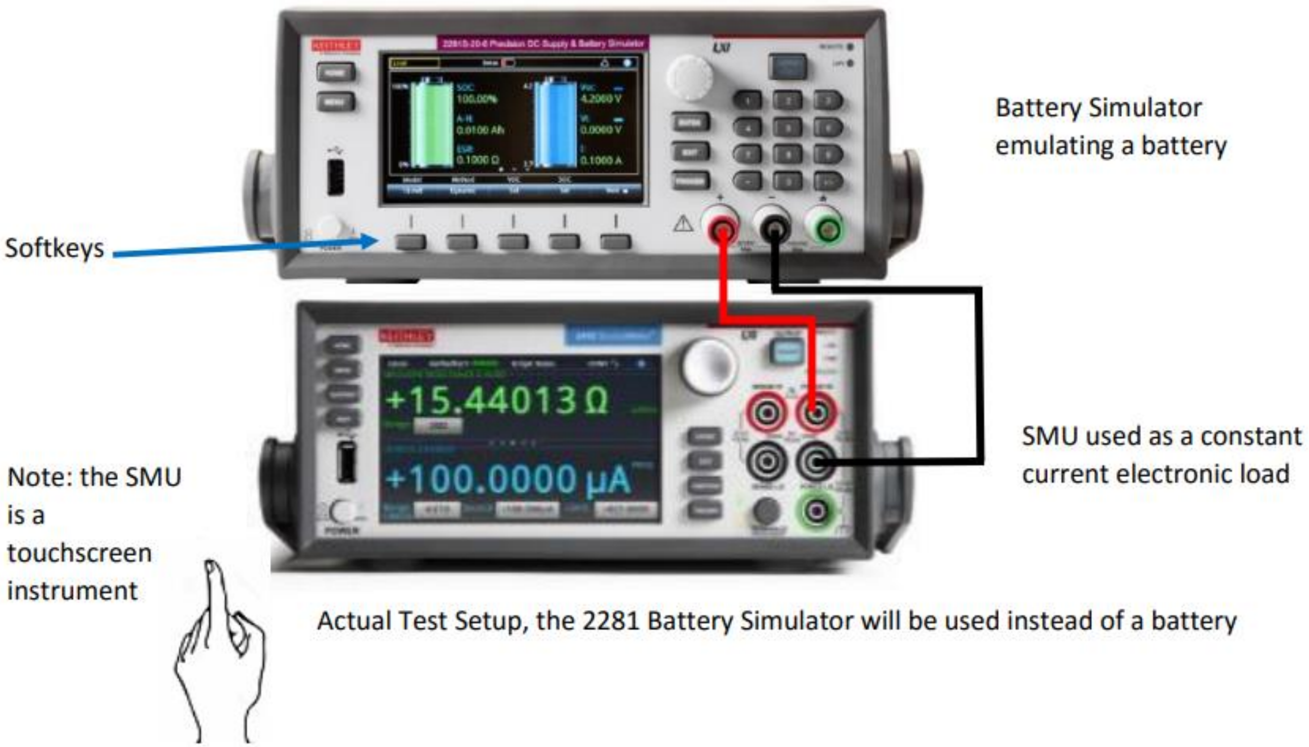

MANAGE SCRIPTS
Internal Scripts
USB Scripts
BatteryDischarge_31Jul2
usb1/BatteryDischarge_
>
<
Delete
Space Available 99%


Source
Measure
Views
Trigger
Scripts
System
Quickset
Graph
Temp
Run
Event Log
Settings
Settings
Histogram
Configure
Manage
Communication
Sweep
Calculations
Reading Table
Create Setup
Settings
Pulse
Config Lists
Record
Calibration
Config Lists
Reading Buffers
Info/Manage

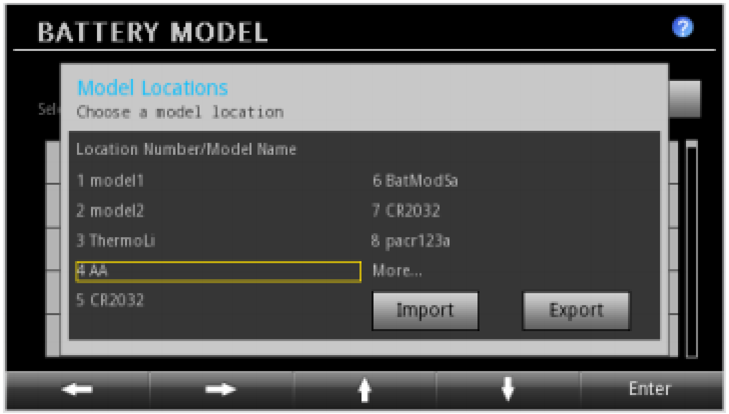

RUN SCRIPTS
Available Scripts
BatteryDischarge_31Jul2017
usb1/BatteryDischarge_31Jul
Run Selected
Copy to Power Up

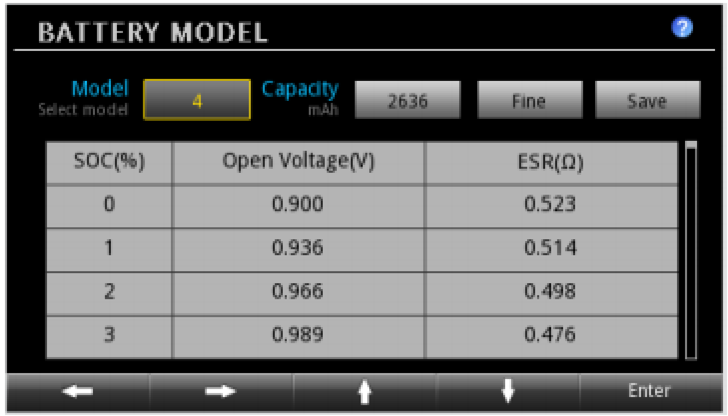
Success cases in low power energy storage

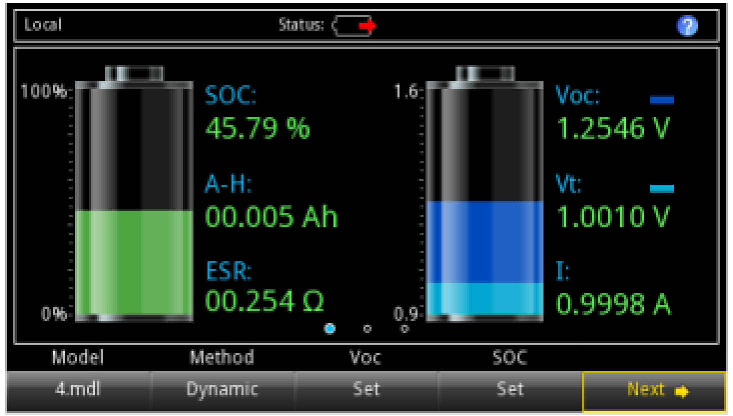
- SMU as constant current Load

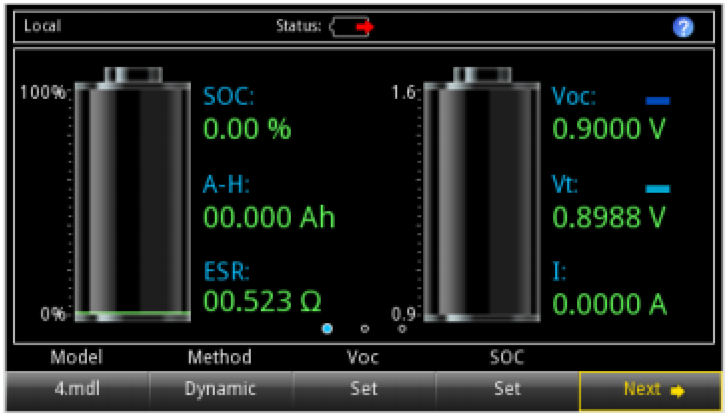


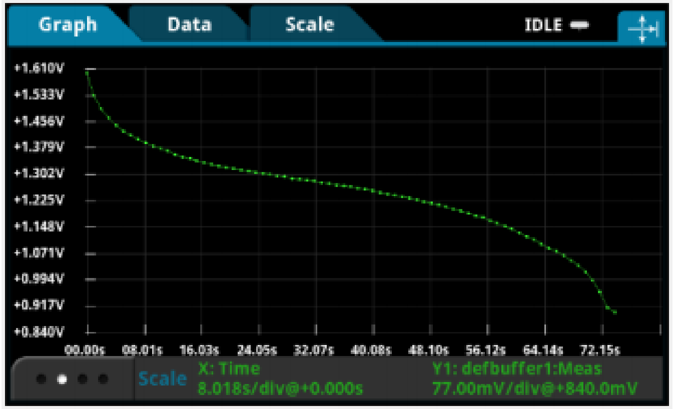
Discharge and recharge







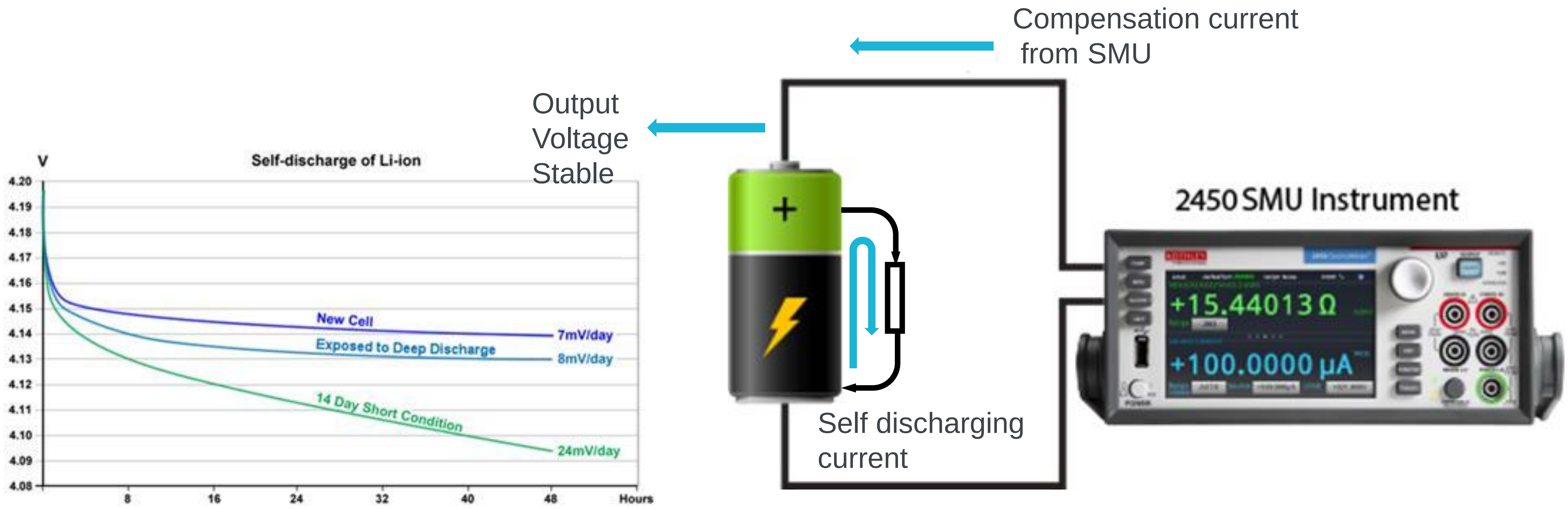




Example: battery self discharge

HOW TO AVOID WAITING FOR LONG TIME?

- Solution: Source very accurate/sable voltage and measure uA level current



Focus on Automotive

- Characterizing the profile and the behavior of real rechargeable batteries

BMS

Lithium Ion Batteries

Voltage, Current, Temperature…

Battery Health

SOC

SOH

SOE

SOP

Improve accuracy of SoC for Lithium Ion Battery for EV

Mathematical Parameter Estimation methods

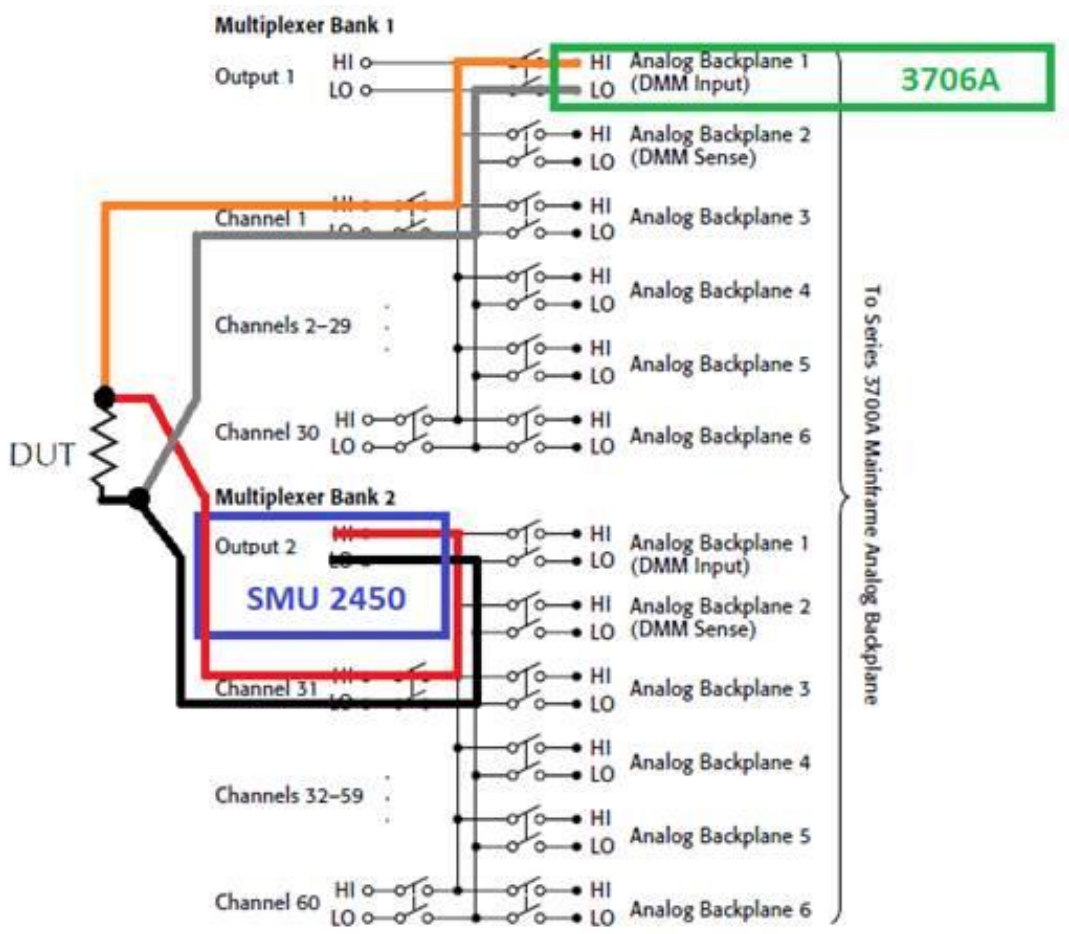
Battery flowing Integrators

Gauges

Available capacity Value

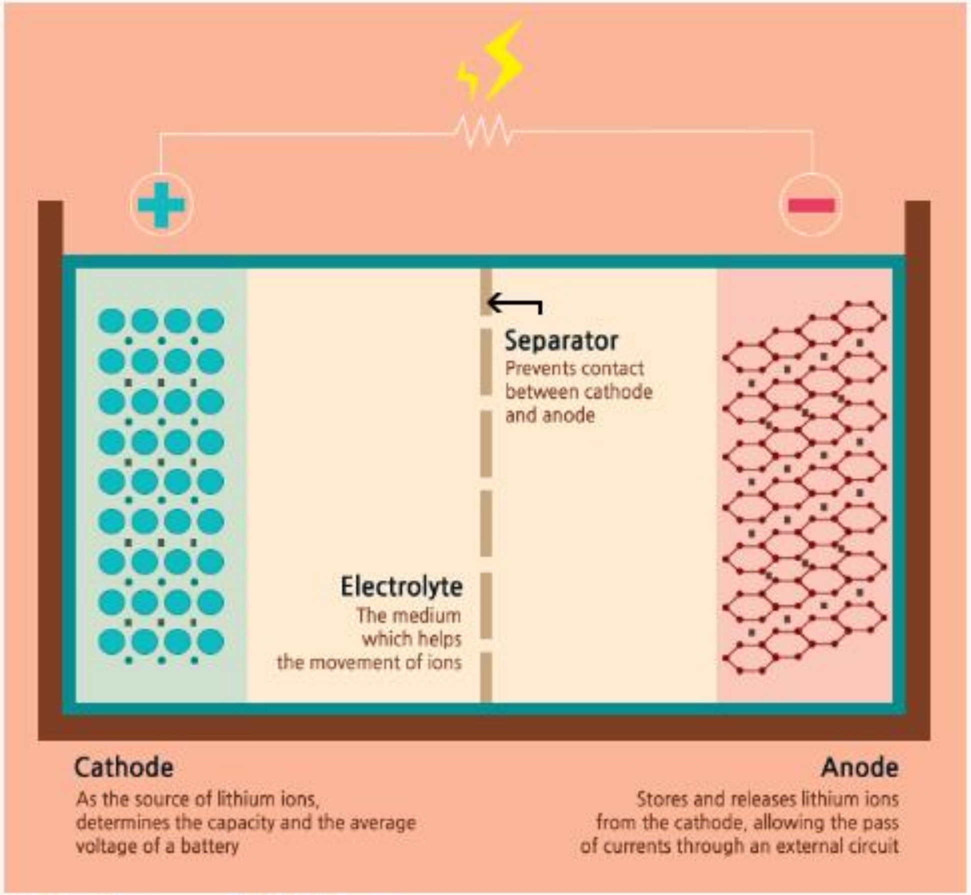
Example: Weld resistance test - EV batteries

- Problem: Design a test bench for multiple batteries weld resistance characterization
- Combine 7.5 digit DMM accuracy with switch capabilities and 4 wires measurements on several independent channels
- Find the right compromise between test time and accuracy to stay within single digit micro-ohms of noise) and stable reading
- Apply TSP-Link technology for multiple instruments master-slave test configuration and intergrate into LabView customer test environment



Example: EV batteries production

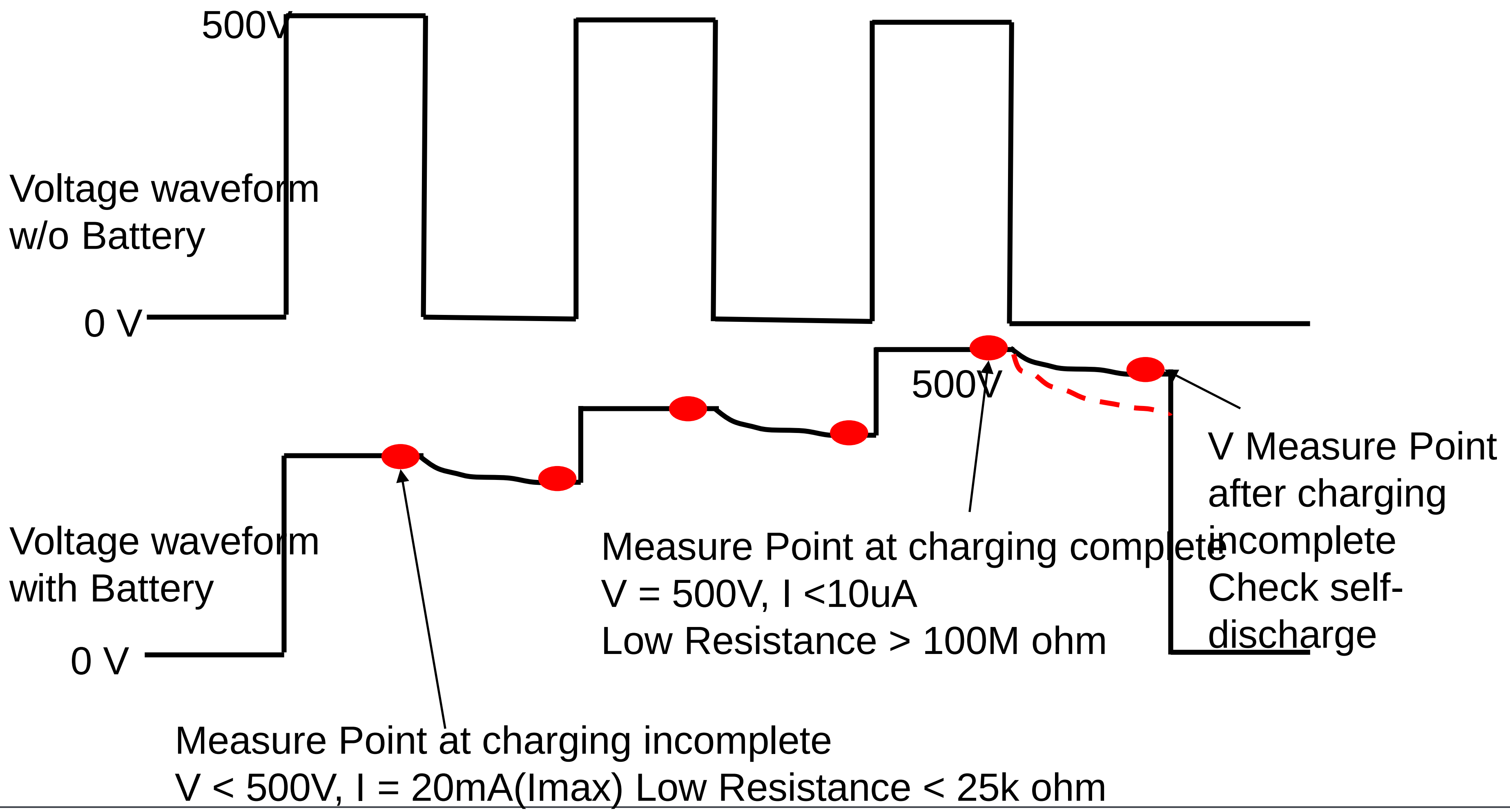
- China – Prismatic Cell batteries
- Insulator (separator) quality test
- Test Method : Apply HV (500V) to charge step by step, measure open circuit voltage (floating voltage) between pulses
- If drop is significant -> Issues with the separator
- Solution: SMU as Current source mode (20mA - 500V), switch to uA range quickly (0A, no leakage) -> measure voltage drop



The Four Components of Li-ion Battery

Battery Short Check Test 500V with 20mA

Output On -> (20mA with 500V limit -> 0A with 500V) X 3 times -> Output Off(Discharge)



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