Tektronix

Battery Discharge Script User's Guide

20 DECEMBER 2017

KEITHLEY
A Tektronix Company

The script

- This document applies to the TSP script files named:
  - BatteryDischarge_20Dec2017.tsp
  - BatteryDischargeScript_20Dec2017.tsp
    - The script was initially released on 07/31/2017 as "BatteryDischargeScript_31Jul2017." However, the name was shortened to "BatteryDischarge_31Jul2017" on 08/03/2017 because the length of the original name caused errors when trying to manage or run the script from the front panel of the instrument. Both versions of the scripts were revised on 12/20/2017 and their names were changed accordingly.
- These scripts are example code written by Keithley Instrument's Applications Engineering. See www.tek.com/sample-license for licensing terms.

The script (continued)

- This script is designed to discharge a battery and create a battery model for use in a Keithley Model 2281S-20-6 Battery Simulator and Precision DC Power Supply. It will run on any of the following Keithley instruments:
  - Model 2450 SourceMeter®
  - Model 2460 SourceMeter®
  - Model 2461 SourceMeter®
- The script can be loaded and run from the front panel of the instrument, or it can be run using Keithley's Test Script Builder (TSB) application.
  - In TSB, setting a "debug" flag in the script causes additional information to be logged to the TSB Instrument Console if desired.

The script (continued)

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.

Configure the script before running it

Edit script with a text editor or Test Script Builder (TSB) if desired

Two variables are defined near the end of the script, :

```
local debug = false        -- Options are true or false; true only applies when
                              running this script from Test Script Builder

local do_beeps = true      -- Options are true or false; true causes certain
                              audible cues to be generated when user interaction
                              is required
```

The user can edit these values to change the behavior of the program:

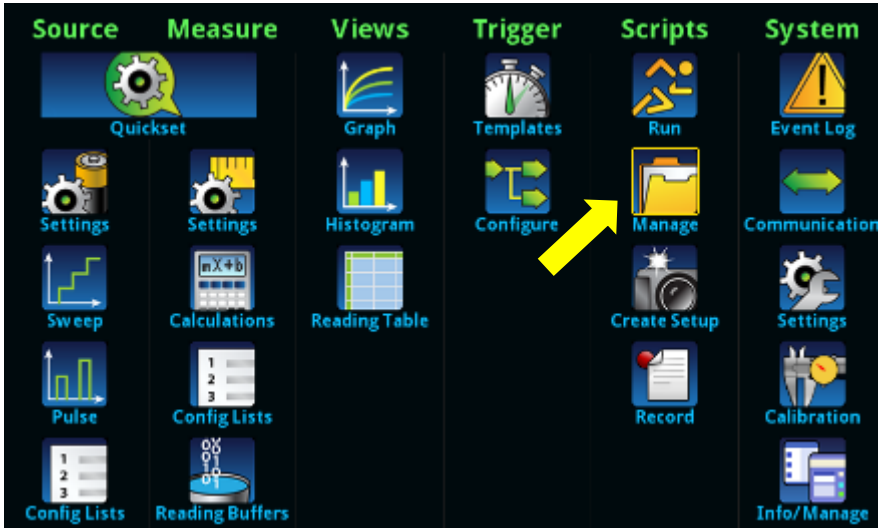
- Setting “debug” to true, will cause additional information to be logged to the TSB Instrument Console.
  - Useful for troubleshooting and monitoring a test
- Setting “do_beeps” to false will disable the majority of the audible cues.

Copy script to internal memory (optional)

See the SourceMeter instrument manuals for additional guidance

- Insert a USB flash drive into the USB port on the front of the instrument.
- Press the MENU button to display the menu screen.

- Touch Scripts/Manage on the menu.

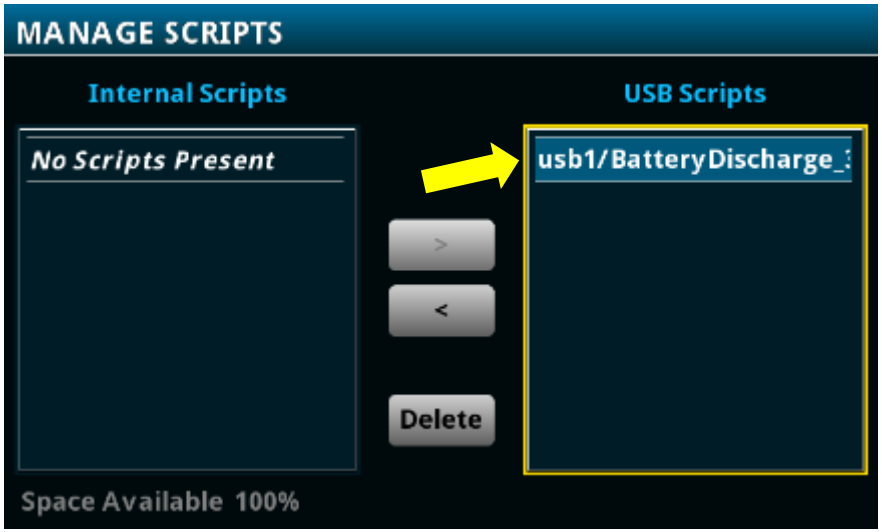


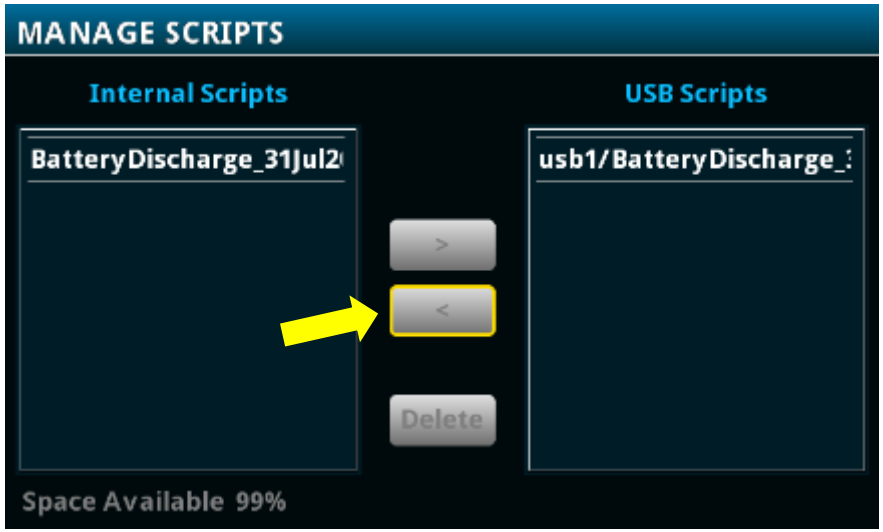
Copy script to internal memory (continued)

See the SourceMeter instrument manuals for additional guidance

- Select the script file that you want to copy to the internal memory of the instrument.
- Date in the script name, if any, will depend on the version being loaded.

- Touch the left “arrow” button to copy the script.



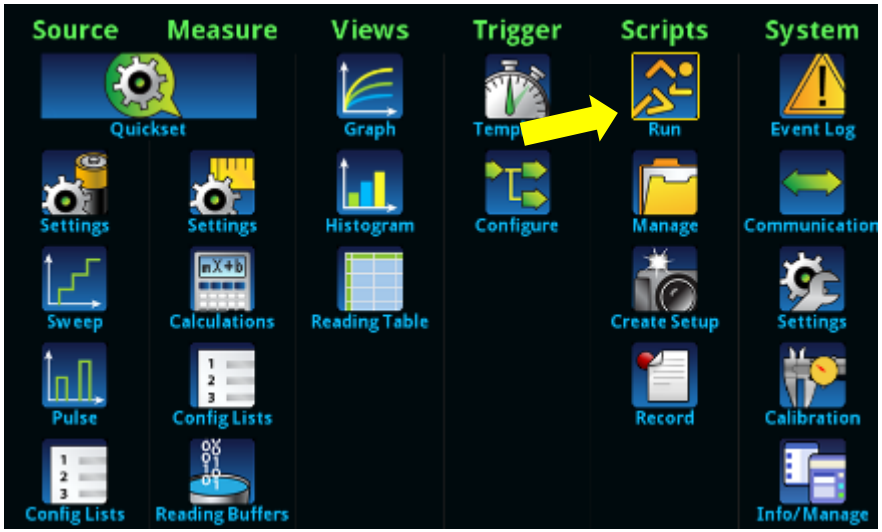


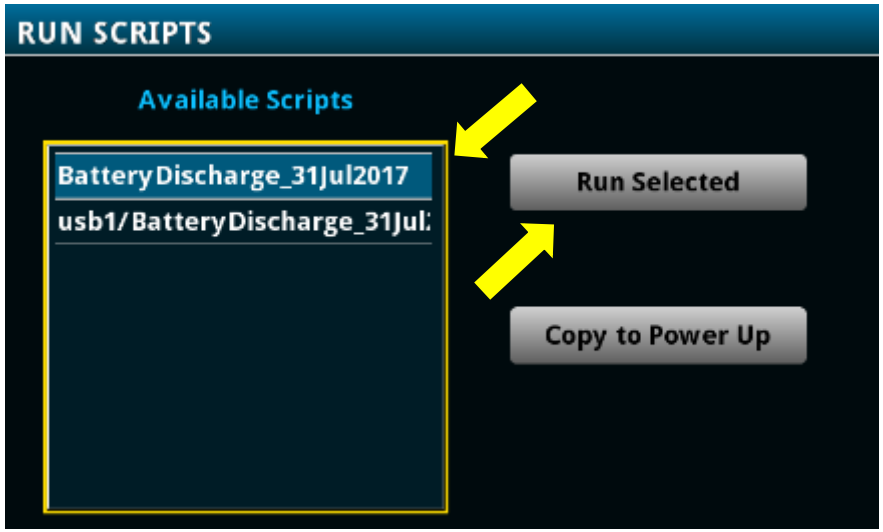
Run the script (Option 1)

See the SourceMeter instrument manuals for additional guidance

- Press the MENU button to display the menu screen.
- Touch Scripts/Run on the menu.

- Select the script to run and then touch Run Selected.
- Note that you can run the script stored in internal memory OR on the USB drive.





CAUTION: Do not connect the battery to the SourceMeter instrument until instructed to do so. Connecting the battery earlier may cause it to start discharging prematurely.

Run the script (Option 2)

Although not shown herein, the script can also be run using Test Script Builder. See the instrument manuals or TSB Help for guidance.

- Press the HOME button to display the home screen.
- Touch the active script indicator.

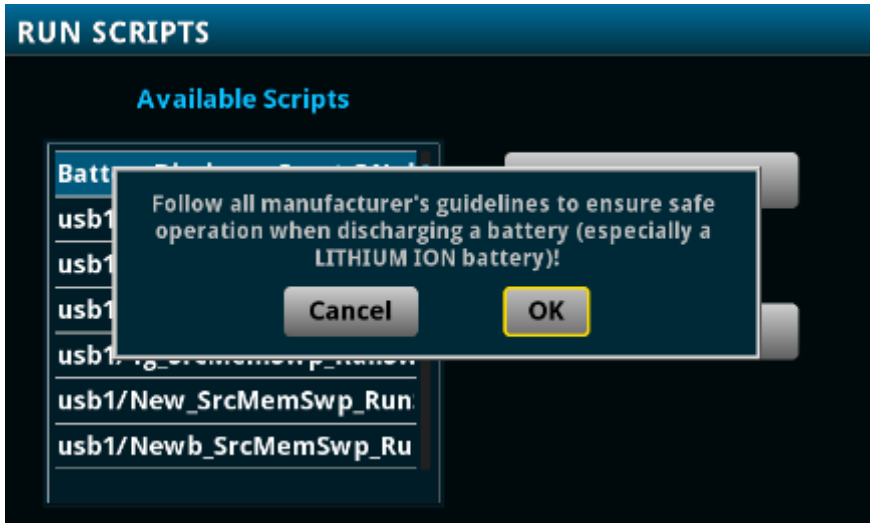
- Touch the script name to run it.
- Note that you can run the script stored in internal memory OR on the USB drive.
- If a another script is running, stop it first.

CAUTION: Do not connect the battery to the SourceMeter instrument until instructed to do so. Connecting the battery earlier may cause it to start discharging prematurely.

After the script starts running,

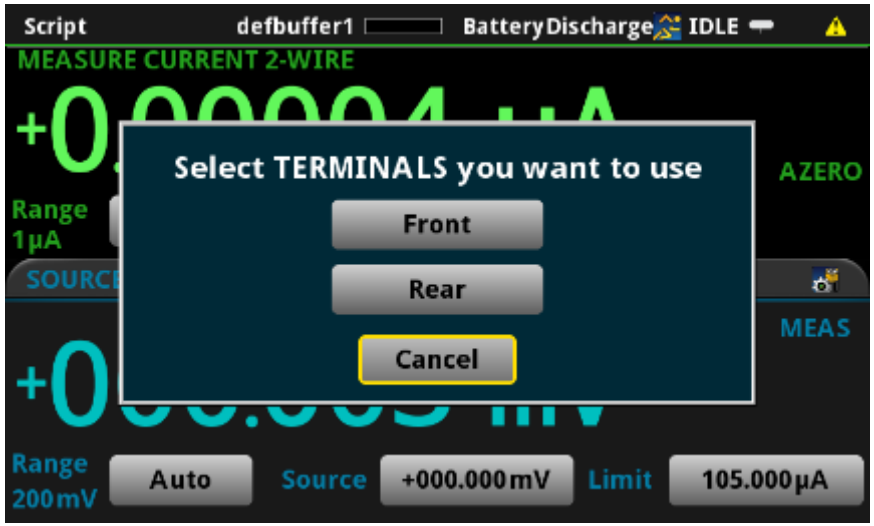
just follow the prompts…

Heed the 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.

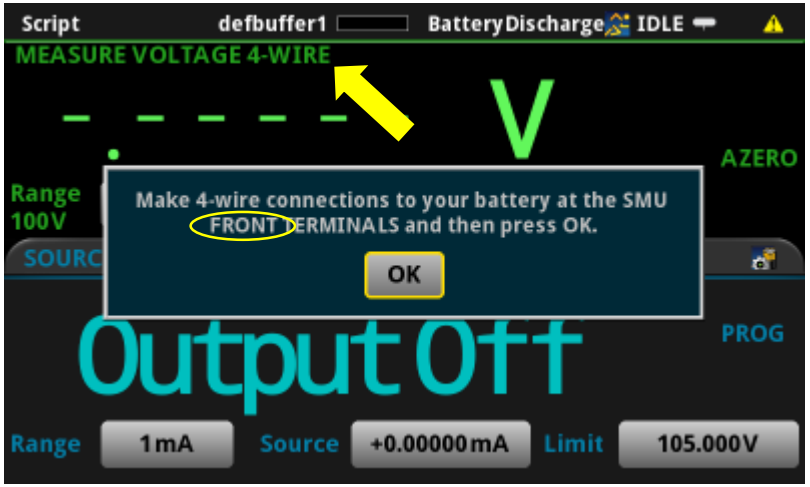
Specify the terminals you want to use

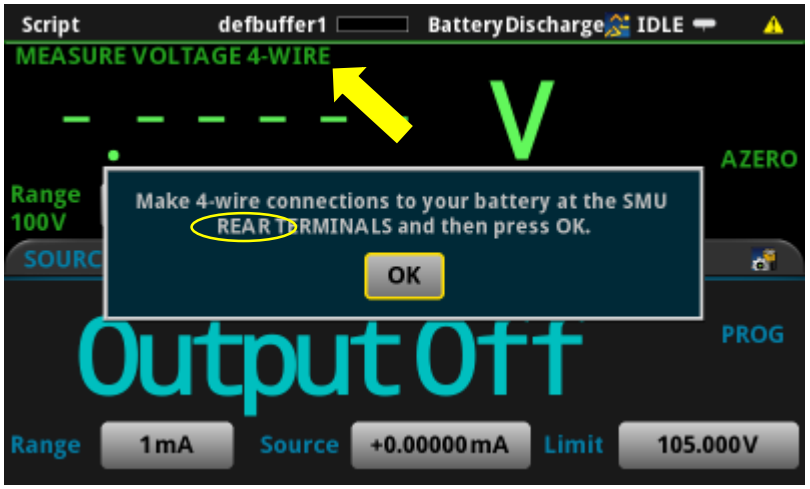


- All 3 compatible SourceMeter instruments have banana jacks on their front panels.
- The Model 2450 has Triax connectors on its rear panel.
- Models 2460 and 2461 have 8-pin Phoenix connectors on their rear panels.

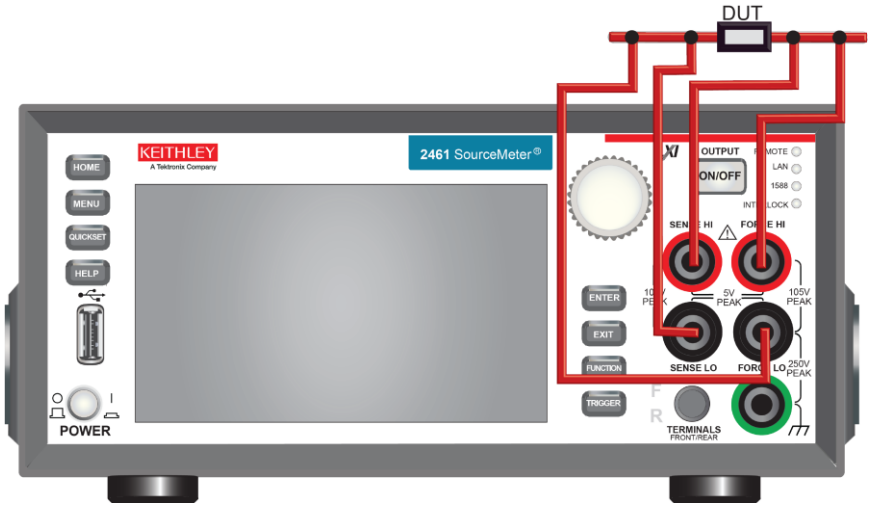
Connect the battery to the SMU using 4-wire connections

Low internal resistance of the battery dictates the use of remote voltage sensing. The instrument is automatically set to the 4-wire mode.



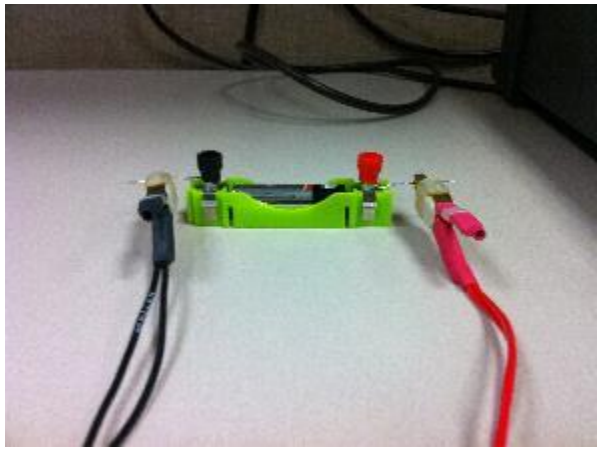


See the instrument manuals for more information about 4-wire connections.

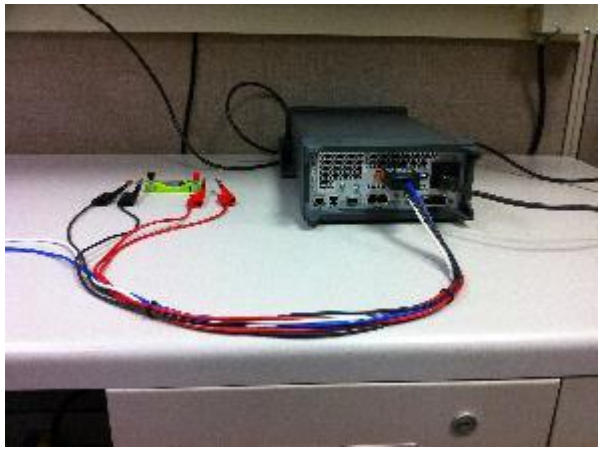


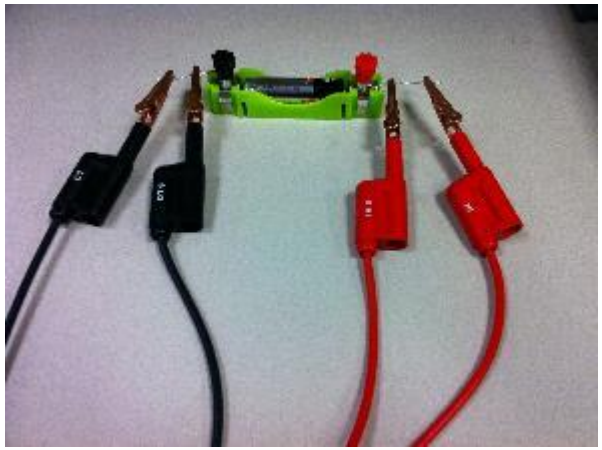
Examples of 4-wire connections

FRONT panel connections to Model 2461 using Keithley Model 5806 Kelvin Clip Test Leads

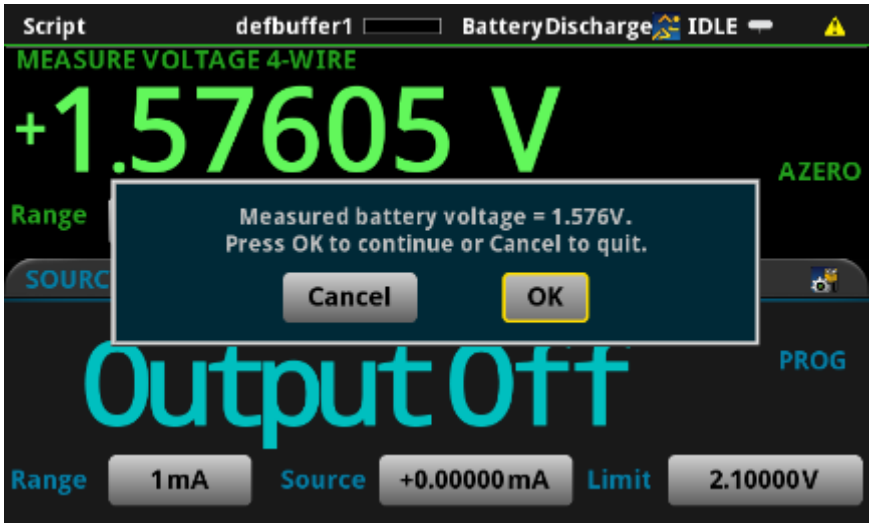


REAR panel connections to Model 2461 using Keithley Model 2460-BAN Safety Banana Test Leads





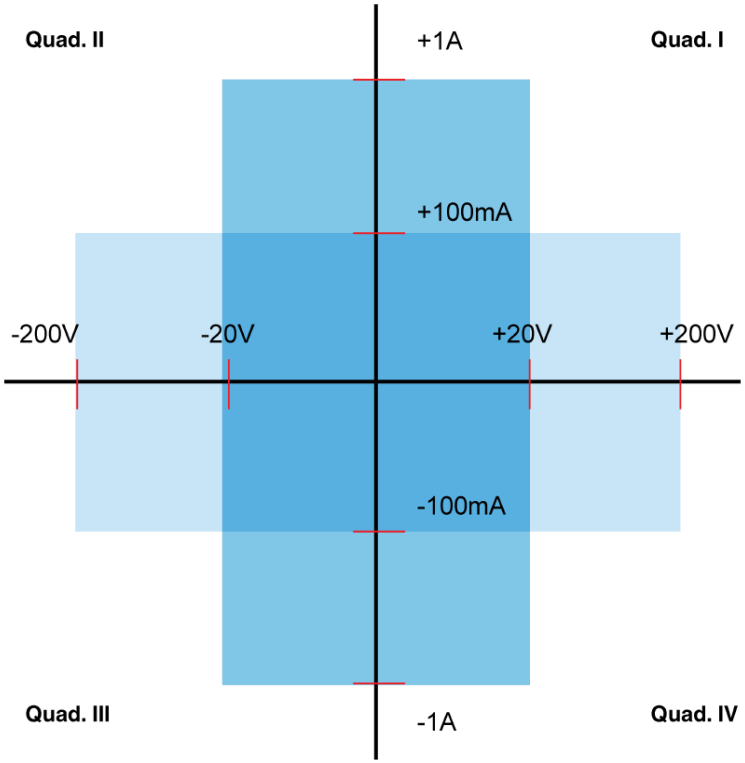
Battery open-circuit voltage is measured after connections are confirmed



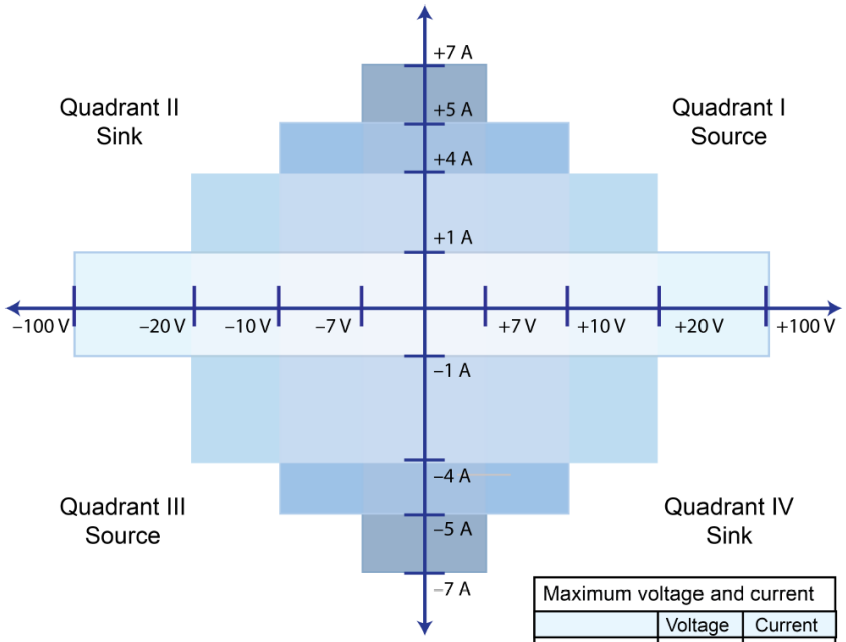
- Measured voltage is used to automatically set the voltage measure range and limit level for the remainder of the test.
- Ranges available for the 2450:
  - 200V, 20V, 2V, 200mV, 20mV
- Ranges available for the 2460 and 2461:
  - 100V, 20V, 10V, 7V, 2V, 200mV
- Note that the maximum output voltage of the Model 2281S is 20V.

Selected voltage measure range determines the maximum allowable discharge current

- Model 2450 power envelope
- Max current is 1.05A for voltages ≤ 20V



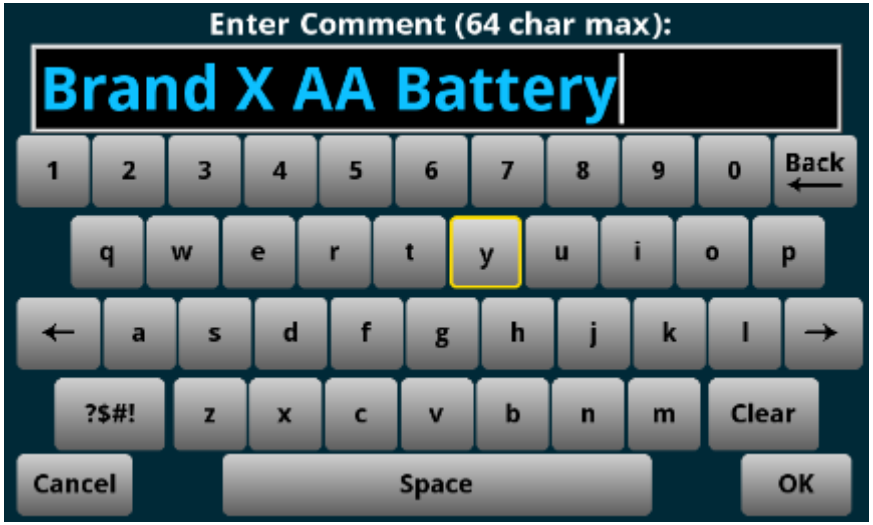
- Model 2460/61 power envelope
- Max current is 7.35A for voltages ≤ 7V



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

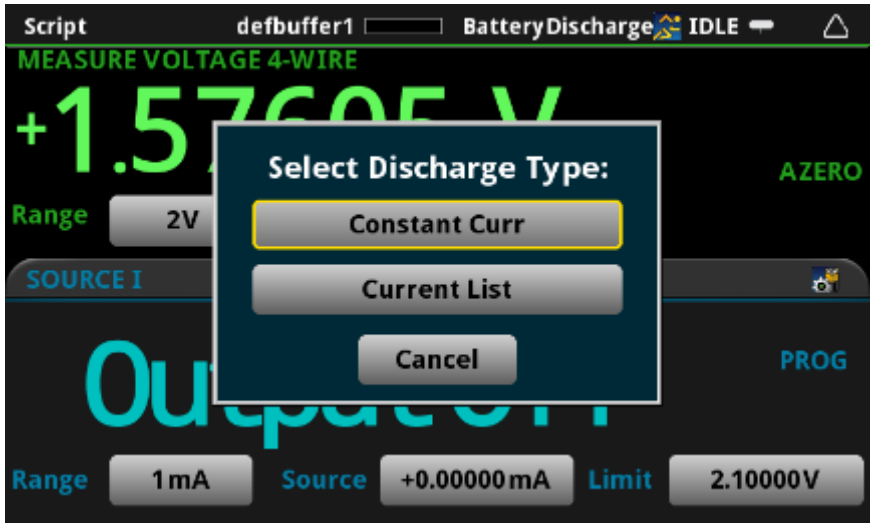
Model 2461 high-power pulse mode is not supported

Enter a general purpose comment if desired



- Comment field can be used to identify the battery manufacturer and type, and/or provide other test details.
- Comment can be up to 64 characters long, and can include spaces and special characters.
- If no comment is entered, or if Cancel is selected, then the comment will default to “NO COMMENT.”
- Comment is saved in the “…_SetupAndRawData” file.

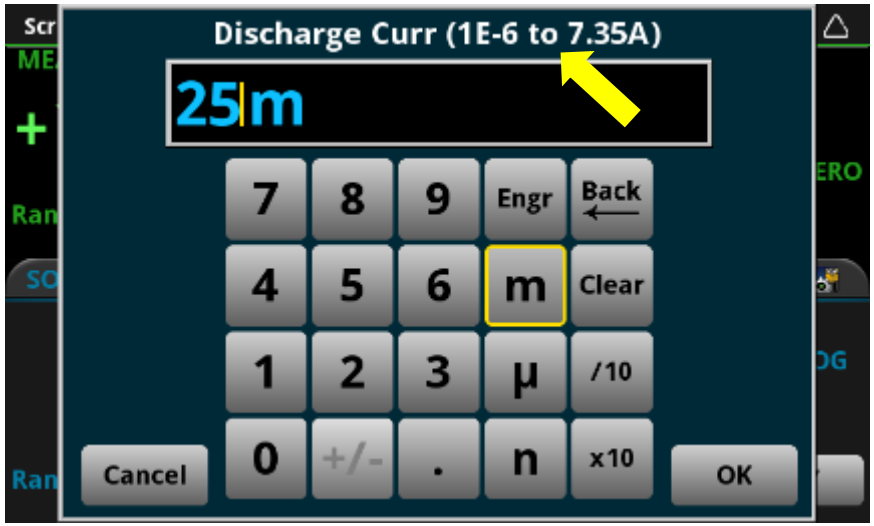
Select the type of discharge to perform



- Constant Current discharges the battery using a constant current (except when interrupted to measure the open-circuit voltage).
- Current List enables the user to specify a list of current levels at which the battery will be discharged. Up to 10 current levels and corresponding durations can be specified.

If you select Constant Current Discharge…

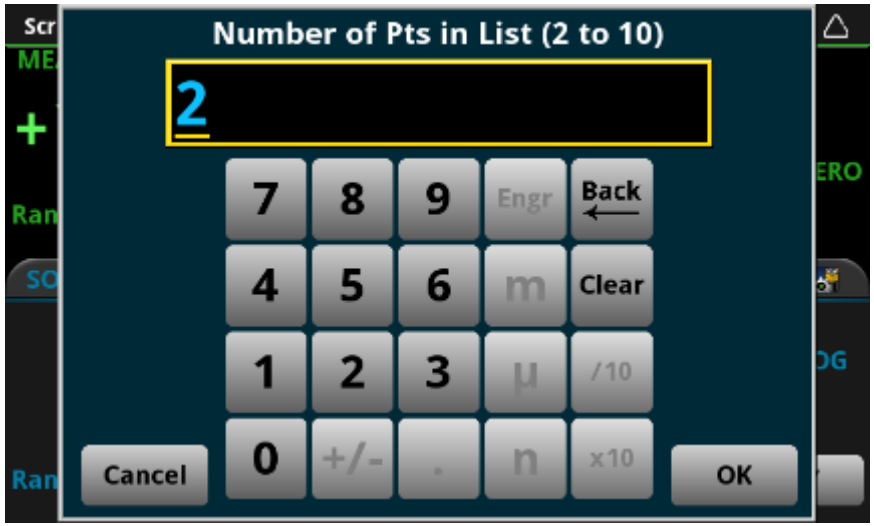
Enter the discharge current as requested.



- Enter the discharge current in amps.
  - The current level the user can enter is limited to range shown.
    - The maximum level varies with the SourceMeter instrument and the selected voltage measure range.
    - The minimum level is fixed.
- Although very low currents are allowed, they may not be practical for ESR measurements, which use a current interrupt method.
  - $ESR = (V_{I=DischargeLevel} - V_{I=0})/(I_{DischargeLevel} - 0A)$
  - Since ESR is generally a very low resistance value, a low discharge current level may result in a relatively inaccurate measurement of $V_{I=DischargeLevel}$ and calculation of ΔV.
  - To be addressed in a future script version.

If you select Current List Discharge…

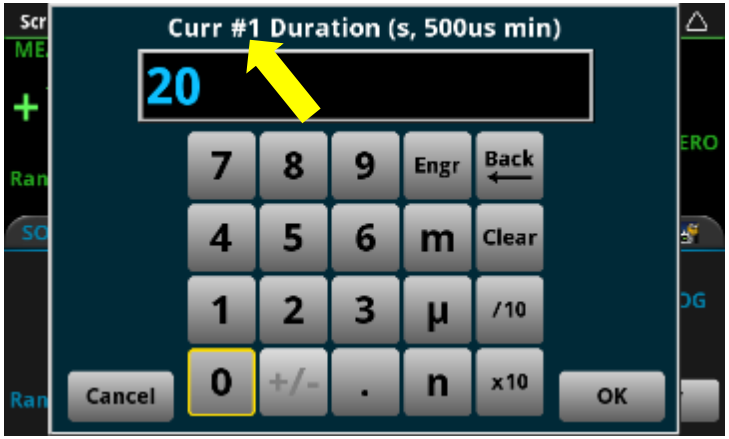
Enter the number of points in the list, and the current level and duration for each point in the list.



- A current list can have from 2 to 10 points.
- Multiple points can have the same current level and/or duration.

Current List Discharge continued…

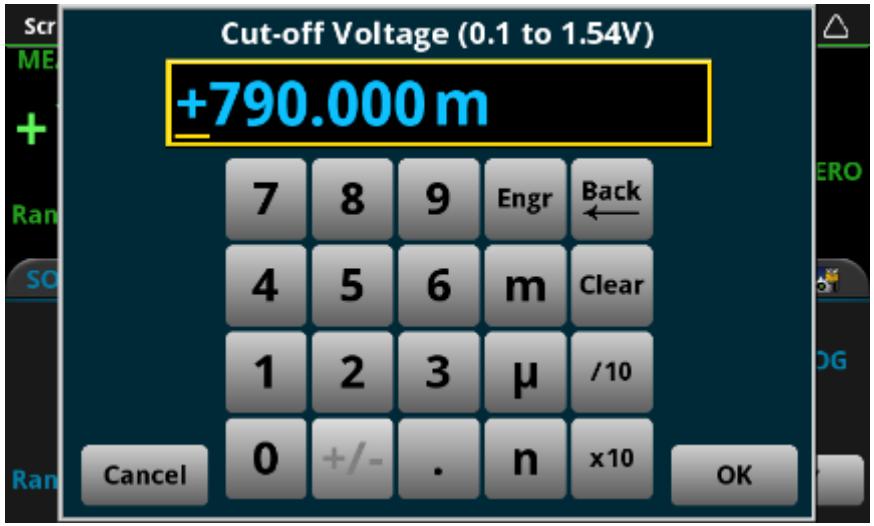
Enter the current level and duration for each point in the list.



- Enter the discharge current in amps for each step in the sweep (Step #1 shown).
  - See the comments under “If you select Constant Current Discharge…”
- Enter the duration in seconds for each step in the sweep (Step #1 shown).
  - The minimum duration is presently limited to 500µs.
  - Although not enforced presently, the maximum duration is 100,000 seconds.

Set the cut-off voltage

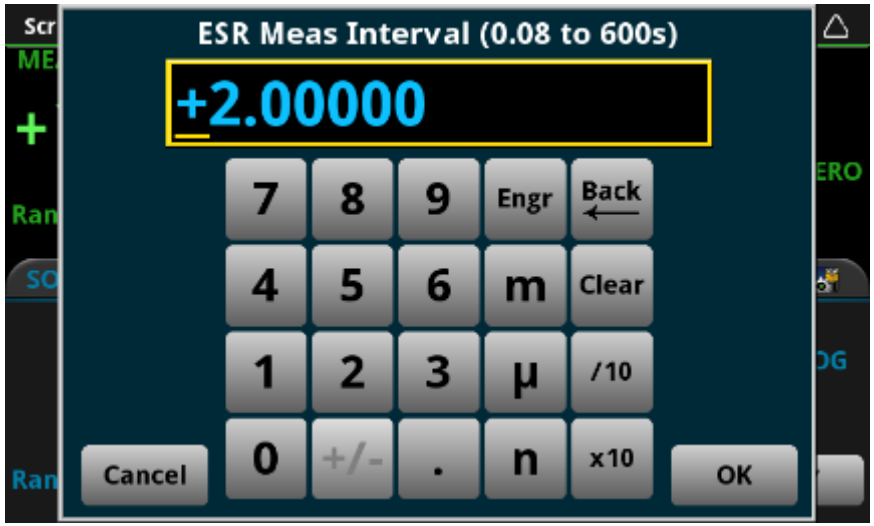
This applies to both the constant current discharge and the current list discharge routines.



- Enter the cut-off voltage in volts.
  - The minimum value is arbitrarily limited to 100mV.
  - The maximum value is arbitrarily limited to 98% of the open-circuit voltage that was measured.
- The discharge process will stop when the measured load voltage ($V_{I=DischargeLevel}$) is less than the specified cut-off voltage.

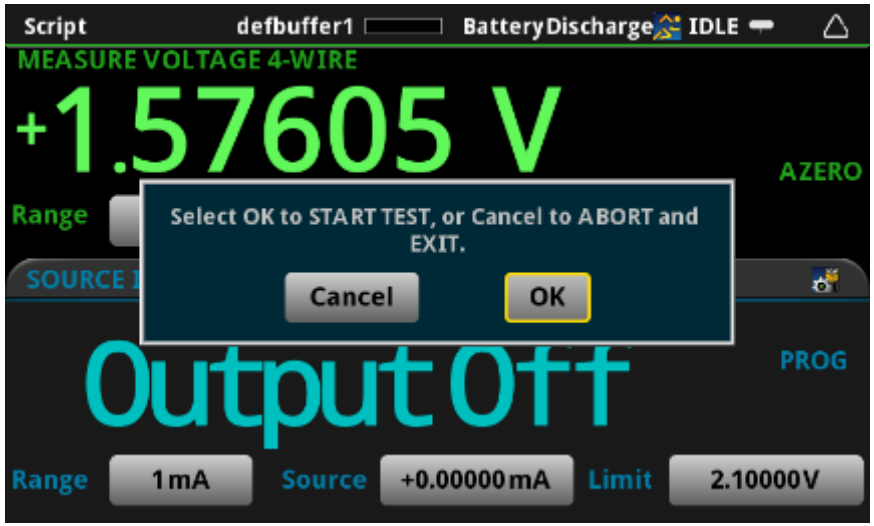
Set the battery ESR measure interval

This applies to both the constant current discharge and the current list discharge routines.



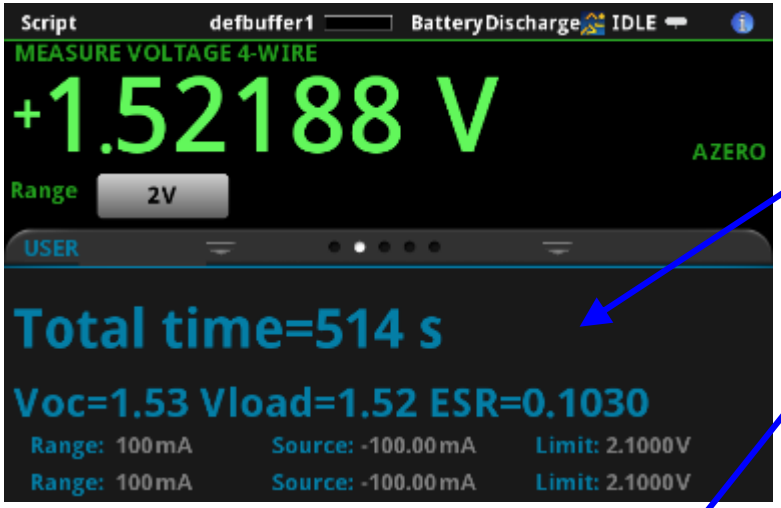
- Enter the battery ESR measure interval in seconds.
  - The minimum value is limited to 80ms, which is a practical minimum based on the test algorithm.
  - The maximum value is arbitrarily limited to 600s.
- Try to choose a measure interval that will result in more than 101 readings, preferably 1000 or more.
  - 101 is the number of points in the Model 2281S battery model.

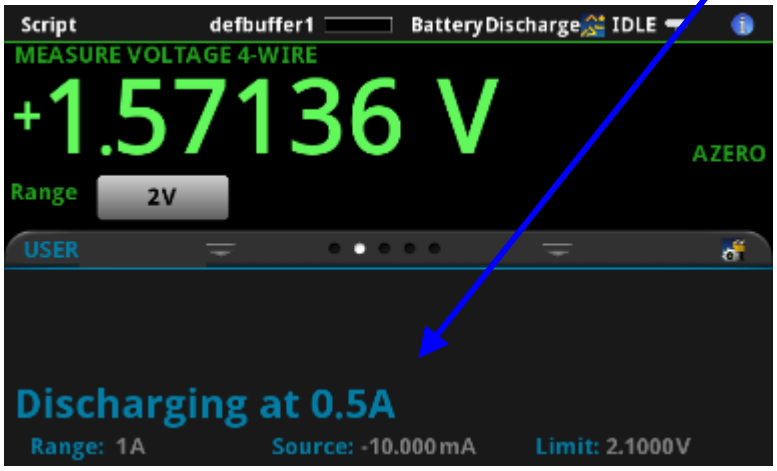
After the test is configured…



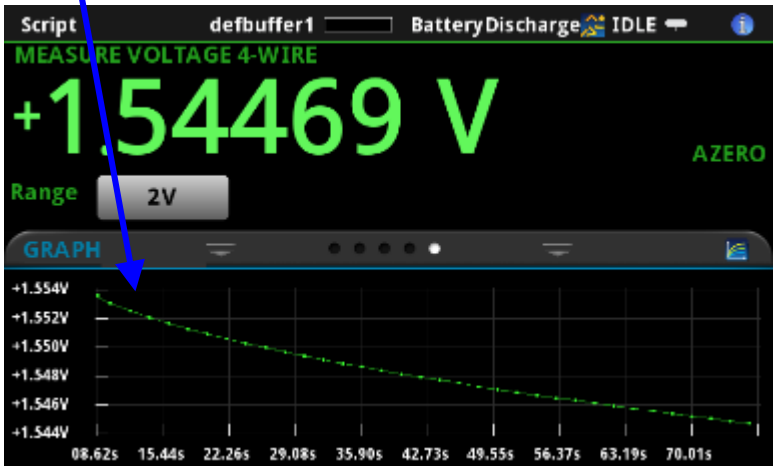
- Touch OK to start discharging the battery, or touch Cancel to abort the test.
- If OK is selected, then the instrument output turns on and the battery begins to discharge.

Status information is provided during the test





- The last measured elapsed time, V_{OC}, V_{LOAD} and ESR are displayed for both routines.
- For a List Discharge, intervals without measurements are identified if time permits.
- The SourceMeter instrument's built-in graph capabilities can be used to observe the voltages over time. Presently, the currents and ESR cannot be plotted.



More about the measurements that are made…

2281S Battery Model

- A battery model for the 2281S consists of the measured battery capacity plus a 101-point list of values as shown below:

SOC (%)	Open Voltage(V)	ESR(ohm)
0	1.598897	0.5186
1	1.80943	0.507661
…	…	…
100	3.146062	0.739088

- The battery discharge script measures the battery open-circuit voltage and internal resistance or ESR (Equivalent Series Resistance) at the specified time interval as the battery discharges.

- After the battery load voltage reaches the cut-off, the script searches the acquired readings and extracts the appropriate 101 points to generate the model.

More about the measurements (continued)

V_{LOAD}, V_{OC} AND ESR

- When it is time to measure the required parameters, the script performs the following:
  - It measures and records the battery voltage at the programmed discharge current level ($V_{LOAD} = V_{I=DischargeLevel}$).
  - It then sets the discharge current to zero (0A), and measures and records the open-circuit voltage of the battery ($V_{OC} = V_{I=0}$).
  - It calculates and records the battery internal resistance as:

$$ESR = (V_{LOAD} - V_{OC}) / (I_{DischargeLevel} - 0A)$$

- The current levels are not measured. They are assumed to equal their programmed values.
- Presently, fixed source and measure ranges are used for all tests.
- Voltage measurements are made with a 1PLC (16.7ms) aperture.

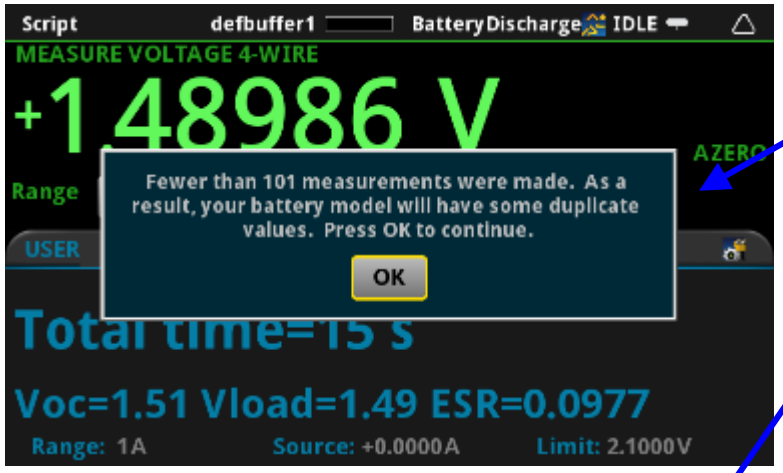
More about the measurements (continued)

Measurement Timing

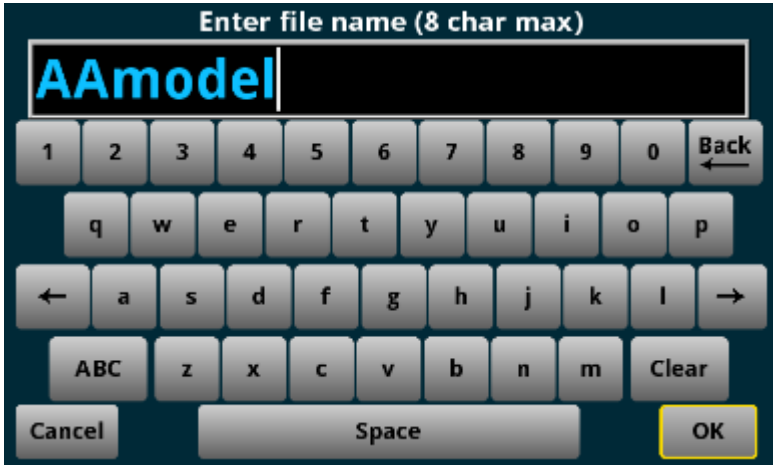
- For a Constant Current Discharge, measurements are made at the specified interval throughout the test.
- For a Current List Discharge, the program determines when to make the measurements as follows:
  - It identifies the step in the list with the longest duration. The current level associated with this duration becomes the “load” current for developing the 2281S model.
    - If there is more than one interval equal to the longest duration, then the largest current level associated with this duration becomes the load current.
  - Measurements are made during any interval in which the discharge current equals the load current. Measurements are NOT made during any other intervals. This is a program limitation at this time.
  - In general, measurements will be evenly spaced within a single step interval, but there may be overall variations depending on the exact profile of the discharge list.

When the cut-off voltage is reached…

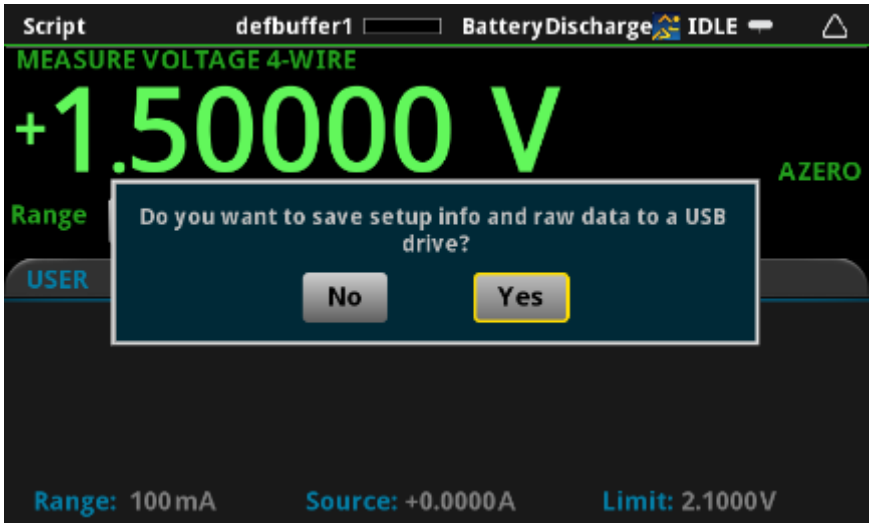
The source is set to 0A and the output is turned off. The battery model is extracted from the raw data.



- The user is notified if fewer than 101 measurements were made.
- The user is given the opportunity to save the model as a CSV file.
  - Insert a USB flashdrive into the front of the instrument, and then touch Yes to save the model.
    - Enter an appropriate file name.



After saving the battery model, the user can save the raw data.



- Touch yes to save the setup information and raw data in a CSV file.
  - "_SetupAndRawData" is appended to battery model file name, e.g. AAModel_SetupAndRawData.csv
- Information includes:
  - The model number, serial number and firmware revision of the SourceMeter instrument.
  - All user-specified values.
  - Pertinent parameters determined or calculated by the script
  - All of the measurements
  - The battery model extracted from the raw measurements.

And then you are finished.