Keysight BT2191A
Self-Discharge Measurement System

BT2192A Self-Discharge Measurement System Software

Data Sheet

A New Way of Looking at Li-Ion Cell Self-Discharge

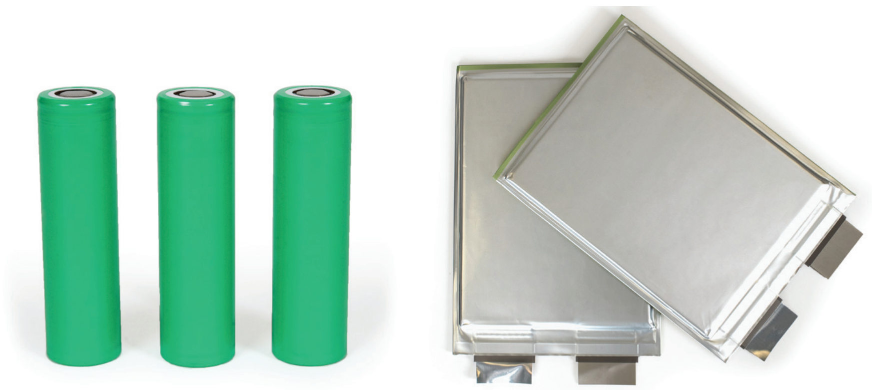
- Characterize self-discharge current in minutes or hours instead of weeks or months
- Faster evaluation results, faster design iterations
- Software for control, graphing, logging, data storage
- Eliminates weeks or months of cell storage time

KEYSIGHT TECHNOLOGIES

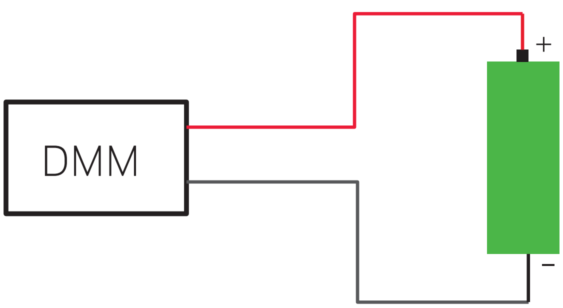
Unlocking Measurement Insights

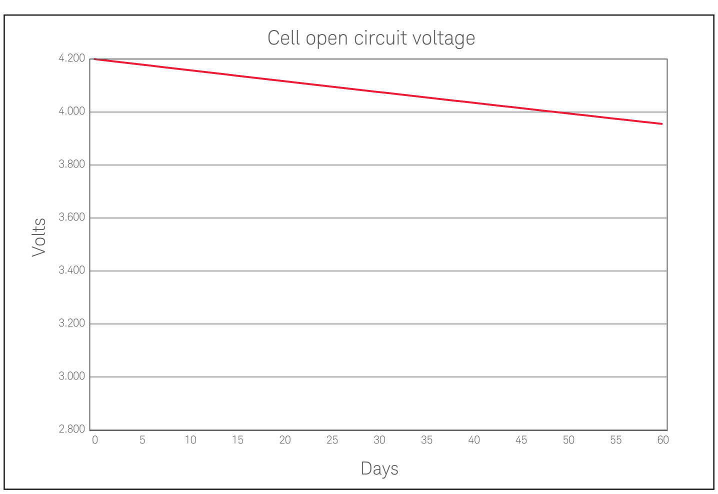
The Challenge in Evaluating Self-Discharge

It's a challenge for Li-Ion cell designers to quickly measure the self-discharge behavior of their cell designs. And it's equally challenging for the users of Li-Ion cells to evaluate the self-discharge behavior of the cells they're considering for use in their electronic equipment and battery pack designs.



The challenge isn't that it's a complicated measurement – the challenge is that it's a very time-consuming measurement. Today, the measurement is typically done by measuring how much the open-circuit voltage (OCV) of the cell changes over time, as an indicator of how much the state-of-charge (SoC) changes due to self-discharge. And since most Li-Ion cells have very little change in OCV as the cells discharge, it takes a long time to see changes in the (SoC) of the cells. This process can take weeks or months, depending on the cell.

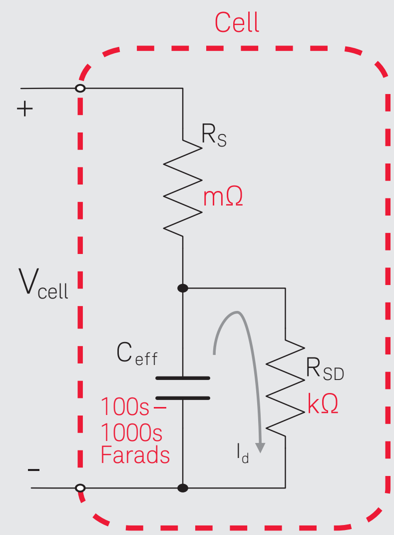




What is self-discharge current?

Most Li-Ion cells will gradually discharge even if they're not connected to anything. This loss of stored energy leads to lower-than-desired cell available capacity. And when cells are assembled into multiple-cell battery packs, differing rates of cell self-discharge leads to cell imbalances within the battery. Typical battery management systems will discharge all the cells to the level of the lowest cell, decreasing effective battery life.

Self-discharge in Li-Ion cells is commonly modeled as shown below.



- C_{eff} is the effective capacitance of the cell, storing the cell's charge.
- R_S is the cell internal or series resistance. R_S causes the cell voltage to drop as you pull more current from the cell, since $V_{cell} = V_{ocv} - (I * R_S)$
- R_{SD} is the parallel resistance through which the self-discharge current flows. When nothing is connected to the cell (open circuit), C_{eff} discharges through the high-value R_{SD}, generating tens or hundreds of µA of self-discharge current (I_d). Over weeks or months, this self-discharge path depletes the stored energy in C_{eff}, thus causing V_{cell} to drop

While the time you spend on any one cell measurement isn't very long, the fact that there's a series of these measurements spread over time has a big impact on your design cycle time. The time from starting the self-discharge evaluation to its conclusion can take weeks or months, even if you aren't spending all your time on cell evaluation during that time. And that makes a real impact on your time to market - either as a cell designer working on a new cell, or a cell evaluator working on the design of equipment that will use the cell you're evaluating.

When you work on a cell design, you charge the cells, allow charge redistribution to finish, and then start the self-discharge evaluation process. You measure the OCVs, then put the cells into storage while you wait for the OCV to change. You likely must store the cells under temperature-controlled conditions since the cell voltage varies with temperature. And then you turn your attention to other designs or tasks

When you come back to those cells, there's always a bit of a learning curve to reacquaint yourself with something you've already started. It's just not as efficient as it would be if you could see the self-discharge picture without waiting.

And this problem is worse for larger capacity cells, which is where a lot of the market growth is these days. Large cells inherently have a more complex test setup and storage issues due to required safety precautions.

The Real Impact of the Challenge

If the time to characterize self-discharge is a gating task in your cell design or evaluation cycle, the number of extra weeks it takes to complete the self-discharge measurement is essentially the number of extra weeks it takes to either get your cell design to market or to get your equipment design to market. And if you need multiple test cycles as you iterate your design, then the delay is multiplied by the number of test cycles you go through. All of which becomes opportunity loss because you didn't get your design to market before its competition.

A Better Way to Evaluate Li-Ion Cell Self-Discharge

To measure the self-discharge performance of a cell, you would like to directly measure the self-discharge current of the cell. A potentiostatic measurement system capable of making this current measurement must have these important characteristics:

- The measurement equipment connected to the cell must create minimum disturbance to the state-of-charge (SoC) of the cell.
- The voltage applied to the cell by the test equipment must be held equal to the cell voltage. Otherwise, the cell will either charge or discharge, and you will initiate charge redistribution currents as well as RC settling currents that will mask the self-discharge current you're trying to measure.
- The voltage applied to the cell must be very stable. Otherwise, any instability or noise in the applied voltage will cause charge redistribution currents that will show up as noise on the self-discharge current measurement.
- The test equipment must accurately measure low-level self-discharge currents in the range of 10's of µA.

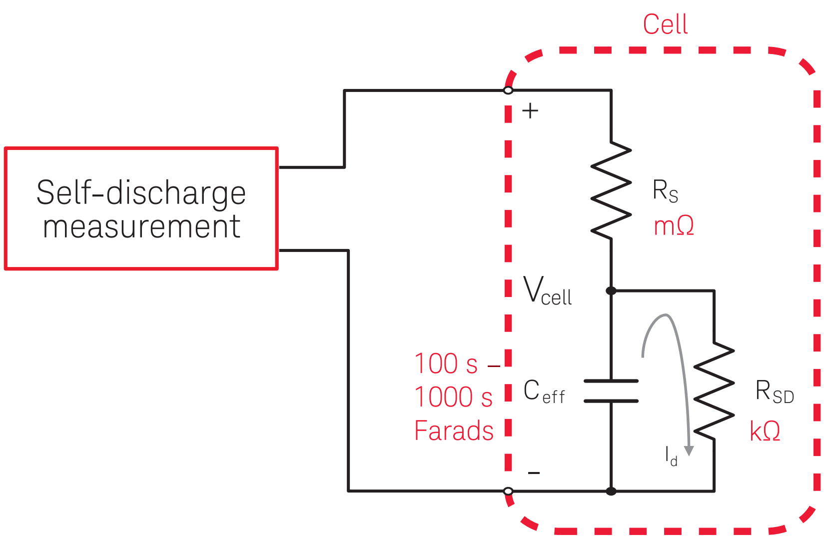
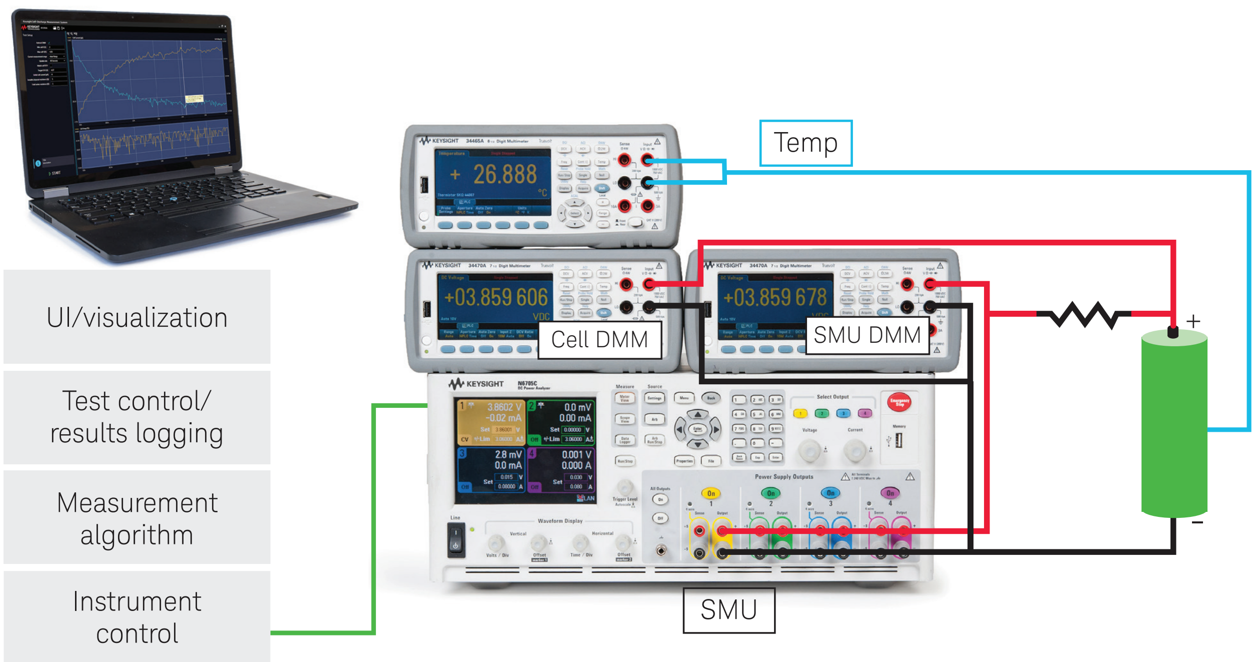


Figure 1. Self-discharge cell model

Keysight Self-Discharge Measurement System



BT2191A Self-Discharge Measurement System

Keysight's new Self-Discharge Measurement System quickly measures self-discharge current. This potentiostatic measurement system has the characteristics needed for quickly making the direct current measurement:

- Minimum disturbance of the cell
  - The voltage applied to the cell is quickly matched (±5 µV) to the actual cell voltage. This minimizes any new charge or discharge and thus limits any new RC settling to a minimum.
  - The voltage applied to the cell is very stable (±10 µVpk) to minimize continuing charge redistribution current noise on the self-discharge current measurement.
- Accurately measures low-level self-discharge currents to ±(0.025% of reading + 100 nA).

The Keysight Self-Discharge Measurement System delivers a revolutionary reduction in the time required to measure cell self-discharge current. Testing indicates that for smaller cells like cylindrical 18650 or 21700 cells, you can quickly determine stable self-discharge current in a time between 30 minutes and 2 hours, depending on the cell characteristics. And for larger capacity pouch cells (e.g., 10-60 Ah), this typically takes 1-2 hours.

That's a significant improvement compared to waiting weeks or months for the cell OCV to change enough to determine cell quality. And it significantly decreases your test cycle and improves your time to market.

The Self-Discharge Measurement System also measures the cell temperature. This allows you to see how cell voltage and self-discharge current vary with temperature. Since cells have a complex temperature coefficient for their voltage, monitoring cell temperature allows you to understand how temperature affects cell voltage. That allows you to control changes in cell voltage caused by changes in temperature. And controlling those voltage changes eliminates a significant source of error in the self-discharge current measurement. You can use the T-type thermocouple supplied with the BT2191A or provide your own sensor and wiring. Supported sensors include: T, J, K, E, N, R-type thermocouples; 5 kΩ thermistor; Pt100 and Pt1000 RTDs.

Self-Discharge Measurement System Software

- Measures and records cell self-discharge current, cell voltage, cell temperature
- Configures the instruments in the system.
- Saves or logs measurement data.
- Recalls previously stored measurements for display and analysis.
- Exports recorded data to Microsoft Excel (xlsx file)
- Matching function measures initial cell voltage and adjusts applied voltage to match so an accurate self-discharge measurement is obtained more quickly.
- Allows the user to adjust the effective total resistance value (including the physical resistor) in series with the cell. This allows the user to select a total resistance value to optimize the RC settling time of the measurement. A lower resistance gives faster settling time but increases current measurement noise due to voltage fluctuation with temperature.

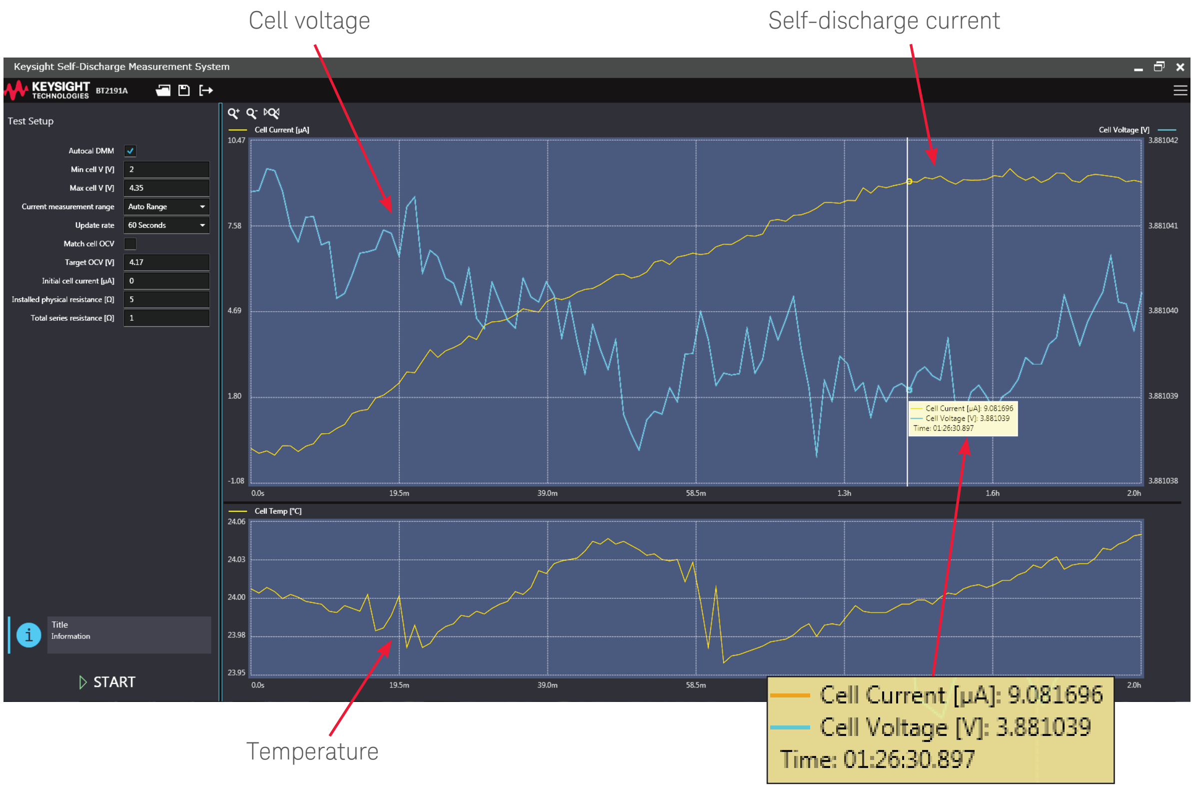


Figure 2. Test results for good 18650 cell: measured stable self-discharge current of 9.08 µA at ~1.5 hours.

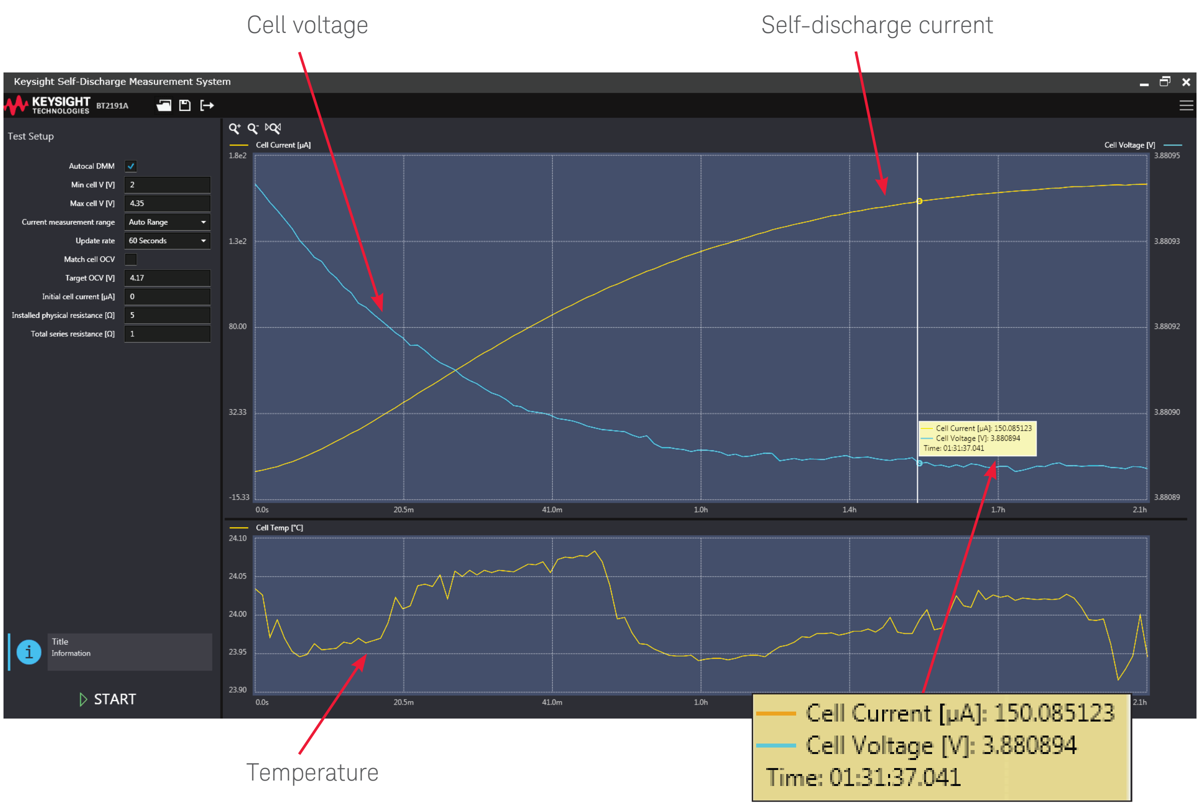


Figure 3. Test results for high-discharge 18650 cell: measured stable self-discharge current of 150 µA at ~1.5 hours.

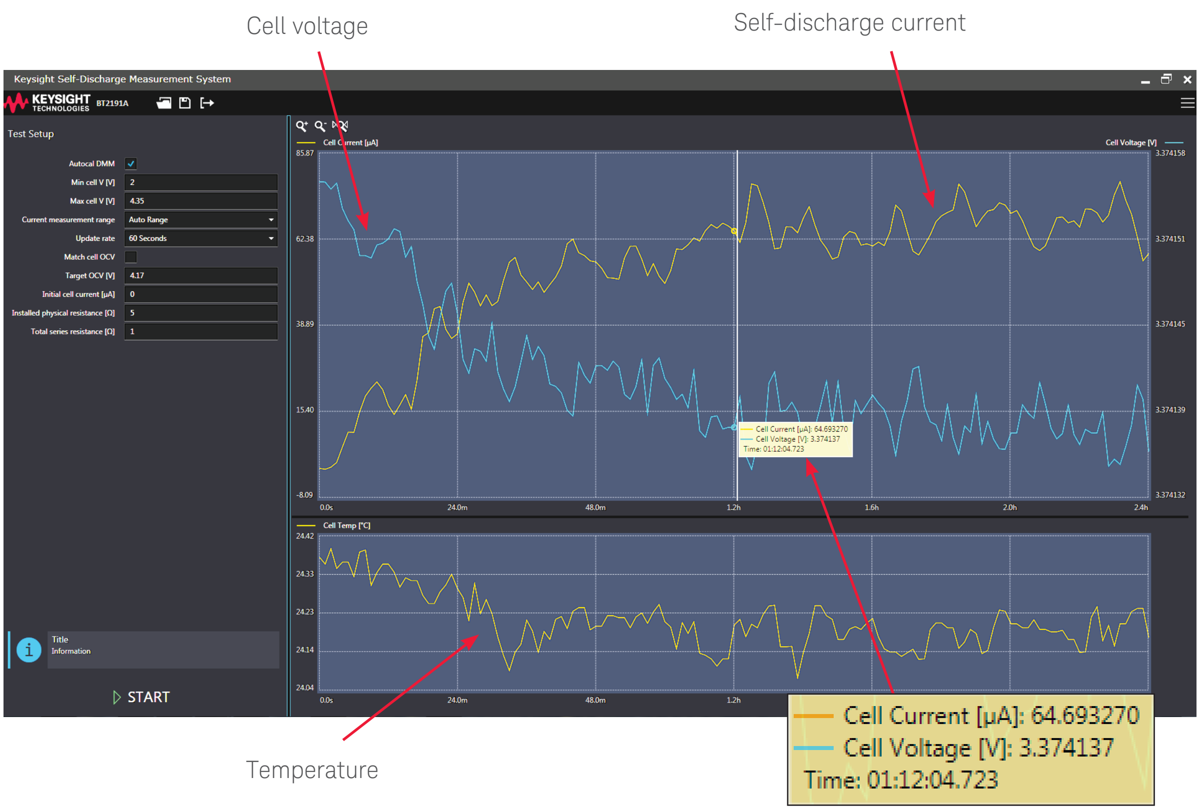


Figure 4. Test results for good 10 Ah pouch cell: measured stable self-discharge current of 65 µA at ~1.2 hours.

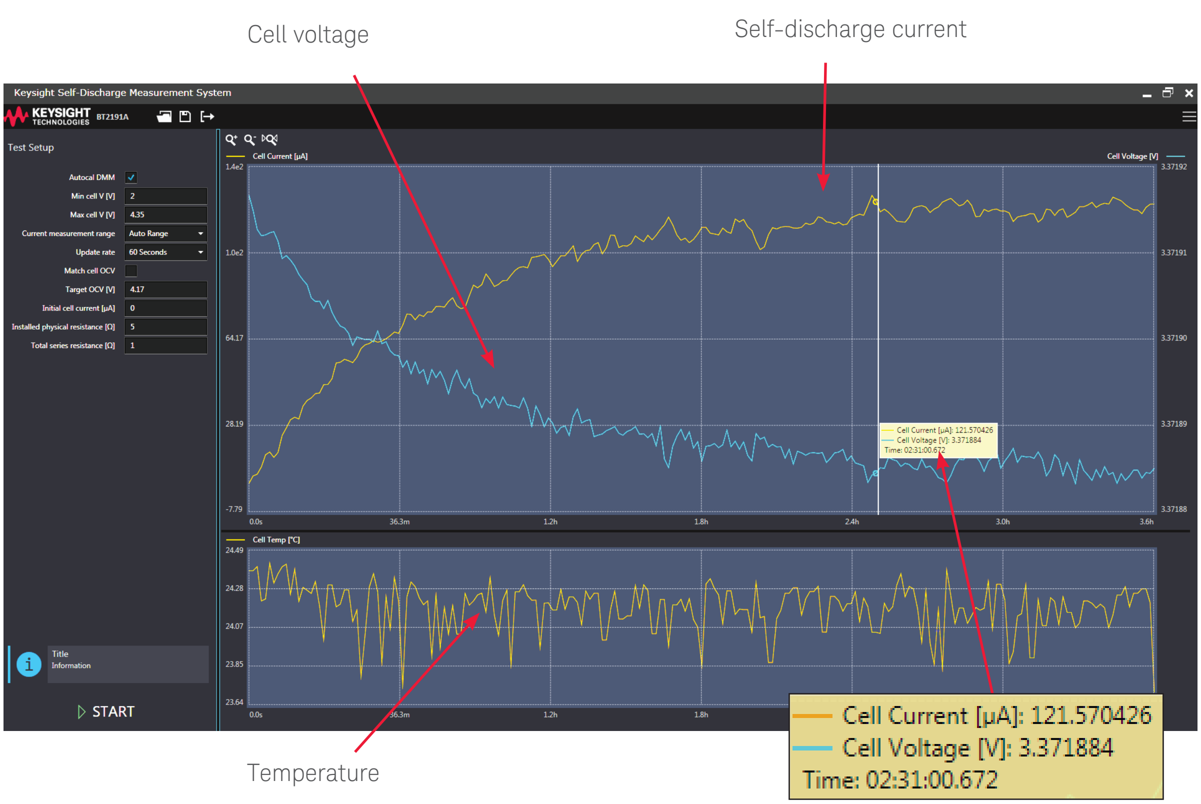


Figure 5. Test results for a high-discharge 10 Ah pouch cell: measured stable self-discharge current of 122 µA at ~2.5 hours.

BT2191A Self-Discharge Measurement System

Specifications

Parameter	Specification
Cell current measurement accuracy (Measured at 1 minute integration, measurement by N6782A) For current ≤ 1 mA For current ≤ 10 mA	 ±(0.025% + 100 nA) ±(0.025% + 10 µA)
Cell voltage measurement accuracy (measurement by 34470A)	±(0.0016% + 20 µV)

Typical characteristics

Parameter	
Voltage sourcing and measurement range	0.5 V to + 4.5 V
Voltage sourcing stability (typical)] Measured over 24 hours at 1 minute integration. Applies at output terminals of the SMU. Cabling and interconnect errors may degrade performance.	±10 µVpk
Programmable resistance range (includes physical resistor installed in wiring harness)	0.1 to 10 Ω
Physical resistance range (includes physical resistor, wiring, and cell internal resistance)	0.1 to 10 Ω
Programmable resistance accuracy	±100 mΩ
Cell current measurement range	± 10 mA
Measurement rate	1 measurement every 10 s, 30 s, or 60 s.
Operating air temperature range Max rate-of-change of ambient air must be < 5°C change per hour.	25 to 35°C
Other Environmental	Refer to relevant information for individual instruments
Warm-up time after power-on	2 hours
Minimum supported cell effective capacitance	100 Farads
Minimum supported R*C (the product of cell effective capacitance and programmable resistance setting)	50 seconds
Maximum measurement results file size	Measure up to 500,000 readings per test run. The test can run for 300 days at 1-minute measurement logging interval, 150 days at 30-second measurement logging interval, or 50 days at 10-second logging interval.
Regulatory compliance (EMC, safety)	Refer to relevant information for individual instruments.
Computer interface	LAN (user provides Ethernet switch and Ethernet cables to connect to instruments)
Acoustic noise	Refer to relevant information for individual instruments.
AC Power input	Refer to relevant information for individual instruments.
Typical weight, physical dimensions	Refer to relevant information for individual instruments.

Ordering Information

Product	Name	Description
BT2191A	Self-Discharge Measurement System	Solution bundle consisting of: – BT2192A Self-Discharge Measurement System Software – N6705C DC Power Analyzer – N6782A 2-Quadrant Source/Measure Unit – 34470A Digital Multimeter, 7½ Digit (Quantity 2) for SMU and cell voltage measurements – 34465A Digital Multimeter, 6½ Digit for temperature measurement – BT2191-60001 Wiring Kit consisting of two wiring assemblies to connect instruments and temperature sensor to cell, and 5 Ω Resistor
BT2192A	Self-Discharge Measurement System Software	Software only

Note: user provides system PC, Ethernet switch, and Ethernet cables to connect to instruments

BT2191A Self-Discharge Measurement System

Product/option	Description
BT2191A	Self-Discharge Measurement System
BT2192A-1FP	Software Perpetual fixed license
BT2192A-1TP	Software Perpetual transportable license
BT2192A-1FY	Software 1-year fixed license
BT2192A-1TY	Software 1-year transportable license

BT2192A Self-Discharge Measurement System Software

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BT2192A	Self-Discharge Measurement System Software
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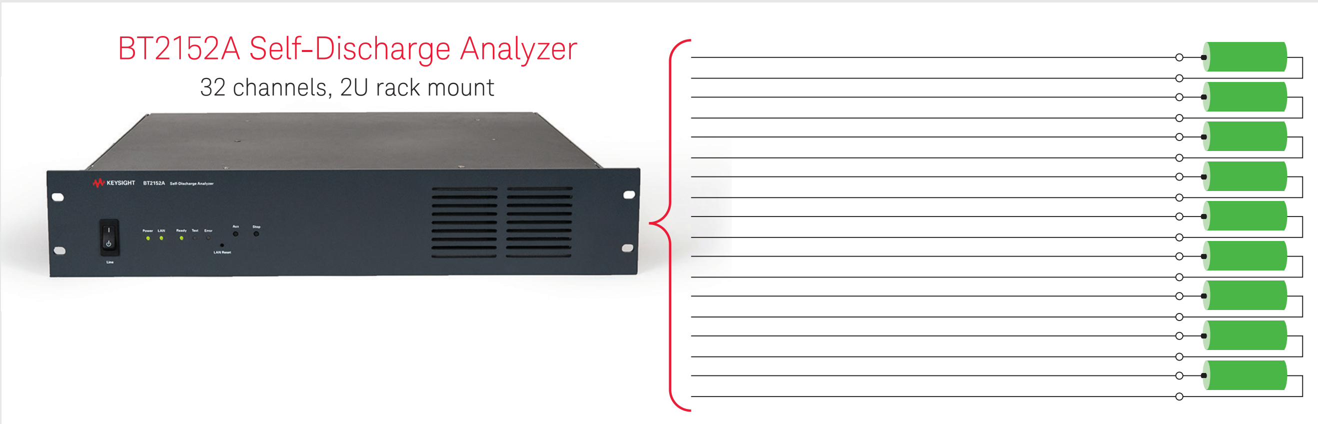
BT2192A-1FY	1-year fixed license
BT2192A-1TY	1-year transportable license

BT2191-60001 Wiring Kit

Product	Description
Cable – Thermocouple, T-Type	2-meter thermocouple wire connected to dual-banana plug for measuring cell temperature. User can provide other temperature sensor and wire if desired. Supported sensors: T, J, K, E, N, R-type thermocouples, 5 kΩ thermistor, Pt100 & Pt1000 RTDs.
Cable Assembly – DUT Harness	Wiring to connect the cell under test to the instruments (SMU DMM, Cell DMM, SMU). Includes alligator clips to connect to cell, and alligator clips to connect to 5 Ω resistor. Connections to instruments are via dual-banana plugs. Cable harness allows approximately 2-meter separation between cell and instruments.
5 Ω Resistor	Resistor is required for valid measurement of self-discharge current. Total resistance of the physical resistor plus the programmed resistance must be between 0.1 Ω and 10 Ω.

For Measuring Self-Discharge in Cell Manufacturing Environments

Keysight's patent-pending implementation of the self-discharge measurement technique delivers a revolutionary reduction in the time required to discern good vs. bad self-discharge performance.

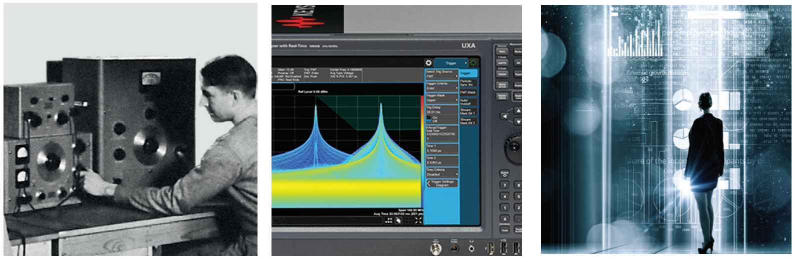


The BT2152A Self-Discharge Analyzer provides a revolutionary reduction in the time required to discern good vs. bad cell self-discharge performance in manufacturing. You gain dramatic reductions in work-in-process, working capital, and facility costs.

For more information, go to **www.keysight.com/find/BT2152** or contact your local Keysight representative.

Evolving

Our unique combination of hardware, software, support, and people can help you reach your next breakthrough. We are unlocking the future of technology.



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