Keysight BT2152A Self-Discharge Analyzer

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

Data Sheet

– Revolutionary reduction in the time required to discern good vs. bad cell self-discharge performance in manufacturing
– Gain dramatic reductions in work-in-process, working capital, and facility costs
– Eliminate weeks or months of cell storage time

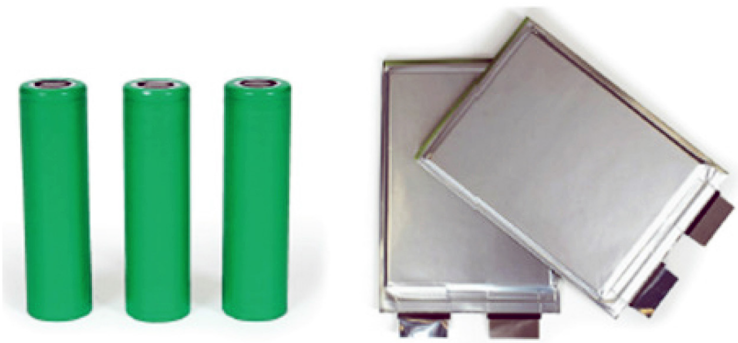
KEYSIGHT TECHNOLOGIES
Unlocking Measurement Insights

The Challenge in Evaluating Self-Discharge

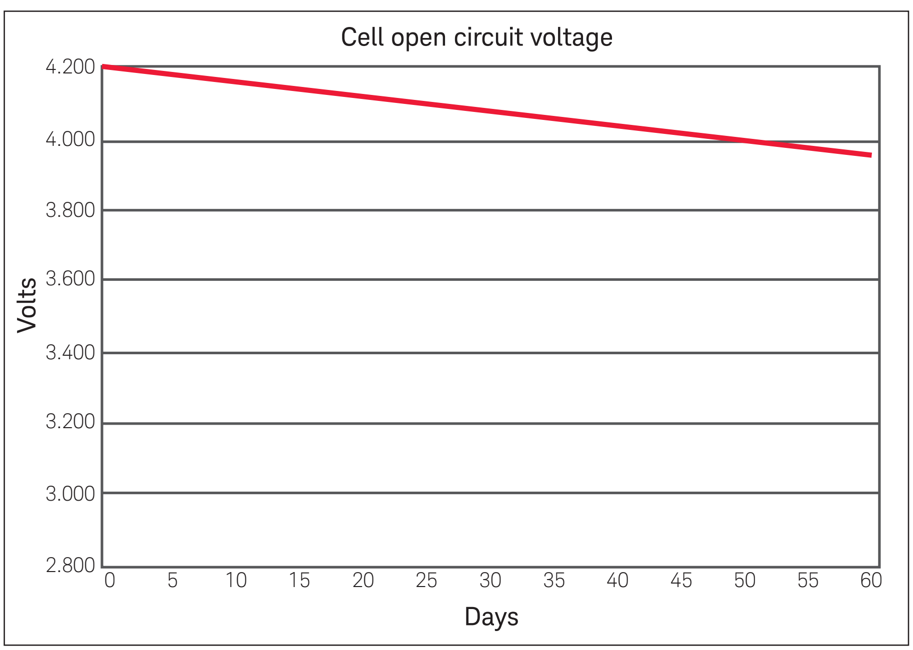
- *Li-Ion cell market growing fast*
- *Self-discharge evaluation takes a long time*
- *Huge impact on manufacturing inventory*

The Li-Ion cell market is experiencing explosive growth, and this growth creates stress on cell manufacturing operations, with pressures on material costs, process costs, and deliveries.

It's a challenge for Li-Ion cell manufacturers to discern whether newly formed cells exhibit acceptable self-discharge behavior.



Today, self-discharge isn't a complicated measurement – it's relatively easy to measure how the open circuit voltage (OCV) of cells changes over time. The issue is how long it takes for that OCV to change enough to tell whether the self-discharge of your questionable or suspect cells is within acceptable limits.



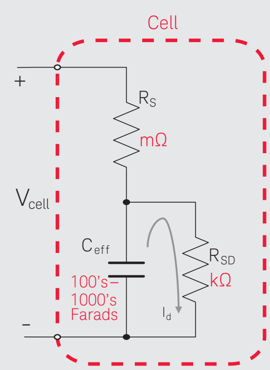
What is self-discharge current?

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 can be 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

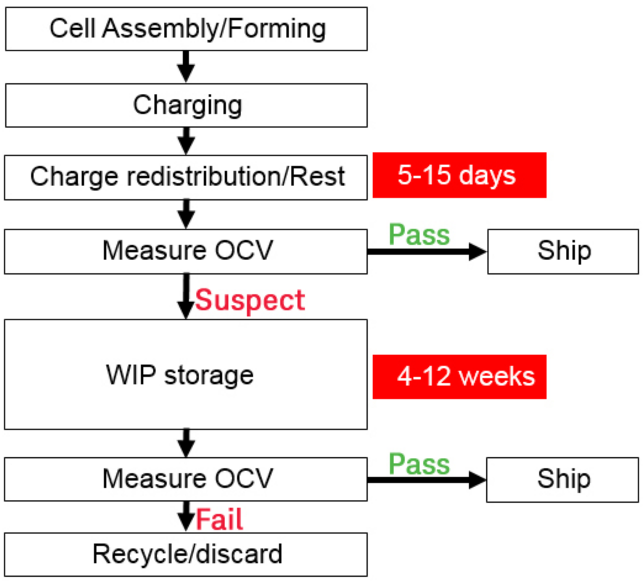


resistance. R_S causes the cell voltage to drop as you pull more current from the cell, since $V_{cell} = V_{ocv} - (I * R_S)$

- 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

Cell manufacturers keep far greater numbers of cells in work-in-process inventory than they would like. That negatively impacts work-in-process inventory metrics, and it consumes expensive floor space to hold that inventory.

This problem is worse for larger capacity cells, where a lot of the market growth is these days. Those larger-capacity cells are higher-value inventory, have longer settling times than smaller cells, and present more risk while sitting in inventory.



How Large Is This Financial Issue?

- *Self-discharge evaluation impacts:*
  - *Manufacturing inventory*
  - *Working capital costs*
  - *Facility cost and usage*

For any manufacturing operation, it depends on a lot of things, including:

- The types of cells manufactured
- Suspect rates – the percentage of cells manufactured that don't pass an initial voltage test and are classified as needing more testing for self-discharge
- Suspect cell holding period
- Cell manufacturing volumes
- Cell manufacturing cost
- The target rate of return on working capital
- Floor space consumed by suspect cell work-in-process inventory
- The cost of floor space

A simple model can estimate the working capital costs and facilities costs resulting from not being able to measure self-discharge behavior and immediately discern good vs. bad self-discharge performance of newly formed cells.

For example, two different scenarios are modeled, with different "suspect" rates and cell costs. The assumed values used in the model are shown below:

Cost Model Assumptions	**Cell Type 1**	**Cell Type 2**
Green = user input required		
Cell volume (M cells/yr)	100	100
Suspect rate	4%	12%
Suspect cell volume (cell/yr)	4,000,000	12,000,000
Number of working days/yr	338	338
Average mfg cost ($/cell)	$2.00	$20.00
Current suspect holding period (days)	60	60
Target rate of return on capital	8%	8%
Number of cells per tray	256	25
Average net area per stack of trays (sq meters)	2	2
Number of trays per stack	10	10
Cost of facility space ($/square meter)	$10	$10
SDM tester utilization rate	95%	95%

The estimated annual costs of working capital and facilities are as follows:

WIP Working Capital Costs	**Cell Type 1**	**Cell Type 2**
Working capital cost = (value of suspect WIP in holding period)*(Rate of return on capital)		
WIP working capital cost/year =	$119,589	$3,587,667

Warehouse/Facility Costs		
Warehouse/facility costs = cost of facility space consumed by cells in holding period		
Warehouse/facility costs/year =	$5,839.30	$179,383.37

As you can see, there can be very significant working capital costs and facilities costs resulting from not being able to immediately discern good vs. bad self-discharge performance of newly formed cells.

Every cell manufacturer is trying to capture as much of the rapid growth of the Li-Ion cell market as possible. That places a lot of pressure on manufacturing operations to reduce their total cost envelope, and to shorten delivery times. Every manufacturer is looking to make breakthrough reductions in process costs and to reduce delivery times.

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

– *Potentiostatic measurement can measure self-discharge current*

To measure self-discharge performance, you would like to directly measure the self-discharge current of the cell. This would tell you whether the cell was good or bad much sooner than waiting for the cell's open circuit voltage to change.

A high-performance potentiostatic analyzer can hold the cell voltage constant and stable. However, the cell will continue to self-discharge.

In the model in Figure 1, self-discharge current continues to flow through the parallel resistance, which would act to decrease the voltage on the effective capacitance of the cell. But since the cell voltage is being held constant by the analyzer, the analyzer must supply current to the cell equal to the self-discharge current. The analyzer accurately measures that current.

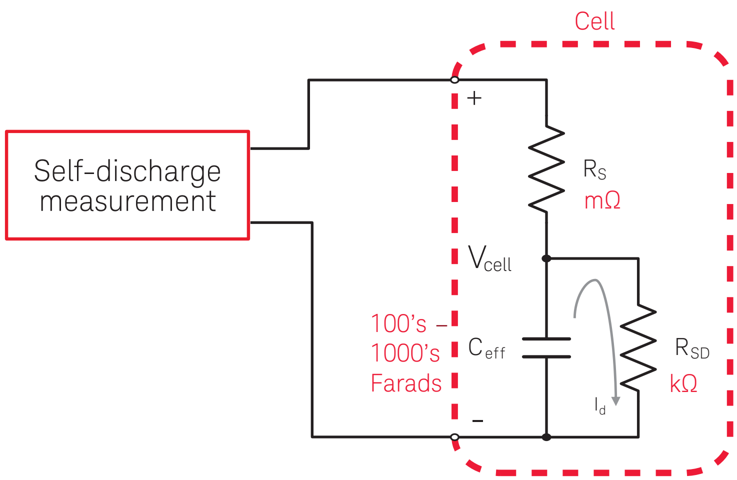


Figure 1. Self-discharge cell model

A New Solution for Self-Discharge Testing

A potentiostatic analyzer capable of making this current measurement must have these important characteristics:	Keysight has developed the only Self-Discharge Analyzer that has the characteristics needed for quickly making this type of current measurement:
– The analyzer needs to accurately measure low-level self-discharge currents in the range of 10's or 100's of µA.	– Accurately measures low-level self-discharge currents with an uncertainty of ± (0.33% + 1 µA)
– The analyzer cannot disturb the cell. – The voltage applied to the cell by the analyzer must precisely equal the cell voltage. It must quickly and accurately match the cell voltage. Otherwise, the cell either charges or discharges, initiating charge redistribution currents as well as RC settling currents that mask the self-discharge current you're trying to measure. – The voltage applied to the cell must be very stable. Any instability or noise in the applied voltage causes the cell to continually slightly charge and discharge, causing charge redistribution currents that show up as noise on the self-discharge 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.

Keysight BT2152A Self-Discharge Analyzer

- *Quickly & accurately measure self-discharge current*
- *Measure self-discharge current value in 1-5 hours*
- *Discern good vs. bad cells in < 30 minutes*

The BT2152A Self-Discharge Analyzer quickly and accurately measures cell self-discharge current on up to 32 cells. Keysight's patent-pending implementation of the measurement technique delivers a revolutionary reduction in the time required to discern good vs. bad self-discharge performance.

Testing indicates that for smaller cells like cylindrical 18650 or 21700 cells, the BT2152A can measure the self-discharge current in as little as 1-3 hours. And for larger capacity pouch cells (e.g., 10-60 Ah), the BT2152A can do this is in as little as 2-5 hours.

That measurement time is much less than the weeks or months required to see much change in the open circuit voltage.

And of greater impact in cell manufacturing, the analyzer's measurements allow you to see a clear difference in the self-discharge current of good vs. bad cells in typically less than 30 minutes.

Figure 2 shows an example test of eight 2.5 Ah cylindrical 18650 cells. A high-discharge rate on one of the cells was simulated by connecting a 46 kΩ resistor around the cell, to create a discharge path.

You can clearly see which current measurement trace belongs to the high-discharge cell. The current measurement traces of the other seven good cells are bunched together. The difference between the good cells and the bad cell is clear within 5-10 minutes. A self-discharge measurement that fast will have a huge impact in cell manufacturing.

The complete test ran for 3 hours to see at what values the self-discharge current measurements would settle. The self-discharge current reached final values at ~ 155 min. The good cells exhibited a settled value of about 20 µA, and the bad cell had a settled discharge current of about 100 µA.

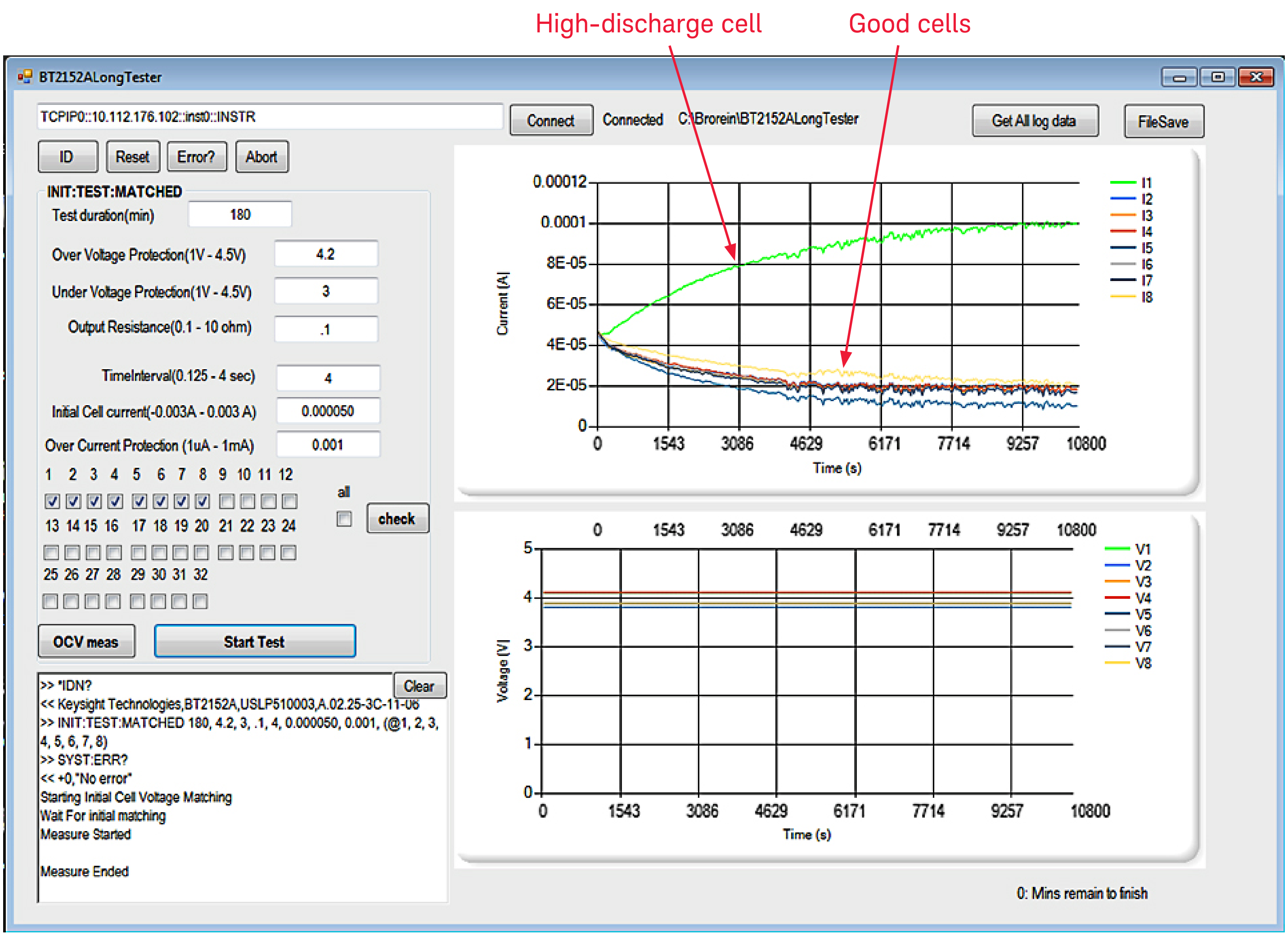


Figure 2. Self-discharge current test on sample of eight 18650 cells. One cell (green trace) had a 46 kΩ resistor connected in parallel to simulate a high-discharge cell.

Figure 3 shows an example test of two 10 Ah pouch cells. A high-discharge rate on one of the cells was simulated by connecting a 46 kΩ resistor around the cell, to create a discharge path.

You can clearly see which current measurement trace belongs to the high-discharge cell, and which belongs to the good cell. The difference between the good cell and the bad cell is apparent within 20-30 minutes. Being able to discern good vs. bad cells that quickly is extremely valuable for manufacturers.

The complete test ran for 6 hours to see at what values the self-discharge current measurements would settle. The good cell's self-discharge current reached a final value of ~50 µA at ~ 4.5 hrs. The bad cell's self-discharge current reached a final value of ~ 150 µA at ~ 3 hrs.

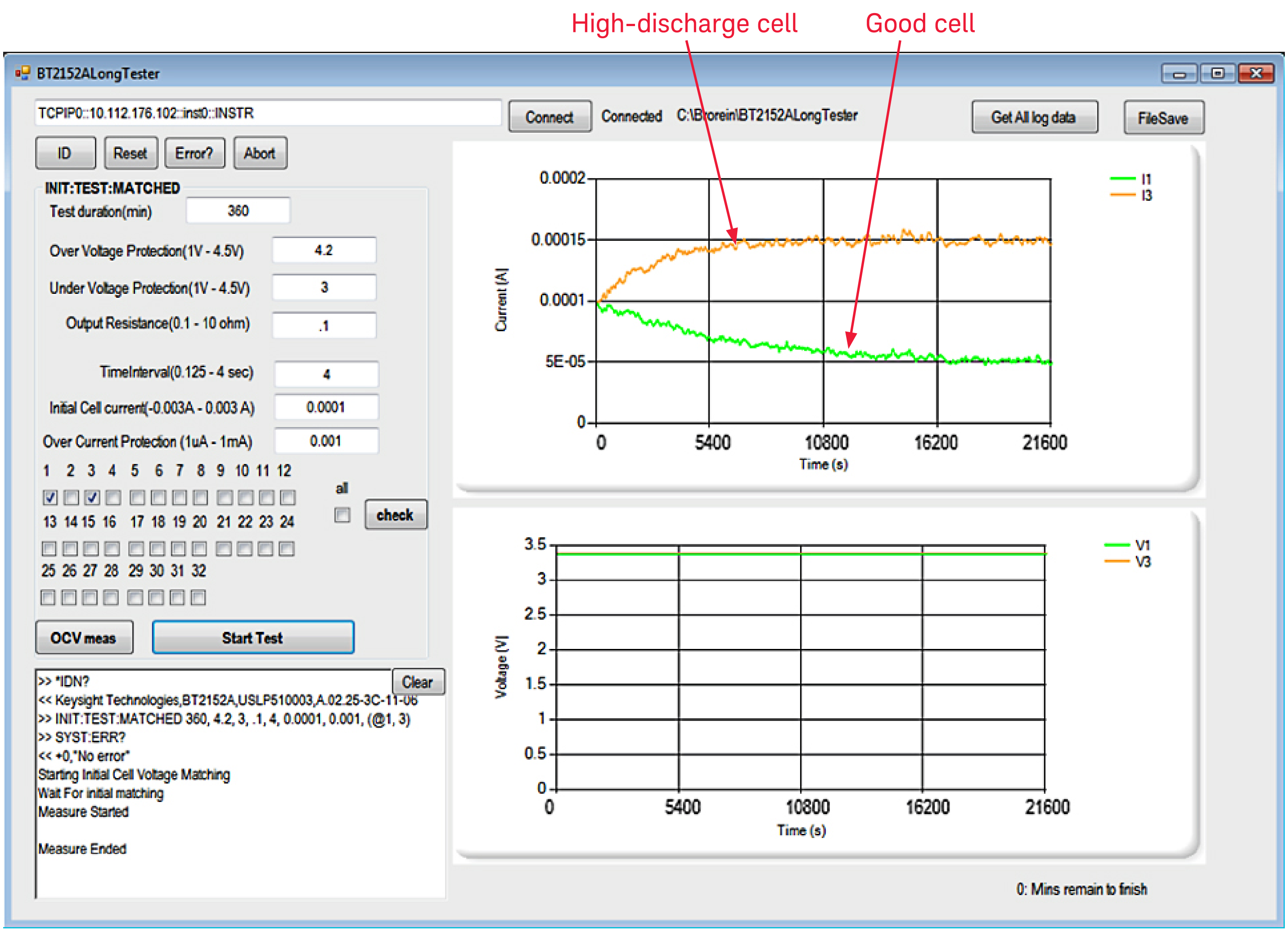
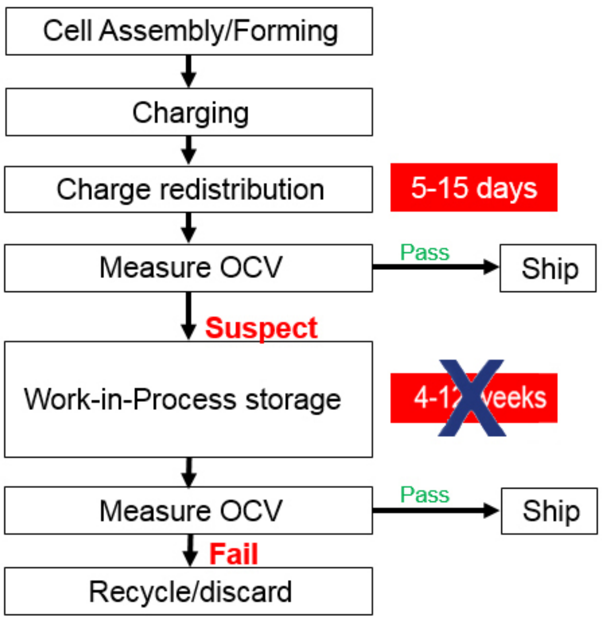


Figure 3. Self-discharge current test on sample of two 10 Ah pouch cells. One cell (yellow trace) had a 46 kΩ resistor connected in parallel to simulate a high-discharge cell.

The BT2152A Self-Discharge Analyzer makes a dramatic impact on the total cost of Li-Ion cell production. It can decrease the “Suspect Cell” holding period from weeks and months to less than 1 hour.

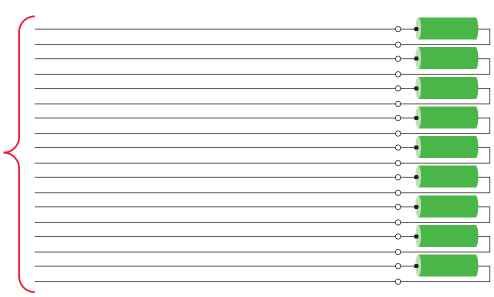
That’s a revolutionary reduction in:

- The work-in-process inventory of questionable or suspect cells
- The floor space required for all those cells
- The risks and problems associated with storing energized cells, typically at constant temperature.



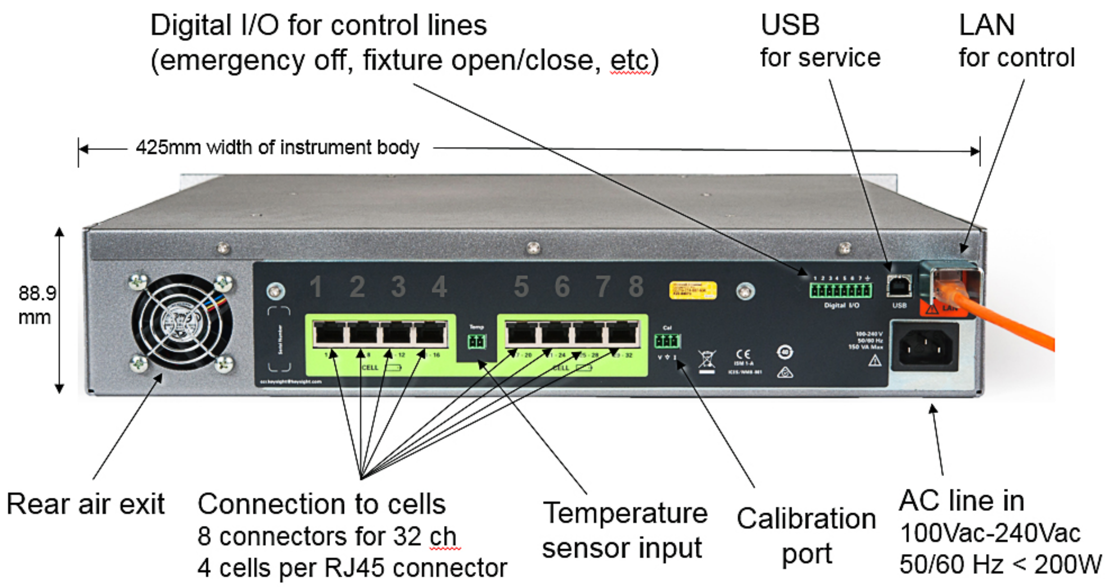
The BT2152A Self-Discharge Analyzer reduces the Suspect Cell holding period to < 1 hour for small cylindrical cells and large pouch cells

BT2152A Self-Discharge Analyzer
32 channels, 2U rack mount



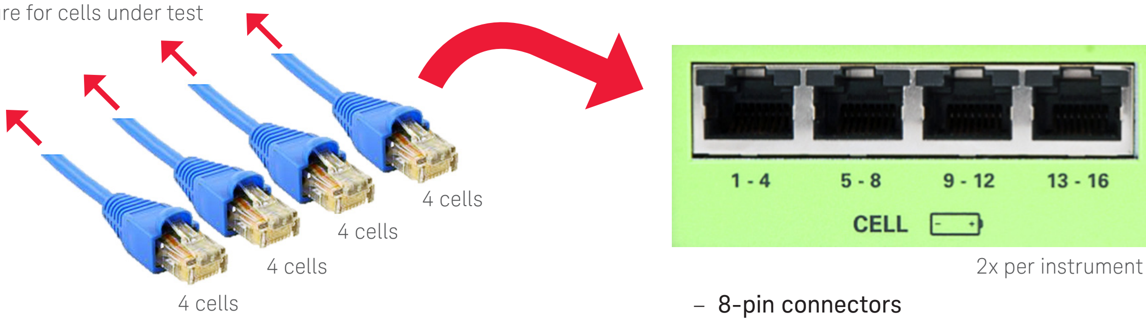
Keysight BT2152A Self-Discharge Analyzer Details

Rear panel



Connections to cells or fixturing

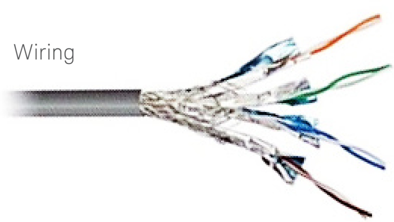
To fixture for cells under test



2x per instrument

- 8-pin connectors
- Each cell requires 2 pins (±)
- 4 wire connectors not needed due to low current
- One RJ45 connects to 4 cells

Wiring



- Standard CAT6a cable
- 4 shielded, twisted pairs
- 1 shielded, twisted pair per cell

- Connection design uses industry-standard, low-cost cables and connectors
- Cables can be purchased pre-assembled or custom cables can be made from CAT6a wire and RJ45 connectors.
- Keysight testing of these cables and connectors confirms good signal integrity suitable for self-discharge measurements.
- If you're measuring the OCV of cells as the means of sorting cells for self-discharge, you can continue to use your existing fixturing or electrical connections to your cells. Just connect the Self-Discharge Analyzer to the same points as the DMM and multiplexer you're using.

BT2152A Self-Discharge Analyzer

Specifications

Parameter	
Number of channels	4 to 32 in 4-channel increments
Voltage range	+ 0.5 V to + 4.5V
Current measurement range	± 10 mA
Current measurement accuracy[1]	± (0.33% + 1 µA)
Voltage measurement accuracy[2]	± (0.05% + 1 mV)

1. Current measurement accuracy specification applies after a 15 second settling delay and when using a minimum integration period of 1 minute.
2. Voltage measurement accuracy specification applies after a 15 second settling delay and when using a minimum integration period of 1 minute.

Supplemental Characteristics

Parameter	
Voltage sourcing stability[1, 2]	± 10 µV peak, ± 5 µV peak typical
Initial cell voltage matching accuracy	± 5 µV typical
Initial cell current programming accuracy	± (0.1% + 1 µA) typical
Voltage/current measurement interval	1.0 s to 256 s in 1 second increments
Maximum number of readings	259200 per channel. One reading = current and voltage data.
Maximum test duration (= measurement interval x max number of readings)	72 hours at 1 s measurement interval 750 days at 250 s measurement interval
Warm-up time after power-on	2 hours
Programmable resistance range	0.1 Ω to 10 Ω
Programmable resistance accuracy[3]	± 100 mΩ
External Temperature Measurement	
Thermistor requirements	Negative Temperature coefficient (NTC) 10 kΩ Nominal Resistance at 25 °C Programable Beta value (4073 default)
Temperature measurement range	5 °C to 100 °C
Temperature measurement uncertainty	± 1.5 °C
Maximum total lead resistance allowed	10 Ω
Output leakage current when off[4]	≤ 1 µA
Required isolation of DUTs across channels[5]	≥ 10 MΩ

1. Output voltage stability is measured over 24 hours at 1-minute integration.
2. Specification applies at output terminals. Cabling and interconnect errors may degrade this.
3. As measured at the output terminals.
4. Assumes differential voltage across output terminals of no greater than ± 5 V
5. Isolation of DUTs connected on different channels is required. Isolation is measured from either terminal of the DUT to earth or to either terminal of any other DUT to be connected to different channels of the same instrument.

Supplemental Characteristics

Parameter	
Measurement terminal isolation maximum rating	No terminal may be more than ± 240 VDC from any other terminal or chassis ground.
Minimum supported cell effective capacitance	100 F
Minimum supported product of cell effective capacitance and cell effective series resistance	50 s
Operating constraint	$0.5\ V \leq V_{CELL} + I*(6.2\ \Omega + R_{CABLES} + R_{ESR} - res) \leq 4.5\ V$ Where – V_{CELL} = cell open circuit voltage of the cell. – I = instantaneous current value measured any time during test.. – R_{CABLES} = resistance of the cabling from analyzer to DUT. – R_{ESR} = cell internal equivalent series resistance. – *res* is the customer selected output resistance used in the INITiate:TEST:MATChed command.
Environmental conditions	
Operating environment	Indoor use, installation category II (for AC input), pollution degree 2
Ambient temperature range[1]	20 °C to 30 °C
Relative humidity	Up to 95% (non-condensing)
Altitude	Up to 2000 meters
Storage temperature:	–30 °C to 70 °C
Dimensions (H x W x D)	88.98 mm (3.50 in) x 425 mm (16.73 in) x 400 mm (15.75 in)
Weight	10.2 kg (22.5 lbs.)
AC input Nominal rating Input voltage range Power consumption	 100–120, 200–240 VAC 50/60 Hz ± 10% of nominal ratings < 200 W
Regulatory compliance	
EMC	Complies with European EMC Directive for test and measurement products Complies with Australian standard and carries C-Tick mark This ISM device complies with Canadian ICES-001 Cet appareil ISM est conforme à la norme NMB-001 du Canada
Safety	Complies with European Low Voltage Directive and carries the CE-marking. Conforms to US and Canadian safety regulations.
Declarations of Conformity for this product may be downloaded from **http://regulations.corporate.keysight.com** and clicking on "Declarations of Conformity."	

1. Maximum rate-of-change (dT/dt) must be < 5 °C/hour.

BT2152A Ordering Information

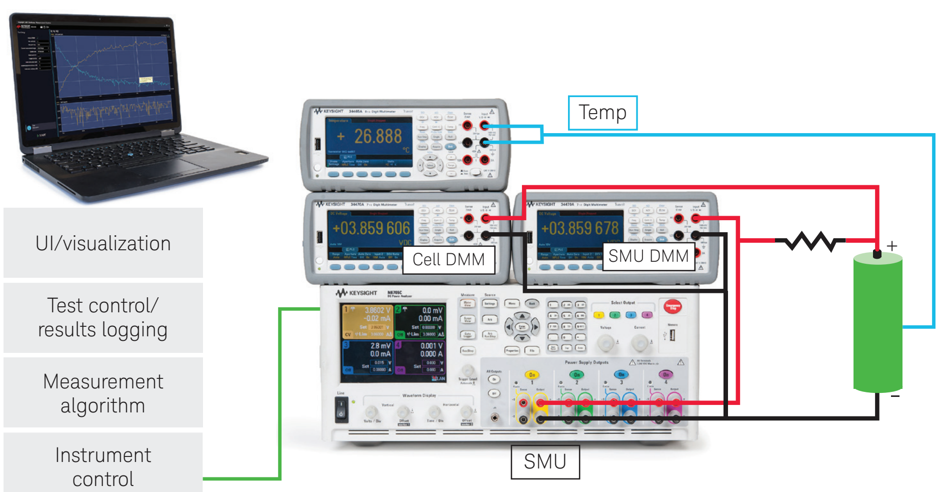
Must choose one and only one channel option

Product/Option	Description
BT2152A	Self-Discharge Analyzer
BT2152A-004	4 Channels
BT2152A-008	8 Channels
BT2152A-012	12 Channels
BT2152A-016	16 Channels
BT2152A-020	20 Channels
BT2152A-024	24 Channels
BT2152A-028	28 Channels
BT2152A-032	32 Channels

For more information, please visit: **www.keysight.com/find/BT2152A**

For Measuring Self-Discharge in Cell Design Environments

– *BT2191A Self-Discharge Measurement System*

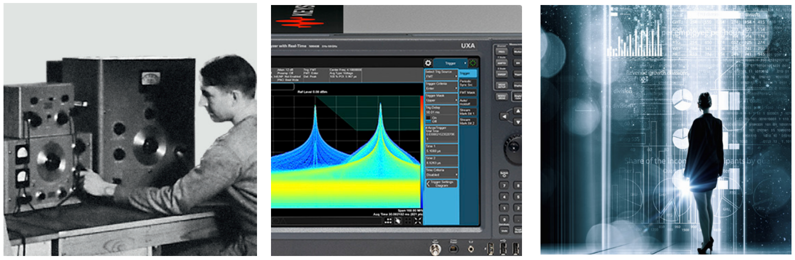


- Provides a revolutionary reduction in the time required to measure & analyze cell self-discharge current in design.
- Gain faster design cycle iterations

For more information, please visit: **www.keysight.com/find/BT2191A**

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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