Evaluation Guide

BT2152B Self-Discharge Analyzer,
BT2155A Self-Discharge Analysis Software

Keysight Self-Discharge Analyzer and Software Evaluation

KEYSIGHT
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Notices

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Sales and Technical Support

To contact Keysight for sales and technical support, refer to the support links on the following Keysight websites:

www.keysight.com/find/BT2152B

www.keysight.com/find/BT2155A

(product-specific information and support, software and documentation updates)

www.keysight.com/find/assist (worldwide contact information for repair and service)

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1. Introduction

Keysight's BT2152B 32-Channel Self-Discharge (SD) Analyzer and its companion BT2155A Self-Discharge Analysis Software provide a new way to measure Li-Ion cell self-discharge. This manual provides basic information so that you can set up the system to perform cell tests and perform a realistic evaluation of the analyzer and software.

Figure 1 Typical BT2155A Display

- This guide assumes that you have reviewed and understand the basic operation of the BT2152B Self-Discharge Analyzer hardware and installation. (For more detailed installation information, see the *BT2152B Self-Discharge Analyzer Operating and Service Guide*, available at: www.keysight.com/find/BT2152B.)
- You do not need to be a programmer to make high quality self-discharge measurements with the BT2155A software.

System Advantages and Abilities

The Keysight BT2152B Self-Discharge Analyzer uses potentiostatic measurements to determine the self-discharge rate for up to 32 Li-Ion cells. This proprietary technique lets you determine the quality of the cell within hours after the cell is initially charged and rested. Testing has shown that:

- For smaller cells, such as cylindrical 18650 or 21700 cells, the BT2152B can measure the self-discharge current in as little as 1 hour.
- For larger capacity pouch cells (that is, 10-60 Ah), the BT2152B can measure self-discharge in as little as 2 hours.
- You can quickly see clear differences in the self-discharge currents of good vs. bad cells. This may take as little as 30 minutes.

Brief Self-Discharge Overview

Self-discharge is the process by which a lithium-ion cell discharges its energy over a period of time, even when the cell is not connected to a load. This discharge behaves like an internal parallel resistance in the cell. Traditional measurements might require days or weeks of cell aging to identify a cell with excessive self-discharge.

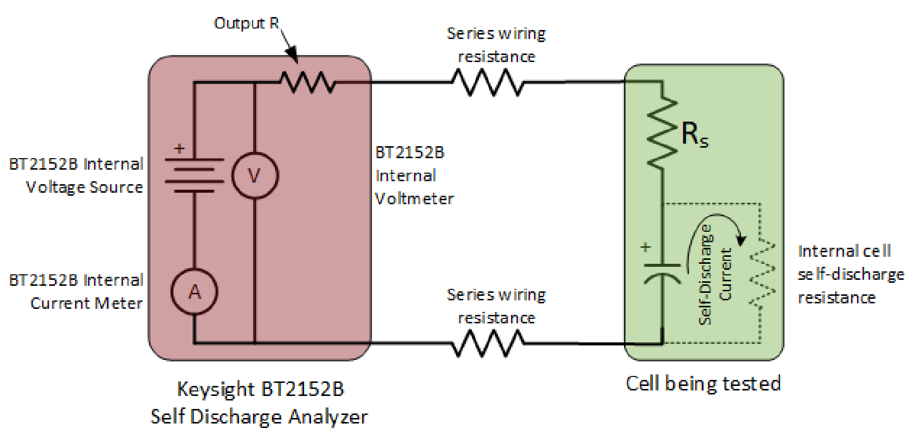


Figure 2 The Potentiostatic Method of Determining Cell Self-Discharge

Keysight's BT2152B analyzer measures the self-discharge current by connecting an external voltage source in parallel with the cell, closely matching the voltage source output to the cell's initial voltage. Over time, the cell reaches equilibrium with the external voltage source, making the measurable current supplied by the source equal to the leakage current. The DC voltage applied to the cell by the BT2152B is very stable and quickly matches the cell's open-circuit voltage (OCV). This minimizes the charge redistribution noise on the self-discharge current measurement and accurately measures low-level self-discharge currents.

Specifications and References

This guide assumes that you have reviewed and understand the basic operation of the BT2152B Self-Discharge Analyzer hardware and installation.

Specifications and References

- Refer to the BT2152B Self-Discharge Analyzer web page at www.keysight.com/find/BT2152B for information and documentation, including:
  - Complete BT2152B specifications provided in the instrument Data Sheet.
  - The *BT2152B Self-Discharge Analyzer Operating and Service Guide*.

Also refer to these resources:

- BT2155A Self-Discharge Analysis Software: www.keysight.com/find/BT2155A
- Keysight IO Libraries Suite: www.keysight.com/find/iosuite

BT2152B Dimensions and Airflow

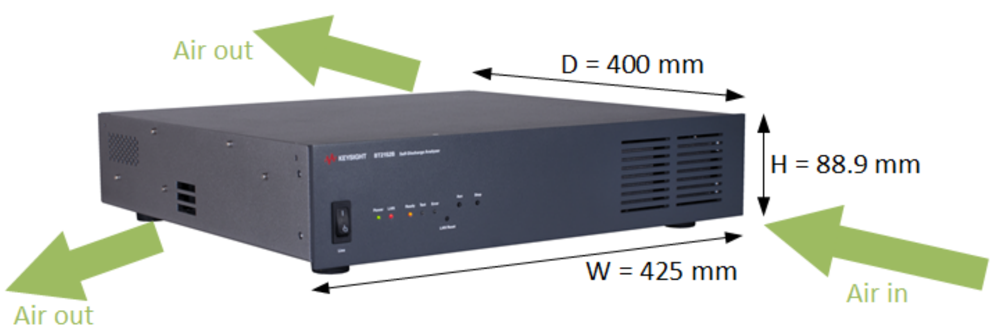


Figure 3 BT2152B Air Flow

- The front air inlet requires a minimum of 6 inch (15 cm) clearance. Inlet air temperature must be within the temperature range of 20°C to 30°C.
- The rear air outlet requires a minimum of 6 inch (15 cm) clearance.
- The small air outlet on the left side of the unit must also be unrestricted, but clearance could be as small as 10 mm if rack mounted.
- The instrument should not be installed in a pressurized rack or enclosure.

BT2152B Front and Rear Panel Features

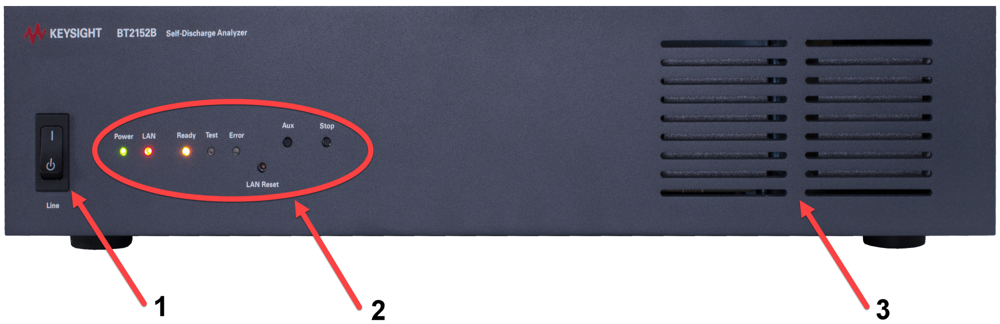


Figure 4 BT2152B Front Panel

	Description
1. Line Switch	Turns the unit on or off
2. Status Indicators and Switches	**Power:** Green LED indicates power is on. **LAN:** Green LED indicates an active LAN connection. Flashing green indicates that the instrument is being addressed. Flashing blue indicates a SCPI command is received. Red indicates a LAN fault. **Ready:** Green indicates the unit is ready to start the test. Amber indicates the unit is warming up. **NOTE: Allow 1 hour of warm-up time.** **Test:** Flashing amber indicates that an external wiring resistance measurement is taking place. Flashing blue indicates that cell matching has started. Solid blue indicates a test is running. Off indicates no test is running. **Error:** Red indicates an error or protection event has occurred. Off indicates protection is cleared. **LAN Reset:** This recessed switch performs a software system LAN reset, which restores the LAN settings back to the default manufacturing state. **NOTE: LAN settings remain unchanged with normal power cycles.** **AUX:** This switch is reserved for future use. **Stop:** Aborts any current measurements and sequences. The unit returns to a state of being ready for initialization.
3. Air Inlet	Air inlet requires a minimum of six inches (15 cm) clearance.

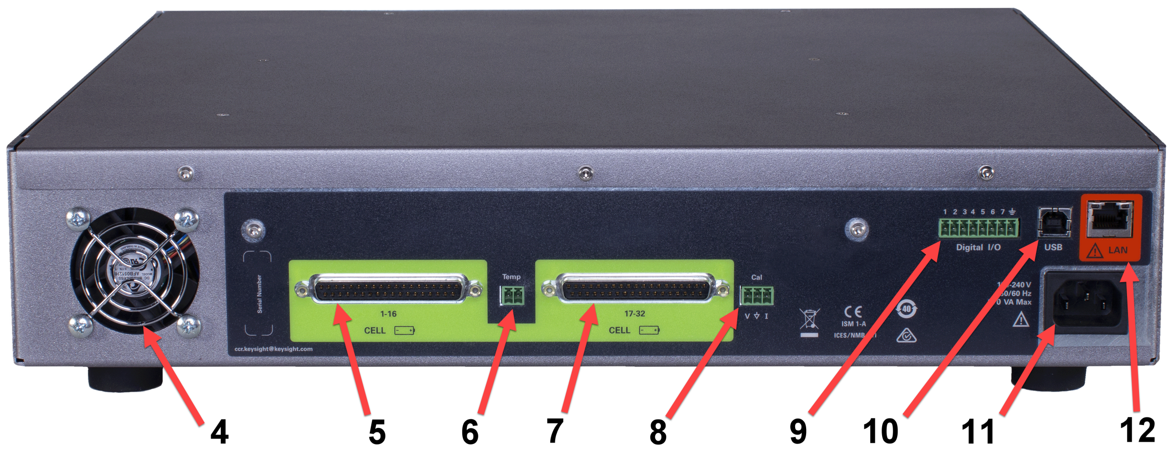


Figure 5 BT2152B Rear Panel

	Description
4. Fan/Air Outlet	The rear panel air outlets require a minimum of six inches (15 cm) clearance.
5. DB-37 Connector	16-pin DB-37 connector for cell channel connections 1-16 (up to 16 cells per connector)
6. Temperature Sensor	Temperature sensor input (requires an external 10 kΩ thermistor)
7. DB-37 Connector	16-pin DB-37 connector for cell channel connections 17-32 (up to 16 cells per connector)
8. Calibration Port	Calibration Port
9. Digital Connector	8-pin digital IO interface
10. USB	USB interface connector
11. Universal AC Input	Standard IEC 320 AC Power Connector
12. LAN	10/100/1000 Base-T LAN Connection: **Left** LED indicates link speed (green 1 Gbps, Orange 100 Mbps, Off is 10 Mbps with activity blinking) **Right** LED indicates activity.

Requirements for BT2152B/BT2155A Evaluation

Use the table below to assess your equipment and software needs for the BT2152B/BT2155A evaluation.

Table 1 Equipment Requirements

Qty	Keysight Model or Description	Supplied with the BT2152B?
1	Host PC: • MS Windows 7 or Windows 10 • Connected to Internet (to connect via LAN)	No
1	BT2155A Self-Discharge Analysis Software	No. If not previously installed on host PC, download from here: www.keysight.com/find/BT2155A
1	Prerequisite software: • Keysight IO Libraries Suite • Keysight License Manager, Version 5 • .NET Framework 4.5.2 • Keysight CCL Licensing Service • Keysight HPP Desktop	Automatically installed with the BT2155A software if not previously installed on host PC. (Note that you do not need to purchase a software license to assess the BT2152B analyzer. See "Install the BT2155A Self-Discharge Analysis Software." on page 18 for more information.)
1	BT2152B Self-Discharge Analyzer and power cord	Yes. Operating and Service Guide is available at: www.keysight.com/find/BT2152B
1	USB or LAN cable to connect BT2152B Analyzer to host PC	No
1	(Optional) fixture for cells under test	No. Li-Ion cells vary widely, so you may choose to create your own cell-test connectors or a fixture. See ***"Fixture Design Guidelines," starting on page 51*** for design guidelines and information on basic fixture designs.
up to 32	Li-Ion cells for testing	No
1 or 2	Cable(s) for connecting BT2152B analyzer to test fixture. Keysight offers BT2181A (2m) or BT2182A (4m) cables. Each cable handles 16 cell test channels.	No. You can order cables from Keysight or use the specifications in the *BT2152B Operating and Service Guide* to create your own cell connection cables.

Table 1 Equipment Requirements

Qty	Keysight Model or Description	Supplied with the BT2152B?
1 or 2	BT2180A Breakout Boards, DB37(f) to Screw Terminals, for 16 measurement channels. One DB37(f) connector to connect to 16 channels of BT2152B. The DB37(f) connects on the board to two 16-pin screw terminal connectors (one for + terminal of all channels and one for - terminal of all channels). The screw terminal connectors support twisted-pair wiring (16 - 30 AWG) to the cells-under-test or to fixturing for the cells.	No. You can order breakout boards from Keysight or construct your own connections. See “Pin Information for Keysight Breakout Boards,” starting on page 57 for more information on the breakout boards.
1	10 kΩ Thermistor/wire pair (Keysight # BT2152-61607) with 2-pin connector (Keysight # 0360-3009), thermally isolated	Yes
1	(Recommended) An environment to maintain cell temperature during test (since most cells are temperature sensitive).	No
1	(Optional) MS Excel to review and analyze test data.	No

For additional items supplied with the BT2152B Self-Discharge Analyzer, see the *BT2152B Operating and Service Guide*, available for download at: www.keysight.com/find/BT2152B

2. General Evaluation and Design Considerations

As you set up your evaluation, consider the design factors discussed in this section.

If you want to create your own test fixture, see "Fixture Design Guidelines" on page 51.

Contact and Wiring Resistance

- Because the BT2152B analyzer makes low-current measurements (in the range of milliamps and microamps), the absolute value of wire and contact resistance are not of primary concern. However, it can be important to achieve low variation in these resistance values between wiring resistance calibrations.
- The BT2152B analyzer requires the total channel resistance to be less than 5 ?. This includes all wiring for the test fixture, cabling and contact resistance. In practice, if you follow the recommendations in this document, you will achieve total wiring resistance of approximately 0.5 ?.

Thermistor Choice

- It is critical to measure temperature as part of the self-discharge measurement process. With each BT2152B, Keysight provides a 2-meter thermistor cable with a 10k thermistor, used with the 2-pin thermistor connector (Keysight 0360-3009) and the thermistor/wire pair (Keysight BT2152-61607). Keysight uses Amphenol Advanced Sensors RL1005-5744-103-SA thermistors, Keysight part number 0837-4194. (Click on red link for more information.)
- Place or mount the thermistor near the cells under test in a position that the temperature measurements represent the temperatures of the cells.
- To avoid the possibility of shorting the thermistor, use only non-metallic and non-conducting materials (tape, glue, etc.) if you attach the thermistor to a cell or cell tray or fixture.

Cable and Connector Requirements

Information in this section refers to the *Keysight BT2152A/B Self-Discharge Analyzer Operating and Service Guide*. You can download a copy of the manual from www.keysight.com/find/BT2152B

- The cables to your fixture must interface with the DB37 receptacles on the rear panel of the BT2152B analyzer, as shown below:

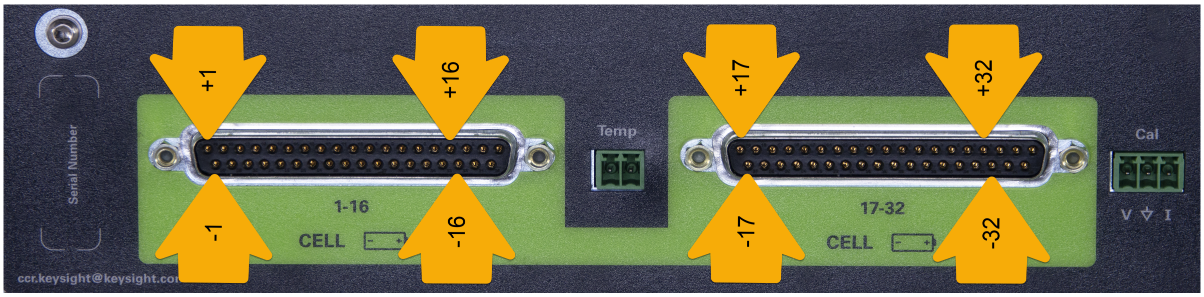


Figure 6 BT2152B Cable Receptacles

- Refer to page 35 of the *Keysight BT2152A/B Self-Discharge Analyzer Operating and Service Guide* for pinout information.
- Keysight recommends that you use cables with DB37 female connectors on your fixture.
- Keysight has pre-made cables available for sale: Keysight BT2181A (2m) or BT2182A (4m) cables should be used to connect the test fixture to the BT2152B analyzer. These cables are shielded, twisted pair, with DB37 (m) to DB37 (m) connectors.
  - The pinouts of the Keysight cables matches the pinouts of the DB37 connectors. Refer to page 33 of the *Keysight BT2152A/B Self-Discharge Analyzer Operating and Service Guide* for pinout information.
- If you prefer to make your own cables:
  - Use shielded test leads and keep the overall test environment shielded from interference, etc.
  - Keep cable length to less than 4 meters.
  - Use twisted pairs of wires for each channel for as much of the distance from analyzer to cell as possible.
  - The bundle of the twisted pairs should be shielded, with a separate braided shield around the bundle.
  - The braid should be connected to the DB37 connector housings, which are made of conductive metal.
  - The DB37(m) connectors should have machined (not stamped) pins. The resistance of stamped pins is higher and has more pin-to-pin variation than machined pins have. This difference can affect measurement performance consistency across channels.
  - Note that Keysight BT2181A and BT2182A cables meet all these requirements.

Thermal Design

Keeping cells at a stable temperature is very important for the accuracy of your testing.

Cell characterization measurements are made at µA and mA levels and are very sensitive to temperature. Controlling the temperature of the cells under test and maintaining a stable temperature (ideally < ±0.2 °C) may be the most challenging part of making successful and meaningful self-discharge measurements. Planning for thermal design as you set up your evaluation may be the most important step to getting good results.

- As per the design standards in this document, Keysight recommends that you measure temperature and consider it when you design your fixture.
- A cell’s Open Circuit Voltage (OCV) varies with temperature. This temperature sensitivity and the cell’s temperature coefficient of voltage (TCV) are functions of the State of Charge (SOC) of the cell. The TCV can be:
  - Positive - which means OCV increases with increased temperature.
  - Negative - which means OCV decreases with increased temperature.
  - Neutral - which means OCV is unaffected by temperature.
- You must allow cells to reach thermal equilibrium with the test environment before you run any tests.
- Keysight also recommends that you create a fixture design that is thermally stable. For fixture thermal design and other design tips, see “Fixture Design Guidelines” on page 51.

3. System Setup

This section shows you how to install the system's PC software, how to connect the PC to the analyzer, and how to set up the measurement hardware

You are responsible for:

- Building or acquiring a fixture to hold the cells under test (up to 32 Li-Ion cell(s)).
- Connecting the cells in the test fixture to the BT2152B Analyzer.
- Connecting the 10 kΩ thermistor (for temperature monitoring) from the fixture to the BT2152B Analyzer.

Refer to the *BT2152B Self-Discharge Analyzer Operating and Service Guide* for more detailed setup information.

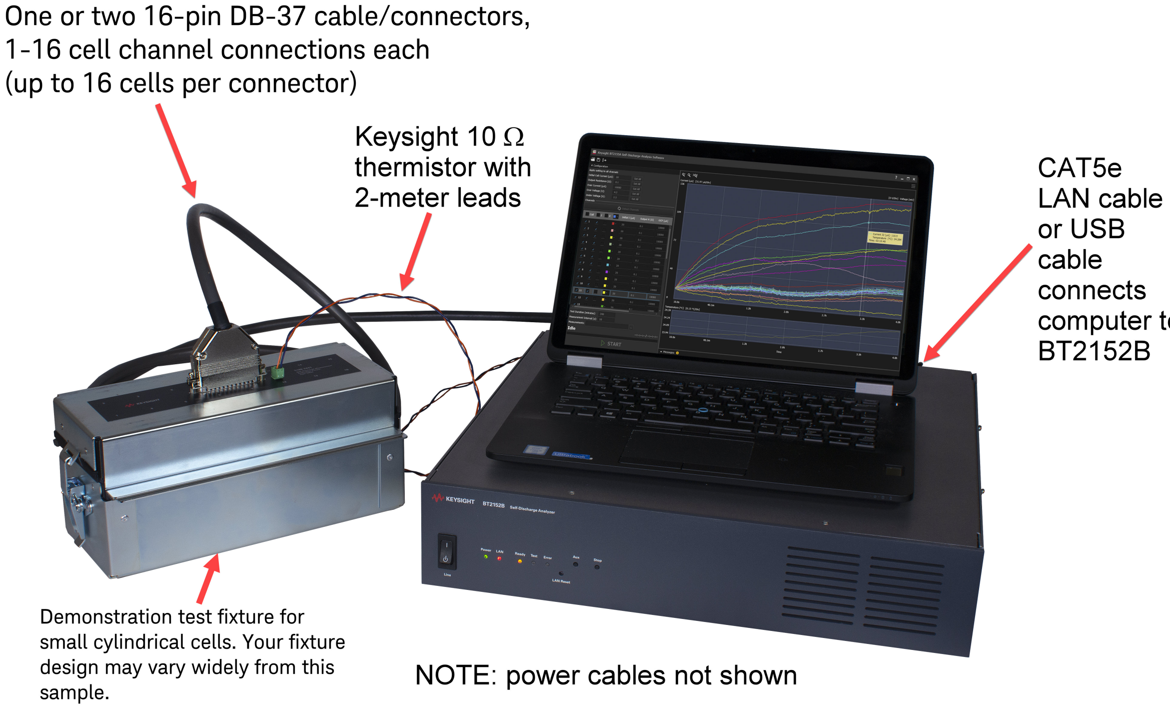


Figure 7 Example of BT2152B System Connections

PC and Analyzer Setup

Install the BT2155A Self-Discharge Analysis Software.

- Download and install the Self-Discharge Analysis software, available at: www.keysight.com/find/BT2155A.
- You can use the BT2155A software for up to 90 days with a free trial license. After 90 days, you must purchase a license to continue using the software. For licensing information, go to: www.keysight.com/find/BT2155A.
- Installing the BT2155A software automatically installs Keysight License Manager and Keysight IO Libraries and other prerequisite software.

Connect the PC to the Analyzer

LAN Connection

1. Connect the BT2152B to your computer or network using a USB or LAN cable.
2. (If connecting through LAN) The as-shipped LAN settings automatically obtain an IP address from the network using a DHCP server (DHCP is set On). The DHCP server registers the instrument's host name with the dynamic DNS server. You can then use the host name and IP address to communicate with the instrument. If you use a private LAN, you can leave all LAN settings as they are. Most Keysight products and most computers automatically choose an IP address using auto-IP if a DHCP server is not present. Each assigns itself an IP address from the block 169.254.nnn. The front panel LAN indicator comes on when the LAN port is configured.
3. Use the Connection Expert utility of Keysight's IO Libraries Suite to add the instrument and verify the connection. (If the instrument is not displayed automatically, refresh the view to scan for it, or click **Add** to enter the instrument's hostname or IP address.)
4. You can now use the Interactive IO utility within the **Connection Expert** to communicate with your instrument. If you wish, you can also program the instrument directly using the applicable SCPI commands.

USB Connection

1. Connect the BT2152B to the USB port on your computer. (You must supply your own USB cable.)
2. With the **Connection Expert** utility of the Keysight IO Libraries Suite running, the computer automatically recognizes the instrument. This may take several seconds. When the instrument is recognized, Connection Expert displays the VISA alias, IDN string, and VISA address.

Measurement Hardware Setup

Connecting cells to the analyzer

Because of the wide variety of Li-Ion cell types, you must provide your own cell connections or test fixture and the DB-37 cables to connect your cells to the BT2152B Analyzer. Figure 8 shows one example of setting up the connections using Keysight cables and breakout boards. (Your connections may vary considerably from this example.)

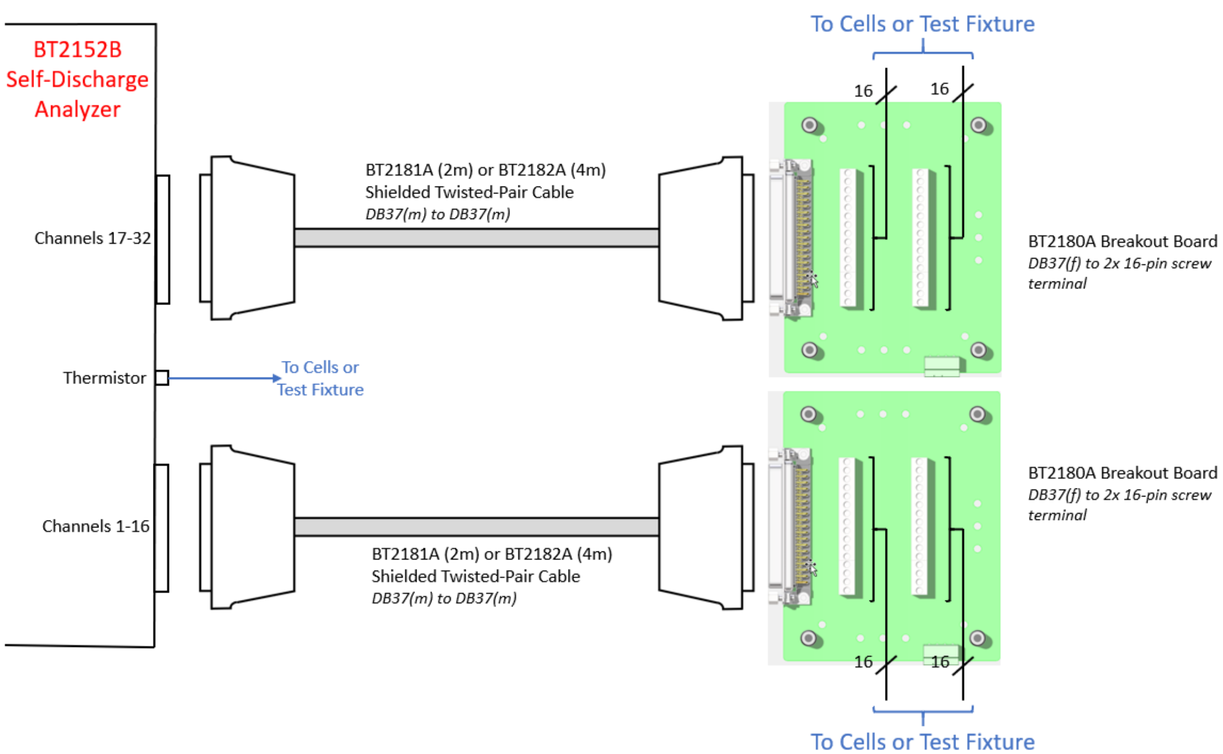


Figure 8 Typical Connections to Cells or Test Fixture Using Keysight Parts

See “Pin Information for Keysight Breakout Boards,” starting on page 57, for more information about pin connections to the BT2152B back panel and to the Keysight breakout boards.

Connecting the thermistor

Keysight provides a 10 kΩ thermistor with a 2-meter attached lead with the BT2152B Analyzer. Connect this to the provided 2-pin connector on the rear panel of the analyzer (see “BT2152B Front and Rear Panel Features” on page 10 for information).

For evaluation purposes, simply tape the thermistor near enough to the cells under test to give a representative reading of the temperature of the cells. The thermistor must not be in electrical contact with any metal part of the cell.

Figure 9 Keysight 10 kΩ Thermistor with 2 Meter leads

NOTE

- **To avoid the possibility of shorting the thermistor, use only non-metallic and non-conducting materials (tape, glue, etc) to attach the thermistor to a cell or cell tray.**
- **The thermistor must not be in electrical contact with any metal part of the cell.**
- **Use only a Keysight 0837-4194 or Amphenol Advanced Sensors RL1005-5744-103-SA thermistor. Some standard, off-the-shelf thermistors may have different characteristics than the Keysight thermistor and may alter your results.**

Creating a Thermally Stable Environment

Controlling the temperature of the cells under test is likely the most challenging aspect of making valid self-discharge measurements as you begin to use the BT2152B Self-Discharge Analyzer. It is also one of the most important things you can do to make sure you get good tests.

Making a valid and accurate self-discharge current measurement using the BT2152B depends on holding the voltage (i.e., the open circuit voltage or OCV) of the cell constant. This is critical to the process of a potentiostatic measurement because the OCV of most Li-Ion cells highly depends on cell temperature. (Cell size, packaging, chemistry and State of Charge (SOC) all impact the cell's sensitivity to temperature.)

As an example of how a thermal change can affect your test results, see the following graphic. At approximately the ten minute mark, the graphic below shows a typical result for someone touching a cell for only five seconds: the temperature rose 0.13 °C, the cell voltage dropped 2 mV, and the cell current rose 2.4 mA for several seconds. Afterward, several minutes passed until the cell temperature and cell current stabilized again. (See "Temperature Control and Effects" on page 40 for more about what happens if you touch a cell.)

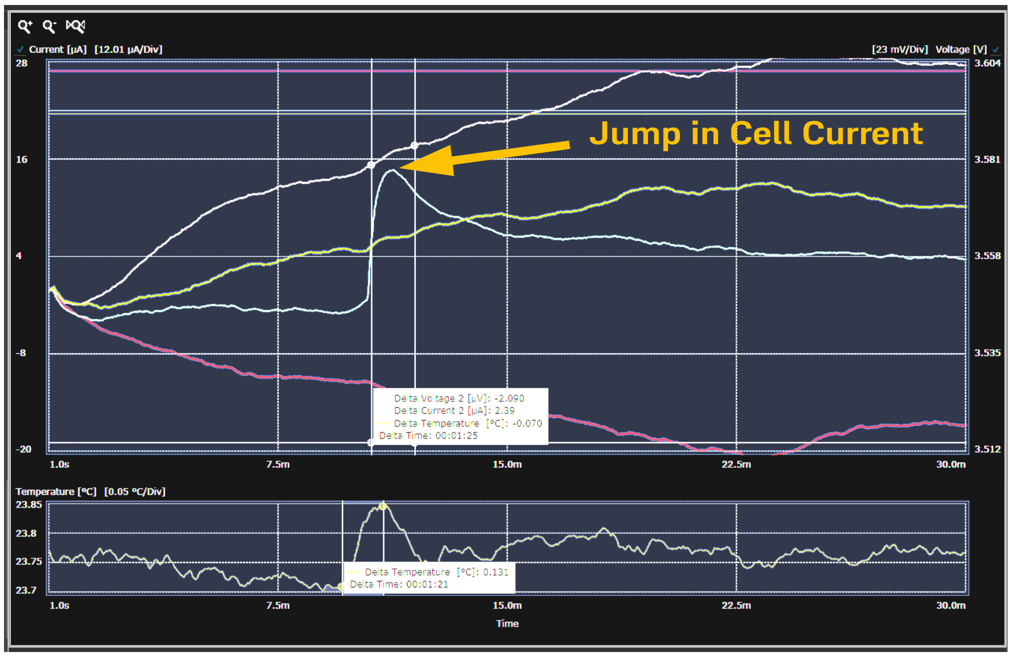


Figure 10 Spiking Cell Current from Temperature Change

- Keysight recommends that you keep the temperature of the cells under test to within ± 0.2° C if possible.
- Keysight does *not* recommend that you use a thermal chamber for this purpose. Most commercially available thermal chambers that actively control their internal temperature through heating or cooling cannot control their temperature in a stable way that supports the needs of potentiostatic self-discharge measurements of Li-Ion cells.

For getting started with initial self-discharge measurements, Keysight recommends a simple set up to provide thermal stability. The key is insulating the cells under test from external or ambient temperature variations during the test. The following best practices can help you create a thermally stable measurement environment:

- Connect the self-discharge analyzer to the cell using shielded twisted pair cabling over as much of the distance from the analyzer to the cell as possible.
- Place the cell inside a thermally insulated box or chamber. A simple corrugated box with good insulation inside the box can work quite well. Inside this box, place a thermal mass such as a metal plate that will help hold the temperature inside the box stable. (Note that it is best to not allow the cells to touch any metal objects that you use as a thermal mass.)
- For greater stability, place the above box or chamber inside another larger box or chamber that is also thermally insulated.

See Figure 11 for a conceptual diagram of what a thermally stable environment might look like.

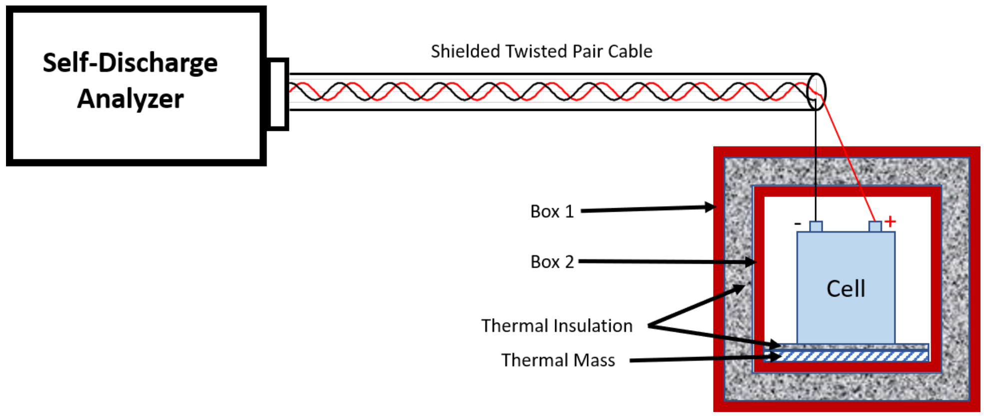


Figure 11 Constructing a thermally stable environment

4. Evaluation Steps

Initial Power-on and Configuration

Turn on the PC running the B2155A software and then turn on the BT2152B unit using the front-panel Line switch. The Power LED turns green, indicating that the instrument has power.

NOTE

- It takes approximately 60 seconds for the unit to completely boot up.
- For running tests, a warm up time of **one hour** is required for the unit to meet its specified test performance.

Get to know what the front panel indicators and buttons do:

- LAN indicator:
  - Turns green when the LAN connection is active.
  - Flashing green indicates an active LXI identification state.
  - Red indicates that the LAN is disconnected. To try to restore a disconnected LAN, use a thin metal rod (such as a straightened paper clip) to press the recessed **LAN Reset** button. If this does not work, try to restore LAN communication via USB using the B2155A software or by using the Connection Expert utility in IO Libraries.
- Ready indicator:
  - Turns orange while the unit is warming up. You can send commands and operate the unit during the warm-up time, but Keysight advises you to let the unit warm up fully before you run any tests.
  - The Ready status is driven by elapsed time. If the unit is powered off and then powered on again, the Ready LED turns orange for one hour.
- Test and Error indicators:
  - The Test indicator turns green when a test is active.
  - A red Error indicator means that a protection event or an error has occurred. For additional information and guidelines for resolving errors, see the *BT2152B Self-Discharge Analyzer Operating and Service Guide*, available for download at: www.keysight.com/find/BT2152B
- Aux and Stop buttons:
  - Press and hold the **Stop** button to abort an active test.
  - **Aux** is not functional.

Starting the BT2155A Software

1 On the control PC, open the Windows Start menu, and select **Keysight BT2155A**. The very first time the software starts on your system, it displays a licensing dialog. For evaluation purposes, Keysight recommends that you select the 90-day trial license. (You can also follow the dialog instructions to install a purchased license if you have one.)

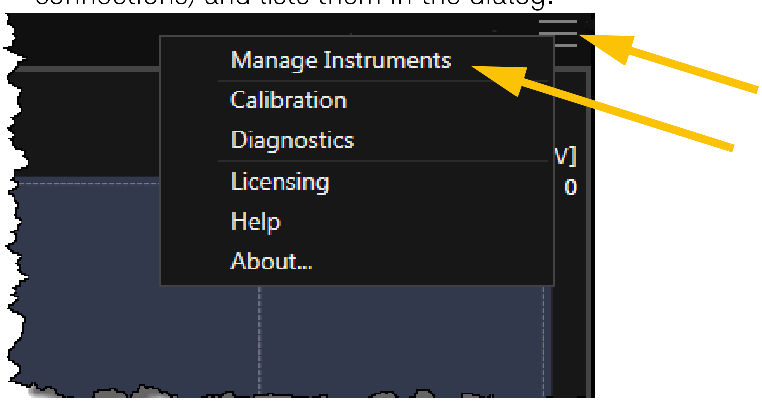
   - The 90-day trial license works locally on the host PC and does not require an Internet connection, licensing files, or use of Keysight License Manager.
   - After the 90-day trial license expires, you must purchase a license to continue using the software. For licensing information, go to: www.keysight.com/find/BT2155A.

2 Close the license dialog.

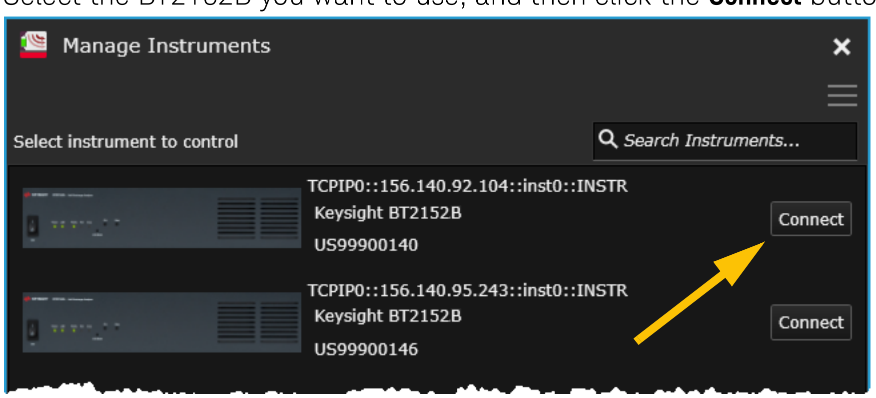
Connecting to the BT2152B Analyzer

1 Click on the main menu button to display the main menu.

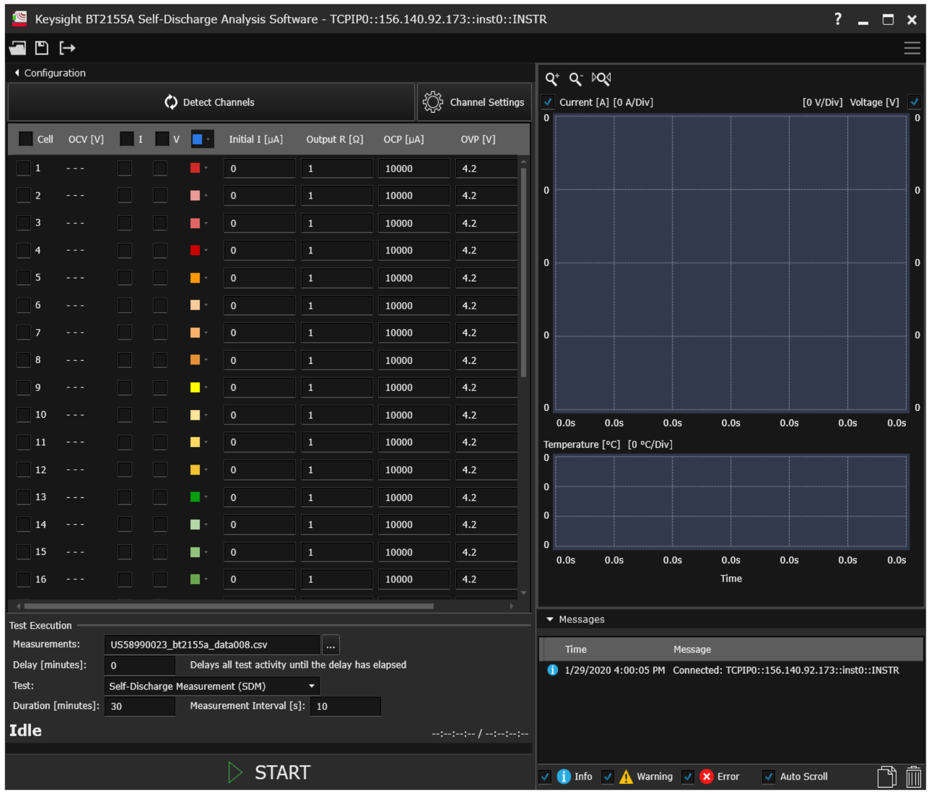
2 Select **Manage Instruments**. This displays the Manage Instruments dialog. The software identifies any BT2152B Analyzers attached to the PC (by LAN or USB connections) and lists them in the dialog.



3 Select the BT2152B you want to use, and then click the **Connect** button.

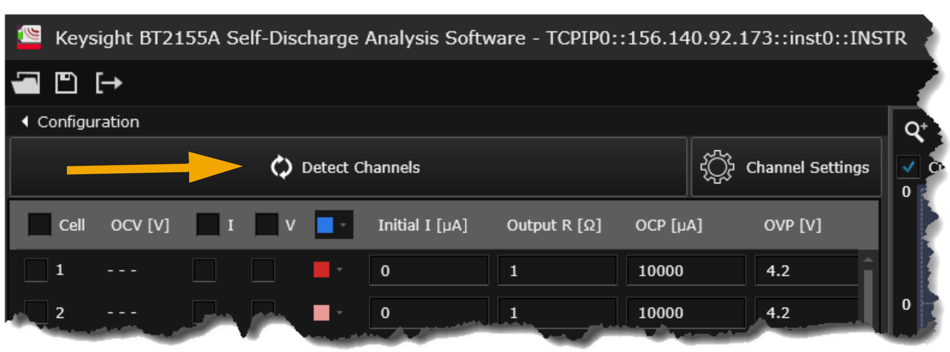


4 Click the **Close** button to close the Manage Instruments dialog. The BT2155 software displays the channel and cell information for the analyzer on the main screen.



Detect Channels

The next step is to detect channels. Click the **Detect Channels** button to automatically detect the channels with connected cells and display the OVC [V] for each channel in the OCV [V] column.



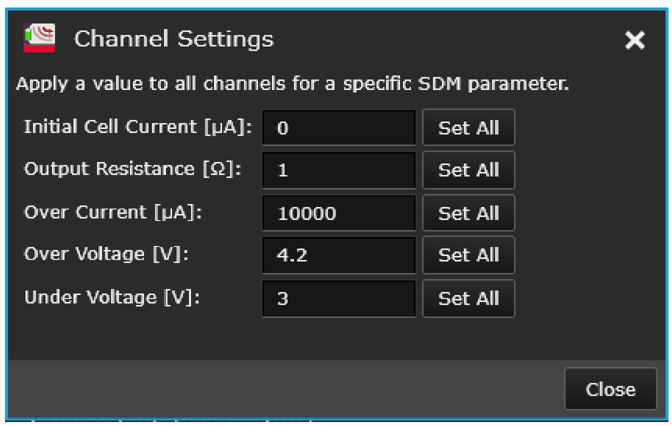
Why do this? The display of the measured cell voltages can show if you have any bad connections. You also need to know the cell voltages before setting the OVP and UVP values for each cell. Knowing your cell voltages helps you see significant differences between the states of charge of each cell. Cells with different SOCs show different self-discharge behavior.

Set Global Channel Settings

You can easily begin your setup by entering common values for all cell channels. (You can set values for individual channels even if you enter global values here.)

1 Begin by clicking the **Channel Settings** button.

This displays the Channel Settings dialog, which shows the default values:



2 Type values into the fields that you wish to set values for. Allowable ranges are as follows:

- **Initial Cell Current [μA]:** -10,000 to +10,000
- **Output (series) Resistance [?]:** 0.001W to 10
- **Over Current protection [μA]:** 0.0 to 10,000
- **Over Voltage protection [V]:** 0.5 to 4.5
- **Under Voltage protection [V]:** 0.5 to 4.5

3 Click the **Set All** button next to each field that you modify. This sets the value for all channels.

4 Click **Close** to close the dialog and apply the values.

Select and Configure Individual Channels

Even if you have set global values for channels, you can override the global value for individual channels. (The total number of channels displayed is determined by the number of channels the BT2152A/B analyzer is licensed to test.)

Select Channels Select (check) the checkbox for each channel you want to include in your test. You can also select the checkbox at the top of the cell column to include *all* channels to include in the test. (You can also select all channels and then deselect (uncheck) any channels you do not want to include.)

Other Channel Settings To set any of the channel parameters manually, select (check) the check boxes or type values into the fields. A checkbox at the top of the column lets you select all channels.

- **I**—select (check) to show current levels for the channel in the test plot.
- **V**—select (check) to show voltage levels for the channel in the test plot.
- **Initial I [µA]**—type a value in micro-amps for the starting current.

  For your initial self-discharge measurements, try to use an initial current value that is close to the final self-discharge current value for your cell. This can shorten the time needed for the measurement to settle to a stable value.

  For the most common types of Li-Ion cells, the typical self-discharge current depends on cell capacity. Keysight recommends that you choose an initial current value near the low end of the range of expected values of self-discharge current.

Cell Capacity	Typical Self-Discharge Current
Coin cells < 2 Ah	0 – 10 µA
Small cells 2-5 Ah	5 – 40 µA
Large cells > 5 Ah	20 – 200 µA

  See “Adjusting Initial I Values” on page 35 for more information.

- **Output R [?]**—type a value in Ohms for the series resistance. A higher value increases the settling time of the measurement but reduces the sensitivity of the measurement to temperature changes. Because of this, Keysight recommends that you use a higher value for your first few SD measurements.

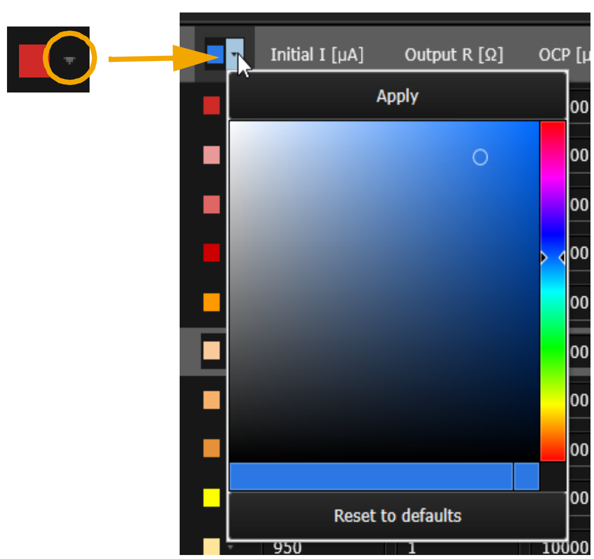
Example The following example shows how a user has: 1) selected channels 5-9; 2) set *global* values for Output R to 0.5 ?; and 3) set different values for Output R and OVP for channels 6 and 7 only:

Cell	OCV [V]	I	V	Color	Initial I [µA]	Output R [Ω]	OCP [µA]	OVP [V]	UVP [V]
1	- - -	✓	✓		0	0.5	10000	4.2	3
2	- - -				0	0.5	10000	4.2	3
3	- - -	✓	✓		0	0.5	10000	4.2	3
4	- - -				0	0.5	10000	4.2	3
✓ 5	- - -	✓	✓		0	0.5	10000	4.2	3
✓ 6	- - -	✓	✓		0	0.6	10000	4.0	3
✓ 7	- - -	✓	✓		0	0.6	10000	4.0	3
✓ 8	- - -	✓	✓		0	0.5	10000	4.2	3
✓ 9	- - -	✓	✓		0	0.5	10000	4.2	3

(Optional) Choose Plots and Colors

You may want to change the plot colors to better see the results for individual channels. If you want to observe only one or a few channels in the plot area, just turn off (uncheck) the I or V plots for any unwanted channels.

Keysight recommends that you use the default plot colors for your first SDM tests. But you can also change the plot colors to make the test plot easier to read. For example, you can use the color selection tool at the top of the column to set all plots to the same colors and then set the desired channels to a highlight color.



Run Your First Tests

Make sure that you have connected the cells to be tested, attached the thermistor, and configured the test parameters. You are now ready to run a test.

For your first test or first few tests, Keysight recommends that you use the following procedure.

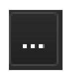
1 Click **Detect Channels**. This gives you updated voltages for the cells attached to the analyzer and shows any bad connections.

2 Make adjustments as needed:

- Adjust any OVP and UVP settings as needed.
- Replace any bad cells.
- Adjust or repair any bad connections.

3 (Optional) Set the file and delay options in the Test Execution part of the screen:

- **Measurements**: This file holds your test results. The system automatically creates the file name. (The file is a comma-separated value (.csv) format so that you can import it into a spreadsheet program. See “Exporting, Saving, and Loading Test Data and Settings” on page 36 for more information.) Click on the selection icon to you choose the folder where you want to save the test results.



- **Delay [minutes]:** You can delay the start of the test. (For example, you may want to give a visual inspection of the connections or the BT2152B may need more time to finish its 1-hour warm-up.)

4 Set up an OCV monitoring test to see how stable the cell temperatures are:

a In the Test Execution part of the screen, use the drop-down menu to select **OCV Monitoring**.

b Set the Duration [minutes] field to at least 60 minutes.

c Click **Start**. 

d Let the test run for its duration and then note the temperature plot in the results area. Ideally, you should see a graph that shows that your test environment is holding the temperature to within ± 0.2° C.

e If your test setup is not keeping the cells in the correct range, adjust your thermal environment. (See “Creating a Thermally Stable Environment” on page 22 for more information.)

Although this test can take a long time (depending on how stable the environment of the cells is), you will learn vital information about how thermally stable your test setup is. Any effort you make now to achieve temperature stability pays for itself by giving you valid and useful self-discharge current measurements.

5 Run an SDM test with in-situ wire calibration.

Accurately calibrating for any resistance of the cabling that connects the BT2152B Analyzer and the actual cells under test is especially important when using Output Resistance settings of < 1 Ω, or when comparing the self-discharge behavior of multiple cells against each other. The BT2155A software lets you perform an automatic calibration as part of your SDM test.

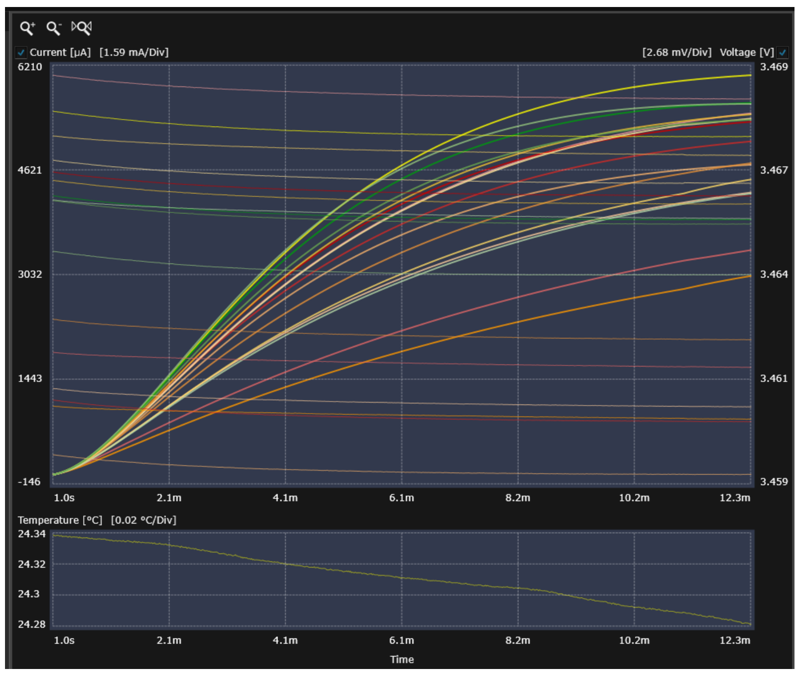
Use this procedure:

- **a** In the Test Execution part of the screen, use the Test drop-down menu to select **Low (1 mA) in-situ cal preceding SDM**. (This calibration adds about 90 seconds to the test duration.)
- **b** Set the Duration [minutes] value to a large value in the range of **480**-**720** minutes (8-12 hours). For your initial tests, it’s generally better to run a long-duration test so that the cells have enough time to settle to their usable or final values

  The long test improves the chances that you can see any issues that affect your measurement results, such as temperature stability, charge redistribution, initial current value. You can then take actions to mitigate and improve those issues. Fixing these issues is important to getting faster measurements that produce valid results.
- **c** Set the Measurement Interval [s] value in the range of **10-60** seconds, which Keysight recommends as a good typical range for your initial measurements.
- **d** Click **Start**. 

What to Expect During a Test

- A test runs until it reaches the **Duration** time that you set in the test execution parameters or unless you click ABORT to stop the test.
- As the system matches cell voltages, it may take a few minutes for the first cell test data to plot on the screen.
- Cell voltage tends to be a flat line. However, as the cell temperature fluctuates, you may also see the cell voltage rise and fall. This allows you to determine the cell's temperature sensitivity.
- The plots that vary most are the current plots. The relatively horizontal plots are the cell voltages. These should not vary much after the start of the test because the BT2152B holds the cell voltages constant.
- Temperature is plotted below the Current/Voltage graph. The following graphic shows the current and voltage plots for 16 cells after 12-minutes.



- If protection is triggered during a test (e.g., if the OCP, OVP, or UVP exceeds their specified test limits), the software automatically disables the channel's visibility on the plot. This prevents the chart from rescaling itself. The program continues and all data from all channels is stored in the log file.
- You can use the **Manage Instruments** dialog to disconnect from a BT2152B during an active test. This action stops any active OCV test and ignores any test delay that you set up in the test execution parameters. However, disconnecting does *not* stop an active SDM test. This allows you to disconnect from the instrument during a long test and then reconnect to it later to check test progress. (See "Connecting to the BT2152B Analyzer" on page 26 for more information.)

After Your Test Runs

What Do Good Test Results Look Like?

- Figure 12 shows a sample what you might see for an I/V plot of a four-hour SDM test.
  - Voltage plots are thinner and are typically flat.
  - You can hold the cursor over each plot line to get a pop-up of SD data.
  - Ideally, the cell temperature will vary no more than ± 0.2° C. (The sensitivity of cells to temperature change varies depending on cell chemistry and design, so you may be able to obtain good self-discharge measurement results with a variation in temperature larger than ± 0.2° C.)

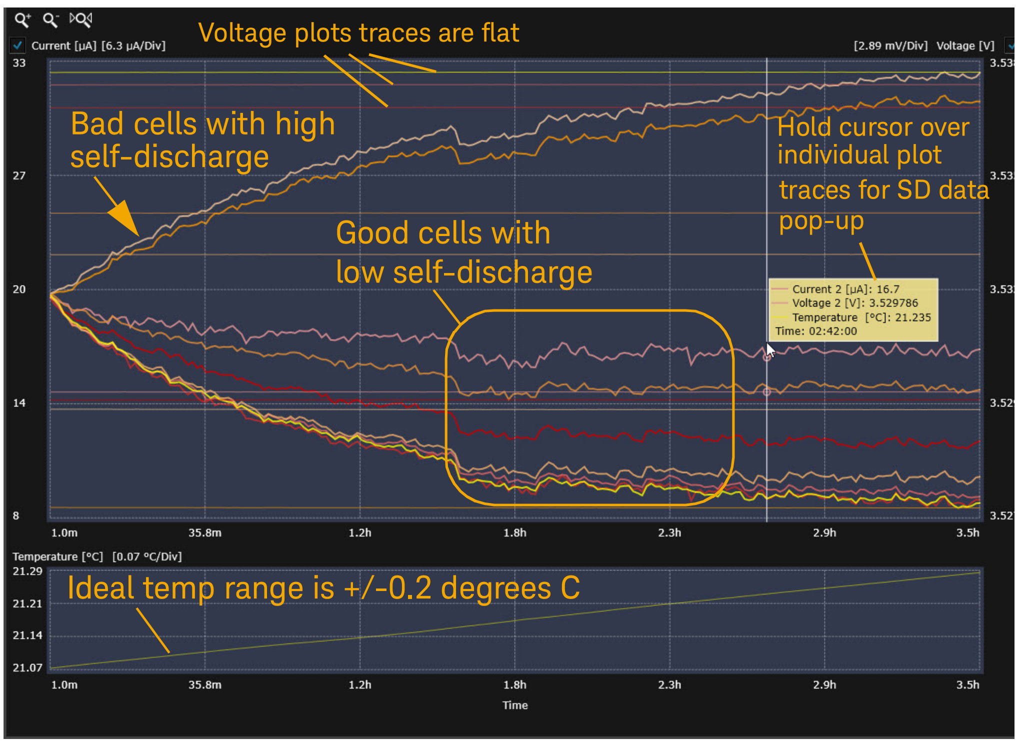


Figure 12 Divergent Current Plot Probably Indicates Bad Cell

- A "good" test result depends on your goals for the test:
  - If your goal is comparing the SD current measurements of cells against each other, perhaps to distinguish good cells (with low self-discharge) from bad cells (with high self-discharge). You can likely see the difference between good versus bad cells while the measured cell currents are settling to their final values, as is shown in Figure 12. Good cells tend to cluster together with the self-discharge trace following a mostly horizontal path on the I/V plot.

- If your goal is to wait for all cells to reach their final, stable SD current measured values, use a longer test that gives the cells adequate time to settle. Again, the I/V plots for good cells tend to cluster around each other as they approach stable values, and the plot traces become more horizontal (as shown in the traces that go through the rounded box in Figure 12). When the current traces do not change much with time, you know you are seeing the practical self-discharge rate. That is, when the self-discharge rate reaches some kind of stable value, the current traces will be mostly horizontal with only small vertical variations.

Adjusting Initial I Values

After the test runs, note the final self-discharge current value for your cells under test. You can then use this value to adjust the Initial I [µA] value for cells in the test configuration settings. (See “Initial Power-on and Configuration” on page 25 above.) This can shorten the time needed for the measurement to settle to a stable value when you run subsequent tests on that set of cells.

Exporting, Saving, and Loading Test Data and Settings

You can save test data and then reload it into the software for future analysis. You can also view your measured data and test setup data in CSV format, usable by Microsoft Excel and other common spreadsheet programs. You can then use the spreadsheet program's features to analyze the measured data.

Exporting Your Test Data to a CSV File Click the export icon ( ) in the task bar. (If you do this while a test is running, only the data collected so far is exported.) The BT2155A software saves the data as a comma-separated (.csv) file. A typical MS Excel export for a 24-cells looks like the following:

A1 | Keysight BT2155A

	A	B	C	D	E	F	G	H	I	J	
1	Keysight BT2155A										
2	App Version 2019										
3											
4	Instrument Configuration										
5		Self Disch	Keysight T	BT2152B	US589900:	A.04.76-3(	TCPIP0::156.140.92.173::inst0::INSTR				
6											
7		Channel	Initial Cell	Output Re	OCP (A)	OVP (V)	UVP (V)	External Wiring Resistance (ohm)			
8		1	0	1	0.01	4.2	3	0			
9		2	0	1	0.01	4.2	3	0			
10		3	0	1	0.01	4.2	3	0			
11		4	0	1	0.01	4.2	3	0			
12		5	0	1	0.01	4.2	3	0			
13		6	0	1	0.01	4.2	3	0			
14		7	0	1	0.01	4.2	3	0			
15		8	0	1	0.01	4.2	3	0			
16		9	0	1	0.01	4.2	3	0			
17		10	0	1	0.01	4.2	3	0			
18		11	0	1	0.01	4.2	3	0			
19		12	0	1	0.01	4.2	3	0			
20		13	0	1	0.01	4.2	3	0			
21		14	0	1	0.01	4.2	3	0			
22		15	0	1	0.01	4.2	3	0			
23		16	0	1	0.01	4.2	3	0			
24		17	0	1	0.01	4.2	3	0			
25		18	0	1	0.01	4.2	3	0			
26		19	0	1	0.01	4.2	3	0			
27		20	0	1	0.01	4.2	3	0			
28		21	0	1	0.01	4.2	3	0			
29		22	0	1	0.01	4.2	3	0			
30		23	0	1	0.01	4.2	3	0			
31		24	0	1	0.01	4.2	3	0			
32											
33	SDM Test										
34	Start Time	#########									
35	Duration	00:00:30:00									
36	Measuren	10									
37	Pre-test C	None									
38											
39	Time (s)	Temp (C)	I1 (A)	I2 (A)	I3 (A)	I4 (A)	I5 (A)	I6 (A)	I7 (A)	I8 (A)	I9
40	10	22.93504	-1.39E-07	-1.18E-07	-2.14E-07	-1.80E-07	-5.55E-08	-1.78E-07	-1.89E-07	-7.91E-08	-7
41	20	22.94487	-2.68E-07	-2.16E-07	-4.17E-07	-3.50E-07	-1.15E-07	-3.31E-07	-3.96E-07	-1.41E-07	-9
42	30	22.94514	-4.30E-07	-3.31E-07	-5.81E-07	-5.83E-07	-1.98E-07	-4.94E-07	-5.79E-07	-2.11E-07	-1

US58990023_bt2155a_data001

Saving and Loading Test Data -To save the instrument settings and data collected in a .kss format file, click the Save Measurement icon ( ) in the task bar. The BT2155A software saves the instrument settings and data collected. (Partial data is saved if a test is currently running.)

To load a previously saved file, click on the Load Measurement icon ( ) in the task bar. This opens a file selection window so that you can load a previously saved settings file (.kss format). When you select a file, the software loads the instrument settings and I/V plots from the saved data into the plot area.

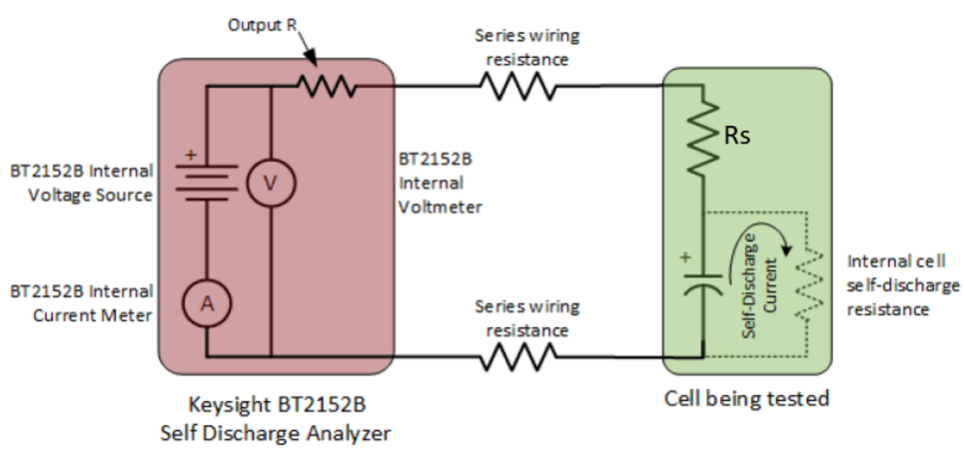
5. Cell Testing Tips and Best Practices

This section provides some concepts to improve your test results and explains how to deal with unexpected results. In general, getting good results with the potentiostatic method requires attention to detail on both the system setup and preparation of the cell.

- Keep the test environment stable:
  1. Use a temperature controlled environment.
  2. Prevent movement of the cells under test or of the connection wiring.
  3. Use shielded test leads and keep the overall test environment shielded from interference, etc.

Understand What Happens During Measurement

During a self-discharge measurement, the combination of the analyzer, wiring, and cell create an electrical circuit that can be modeled as shown below.



- The capacitance of the cell is very large, typically hundreds to tens of thousands of farads.
- The effective series resistance of the cell (Rs) is very small, typically a few milliohms.
- The output resistance (Output R) of the analyzer is programmable with a range from 10 m Ω to 10 Ω.

- Good measurement practice is to calibrate the resistance of the wiring for each channel. (The BT2155A software allows you to include this calibration function as part of SDM test execution.) This effectively eliminates the resistance of the wiring from the circuit for the purposes of the measurement.
- All of the above means that the voltage and current sources in the analyzer "see" a simple RC series circuit. In this circuit, the R value is usually dominated by the Output R of the analyzer.

These facts have implications for the behavior of the measurement process that you will see as you use the analyzer.

- The measured current, which is also the current being sourced by the analyzer, tends to change exponentially with a time constant equal to R*C. The current either rises or falls exponentially, depending on the relative values of the analyzer's voltage source and the cell's voltage. You can see this most clearly when there are no other phenomena active in the circuit, such as:
  - The cell's voltage changing during the measurement.
  - Other sources of current being present in the cell, such as charge redistribution effects.
- The higher the Output R value, the larger the RC time constant, and the slower the current settles to a final or stable value. Conversely, the lower the Output R value, the faster the current settles to a final or stable value, which means a faster self-discharge measurement.

  However, the voltage of the cell is typically highly sensitive to temperature. If the temperature of the cell changes, even by a degree or two Celsius, the voltage can change either up or down by several millivolts or more.
- In the equivalent circuit, if the total R is constant, then as the cell voltage decreases, the measured current increases, and vice versa. Thus, temperature changes create unwanted variation or noise in the current measurement.
- For relatively large values of R, a given change in cell voltage produces a relatively small amount of variation in the measured current. For relatively small values of R (especially if the Output R starts to approach zero), the same given change in the cell voltage produces a relatively large amount of variation or noise in the measured current. Thus, you must decide which values give you the best trade-off between decreasing Output R (to decrease the measurement time) or increasing Output R (to decrease the sensitivity of the measured current to temperature changes).

Considerations for Good Self-Discharge Measurement

Here are some basic considerations for making good self-discharge measurements (SDM):

- Two necessary conditions for valid SD current measurements are that the measured cell voltage and cell temperature must be stable. Without stable temperature, cell voltage cannot be stable. If cell voltage is not stable (because of temperature or other variations), currents flow in the potentiostatic measurement setup (including within the cell). These currents are different than the self-discharge current itself and act as noise interfering with the SD current measurement.
- While these are necessary conditions, by themselves they are not sufficient conditions for good measurement. If cell temperature and voltage are perfectly stable, it still takes time for the SD current measurement to settle to a final value.

  Note that if your goal is to compare the SD current measurements of cells against each other, perhaps for the purpose of distinguishing good cells from bad cells, you probably don’t need to wait for all cells to reach their final, stable SD current measured values. Likely, you will be able to distinguish good versus bad cells while the measured cell currents are settling to their final values.
- If the measured SD current is negative, it means that the cell voltage has increased above the voltage applied to the cell by the BT2152B analyzer, and therefore the cell is discharging into the analyzer. This is not a valid SD current measurement. Negative measured current is typically caused by the cell temperature changing after the start of the measurement in a way which caused the cell voltage to increase.
- Keysight recommends that you plan to make your first SD measurements of long duration. This lets you see any effects on the measurement caused by instability in cell temperature and by the initial current setting that you have chosen. (This is the initial value of that current that the analyzer attempts to source into the cell that eventually equals the cell’s SD current). See “Select and Configure Individual Channels” on page 28 for information on setting Initial I.
- Another factor that greatly affects the time needed to reach a stable measurement value is the output resistance setting for the measurement. Selecting a higher output resistance value causes the settling time of the measurement to increase but reduces the sensitivity of the measurement to temperature changes. Using a smaller value for Output R may shorten your test time, but for your first few SD measurements, it is generally better to choose a higher output resistance value (and the longer measurement time) to minimize the temperature sensitivity of the measurement. See “Select and Configure Individual Channels” on page 28 for information on setting Output R.

Temperature Control and Effects

A cell's "natural" rate of self-discharge current depends on temperature. Cells normally have a small amount of self-discharge. Many factors in a cell's design and makeup affect this value. For cells at a typical room temperature of 23 ^{O}C, testing has shown typical discharge rates that range from just a few micro-amperes for sub 1 Ah cells to 50 to 100 micro-amperes for 10 to 20 Ah cells.

A cell's self-discharge current approximately doubles for a 10 ^{O}C increase in temperature. (This applies to good cells not exhibiting excessive self-discharge leakage current caused by internal defects or other problems.)

Temperature affects the measured self-discharge rate

Temperature also affects self-discharge current *measurement*. A cell's voltage-to-temperature dependency is expressed as a temperature coefficient of voltage (TCV), quantified in microvolts per ^{O}C (µV/^{O}C). The potentiostatic measurement of a cell's self-discharge current relies on matching an external voltage to the cell's voltage and then connecting them together. The self-discharge current measurement is thus impacted by any change of the cell's temperature (and thus voltage) afterwards.

You can do several things can reduce the effect of temperature on self-discharge current measurements:

- A cell's TCV depends on its SOC. It can vary from as low as zero at certain points to as much as 100s of µV/^{O}C (positive or negative), typically at very low SOC levels. Generally, having the cell charged to 70% SOC or better helps reduce the cell's TCV. However, you may have to contend with a TCV in the range of 20 to 100 µV/^{O}C.
- An indoor test environment can experience temperature variations of a few ^{O}C each day. The series resistance between the potentiostatic source and cell affects the measurement's sensitivity to the cell's TCV.
  - Increasing this series resistance reduces the sensitivity to a cell's TCV but increases the time it takes for the measurement to settle to the final self-discharge current value.
  - The BT2152B has a programmable series resistance for this purpose.
- Depending on how long the self-discharge measurement takes, you may find it necessary to take further steps to hold the cell's temperature steady. Possibilities solutions include:
  - Surround the cell with thermal insulation
  - Use a substantial thermal mass to stabilize the cell temperatures.
  - Use a stable thermal environment, ideally < ±0.2 ^{O}C.

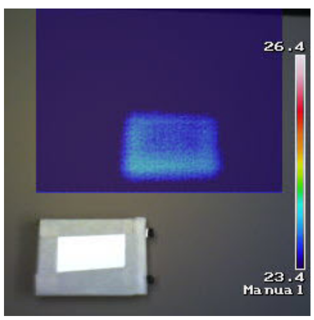
Ambient temperature causes OCV to change

The BT2152B uses current to oppose temperature-induced OCV changes. The amount of current is proportionally opposite of the OCV change. Cell temperature is the key here. Check the temperature plot for significant variations. It is best to keep the cells in a stable, temperature-regulated environment.

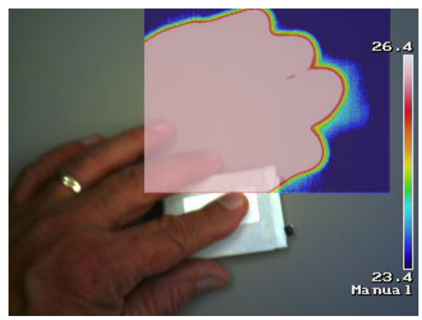
Avoid physical contact with cells

Touching a cell under test can affect cell voltage by causing a temperature variation in the cell. This effect may last for several minutes after releasing the cell. Once you connect the cells to the wiring or a fixture connected to the analyzer, wait for the temperature of the wiring and clips or probes to stabilize and reach equilibrium with the cells before you start the SD measurement.

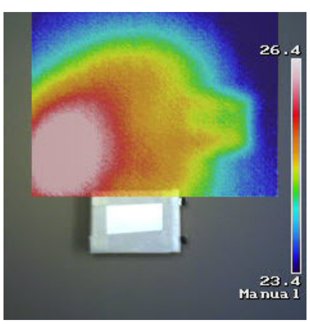
The following thermal plots show how thermal effects can last for up to five minutes.



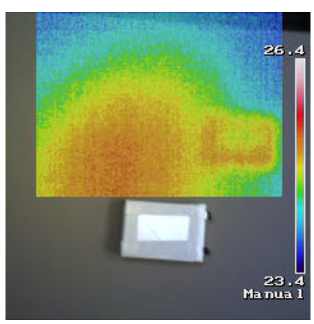
Prior to touching the cell



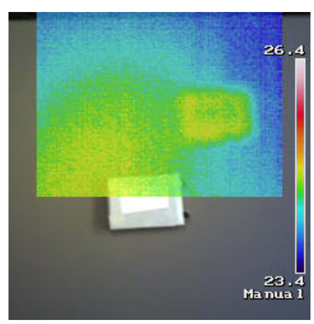
Holding cell for one minute



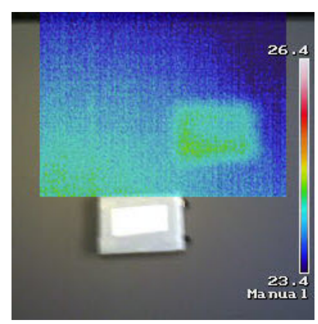
Immediate after releasing cell



One minute after releasing cell



Two minutes after releasing cell



Three minutes after releasing cell

Figure 13 Thermal plots showing effects over one minute intervals

Wiring and Cell Contacts

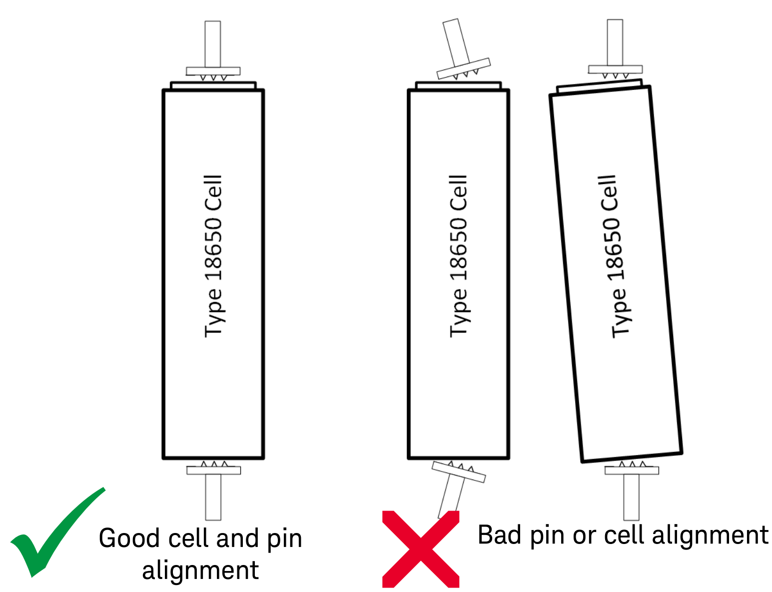
Ensure a high quality connection to the cell(s) under test by making sure the contacts of the wiring that connect the analyzer to the cells are solid and secure. SDM tests require high-precision current measurements made at very low current levels (typically 1 -100 µA). Thus, small changes in the voltage of the cell can cause noise in the current measurement.

The BT2152B analyzer provides very low current levels into the cell during the measurement process. These low currents may not burn though any oxidation or contamination on the cell contacts. Ensure that the cell contacts are clean and free from an oxidation layer that can affect the effective total series resistance of the current path from the analyzer through the cell.

If measuring the SD of a pouch cell, make sure that the clips or grabbers make good contact with the tabs of the cell, piercing through any insulating layer on the tabs.

If you measure the SD of a cylindrical or prismatic cell, ensure the test leads or wiring make good contact with the cell. Spring-loaded cell holders or contacts must make solid contact. If you use probes to make contact with the cell, ensure the probes are positioned correctly on the cell contacts. A probe with a rounded head allows a greater tolerance of probe-pin position relative to the cell, but the trade-off is that a probe with a rounded head is less likely to puncture through any oxidation on the cell contacts. A probe pin with a pointed tip can puncture an oxidation layer but may require tighter control of position, especially for cylindrical cells where a mis-positioned probe pin can enter the cell's vent holes.

Also, make certain the connections to the cell(s) are solid. If you use a fixture to hold the cells, the individual cells or test bed pins could get misaligned or moved slightly. This causes poor contact with the test fixture. You might see this on a current/voltage plot as one or more cells wandering or looking more unstable than the others.



Output Resistance

- Keep the series resistance (Output R) high enough to reduce the impact of changing Open Circuit Voltage (OCV) on the measured current. High series resistance means long settling time, a low resistance means the test runs faster.
- You can get faster tests by setting a low series resistance, *but* this increases the temperature sensitivity. If you must use a low R value to reduce test time, the test data may have excessive noise due to temperature variations.
- See “Select and Configure Individual Channels” on page 28 for information on setting the Output R setting.

Stress and Vibration

Mechanical stress, deflection, or vibration can alter a cell’s voltage and thus change the self-discharge current.

Static stress can induce a relatively fixed voltage shift while vibrations can create substantial peak-to-peak deviations in the measurement. Take care that you:

- Do *not* subject the cell to stress or movement.
- *Do* isolate the cell from any direct vibration that may exist.

Cells can be microphonic: any touching or tapping of them or any vibration or shock affects the cell’s voltage and thus the measured current value.

- Mount the temperature sensor or attach it to the cell *before* you begin a test so that you do not have to touch the sensor or adjust its connection during the test.
- Make sure the cell is not subjected to vibration in the physical test environment.
- Once a self-discharge test has started, do not move or otherwise disturb the cell.

NOTE In addition to avoiding vibration *during* a test, make sure that all cells “rest” and stabilize after being handled. This reduces the effects of mechanical stress from handling and heat transfer from the body temperature of the person handling the cells.

Redistribution and Achieving Charge Equilibrium

You will get your best SD measurement results from cells that are sufficiently rested or with sufficient redistribution of their charge. Redistribution effects creates current offsets or noise on top of the SD current measurement, and may make the measured SD current appear higher than anticipated.

Right after a cell is charged or discharged, it takes a considerable amount of time for the electron charge to uniformly distribute itself within the cell and reach equilibrium. During this time, the cell's voltage drops or rises, depending on whether it had been charged or discharged. In comparison, when a cell's charge is fully distributed and at equilibrium, cell voltage falls off at a much lower and more linear rate due to the internal self-discharge current. Depending on the cell's makeup, it can take from a few hours to a week for a cell to reach charge redistribution equilibrium.

When you connect a cell to the BT2152B, the analyzer holds its output voltage constant after it goes through the cell voltage matching process. If the cell is at charge equilibrium, one influence on the cell's voltage is due to self-discharge. Using potentiostatic measurement, the BT2152B holds the cell voltage constant and needs only to replenish the self-discharge current to maintain constant voltage. However, a cell that has recently been charged or discharged and then connected to the BT2152B temporarily sources additional charging current (after charging) or temporarily sources less current to the cell (after discharging). The peak of this transient current can be greater than the self-discharge current alone.

Current Transients

If you see transients that diminish with time in the current plot, there may be several possible causes:

- The BT2152B analyzer may not be sufficiently warmed up. Make sure that you have allowed at least one hour for the analyzer to warm up and stabilize.
- The cells may be undergoing charge redistribution following a charge or discharge event. (See "Redistribution and Achieving Charge Equilibrium" above.)
- The Initial I current value is different than the cell's self-discharge current level. When the analyzer begins to source current into the cell at the start of the measurement, the combination of analyzer, wiring, and cell behaves like a simple RC circuit with the measured current exponentially changing to its final value.

RF Noise and Interference

RF interference can result in very noisy I/V plots for all cells, as shown in the following example, which shows very noisy measurements of 30 μA peak-to-peak.

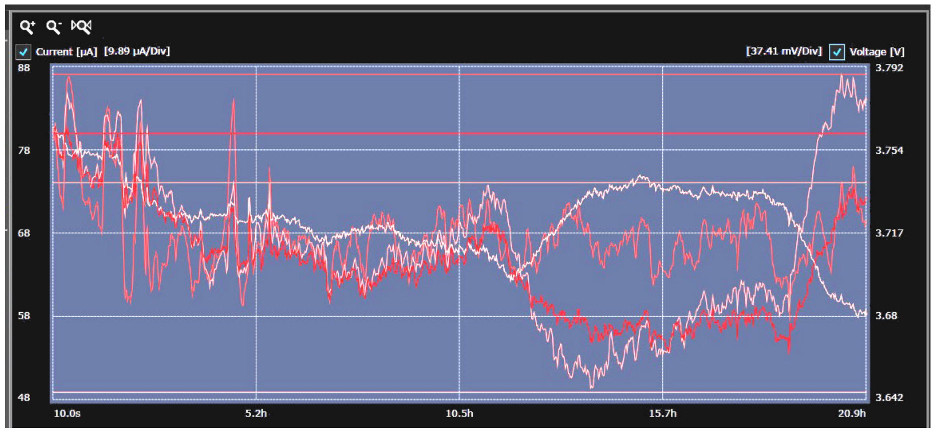


Figure 14 Very Noisy Measurements Possibly Caused by RF Interference

If you see this kind of plot, check for RF interference. Use high-quality, shielded, twisted pair cabling for as much as possible of the distance between the analyzer and the cells under test.

Compare the I/V plot shown above to the following, which uses shielded cables and twisted pigtail leads, etc. Noise is not as prevalent, and the overall measurements are much quieter.

Figure 15 Quieter Measurements

The cells themselves are also susceptible to RFI interference. Make sure the cells are in an appropriate shielded enclosure. Note also that some cell types are more susceptible to RFI than others.

Oscillations

In the equivalent circuit of the measurement, the total series resistance must be a positive value, or the circuit becomes unstable. If you see an oscillation in the measured current similar to those shown in Figure 16, a slightly negative total R could be the cause. This could happen if the Output R of the analyzer is programmed to a very low value and the actual wiring and contact resistance has decreased since the external wiring calibration was done. If the actual wiring and contact resistance decrease enough, the potentially negative value of the internal programmed resistance in the analyzer can cause the total circuit resistance to become negative as the analyzer operates on it.

In such an event, check that the wiring and contacts are good, and make sure that you recalibrate the external wiring resistance. (You can perform wire calibration before each SDM test. See “Run Your First Tests” on page 31 or perform a a calibration by clicking on the main menu and then **Calibration**.)

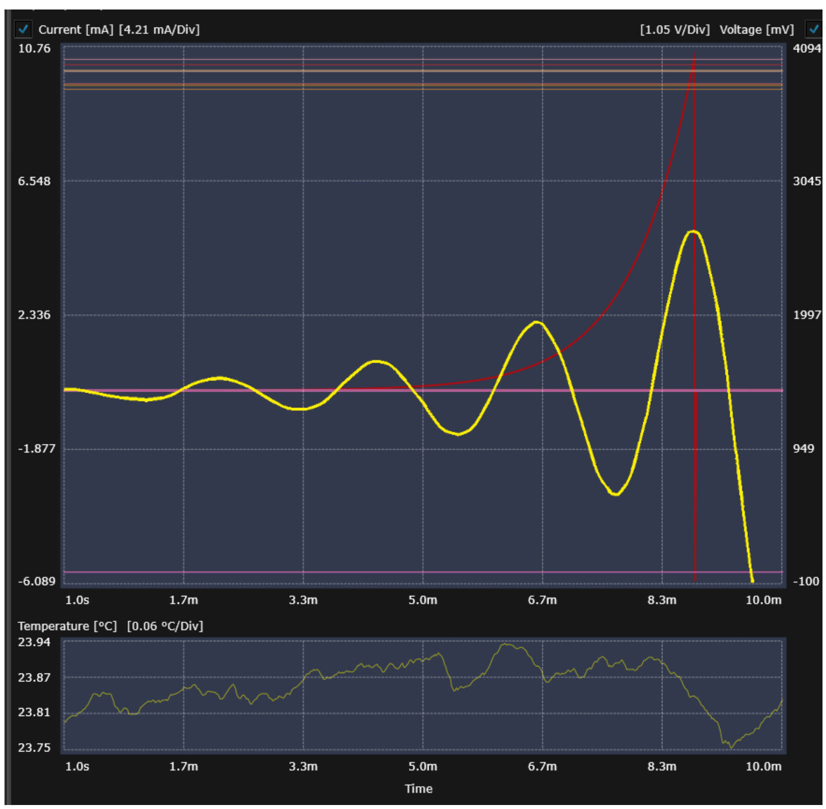


Figure 16 Oscillating and Spiking Current Waveforms

Effect of SOC on Measurements

The temperature sensitivity and final SD current value both depend on the state of charge (SOC) of the cell. Cells at different SOC show differences between the test traces displayed. This can help if you want to observe differences in SDM measurements across cells of various states of charge in the same test run. Alternatively, if you want measurements with tightly grouped traces, make sure all cells are tightly grouped by SOC before taking measurements. Temperature also affects the measured self-discharge rate. (See also “Temperature affects the measured self-discharge rate” on page 40.)

Non-Matched Current Behavior

Cells with different chemistries or different SOC levels likely present different self-discharge current characteristics when measured. Also, cells that are at different temperatures or that have different SOC levels likely have different open circuit voltages that you can see in the measurement.

If a cell has a high level of self-discharge current (perhaps a bad cell), and the Initial Current Value is set below the self-discharge level, the measured current increases with time, starting at the initial value and climbing to the level of the cell’s self-discharge. In contrast, if a cell has a relatively low level of self-discharge, and the Initial Current Value is set above the self-discharge level, the measured current decreases with time, starting at the initial value and dropping to the level of the cell’s self-discharge.

Cell Matching Failures

A cell match failure shows in the Diagnostics dialog (available from the main menu button). A cell match failure might be caused by:

- Poor connections to the cell. (See “Wiring and Cell Contacts” on page 42.)
- Excessive noise picked up in the measurement. (See “RF Noise and Interference” on page 45.)
- Negative total output resistance due to an incorrect wiring resistance value. (See “Run Your First Tests” on page 31 or perform a a calibration by clicking on the main menu ☰ and then **Calibration**.)

6. Build on Your Test Experience

After you have succeeded with making an initial evaluation of the BT2152B analyzer, you may wish to find out more information. The Keysight BT2152A/B Operating and Service Guide, available from keysight.com, contains detailed information on topics such as the following:

Optimizing Initial I and Output R Values

Although you can get good results for evaluation purposes by using estimated values suggested in this guide, finding optimal values for Initial I current and Output R resistance can save measurement time without using excessively low output impedance (which is more susceptible to noise). The *Keysight BT2152A/B Operating and Service Guide* contains a more detailed procedure if you choose to perform more exacting measurements and consider additional tests.

Programming the BT2152B Analyzer

Although you do not need to be a programmer to get good initial SDM test results, you may wish to experiment with programming your BT2152B Analyzer using Standard Commands for Programmable Instruments (SCPI). You can use the **Instrument IO** utility from the BT2152B Web Interface Control Instrument Page or the **Interactive IO** utility from within the IO Libraries Suite to communicate with your analyzer. The *Keysight BT2152B/B Operating and Service Guide* contains much more information about programming and a reference of SCPI commands for the BT2152B.

Denoising Techniques

The BT2152B analyzer has built-in denoising algorithms to give you better data from your tests. However, you can also take steps to get additional denoising performance if you need more exact measurements. The *Keysight BT2152A/B Operating and Service Guide* contains a procedure for using this extra capability.

A. Fixture Design Guidelines

Although you may start with a simple desktop test setup for a few cells, you may eventually want to create a test fixture that can hold more cells. A good fixture can give you better measurements by reducing EM noise and thermal variations.

Due to the wide variation in cells, there are many ways to build a functioning test fixture. Keysight Technologies offers these guidelines and best practices to help you design and construct a test fixture that will successfully work for you when you use the BT2152B Self-Discharge Analysis system. In general, you need to consider:

- A case or framework for the fixture
- A base or cell tray to hold the cells under test within the fixture
- Cell-contact pins and wiring to connect cells to cabling connections
- Thermistor mounting and connection
- Consideration of temperature stability and minimizing EM interference

Specific Fixture Design Considerations

- The BT2152B Analyzer can test a maximum of 32 cells per analyzer.
- Self-discharge measurements are in the range of milliamps and microamps. This means the fixture design should be for low current, high precision measurements.
  - There is no need to use heavy wiring or high-current-capacity pins.
  - Wire path resistance and contact resistance are less critical.
  - There is no need for 4-wire measurements because the voltage drop with microamps flowing through the wire is minimal. Furthermore, the BT2152B Self-Discharge Analyzer can compensate for voltage drops in the wire without the need for 4-wire measurements.
  - These design recommendations include guidelines on how to minimize noise pickup.
- Self-discharge measurements have similar requirements to open-circuit voltage (OCV) measurements of cells. Therefore, you may be able to re-purpose an existing OCV fixture for these measurements. If you re-purpose an OCV fixture, please ensure it follows Keysight's recommendations in this document.
- Construction of the cell-holding base or tray depends on the shape and dimensions of the cell you want to test. With careful design, you can use the same base to hold multiple types of cells.

- Design of the cell-holding base or tray must prevent movement of the cells under test or of the connection wiring.
- The fixture design should include space for the thermistor to collect good temperature readings without touching the contact pins or cells under test.
- A metal case is not required but can provide advantages:
  - Metal provides RF shielding to prevent EM interference.
  - Metal acts as a thermal mass, which improves temperature stability.

Pin Choice

- Pin contact resistance should be low, in the range of 1 to several tens of milliohms. This is a reasonable specification for many probe types. You should be mindful of probe contamination and wear-out, which can result from changes caused over time by opening or closing the fixture or inserting cells for testing.
- Do not use high current pins with high mass. These pins may be at a different temperature than the cells. When the cells and high mass pins have different temperatures and then the pins touch the cell, the cell contacts change temperature slightly. This produces a short-term error in the self-discharge measurement. Thin pins used for voltage measurement are much better than high-current pins.
- For cylindrical or prismatic cells, round-headed, spring-loaded contact pins with sleeves give better results for minimizing wear and maintaining good contact with the cells under test.
- If you are designing the cell-holding base to accommodate multiple types of cells, you must find a common area for each pin to maintain contact with each type of cell.

Fixture Thermal Design

- Keysight also recommends that you create a fixture design that is thermally stable. One way to increase stability is to prevent airflow over the cells during the measurement. You can do this by:
  - Enclosing cells in a box with insulation
    —or—
  - Enclosing cells within insulation
    —or—
  - Using plastic shielding to block external airflow around the fixture
- Large cells have a high thermal mass. Often when these cells are under test, their thermal mass can stabilize the temperature inside the fixture. Also, adding thermal mass to the fixture itself (for example, by adding a heavy metal plate) creates additional dampening against temperature swings.

Sample Test Fixture Solutions

To facilitate evaluations, Keysight has produced small protective cell fixtures that meet all these requirements in this document. You can build a similar design for your own cells. The photos in Figure 17 and Figure 18 below show a metal enclosure that provides thermal insulation and EMI protection for one type of prismatic Li-ion cell. Spring-loaded pins make contact with the cells inside. The pins are mounted on a circuit board installed in the top cover of the metal box. This box contains 16 cells and 1 thermistor. The cable is a Keysight BT2181A 2-meter cable that plugs directly between the rear panel of the BT2152B and the top cover of the fixture.

Figure 19 on page 54 and Figure 20 on page 55 show another sample design for a test fixture for small cylindrical cells.

These designs are not compatible with automation or high-volume testing. To evaluate self-discharge measurements, however, these designs give you:

- A simple and safe way to connect to cells
- A good way to ensure that your cells stay at a stable temperature
- An easy way to ensure nothing shorts out the cells during testing

Figure 17 Sample Keysight Test Fixtures for One Type of Prismatic Cell

Figure 18 Sample Keysight Test Fixture for Prismatic Cells, Lid Removed

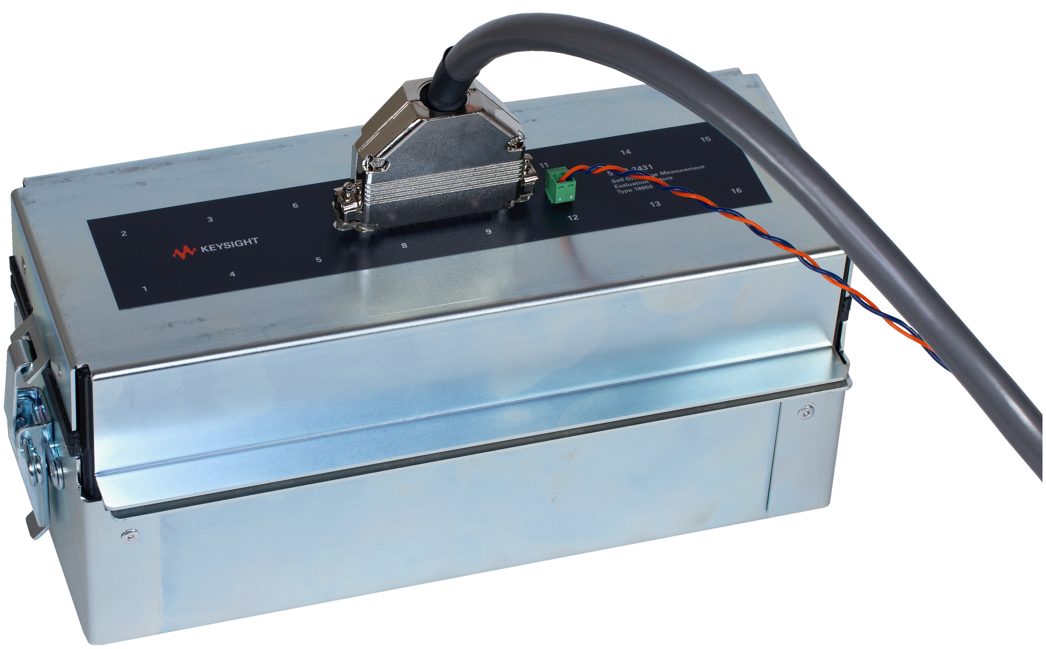


Figure 19 Sample Keysight Test Fixture for Cylindrical Cells with Cable and Thermistor

Figure 20 Sample Keysight Test Fixture for Cylindrical Cells, Lid Removed

B. Pin Information for Keysight Breakout Boards

If you plan to use a Keysight BT2180A breakout board with your system, you need to know which pins of the screw terminals on the breakout board connect to which pins of the BT2152B rear panel and to which channels of the analyzer. This appendix gives you the necessary pin-assignment information.

For additional information on cables and wiring connections, refer to the *BT2152B Self-Discharge Analyzer Operating and Service Guide*

32-Channel Mapping to 37-pin D Subminiature Connectors

CAUTION **Equipment Damage: Do not connect any channel wires to earth ground.**

Connector pins as viewed from the rear panel of the instrument. Pin numbers on the 2- and 4- meter accessory cables are reversed.

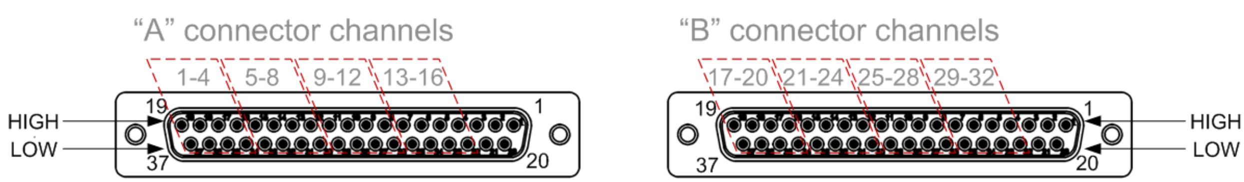


Figure 21 32-Channel Mapping to 37-pin

NOTE Connector pins 3, 2, 1, 21, and 20 are not used. Do not make any connection to these pins. Leave them floating, open, and disconnected

See Table 2 and Table 3 for additional pin information.

Table 2 "A" connector channels

Channels	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
HIGH pin	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4

Table 2 “A” connector channels

Channels	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
LOW pin	37	36	35	34	33	32	31	30	29	28	27	26	25	24	23	22

Table 3 “B” connector channels

Channels	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
HIGH pin	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4
LOW pin	37	36	35	34	33	32	31	30	29	28	27	26	25	24	23	22

Screw Terminals on the Breakout Board

See the following diagram for dimensions and screw terminal placements.

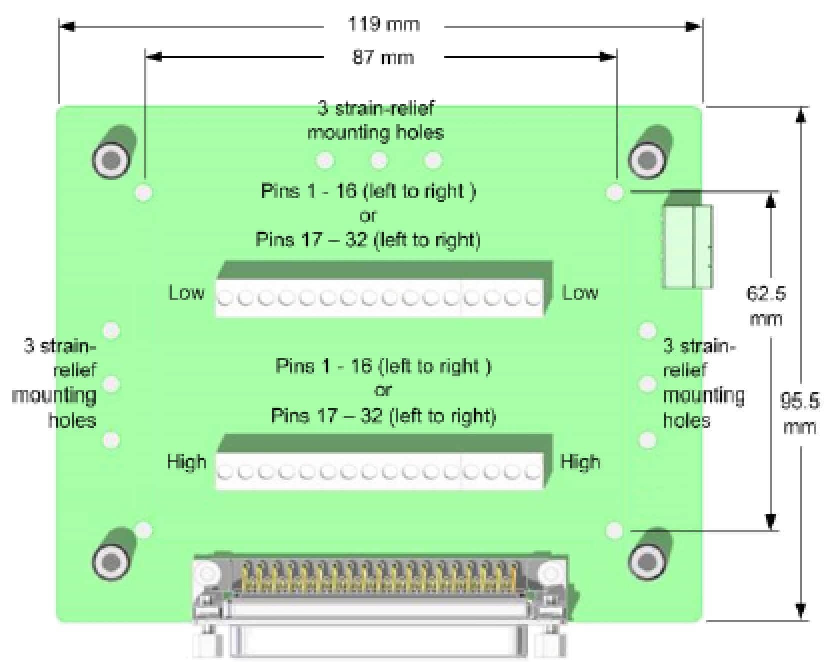


Figure 22 Keysight BT2180A Breakout Board Dimensions and Connections

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