User Guide

BT2191A, BT2192A

Self-Discharge Measurement System and Software

KEYSIGHT TECHNOLOGIES

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/BT2191A

www.keysight.com/find/BT2192A

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

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

Declaration of Conformity

Declarations of Conformity for this product and for other Keysight products may be downloaded from the Web. Go to http://keysight.com/go/conformity and click on "Declarations of Conformity." You can then search by product number to find the latest Declaration of Conformity.

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Safety Information

The following general safety precautions must be observed during all phases of operation of these instruments. Failure to comply with these precautions or with specific warnings or operating instructions in the product manuals violates safety standards of design, manufacture, and intended use of the instruments. Keysight Technologies assumes no liability for the customer's failure to comply with these requirements.

General

Do not use these instruments in any manner not specified by the manufacturer. The protective features of these instruments must not be impaired if it is used in a manner specified in the operation instructions.

Before Applying Power

Verify that all safety precautions are taken. Make all connections to the instruments before applying power. Note the external markings described under "Safety Symbols".

Ground the Instrument

Keysight instruments are provided with a grounding-type power plug. The instruments must be connected to an electrical ground to minimize shock hazard. The ground pin must be firmly connected to an electrical ground (safety ground) terminal at the power outlet. Any interruption of the protective (grounding) conductor or disconnection of the protective earth terminal will cause a potential shock hazard that could result in personal injury.

Unless otherwise noted in the specifications, these instruments or system is intended for indoor use in an installation category II, pollution degree 2 environment per IEC 61010-1 and 664 respectively. They are designed to operate at a maximum relative humidity of 5% to 80% at 40 °C or less (noncondensing). These instruments or system are designed to operate at altitudes up to 3000 meters, and at temperatures between 0 and 55 °C.Do Not Operate in an Explosive Atmosphere Do not operate in the presence of flammable gases or fumes.

Do Not Operate Near Flammable Liquids

Do not operate the instruments in the presence of flammable liquids or near containers of such liquids.

Cleaning

Clean the outside of the Keysight instruments with a soft, lint-free, slightly dampened cloth. Do not use detergent or chemical solvents.

Do Not Remove Instrument Cover

Only qualified, service-trained personnel who are aware of the hazards involved should remove instrument covers. Always disconnect the power cable and any external circuits before removing the instrument cover.

Keep away from live circuits

Operating personnel must not remove equipment covers or shields. Procedures involving the removal of covers and shields are for use by service-trained personnel only. Under certain conditions, dangerous voltages may exist even with the equipment switched off. To avoid dangerous electrical shock, DO NOT perform procedures involving cover or shield removal unless you are qualified to do so.

DO NOT operate damaged equipment

Whenever it is possible that the safety protection features built into these instruments have been impaired, either through physical damage, excessive moisture, or any other reason, REMOVE POWER and do not use the instrument until safe operation can be verified by service-trained personnel. If necessary, return the product to a Keysight Technologies Sales and Service Office for service and repair to ensure the safety features are maintained.

DO NOT block the primary disconnect

The primary disconnect device is the appliance connector/power cord when an instrument used by itself, but when installed into a rack or system the disconnect may be impaired and must be considered part of the installation.

Do Not Modify the Instrument

Do not install substitute parts or perform any unauthorized modification to the product. Return the product to a Keysight Sales and Service Office to ensure that safety features are maintained.

In Case of Damage

Instruments that appear damaged or defective should be made inoperative and secured against unintended operation until they can be repaired by qualified service personnel.

Measurement Limits

The Truevolt Series DMMs provide protection circuitry to prevent damage to the instrument and to protect against the danger of electric shock, provided the Measurement Limits are not exceeded. To ensure safe operation of the instrument, do not exceed the Measurement Limits shown on the front and rear panel.

The DMMs comply with EN/IEC 61326-2-1, for sensitive test and measurement equipment.

When subjected to transient radiated and/or conducted electromagnetic phenomena, the DMMs may have temporary loss of function or performance which is self-recovering. Recovery may take longer than 10 seconds.

When subjected to continuously present electromagnetic phenomena, some degradation of performance may occur.

Safety and Regulatory Symbols

CAUTION

A CAUTION denotes a hazard. It calls attention to an operating procedure or practice that, if not correctly performed or adhered to, could result in damage to the product or loss of important data. Do not proceed beyond a CAUTION notice until the indicated conditions are fully understood and met.

WARNING

A WARNING denotes a hazard. It calls attention to an operating procedure or practice, that, if not correctly performed or adhered to, could result in personal injury or death. Do not proceed beyond a WARNING notice until the indicated conditions are fully understood and met.

Products display the following symbols:

Refer to manual for additional safety information.

Earth Ground.

Chassis Ground.

Alternating Current (AC).

Direct Current (DC).

Standby Power. Unit is not completely disconnected from AC mains when power switch is in standby position

Indicates that antistatic precautions should be taken.

The CSA mark is a registered trademark of the Canadian Standards Association and indicates compliance to the standards laid out by them. Refer to the product Declaration of Conformity for details.

Notice for European Community: This product complies with the relevant European legal Directives: EMC Directive and Low Voltage Directive

The Regulatory Compliance Mark (RCM) mark is a registered trademark. This signifies compliance with the Australia EMC Framework regulations under the terms of the Radio Communication Act of 1992.

ICES/NMB-001

ICES/NMB-001 indicates that this ISM device complies with the Canadian ICES-001.

Cet appareil ISM est conforme a la norme NMB-001 du Canada.

This symbol represents the time period during which no hazardous or toxic substance elements are expected to leak or deteriorate during normal use. Forty years is the expected useful life of this product.

MSIP-REM-Kst-xxxxxxx

South Korean Class A EMC Declaration. this equipment is Class A suitable for professional use and is for use in electromagnetic environments outside of the home.

A 급 기기 (업무용 방송통신기자재)
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This product complies with the WEEE Directive (2002/96/EC) marking requirement. The affixed product label (see below) indicates that you must not discard this electrical/electronic product in domestic household waste.

Product Category: With reference to the equipment types in the WEEE directive Annex 1, this product is classified as a “Monitoring and Control instrumentation” product.

Do not dispose in domestic household waste.

To return unwanted products, contact your local Keysight office for more information.

Contents

Introduction

Keysight's BT2191A Self-Discharge Measurement System quickly measures the self-discharge current on individual lithium ion cells. This potentiostatic measurement system quickly makes necessary DC measurements with minimum disturbance to the cell-under-test.

- The voltage applied to the cell is quickly matched to the actual cell voltage. This minimizes new charge or discharge and limits new RC settling to a minimum.
- The voltage applied to the cell is very stable (±10 μV_{pk}) to minimize continuing charge redistribution current noise on the self-discharge current measurement.
- The Measurement System accurately measures low-level self-discharge currents to ±(0.025% of reading + 100 nA) for currents less than 1 mA.

BT2191A Self-Discharge Measurement System

System consists of:

- BT2192A Self-Discharge Measurement System Software
- N6705C DC Power Analyzer
- N6782A 2-Quadrant Source/Measure Unit (SMU)
- 34470A Digital Multimeter, 7½ Digit (quantity 2) for SMU and cell voltage measurements
- 34465A Digital Multimeter, 6½ Digit for temperature measurement
- BT2191-60001 Wiring Kit consisting of two wiring assemblies; one to connect the test instruments (with internal 4.7 Ω Resistor) to the cell-under-test, and one T-type thermocouple temperature sensor wire.

This BT2191A User Guide focuses primarily on setting up the system hardware and initiating a cell test. For detailed information on using the BT2192A Self-Discharge Measurement System Software, refer to the BT2192A help file.

System Requirements

Microsoft Windows Requirements	
Operating System	Windows 7 SP1, 32- and 64-bit Windows 10, 32- and 64-bit
Processor Speed	2 GHz 64-bit (x64)
Available Memory	4 GB minimum (8GB recommended for 64-bit OS)
Available Disk space for installation	300 MB
Software Requirements	
Keysight IO Libraries Suite (version 18.0 or later)	
BT2192A Self-Discharge Measurement System Software	
Firmware Requirements	
N6705A/B DC Power Analyzer: firmware revision: D.02.13 (or later)	
N6705C DC Power Analyzer: firmware revision E.01.00.2699 (or later)	

NOTE

The user provides the following: a host PC/System Controller (with access to the Internet), an Ethernet switch, and five Ethernet cables to connect the instruments and PC together.

This system is I/O intensive, Keysight recommends that a PC be dedicated to this system which would not be used for other purposes. Optionally, install Microsoft Excel on this PC for reviewing test results.

Abbreviated Theory of Operation

A cell's self-discharge current is internal leakage current that slowly discharges the cell. Self-discharge current is typically on the order of 10's of micro-amperes (μA). As the cell discharges, its voltage very slowly drops. The self-discharge current is measured by connecting an external voltage source in parallel with the cell with the voltage source's output matched very closely to the cell's initial voltage. Over time, as the cell reaches equilibrium with the external voltage source, the voltage source ends up externally furnishing the leakage current as it holds the cell's voltage constant, preventing it from dropping further. This is illustrated in Figure 1.

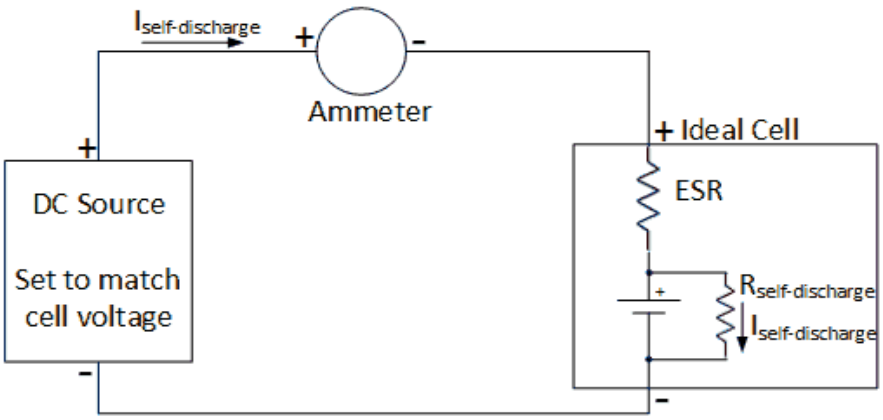


Figure 1 Traditional Method to Measure a Cell's Self-discharge Current

The main advantage of using the potentiostatic method for measuring a cell's self-discharge leakage current is that it yields results in a few hours compared to the traditional open circuit voltage measurement performed over weeks to months to determine self-discharge.

To get good results using the potentiostatic method requires attention to detail on both the setup and preparation of the cell. Tight voltage stability and operating environment must be maintained for both the cell and the DC source and then maintained for the duration of the testing.

Keysight's BT2191A matches the cell's voltage within a few microvolts. If a non-zero Initial cell current is set in the Test Setup (see "Configure the BT2192A Test System Parameters") it then further adjusts its output voltage to cause the specified level of current to flow. Ideally, this closely matches the cell's self-discharge current, thus reducing the overall time to reach equilibrium. The BT 2191A maintains microvolt-level stability over time and the normal range of ambient room temperature providing the stability required for the source.

The BT2191A's Equipment Setup and Wiring Configuration

Figure 2 shows the BT2191A's wiring connecting the test equipment and the cell-under-test.

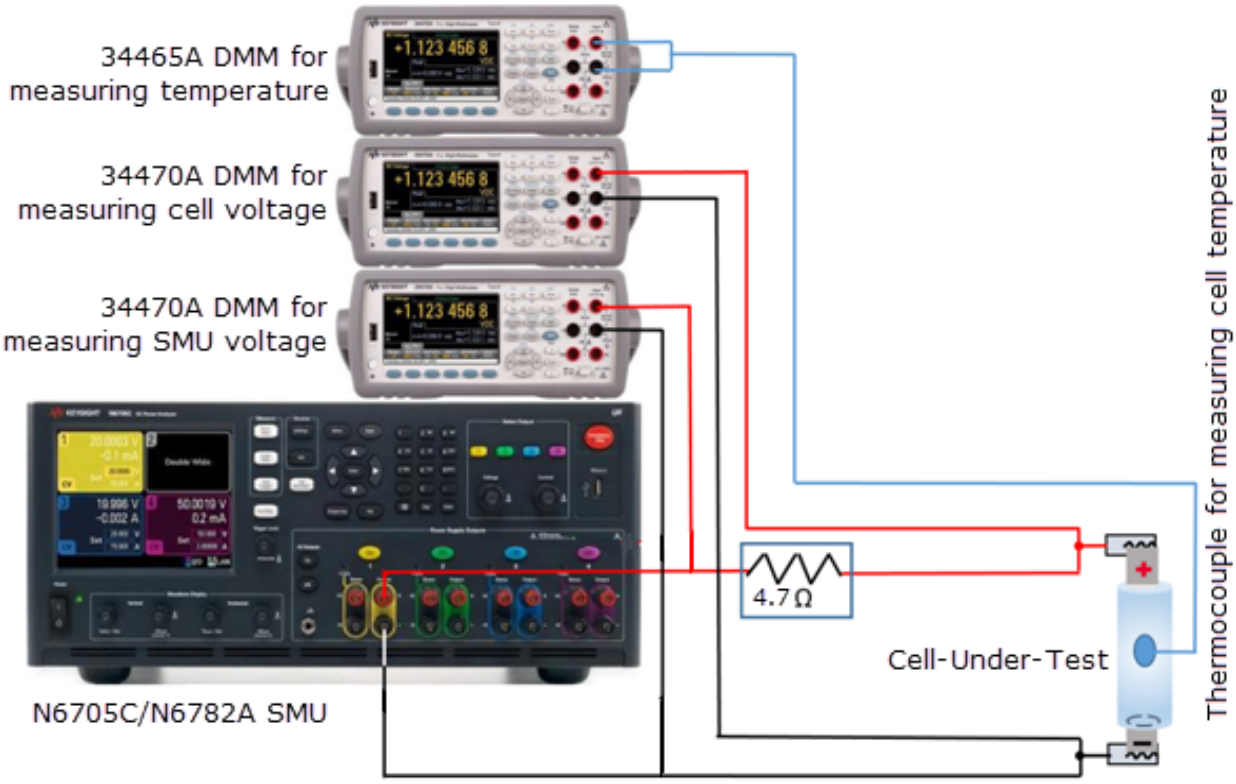


Figure 2 BT2191A Self-Discharge Measurement System Setup and Wiring Configuration

An N6782A Source/Measure Unit (SMU) module within the N6705C DC Power Analyzer mainframe works with a 34470A DMM to monitor the SMU's output voltage to provide precise and stable voltage sourcing to the cell-under-test. A twisted-wire pair with an internal 4.7Ω series resistance connects the SMU's output to the cell-under-test. The SMU's precision current measurement system measured the cell's self-discharge current with micro-ampere accuracy. A second 34470A DMM monitors the cell's voltage via a separate twisted-wire pair. Finally, a 34465A DMM together with a thermocouple assembly monitors the cell's case temperature.

NOTE If this wiring harness is modified or fabricated in any manner, it must strictly adhere to this layout. Any lengthening or shortening of the cable assembly is accomplished by modifying the twisted-wire pairs along with modifying the thermocouple assembly. The wire pairs for the SMU, SMU DMM, and Cell SMU are individual twisted-wire pairs to minimize electrical noise pick up. The wiring harness must be recalibrated.

NOTE The voltage of most Li-Ion cells is very sensitive to vibration and mechanical stress or deflection. Once a self-discharge test has started, it is important that the cell not be moved or disturbed, and is not subjected to vibration. The temperature sensor must be mounted on or attached to the cell before the test and not touched or have its connection adjusted during the test. Cells are microphonic – any touching or tapping them, or any vibration or shock affects the cell's voltage and thus the measured current value.

System Documentation

This *BT2191A Self-Discharge Measurement System User Guide* is the only system documentation provided. Refer to the individual instrument documentation provided with your system for calibration instructions as well as specific warranty and support information.

Support

Refer to the individual instrument documentation and help files provided with your system for warranty and support information. Hardware support (repairs and calibration) is provided for each of the individual instruments in the BT2191A system. If a test instrument requires support and must be returned to Keysight, send only the individual instrument; do not send the entire system.

Step 1. Verify Shipment Contents

Your BT2191A system will arrive in one large shipping container. Test instruments and the wiring harness are individually boxed within the container. Carefully inspect your shipment for any shipping damage. Report damage to the shipping agent immediately, as such damage is not covered by warranty.

NOTE Keysight suggests that you save the shipping boxes in case it becomes necessary to return the equipment to Keysight for service.

Shipment Verification

Verify that your shipment contains the following items:

Product*	Qty.	Description
N6705C	1	DC Power Analyzer
N6782A	1	2-Quadrant Source/Measure Unit, plug-in for N6705C
34470A	2	Digital Multimeter, 7½ Digit. Quantity 2: one for measuring SMU voltage and one for measuring cell voltage
34465A	1	Digital Multimeter, 6½ Digit for temperature measurement
BT2191-60001	1	Wiring Harness consisting of: one wiring test harness with integrated 4.7 Ω resistor to connect test instruments to the cell-under-test, one T-Type thermocouple wire. See “BT2191-60001 Wiring Harness” on page 18.

* Each instrument should have the appropriate power cord and line voltage setting for your location.

NOTE The user provides the following: a host PC/System Controller (with access to the Internet for downloading and licensing the software), an Ethernet switch, and five Ethernet cables to connect the instruments and PC together.

This system is I/O intensive, Keysight recommends that a PC be dedicated to this system which would not be used for other purposes. Optionally, install Microsoft Excel on this PC for reviewing test results.

Step 2: Install the Measurement System Hardware

Refer to the individual instrument documentation and help files provided with your system for calibration and safety instructions as well as specific warranty and support information.

N6705A/B/C Firmware

The N6705C does not require an IVI driver. However, the analyzer must have the correct firmware installed. Refer to the following table.

N6705A/B/C Firmware Requirements
N6705A/B DC Power Analyzer -- firmware revision: D.02.13 (or later)
N6705C DC Power Analyzer -- firmware revision E.01.00.2699 (or later)

Firmware updates are available at: www.keysight.com/find/N6705C

System Hardware Setup

1. Install the N6782A 2-Quadrant Source/Measurement Unit (SMU) in the N6705C DC Power Analyzer mainframe. Any channel may be used; the examples in this User Guide use Channel 1. Refer to the *N6705C User Guide* for specific information on installing the SMU.

2 Set the N6705C Power Analyzer and the three DMMs on your test bench. To simplify cabling and minimize desk space, consider stacking the instruments as shown in Figure 3 below.

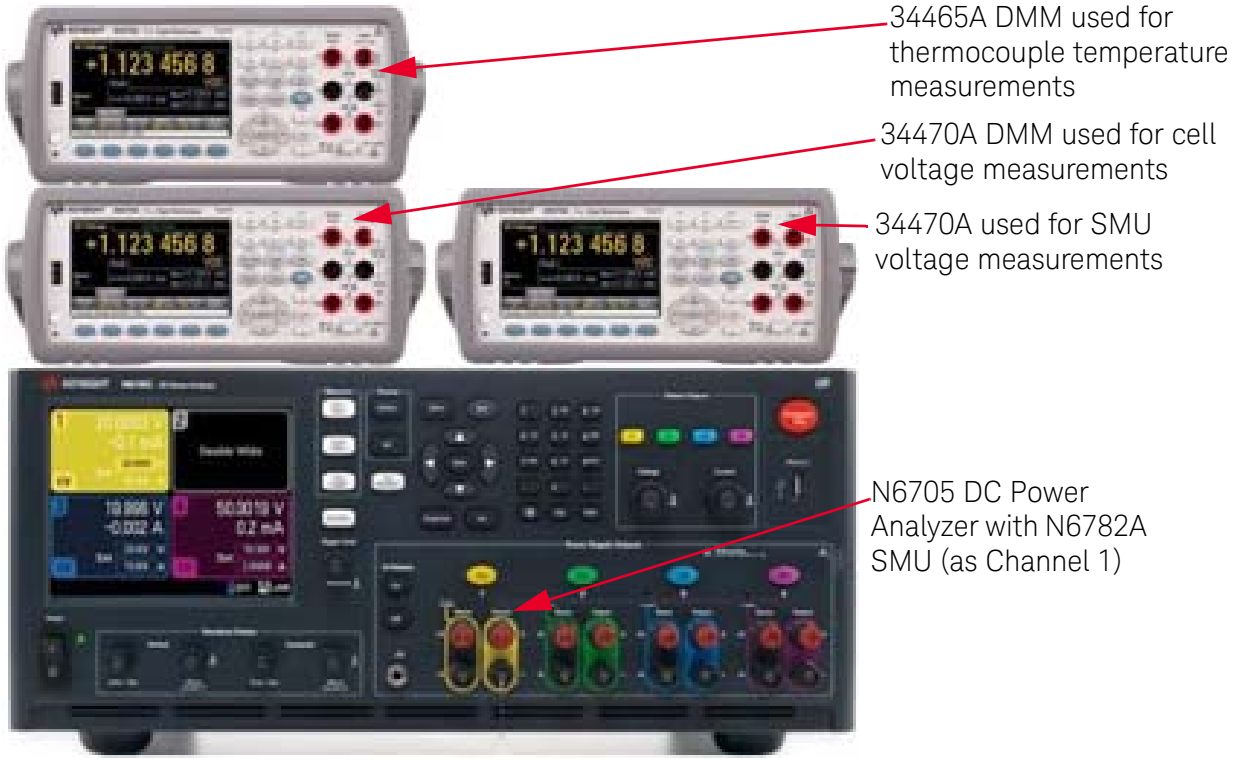


Figure 3 Typical BT2191A Instrument Setup

3 Use five standard Cat5 Ethernet LAN cables (not supplied) to connect each instrument and the PC to the Ethernet Switch. See Figure 4 below.

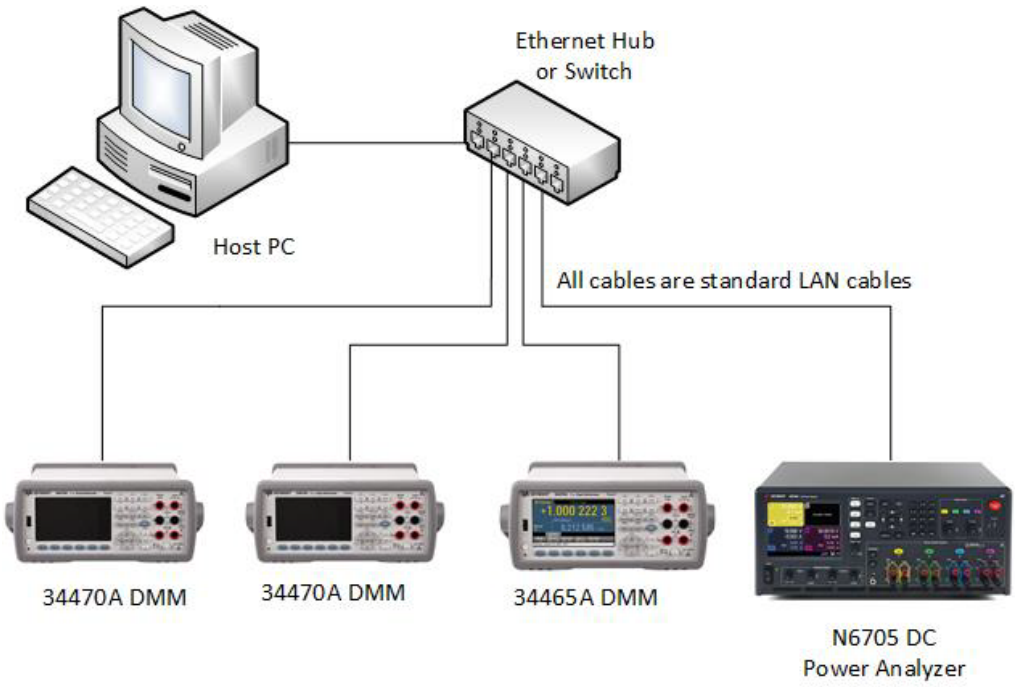


Figure 4 Connect Instruments and PC to an Ethernet Switch (not supplied)

CAUTION

The DMMs comply with EN/IEC 61326-2-1, for sensitive test and measurement equipment.

When subjected to transient radiated and/or conducted electromagnetic phenomena, the DMMs may have temporary loss of function or performance which is self-recovering. Recovery may take longer than 10 seconds.

When subjected to continuously present electromagnetic phenomena, some degradation of performance may occur.

Step 3. Connect the Wiring Harness

BT2191-60001 Wiring Harness

The BT2191-60001 Wiring Harness connects the test instruments to the cell-under-test. Spring loaded electrical clips connect to the positive and negative terminals of the cell-under-test.

- **Cell-Under-Test Wiring Harness:** The cable ends are labeled as depicted in Figure 5 for convenience and quick set up. Banana plugs are included on the cable ends for the Cell DMM, SMU DMM, and SMU connections. The wiring harness allows approximately 2-meter separation between cell and instruments.

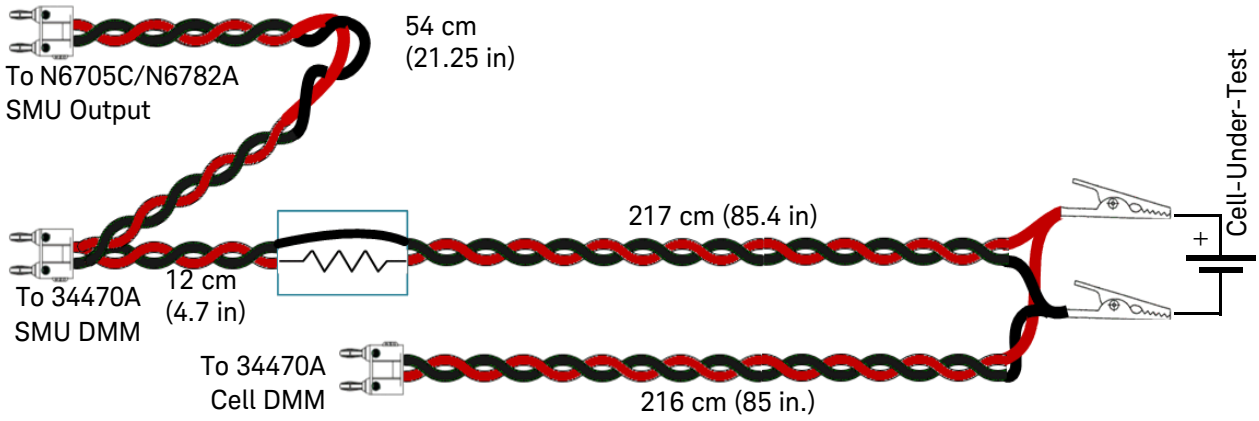


Figure 5 DUT Wiring Harness

WARNING

- **Do not reverse the polarity of the connections to the cell. Cells can vent, leak, or combust if a negative voltage is applied.**
- **Do not short the terminals of a cell. This can cause dangerous currents and overheat the cell which can lead to venting, leakage, or combust. This also means that the cell must not be accidentally shorted by any part of the wiring harness.**
- **Do not charge the cell beyond its rated capacity. Do not apply a voltage above the rated maximum voltage of the cell. Doing either of these can cause overheating, venting, leakage, or fire.**

NOTE

If this wiring harness is modified or fabricated in any manner, it must strictly adhere to this layout. Any lengthening or shortening of the cable assembly is accomplished by modifying the twisted-wire pairs along with modifying the thermocouple assembly. The wire pairs for the SMU, SMU DMM, and Cell SMU are individual twisted-wire pairs to minimize electrical noise pick up.

- **T-Type Thermocouple wire:** an ~2-meter T-type thermocouple wire with dual-banana plug for measuring cell temperature. You can use other temperature sensor and wire if desired. Supported sensors: T, J, K, E, N, R-type thermocouples, 5 kΩ thermistor, Pt100 and Pt1000 RTDs. See "Preparing the T-Type Thermocouple".

SMU Series Resistor

The BT2192A software generates a positive or negative resistance that adds to or subtracts from the fixed 4.7Ω physical resistor (internal to the test harness cable) to provide a net range of total series resistance from 0.1Ω to 10Ω. Figure 5 shows the internal 4.7Ω resistor between the SMU output and the positive terminal of the cell-under-test.

More information on this topic is available at "The BT2192A's Total Series Resistance" on page 36.

Cell Temperature Sensor (Thermocouple)

The BT2192A software also measures the temperature of the cell-under-test. This allows monitoring cell voltage and self-discharge current as they vary with temperature. Since cells have a complex temperature coefficient for their voltage, monitoring cell temperature allows you to understand how temperature affects cell voltage. That allows you to control changes in cell voltage caused by changes in temperature. Controlling those voltage changes eliminates a significant source of error in the self-discharge current measurement.

You can use the T-type thermocouple wire supplied with the BT2191A or provide your own sensor and wiring. Supported sensors include: T, J, K, E, N, and R-type thermocouples; 5 kΩ thermistor; Pt100 and Pt1000 RTDs.

Preparing the T-Type Thermocouple

The ~2 meter T-type thermocouple wire supplied with the BT2191A System, provides only the thermocouple wire with a dual banana plug for connection to the DMM. You are responsible to:

1. Strip the end of the thermocouple couple wire.
2. Tightly twist the end of the wire together, solder, crimp, or in any manner you prefer, create the actual thermocouple.

3 Attach the thermocouple to the cell-under-test. Figure 6 shows an example of taping the thermocouple to the cell.

Figure 6 Attaching the thermocouple to the Cell-Under-Test

NOTE The thermocouple should be attached to the cell with non-metallic and non-conducting materials (tape, glue, etc) to avoid altering the thermocouple.

Step 4. Install the IO Libraries Suite

IO Libraries Suite is a collection of libraries and utilities that enable you to connect your instruments to the host controller and run programs on the host controller that interact with the instruments. The IO Libraries Suite is used with all Keysight instruments.

NOTE The latest version of Keysight IO Libraries must be installed prior to installing and running the BT2192A software. The latest version can be downloaded from: www.keysight.com/find/iosuite

Install Keysight IO Libraries Suite

When installing IO Libraries Suite from the web site above, follow all installation instructions.

NOTE Only one installation of the Keysight IO Libraries Suite is required on the host controller PC. This installation is used by all instruments in the system.

Two libraries, IVI Shared Components and VISA Shared Components, are required by the IO Libraries Suite. If these libraries are not already installed on your controller, the IO Libraries Suite installer will install them. If IVI Shared Components and VISA Shared Components are already installed, the IO Libraries Suite installer will, if necessary, upgrade these libraries to the latest version using the same installation location used by the previous version.

Configure the Test Instruments with IO Libraries Suite

This step ensures proper communication with all four test instruments and shows the VISA addresses of the instruments. You must enter the VISA addresses in the BT2192A software.

1 Run IO Libraries Suite Connection Expert. Double-click the IO Control icon ( ) in the Windows Notification area to start Keysight Connection Expert.

- All four test instruments are automatically discovered in the Connection Expert *My Instruments* list. Figure 8 shows the IO Libraries Suite Connection Expert. In this graphic, the N6705 was auto discovered and added to the *My Instruments* list, the three DMMs are listed in the **Add a LAN Device** window and are added manually. Refer to the IO Libraries Suite documentation for additional help if necessary.

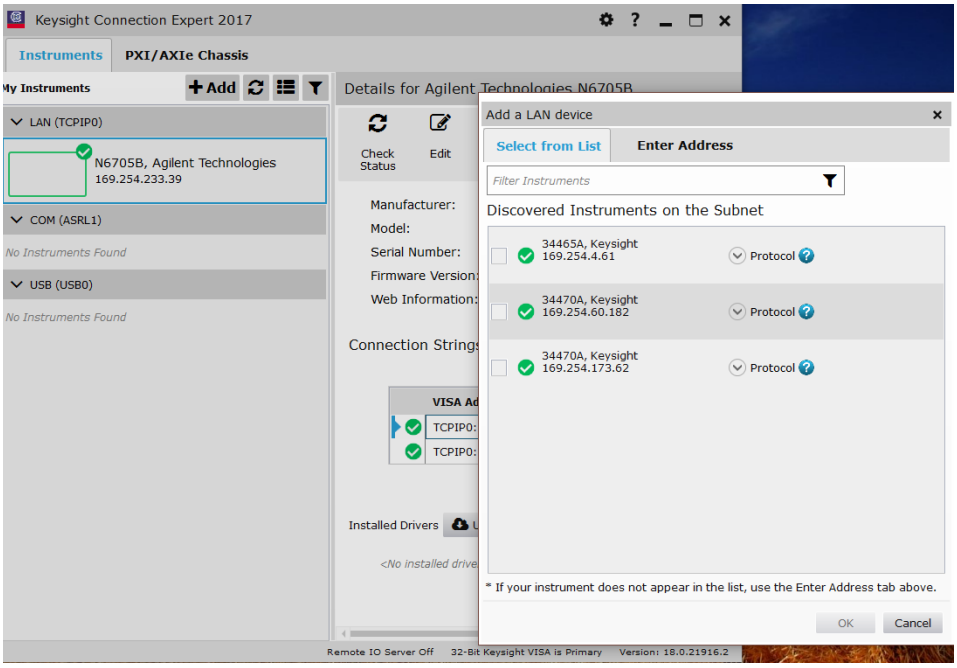


Figure 7 IO Libraries Connection Expert Add a LAN Device

2 Record the VISA address of each of the four test instruments. You will enter the VISA address in the BT2192A Hardware Configuration.

- VISA Address for **N6705C DC Power Analyzer:** _____
- VISA Address for **34465A Temperature DMM:** _____
- VISA Address for **34470A SMU DMM:** _____
- VISA Address for **34470A Cell DMM:** _____

NOTE Do not use the HiSlip VISA address (e.g., *TCPIP0::169.254.60.182::hislip0::INSTR*). Always use a standard *TCP:IP::<address>::inst0::INSTR* VISA address.

Figure 8 shows the VISA address of the N6705 Power Analyzer.

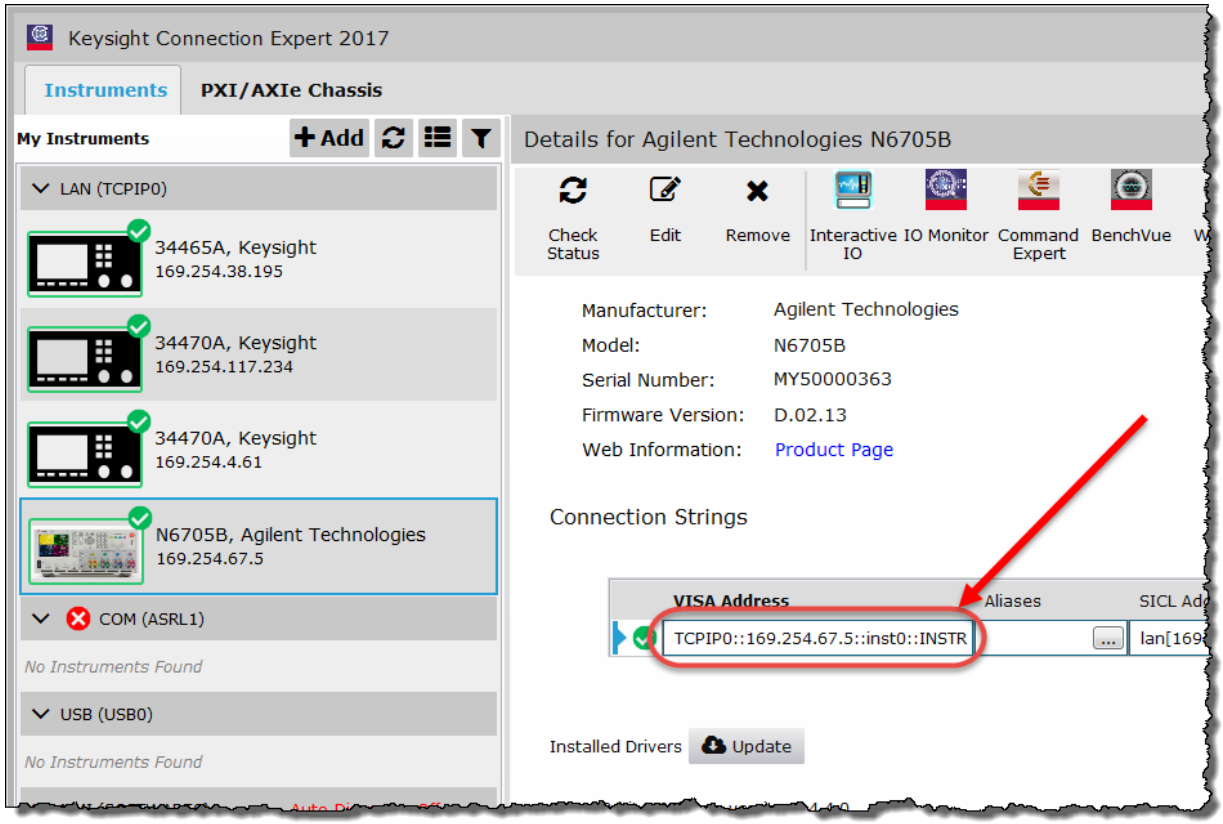


Figure 8 IO Libraries Connection Expert showing the N6705 Power Analyzer VISA Address

Alternate Methods to Identify the Test Instruments

If IO Libraries Suite Connection Expert is not able to identify the test instruments connected by LAN, use either of the following methods to identify the instruments and run the software.

1. Connect the instruments to the PC by USB cable rather than a LAN cable. Use IO Libraries Suite Connection Expert to identify the VISA address.
2. Connect with a LAN cable and enter the instrument IP address into a web browser. The Web Browser screen displays the VISA Address.

Step 5. Install the BT2192A Self-Discharge Measurement System Software

The system software may be downloaded from Keysight at any time. A free trial version of the software is available.

NOTE This trial version may be used for 90 days with no obligation. After 90 days, you must purchase a software license to continue using the software. Each host controller PC requires a separate license. For purchasing information, go to either of the following websites.

Download the BT2192A software from either of the following websites:

www.keysight.com\find\BT2191A

or

www.keysight.com\find\BT2192A

1. Select the **Trials & Licenses** tab.
2. Click the **Details & Download** button.
3. Read the instructions and click the red **Download** button. Follow all on-screen instructions.

Installing the Software License

The BT2192A Software can be installed and used for 90 days without a license. After 90 days a permanent software license is required to continue to use the software. Each host controller PC requires a separate software license. For software and licensing information, go to: www.keysight/com/find/BT192A.

NOTE **The 90 day licensing does not require a licensing file. When installing the software, if no valid license is found (and no 90 day trial was activated yet) the software prompts the user to activate the 90 day trial period. This works locally on the host PC; no Internet connection or licensing files are involved.**

Other than the initial trial software license, there are four available licenses for the BT2192A software. These are:

- **BT2192A-1FP** -- A perpetual fixed license. This license enables the software only on the host controller PC the license is originally assigned to; without a time limit.
- **BT2192A-1TP** -- A perpetual transportable license. This license allows the software to be transported to a different PC; without a time limit.
- **BT2192A-1FY** -- A 1-year fixed license. This license enables the software only on the PC the license is originally assigned to for a period of one year.
- **BT2192A-1TY** -- A 1-year transportable license. This license allows the software to be transported to a different PC. Maximum time period for this license is one year.

NOTE You will need to install the Keysight License Manager software on your host controller PC (if it was not previously installed by other Keysight software). www.keysight.com/find/licensemanager

1. Once you purchase the BT2192A software, you will be given the choice to receive a printed copy of an Entitlement Certificate, an email with the certificate, or both.
2. On the host controller PC where you have installed and plan to run the BT2192A software (you must be logged on with Administrator privileges), log onto Keysight's Licensing website at: www.keysight.com/find/softwaremanager. Note, you will need to register if you don't have an account.
3. Follow the instructions in the Entitlement Certificate to redeem the license. You will need to enter the Entitlement Certificate number and the host ID of the PC (see "Your PC Host ID" on page 26 of this guide for host ID information).
4. Once you have entered the information, a license file is emailed (as an attachment) to the PC. The license file has a *.lic* file extension; for example: 10000996212_829728.lic.
5. In this email, save the attached license file to a temporary location on the **C:** drive of the computer where you have installed the BT2192A software.
6. Start the Keysight License Manager on your computer. Click Windows **Start > All Programs > Keysight License Manager > Keysight License Manager**.
7. Use **File > Install** to browse and open the license file that was attached to the email and then minimize Keysight License Manager. **Note**: on some versions of Keysight License Manager, select the wrench icon (🔧), then **Install License File...**.
8. An **Install License File(s)** window appears. In this window, browse to the location of the license file. Select the license file, and click the **Open** button.

The license automatically installs and now appears in the Tree View of the Keysight License Manager as an installed license under the host system. The BT2192A software is now licensed and ready for use.

Transporting a license to another host PC

To easily transport a license, Keysight recommends that you configure your system so that the host system running Keysight License Manager (KLM) connects both to the Internet and to the LAN connecting the source and target systems.

- The system running KLM can be either the source system, the target system, or a separate Windows-based computer.
- When the source system and the target system both have LAN connectivity, you can use a simple drag-and-drop action to transport a license using KLM.

NOTE To transport a license, KLM must connect to the services available on the Keysight Software Manager Transport License Web site. This connection takes up to 90 seconds to complete a license transport operation.

KLM automatically removes a transported license from the source system. The license is then re-issued by the Keysight Software Manager Transport License Web Service, and then installed onto a target system

For additional information and procedures to transport a license, refer to the **Keysight License Manager Help**. Open the **About Keysight License Service** dialog box:

1. Double-click the **Keysight License Manager** icon  in the Windows toolbar. (If the icon is hidden, click the “Show hidden icons” button on the right side of the toolbar.
2. Click **Help > Keysight License Manager Help**.

Your PC Host ID

Host ID is a permanent, unique identifier to a computer or a Keysight instrument or application that locks licenses to that particular computer, instrument or application. If the host information provided at the time the license is generated is wrong, then the license will not enable the features purchased.

NOTE It is important that you enter the correct host ID information. Your license will not enable the software if the host information does not exactly match your instrument or application.

Where can I find the Host ID?

You will need to install the Keysight License Manager software on your host controller PC (if it was not previously installed by other Keysight software).

To obtain a Host ID from the Keysight License Manager (KLM) application, follow these steps:

1. Open the **About Keysight License Service** dialog box:
   - **a** Right-click the Keysight License Manager icon in the Windows toolbar. (If the icon is hidden, click the "Show hidden icons" button on the right side of the toolbar.
   - **b** Select the **About Keysight License Service**.
2. Click the **Copy Host ID** link to copy the host ID to the Windows clipboard.

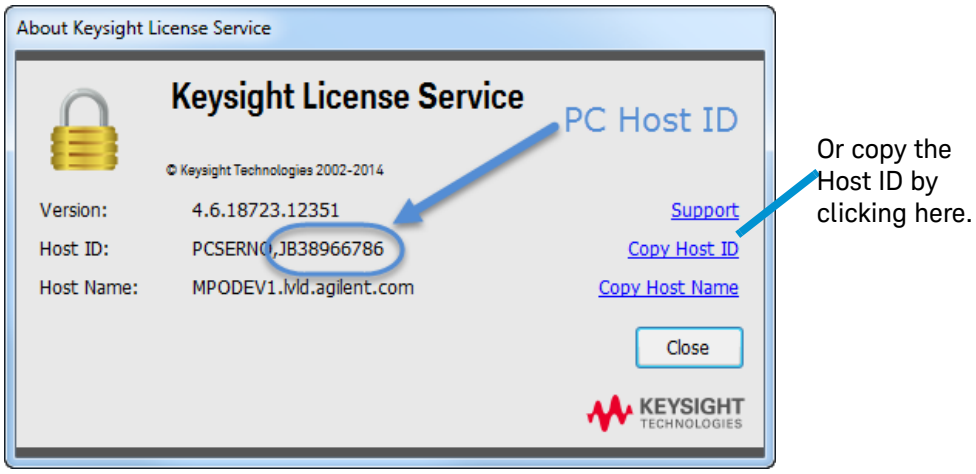


Figure 9 Keysight License Service Dialog Box

3. You can request a license file from: www.keysight.com/find/softwaremanager. A Keysight order number, Entitlement Certificate numbers and Host ID, from Step 2 above, are required.

Step 6. Preparing the System

After installing the BT2192A System software, you are ready to run it. But first, calculate the total wiring harness resistance.

NOTE **Important:** Always allow the test instruments to warm up for a minimum of two hours before calibrating the test harness or using the system.

Measure Total Physical Resistance of the Test Harness

The combined physical resistance of the twisted-wire pair and an internal series 4.7Ω resistor (between the SMU output and the cell-under-test) must be accurately determined as this is a critical parameter for correct and stable operation of the BT2191A. The value of this resistance is entered into the software for this purpose. Any modifications to the cable assembly will likely change the value of this resistance and must be accounted for.

A simple manual procedure accurately determines the value of the Test Harness resistance:

1. Connect the test harness as indicated in Figure 5, “DUT Wiring Harness,” on page 18. Do not connect a cell to the clip leads.
2. Without a cell in place, short the + and – clips (which would normally connect to the cell-under-test) to each other.
3. From the front panel of the N6705C Power Analyzer mainframe, set the N6782A module to source 100 mA of current:
   a. Use the front panel **Source > Settings** buttons to select the channel the N6782A is installed in. In this example the SMU is in channel 1 of the N6705C mainframe.
   b. Use the front panel **Source > Settings** buttons to display the source Settings screen. Using the navigation and entry buttons, set up the source settings as follows (depicted in Figure 10).
      -- Emulate a 2-quadrant power supply
      -- Operating in current priority
      -- Current setting of 0.1 A
      -- Range of 3.06 A
      -- Positive (+) voltage limit of 6.12V

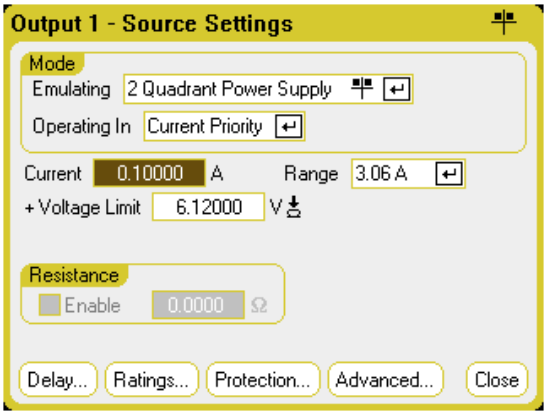


Figure 10 N6782A SMU's Source Settings from the N6705C Front Panel Display

4 On the front panel of the N6705C, press the **Meter View** button under the **Measure** selections.

5 On the front panel of the N6705C, press the **On** button for the channel where the N6782A is installed. This enables its output to source 100 mA of current through the cable assembly.

6 Figure 11 shows a typical front panel display of the N6705C showing the output channels' voltage and current readings and settings. Use the voltage and current readings to calculate the cable assembly's physical resistance. In this example the physical resistance is 5.238Ω (0.5240V/0.10003A = 5.238). Record this value for later use; it gets entered into the BT2152A's software's "**Total Physical Resistance**" setting in the Hardware Configuration screen. See "Configure the BT2192A Test System Parameters" on page 32.

Resistance = _____Ω

Figure 11 N6782A SMU's Meter View from the N6705C Front Panel Display

7 Turn off the N6782A SMU's output and set its mode back to operating in voltage priority. Disconnect the + and - clips to the cell from each other.

Step 7. Testing the Cell

NOTE This section provides an abbreviated introduction to using the BT2192A software. For more detailed descriptions and information on using the BT2192A software, refer to the BT2192A Help File. It is available from the BT2192A menu **View Help...** button.

Before running a test, ensure that:

- All test instruments have warmed up for at least two hours.
- All test instruments are found in Keysight IO Libraries.
- Wiring harness is properly connected to the cell-under-test and test equipment.
- Thermocouple is attached to the cell-under-test.

Before the Test Begins

Prior to actually running the test, if the DMMs are in their default, power-on state, the 34470A cell-under-test DMM will display the Open Circuit Voltage (OCV) of the cell. This voltage should be entered in the **Test System Parameters** screen.

Note that during the actual test, the DMM displays may not be able to keep up with the speed of the test and may erratically flash.

You are ready to begin testing.

Running the Software

1. From the Windows **Start** button, select **All Programs**.
2. Scroll down to **Keysight Technologies** then select **Keysight BT2192A.**

The BT2192A Software has Two Configuration Steps:

- “Configure the BT2191A Test System Hardware” on page 31.
- “Configure the BT2192A Test System Parameters” on page 32

Configure the BT2191A Test System Hardware

1 From the main BT2192A Software screen, click the **Menu** icon (the three bars in the upper right corner).

2 From the six menu selections, select, **Configure Hardware...**. This opens the hardware **Configuration Editor**. See Figure 12 below.

3 In this editor, enter the:

-- VISA addresses of the four test instruments identified in the Keysight IO Libraries Suite Connection Expert (see "Configure the Test Instruments with IO Libraries Suite" on page 22).

-- The slot or channel number of the N6782A installed in the N6705A DC Power analyzer. Channel 1 is the default.

-- The **Total physical resistance**, that is the total resistance (including the built-in 4.7 Ω resistor, test lead wire and clips) calculated in "Measure Total Physical Resistance of the Test Harness" on page 28.

-- The type of temperature sensor; the T-Type thermocouple is default.

-- The type of temperature sensor wiring to the DMM; TwoWire is default.

4 When you have entered all of the data, click the **OK** button.

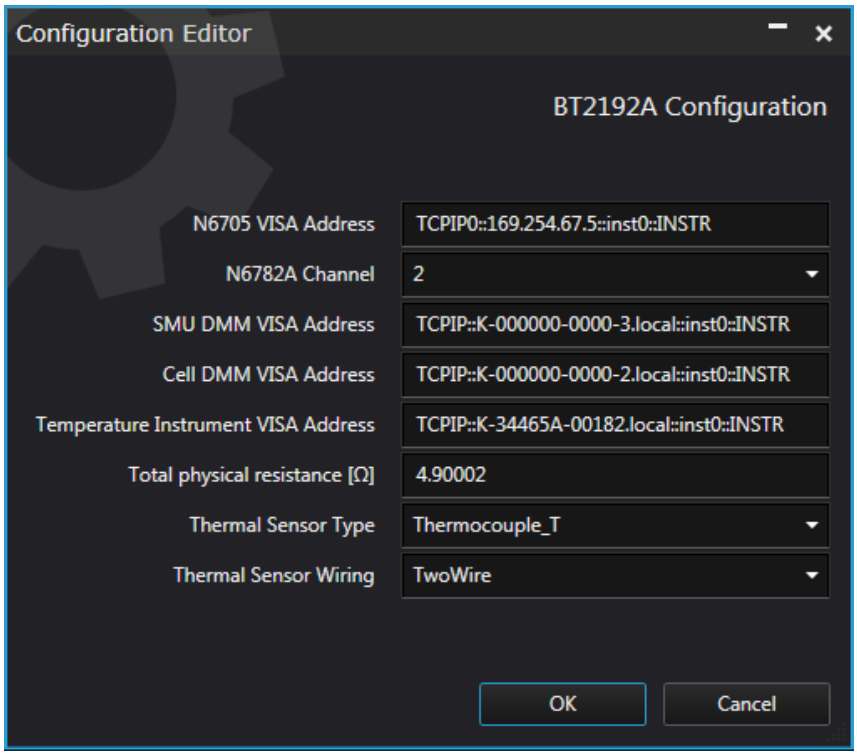


Figure 12 BT2192A Configuration Editor Screen

Configure the BT2192A Test System Parameters

From the main BT2192A screen, set the test parameters:

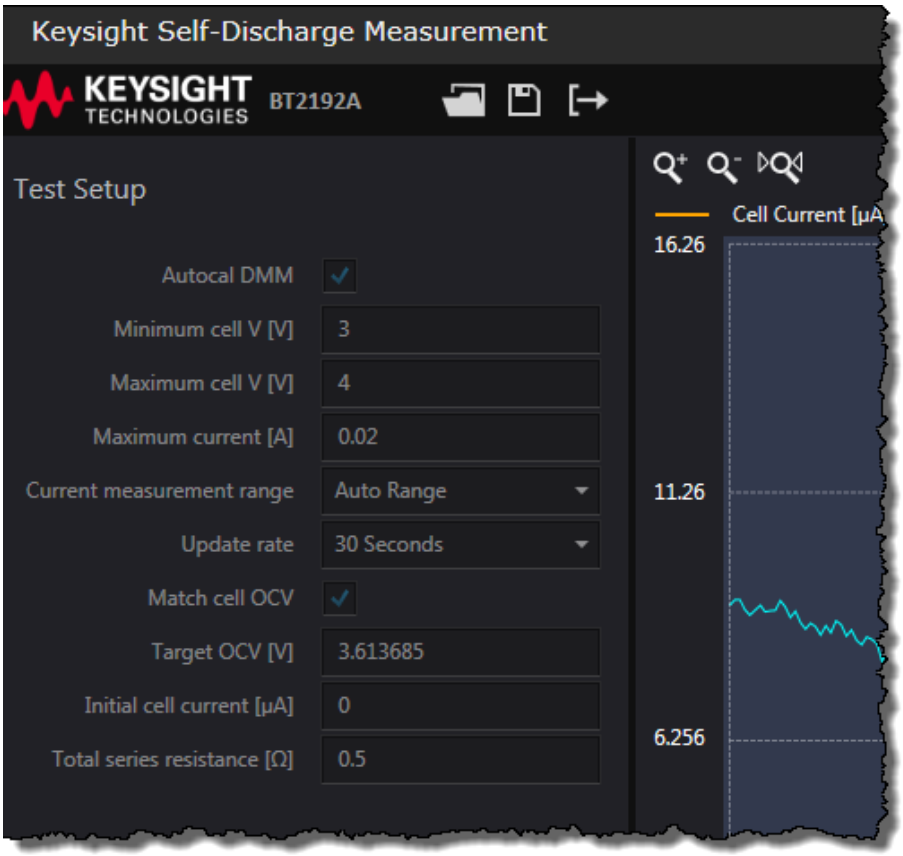


Figure 13 BT2192A Test System Parameters

The fields are:

- **Autocal DMM**: This causes the DMMs to run their Autocal procedure at the start of each BT2192A test. Default is **Yes** (box is checked). In general, you should always leave this checked.
- **Minimum cell voltage:** Voltage applied to the cell-under-test: The cell voltage must be positive, Min must be less than Max cell voltage.
- **Maximum cell voltage:** Voltage applied to the cell-under-test: The cell voltage must be positive, Min must be less than Max cell voltage.
- **Maximum current:** Limits the current into (charge) or out of (discharge) the cell-under-test.
- **Current measurement range:** Measurement range for SMU. Default is **Autorange**. Possible ranges are 1 mA, 100 mA, and 3A.

- **Update rate:** A shorter update rate produces more data and more updates to the screen plot. Default setting is: **60 Seconds**. Possible selections are: 10, 30 or 60 seconds.
- **Match cell open circuit voltage** (OCV): OCV at the start of the Self-Discharge measurement. Default is **Yes** (box is checked). In general, this box should always remain checked.
- **Target open circuit voltage** (OCV): Expected OCV in volts. Keysight recommends that you measure the OCV of the cell prior to testing and enter that voltage. Default is: **+3.8 DCV**. Possible range is: The **Minimum Voltage** and **Maximum Voltage** as set by user. Absolute maximum is +20 DCV in the ±1A range.
- **Initial cell current:** Current applied to cell-under-test at start of test, in μA. Default is **0.0 μA**. Possible range is: **-10 mA to +10 mA.** You may want to change the initial cell current for several reasons, including:
  - -- You want to resume a test that was interrupted but using the same current level when the test was interrupted.
  - -- You know the expected self-discharge current and the cell is well rested since its last charge or discharge event, so you want to minimize the time required to get to a stable measurement (assuming the cell is good).
- **Total Series Resistance**: Total system series resistance applied to the cell-under-test. Default value is **4.7 Ω**. See "The BT2192A's Total Series Resistance" on page 36 for detailed information on this value. Possible range is: 0.1Ω to 10Ω.

When you have completed all of the parameter fields, click the 

button to start the cell test. It may take three to four minutes before the first test data is displayed on the screen.

Upon starting a test, the system:

- Autocals the three DMMs (if you have that selected in the Parameters Configuration).
- Measures the initial cell voltage. This is the cell's Open Circuit Voltage.
- Attempts to match the cell voltage.
- Then starts measuring the SMU current.

Watch the test message area just above the **Start/Stop** button to monitor the progress of the test.

Figure 14 shows a display after running a test for an 18650 Li-Ion cell for over four hours.

Figure 14 BT2192A Display for an18650 LI-Ion Cell

NOTE

The voltage of most Li-Ion cells is very sensitive to vibration and mechanical stress or deflection. Once a self-discharge test has started, it is important that the cell not be moved or disturbed, and is not subjected to vibration. The temperature sensor must be securely mounted on or attached to the cell before the test and not touched or have its connection adjusted during the test. Cells are microphonic – any touching or tapping them, or any vibration or shock affects the cell's voltage and thus the measured current value.

NOTE

For best test results:

- Put the cell-under-test in a temperature-stabilized environment such as an insulated box. Do NOT use an oil bath, the oil pump may cause vibrations.
- Minimize stress and vibration on the cell-under-test.

For detailed information, refer to "Appendix A. Recommendations for Maintaining Cell Stability During Testing" on page 42.

Completing a Cell Test

A BT2191A Cell Test can run for up to:

- 300 days at 1-minute measurement logging interval
- 150 days at 30-second measurement logging interval
- or 50 days at 10-second logging interval.

However, you may not need to run a test for that long. In general, the minimum settling time constant for a cell is the RC product of the cell's estimated capacitance times the **Total Series Resistance** setting being used for the self-discharge measurement test. It takes two to three time constants for a measurement to settle out. Refer to "Representative Examples of a Good Self-Discharge Measurements" on page 40 for a detailed explanation.

If you need to stop a running cell test prior to the maximum logging interval above, click the STOP button. The DMMs are left in their default power-on state except that the integration time is set to maximum (10 PLC). This allows you to record the final cell voltage.

The BT2192A's Total Series Resistance

The **Total Physical Resistance** is the total measured resistance value of the cabling (internal 4.7 Ω resistor plus cable leads). See "Measure Total Physical Resistance of the Test Harness" on page 28.

The **Total Series Resistance** is the total system series resistance applied to the cell-under-test. Start with the **Total Physical Resistance** value. Then, to run various "experiments" you can change the value of the Total Series Resistance to adjust between long term measurement settling time and low frequency measurement stability. A smaller resistance provides faster settling but at the expense of greater low frequency peak to peak deviation.Possible range is: 0.1Ω to 10Ω.

For example, if the **Total Physical Resistance** is 4.9 Ω (4.7 Ω resistor plus 0.2 Ω test lead resistance) but you want to test the response at 5.5 Ω, then enter 5.5 Ω in the **Total Series Resistance** field. The BT2192A software adds 0.6 Ω of simulated resistance (4.9 Ω plus 0.6 Ω = 5.5 Ω). Conversely, if you want 0.5 Ω of **Total Series Resistance**, then enter 0.5 Ω in the **Total Series Resistance** field. The BT2192A system adds a 'negative' 4.4 Ω to yield a **Total Series Resistance** of 0.5 Ω.

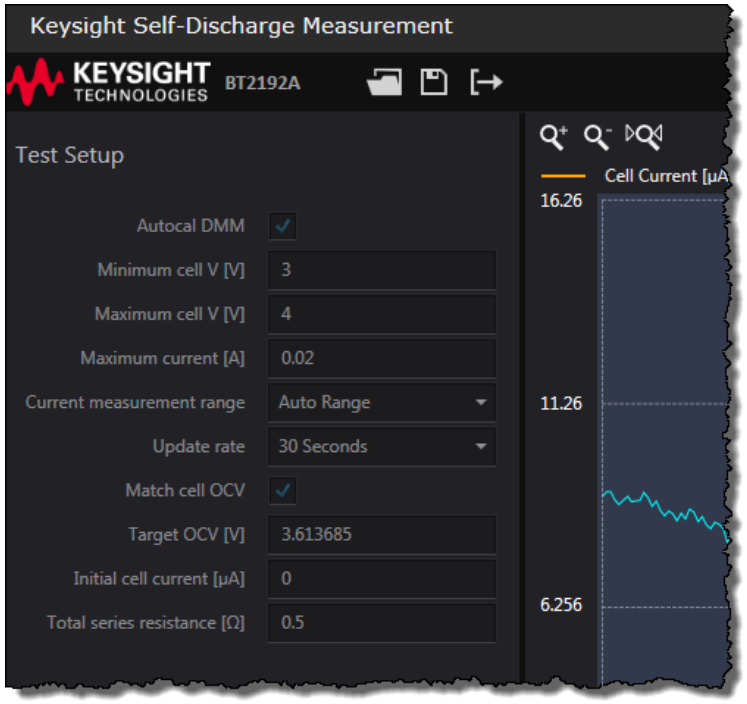


Figure 15 BT2192A Test System Parameters

Estimating the Measurement Response Time

The response time of the measurement is related to the cell's effective capacitance, which can be roughly estimated from the cell's capacity plots. Figure 16 illustrates a sample Cell Capacity plot for a 2.2 Ah cell.

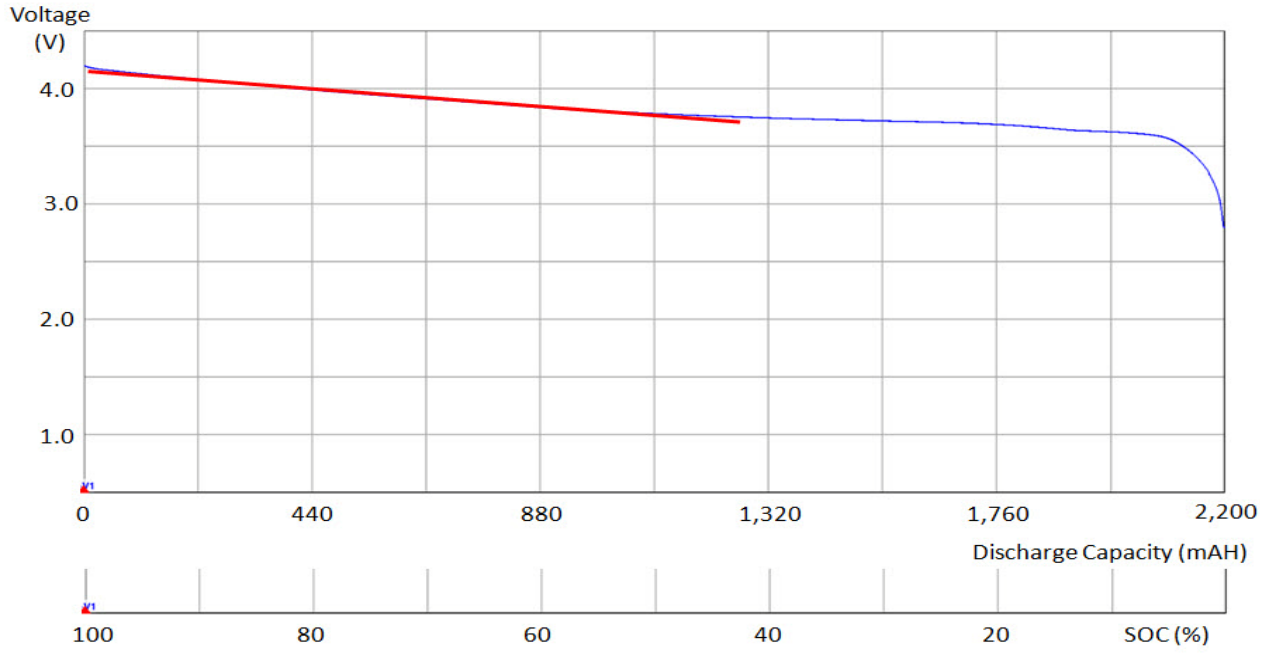


Figure 16 Example Cell Capacity Plot

Draw a straight line depicting the slope of the discharge plot at the 80% State of Charge (SOC) point (indicated by a red line in the sample plot above). The capacitance can be estimated from the inverse of this slope in Amps-seconds/volts[1] (A-s/V). By taking two points from the line, you can calculate the inverse of the slope to be about 9,140 Farads for this cell at 80% SOC.

The settling time constant is the RC product of the cell's estimated capacitance times the **Total Series Resistance** setting being used for the self-discharge measurement test. For example, if the **Total Series Resistance** setting is 1Ω, then the RC time constant is 9,140 seconds, or 2.54 hours. It takes two to three time constants for a measurement to settle out, depending on how close one is looking to be to the final value. This would be 5 to 7.62 hours for this example.

1 Amp-seconds is the charge in coulombs. The existing X-axis on the graph is in milliamp-hours. Convert milliamp-hours to amp-seconds by dividing by 1,000 A/mA and multiplying by 3,600 seconds/hour. An expression that relates voltage and current for a capacitor when the current is constant is: I = C*(Δ Volts/Δ Time). This can be rearranged to C (Farads) = (I*Δ Time)/(Δ Volts). I *Δ time is just change in charge (X-axis) and Δ volts is the change in voltage (y-axis). The capacitance is the inverse of the slope of the discharge curve.

Larger capacity cells take proportionally longer time. Using a smaller **Total Series Resistance** setting can be used to reduce the time it will take for the measurement to settle out to its final value; the trade-off being that the sensitivity to variation of the cell's voltage, mainly due to temperature changes, increases inversely with the **Total Series Resistan**ce setting.

Diagnostic Mode

Diagnostic mode (from the drop-down menu in the upper right corner of the display) displays additional traces to show what the various instruments are doing in the system for cross reference.

Figure 17 Diagnostic Mode Display (Diagnostic data is expanded)

Load and Save Measurements

To save your test measurement data, click the **Save Measurement** icon ( ) in the taskbar. The BT2192A software saves the file as an XML file with a Keysight Solution Storage file (.kss) extension. System setup information is also saved.

You can open the saved .kss file with the **Load Measurement** icon ( ) and see your saved data in the plot area. When you open a previously recorded measurement, a new window opens with the previous measurement settings.

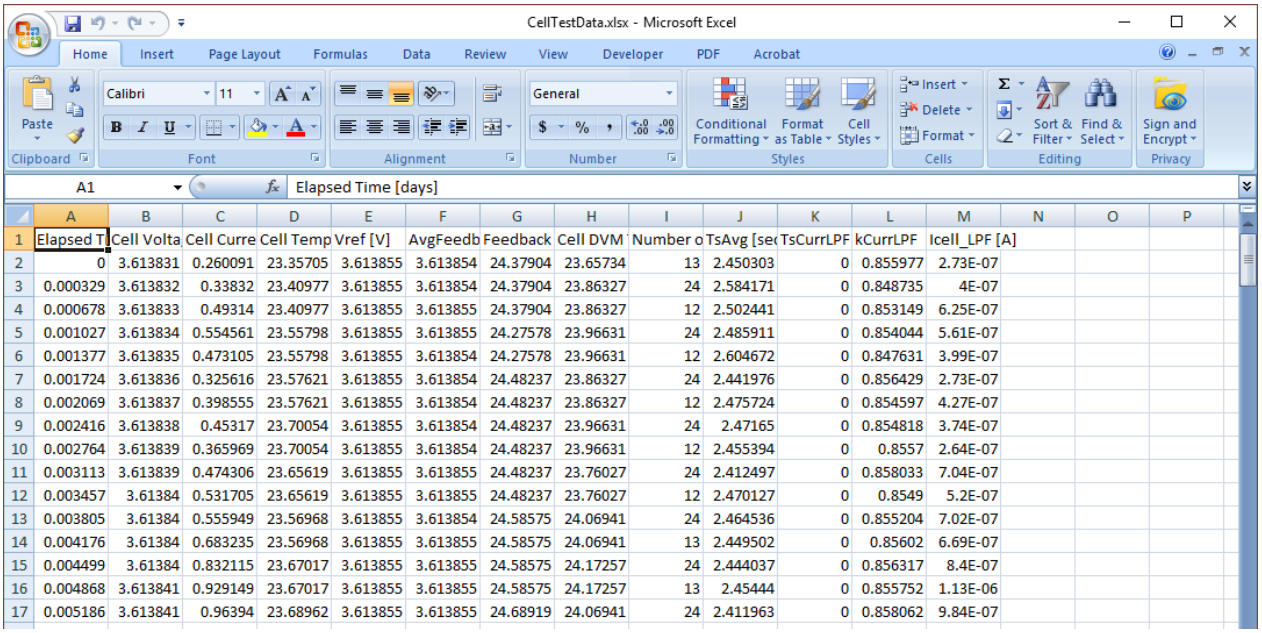
Export Your Data to Excel

To view your recorded data in Microsoft Excel format, click the export icon ( ) in the taskbar. You can then use Excel to analyze the measured data.

NOTE

Use the **Automatic CSV Export** (select **Configure CSV Export...** and **Automatic CSV Export** from the drop-down menu) to save all measurement data to the hard disk while the test is running. This works independent of the Save Measurement icon or Export icon accessible from the toolbar. For detailed information, refer to the *BT2192A Self-Discharge Measurement System* help file.

If Excel is not installed on the host PC, the BT2192A software opens a Windows browser screen and offers to save it as a comma-separated (.csv) file.



	A	B	C	D	E	F	G	H	I	J	K	L	M
1	Elapsed T	Cell Volta	Cell Curre	Cell Temp	Vref [V]	AvgFeedb	Feedback	Cell DVM	Number o	TsAvg [se	TsCurrLPF	kCurrLPF	Icell_LPF [A]
2	0	3.613831	0.260091	23.35705	3.613855	3.613854	24.37904	23.65734	13	2.450303	0	0.855977	2.73E-07
3	0.000329	3.613832	0.33832	23.40977	3.613855	3.613854	24.37904	23.86327	24	2.584171	0	0.848735	4E-07
4	0.000678	3.613833	0.49314	23.40977	3.613855	3.613855	24.37904	23.86327	12	2.502441	0	0.853149	6.25E-07
5	0.001027	3.613834	0.554561	23.55798	3.613855	3.613855	24.27578	23.96631	24	2.485911	0	0.854044	5.61E-07
6	0.001377	3.613835	0.473105	23.55798	3.613855	3.613854	24.27578	23.96631	12	2.604672	0	0.847631	3.99E-07
7	0.001724	3.613836	0.325616	23.57621	3.613855	3.613854	24.48237	23.86327	24	2.441976	0	0.856429	2.73E-07
8	0.002069	3.613837	0.398555	23.57621	3.613855	3.613854	24.48237	23.86327	12	2.475724	0	0.854597	4.27E-07
9	0.002416	3.613838	0.45317	23.70054	3.613855	3.613854	24.48237	23.96631	24	2.47165	0	0.854818	3.74E-07
10	0.002764	3.613839	0.365969	23.70054	3.613855	3.613854	24.48237	23.96631	12	2.455394	0	0.8557	2.64E-07
11	0.003113	3.613839	0.474306	23.65619	3.613855	3.613855	24.48237	23.76027	24	2.412497	0	0.858033	7.04E-07
12	0.003457	3.61384	0.531705	23.65619	3.613855	3.613855	24.48237	23.76027	12	2.470127	0	0.8549	5.2E-07
13	0.003805	3.61384	0.555949	23.56968	3.613855	3.613854	24.58575	24.06941	24	2.464536	0	0.855204	7.02E-07
14	0.004176	3.61384	0.683235	23.56968	3.613855	3.613855	24.58575	24.06941	13	2.449502	0	0.85602	6.69E-07
15	0.004499	3.61384	0.832115	23.67017	3.613855	3.613855	24.58575	24.17257	24	2.444037	0	0.856317	8.4E-07
16	0.004868	3.613841	0.929149	23.67017	3.613855	3.613855	24.58575	24.17257	13	2.45444	0	0.855752	1.13E-06
17	0.005186	3.613841	0.96394	23.68962	3.613855	3.613855	24.68919	24.06941	24	2.411963	0	0.858062	9.84E-07

Figure 18 Microsoft Excel Display

Representative Examples of a Good Self-Discharge Measurements

Figure 19 shows a self-discharge measurement taken on an 18650 2.5 Ah cylindrical cell using the BT2191A. The test was performed using a 0 µA start current and 0.35Ω total series resistance. The measurement rose slowly and steadily, and leveled off at 19 µA after nearly three hours. Note that "positive current" is current being delivered into the cell, in this case it is the current being furnished to offset the self-discharge current being drawn by the cell. "Negative current" is current that is drawn from, or discharging the cell and usually not encountered if the cell is properly rested and its temperature kept reasonably stable as to not induce significant shifts in the cell's voltage.

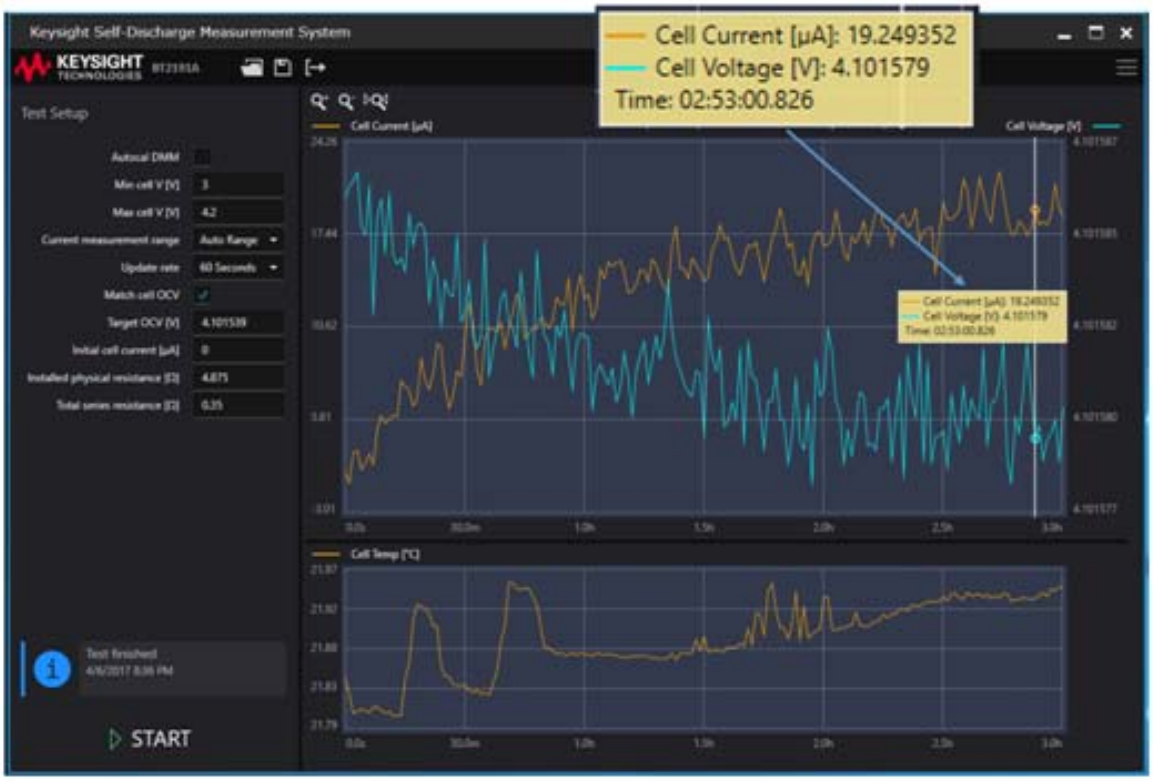


Figure 19 Self-discharge current on an 18650 2.5 Ah cell

Figure 20 is an example taken on the same cell as above, but having a higher self-discharge rate simulated by attaching a high value (47 KΩ) resistor across the cell. Higher self-discharge currents provide greater signal-to-noise, all other things remaining equal. The marker is placed at 4.25 hours it can be seen the measurement is settled out well before that time. Comparing Figure 19 to Figure 20 shows the difference between a cell exhibiting a relatively high level of self-discharge from a low self-discharge cell much more quickly than the settling time.

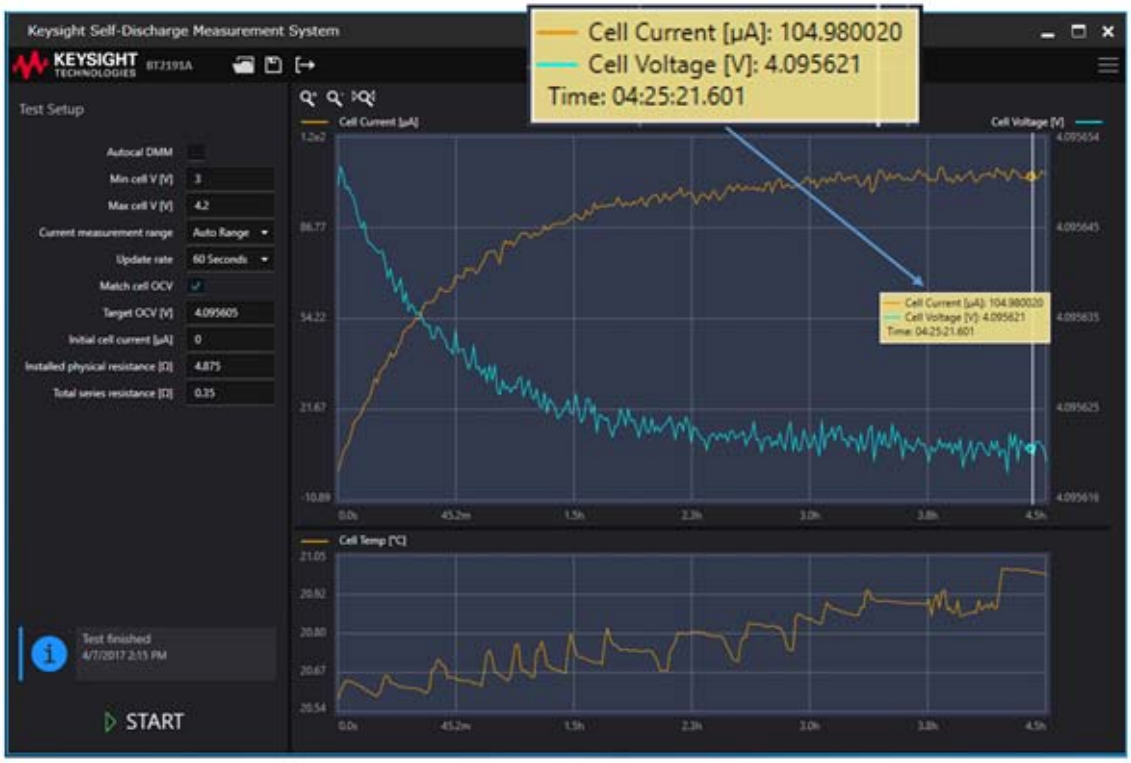


Figure 20 Self-discharge current on an 18650 2.5 Ah cell with a greater self-discharge current

Appendix A. Recommendations for Maintaining Cell Stability During Testing

NOTE

The voltage of most Li-Ion cells is very sensitive to vibration and mechanical stress or deflection. Once a self-discharge test has started, it is important that the cell not be moved or disturbed, and is not subjected to vibration. The temperature sensor must be mounted on or attached to the cell before the test and not touched or have its connection adjusted during the test. Cells are microphonic – any touching or tapping them, or any vibration or shock will affect the cell's voltage and thus the measured current value.

A Cell's Percent State of Charge (% SOC) for Performing Self-Discharge Measurements

Self-discharge current is somewhat less for lower levels of % SOC, falling off at a greater rate below ~45% SOC. The cell's voltage tends to be less stable and more temperature sensitive at lower levels of % SOC. For these reasons, it is generally recommended that the cells should ideally be at 60% SOC or higher for achieving good self-discharge current measurements.

Redistribution and Achieving Charge Equilibrium

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 be at equilibrium. During this time, the cell's voltage is dropping or rising at an exponential rate, depending on whether it had been charged or discharged. In comparison, when a cell's charge is fully distributed and at equilibrium, its voltage falls off at a much lower and linear rate, due to the internal self-discharge current. Depending on the cell's makeup, it can take from several days to two weeks for a cell to reach charge equilibrium.

When the cell is connected to the BT2191A, the system holds its output voltage constant after it goes through the cell voltage matching process. If the cell is at charge equilibrium, the only influence on the cell's voltage is due to self-discharge. As the BT2191A holds its voltage constant, the net result is the BT2191A needs to only replenish the self-discharge current to maintain constant voltage. However, when a cell has recently been charged or discharged and then connected to the BT2191A, additional charging current will be drawn from the BT2191A (after charging) or discharging current will be sourced back into the

BT2191A (after discharging) in addition to the self-discharge current. The peak of this current can be several orders of magnitude greater than the self-discharge current alone.

A Cell's Expected Level of Self-Discharge Current and Temperature Dependency

It is normal for cells to exhibit a small amount of self-discharge. It is difficult to definitively state what a cell's expected self-discharge current should be, as many factors exist regarding a cell's design and makeup that can affect this value. Notwithstanding, for cells at a room temperature of typically 23 ^{O}C, testing has shown it can typically range from just a few micro-amperes for sub 1 Ah cells to 50 to 100 micro-amperes for 10 to 20 Ah cells.

All other things being equal, a cell's self-discharge current can approximately double 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 and its Impact on Self-Discharge Current Measurement

A cell's voltage temperature dependency can be expressed as a temperature coefficient of voltage (TCV), and can be quantified in microvolts per degree C (µV/^{O}C). Since the potentiostatic method to measure a cell's self-discharge current relies on matching an external source's voltage to the cell's voltage and then connecting them together, it is easy to see how the self-discharge current measurement is impacted by any change of the cell's voltage afterwards. Several things can be done to reduce the effect of temperature on self-discharge current measurements:

- A cell's TCV is dependent on its % SOC. It can vary from as low as zero at certain points to as much as 100's of µV/^{O}C, typically at very low % SOC levels. Generally having the cell charged to 70% SOC or better helps reduce the cell's TCV. Still, you may have to contend with a TCV in the range of 20 to 100 µV/^{O}C.
- An indoor test environment can experience a few ^{O}C temperature cycle 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 BT2191A has a programmable series resistance for this purpose.
  - -- Temperature sensitivity is a significant factor for larger cells, as they usually require a longer measurement settling time due to their proportionally larger capacity.

- Depending on how long the self-discharge measurement takes, it may be necessary to take further steps to hold the cell's temperature steady. Possibilities include:
  - -- Surrounding the cell with thermal insulation.
  - -- Incorporating a substantial thermal mass (metal plate) that the cell is held against, to dampen temperature change. The thermal mass can be passive or actively temperature regulated.
  - -- Using a thermal chamber having a regulated temperature.

Stress and Vibration and their Impact on Self-Discharge Current Measurement

A cell's voltage can be altered by mechanical stress and vibration. Any change of the cell's voltage impacts 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 to:

- Isolate the cell from any direct vibration that may exist.
- Not subject the cell to stress during a test.

Appendix B. Troubleshooting

A common problem after many hours of use is a broken test harness (cable).This is often apparent when test plots are essentially unchanging DC values with small amounts of noise.

System Setup

1. Make certain you have the cable(s) properly connected to the cell-under-test.
2. Make certain the correct VISA addresses are entered into the Configure Hardware screen (see "Configure the BT2191A Test System Hardware" on page 31).

Testing the Cable

Testing the wiring harness consists of making two resistance measurements. Use a DC ohmmeter to measure the cable resistance. Follow the procedure below.

1. Ensure the two alligator-style clips do not touch each other or any other metallic surface.
2. Measure the DC resistance between the positive (red wires) of the **SMU DMM** banana plug and the positive of the **Cell DMM** banana plug. This resistance should be approximately 4.7 Ω (4.7 Ω ±1% plus the resistance of the wire).

Measure the DC resistance between the negative (black wires) of the **SMU DMM** banana plug and the negative the **Cell DMM** banana plug.

BT2191A System Specifications

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

Typical Characteristics

Parameter	
Voltage sourcing and measurement range	0.5 V to + 4.5 V
Voltage sourcing stability (typical)] Measured over 24 hours at 1 minute integration. Applies at output terminals of the SMU. Cabling and interconnect errors may degrade performance.	$\pm 10 \mu V_{pk}$
Total resistance range (includes physical resistor installed in wiring harness and programmable resistance)	.1 to 10 Ω
Programmable resistance accuracy	±100 mΩ
Cell current measurement range	± 10 mA
Measurement rate	1 measurement every 10 s, 30 s, or 60 s.
Operating air temperature range Max rate-of-change of ambient air must be < 5°C change per hour.	25 to 35°C
Other Environmental	Refer to relevant information for individual instruments
Warm-up time after power-on	2 hours
Minimum supported cell effective capacitance	100 Farads
Minimum supported R*C (the product of cell effective capacitance and total resistance setting)	50 seconds

Parameter	
Maximum measurement results file size	Measure up to 500,000 readings per test run. The test can run for 300 days at 1-minute measurement logging interval, 150 days at 30-second measurement logging interval, or 50 days at 10-second logging interval.
Regulatory Compliance (EMC, Safety)	Refer to relevant information for individual instruments.
Computer interface	LAN (user provides Ethernet switch and Ethernet cables to connect to instruments)
Acoustic noise	Refer to relevant information for individual instruments
AC Power input	Refer to relevant information for individual instruments
Typical weight, physical dimensions	Refer to relevant information for individual instruments

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