BT2200 Series Charge-Discharge System

BT2202A, BT2203A, BT2203B Chassis
BT2204A, BT2204B, BT2205A Modules

KEYSIGHT

OPERATING AND SERVICE GUIDE

Copyright Notice

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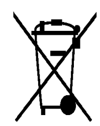
The following crossed out wheeled bin symbol indicates that separate collection for waste electric and electronic equipment (WEEE) is required, as obligated by DIRECTIVE 2012/19/EU and other National legislation.

Do not dispose in domestic household waste. Please refer to about.keysight.com/en/companyinfo/environment/takeback.shtml to understand your trade in options with Keysight in addition to product takeback instructions.



Safety Symbols

WARNING A WARNING notice denotes a hazard. It calls attention to an operating procedure, practice, or the like 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.

CAUTION A CAUTION notice denotes a hazard. It calls attention to an operating procedure, practice, or the like 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.

Direct current

Alternating current

Frame or chassis terminal

Standby supply. Unit is not completely disconnected from AC mains when switch is off.

Risk of electric shock

Hot surface

The user must read the instructions before operating to avoid incorrect use - potentially leading to a hazard.

Earth ground terminal

The CE mark is a registered trademark of the European Community.

ISM1-A Indicates that the instrument is an Industrial Scientific and Medical Group 1 Class A product (CISPER 11, Clause 4)

ICES/NMB-001 Indicates product compliance with the Canadian Interference-Causing Equipment Standard.

Intertek The ETL mark is a registered trademark of Intertek. The text indicates product compliance with the Canadian Interference- Causing Equipment Standard (ICES-001).

The RCM mark is a registered trademark of the Spectrum Management Agency of Australia. This signifies compliance with the Australian EMC Framework regulations under the terms of the Radio Communications Act of 1992.

Contains one or more of the 6 hazardous substances above the maximum concentration value (MCV), 40 Year EPUP.

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.

사 용 자 안 내 문
이 기기는 업무용 환경에서 사용할 목적으로 적합성평가를 받은 기기로서 가정용 환경에서 사용하는 경우 전파간섭의 우려가 있습니다.

※ 사용자 안내문은 "업무용 방송통신기자재"에만 적용한다.

Safety Notices

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

WARNING General
Do not use this product in any manner not specified by the manufacturer. The protective features of this product may be impaired if it is used in a manner not specified in the operating instructions.

WARNING Environmental Conditions
Never use the instrument outside of the specified environmental conditions described under **Common Characteristics**.

WARNING Heavy Weight
Danger to hands and feet. To avoid personal injury and damage to the instrument, always use a sturdy cart or other suitable device to move the instrument. Do not lift the instrument alone; always use two people to lift the instrument.

WARNING SHOCK HAZARD Ground the Instrument
This product is provided with protective earth terminals. To minimize shock hazard, the instrument must be connected to the AC mains through a grounded power cable, with the ground wire firmly connected to an electrical ground (safety ground) 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 injury or death.

WARNING Do Not Operate in an Explosive Atmosphere
Do not operate the instrument in the presence of flammable gases or fumes.

WARNING Do Not Remove the Instrument Cover
Only qualified, service-trained personnel who are aware of the hazards involved should remove covers. Always disconnect external power.

WARNING 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 for service and repair to ensure that safety features are maintained.

WARNING Fuses

The instrument contains internal fuses, which are not customer accessible.

WARNING Cleaning

To prevent electric shock, always unplug the unit before cleaning. Use a dry cloth or one slightly dampened with water to clean the external case parts. Do not use detergent or chemical solvents. Do not attempt to clean internally.

WARNING In Case of Damage

Instruments that are not functioning correctly, appear damaged or defective should be made inoperative and secured against unintended operation until they can be repaired by qualified service personnel.

WARNING Possible Sharp Edges

The BT2204 modules may potentially have sharp edges that require careful handling. Exercise caution when touching the edges around the perimeter of the module and the solder points on the bottom of the module.

1
Quick Reference

KEYSIGHT TECHNOLOGIES

Welcome

What is battery charge-discharge?

Battery charge-discharge is the process by which a lithium-ion cells are formed.

The typical cell forming process consists of a series of steps or actions, commonly referred to as a sequence, which consists of three steps: charging the cell, resting the cell, and discharging the cell. These steps may be repeated any number of times and in any order within the sequence, depending on the process. The transition from one step to the next is controlled by tests within the step that specify what action to take if the test either passes or fails. When all tests and steps have successfully completed, the cell is formed.

Advantages of the Keysight BT2200 Series Charge-Discharge System

The Keysight BT2200 Series Charge-Discharge System (CDS) has been designed to address the unique requirements and needs of lithium-ion cell manufacturing. The CDS can accurately charge, discharge, and measure lithium-ion cells. It consists of a Keysight BT2202A or BT2203A/B mainframe with up to eight Keysight BT2204A/B or BT2205A Charge-Discharge Modules. With BT2204A/B modules, a fully loaded mainframe has 256 charge-discharge channels rated at 6 A. With BT2205A modules, a fully loaded mainframe has 16 charge-discharge channels rated at 100 A. Mainframes and modules can be configured to form a low cost, high performance cell charge-discharge station in a cell manufacturing process.

Overall features include:

- Compact size
- Significant savings in operating costs: high efficiency with power regeneration during discharge
- Accurate and safe cell forming with laboratory grade measurements
- Current per module is configurable from 6 A to 200 A
- Expandable design consisting of up to 8 plug-in modules
- LAN or USB controlled

Operating features include:

- Discharge energy is regenerated into any charging cells, or back to the AC line
- Less wasted energy provides significant cost saving and reduces climate control costs
- Efficiency
- Charge efficiency: 80% or higher
- Discharge efficiency: 75% or higher
- ~450W (2%) fixed loss from mainframe and interface card overhead
- Air cooled system

Maintenance features include:

- Simple, fast calibration via a dedicated calibration port using two DMMs and a power supply
- Mainframe performs channel alignment (automatic calibration) on module channels
- No disconnection of cell channels when calibrating entire system
- Fast cell module swap to calibrate or repair
- Calibration data stored on plug-in modules
- No need to recalibrate when swapping modules
- Remote management over LAN to identify out of calibration or faulty channels

Contact Keysight Technologies

You can contact Keysight Technologies for warranty, service, or technical support.

Use www.keysight.com/find/assist for information on contacting Keysight worldwide, or contact your Keysight Technologies representative.

Models and Specifications

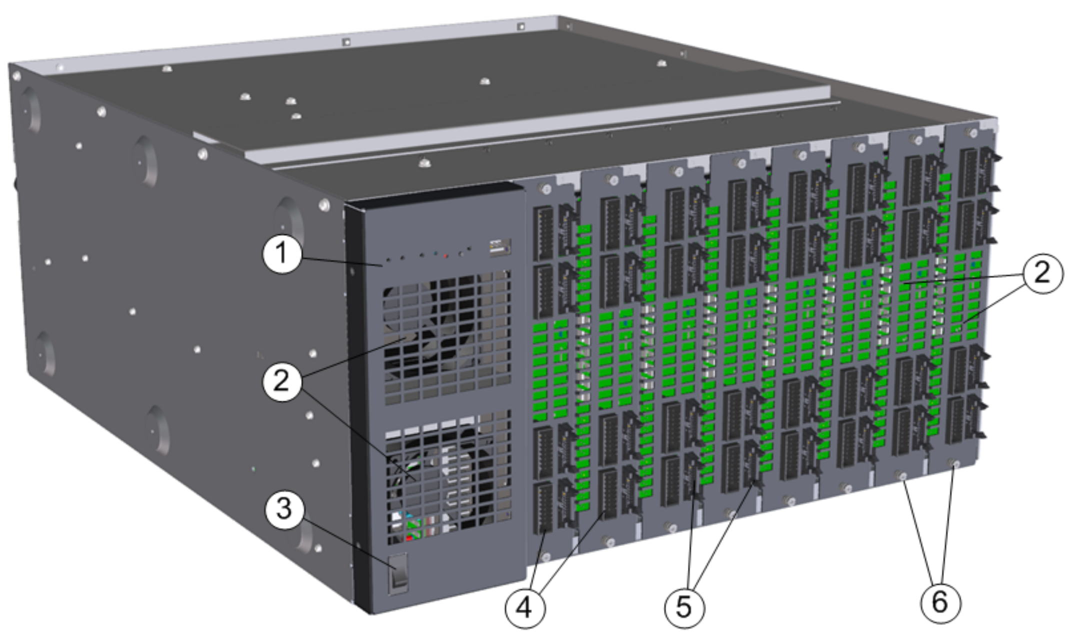
Models

- Keysight BT2202A - Charge-Discharge 400/480 VAC Chassis
- Keysight BT2203A and BT2203B - Charge-Discharge 200/208 VAC Chassis
- Keysight BT2204A and BT2204B - 32-Channel Charge-Discharge Module
- Keysight BT2205A - 2-Channel, 100 A, Charge-Discharge Module

The BT2204A modules install in the BT2203A chassis.
The BT2204B modules install in the BT2202A or BT2203B chassis.
The BT2205A modules install in the BT2202A or BT2203B chassis.

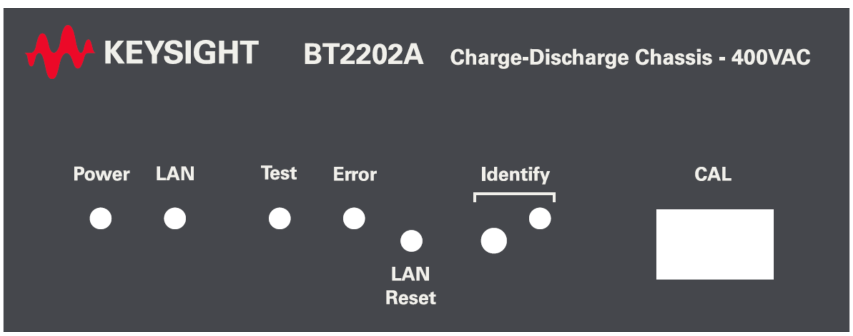
CAUTION You cannot mix Keysight BT2205A modules with Keysight BT2204A/B modules in the same mainframe. Keysight BT2205A modules require their own dedicated mainframe.

Front View



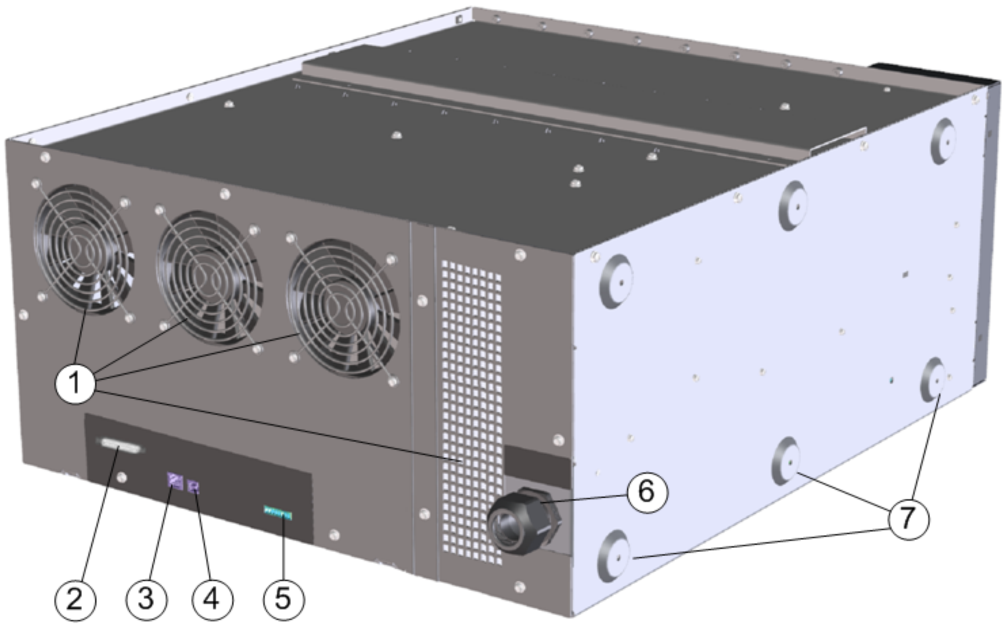
	Description
1. LED Indicators	See below
2. Air Inlets	Air inlet requires a minimum of 12 inch (30.5 cm) clearance
3. Line switch	Turns the unit on or off
4. Power connectors	Four 16-pin power connectors for each BT2204A/B charge-discharge module (8 cell connections @ 6.25 A are available on each connector). Four bus-bar connectors for each BT2205A charge-discharge module (2 cell connections @ 100 A are available on each module).
5. Sense connectors	Four 16-pin sense connectors for each charge-discharge module (8 sense connections are available on each connector). One 10-pin sense connector for each BT2205A charge-discharge module (2 sense connections are available on the connector).
6. Charge-discharge modules	Up to eight plug-in Keysight BT2204A/B or BT2205A Charge-Discharge Modules. You cannot mix Keysight BT2205A modules with Keysight BT2204A/B modules in the same mainframe.

LED Indicators and Switches



Power	Green LED indicates power is on.
LAN	Green LED indicates the LAN connection is active. Flashing blue indicates a SCPI command is received. Red indicates a LAN fault.
Test	Blue indicates a sequence is running. Flashing blue indicates calibration or self-tests are in progress. Off indicates no sequence is running.
Error	Red indicates a protection fault has occurred. Off indicates protection is cleared.
LAN reset	This recessed switch performs a software system LAN reset. This resets all network settings to their factory defaults and restarts the interface. Refer to Reset Settings.
Identify	The right LED blinks when the LXI identify command is sent. The lower switch turns off the LXI identify LED
CAL	The calibration port

Rear View



	Description
1. Air Outlets	The rear fan outlets requires a minimum of 12 inch (30.5 cm) clearance
2. Expanded digital connector	An expanded 25 pin digital connector. Not available on Keysight BT2203A main-frames.
3. LAN	10/100/1000 Base-T (Left LED indicates activity; right LED indicates link integ-rity)
4. USB	USB interface connector
5. Digital connector	An 8-pin digital IO interface
6. AC input	3-phase AC input L1, L2, L3, with chassis ground connector (the AC input is bi-directional)
7. Embosses	For attaching stick-on feet or mounting hardware (see Instrument Orientation)

BT2204A/BT2204B Charge-Discharge Specifications

Specifications are valid 20 seconds after starting a charge/discharge step.

BT2204A/B Parameter	Individual Channels	Paralleled Channels where N = the number of channels
Number of channels per module:	32	Up to 32
Voltage range for charging:	0 V to +6 V	0 V to +6 V
Voltage range for discharging	+6 V to +1.9 V (@ 6.25 A) +6 V to +1.2 V (@ 0 A)	+6 V to +1.9 V (@ 6.25 A * N) +6 V to +1.2 V (@ 0 A)
Current range:	-6.25 A to +6.25 A	(-6.25 A * N) to (+6.25 A * N)
Voltage measurement accuracy:	±[(0.02%)*(Voltage_reading)+1 mV] [1, 4, 5]	±[(0.02%)*(Voltage_reading)+1 mV] [1, 2, 4, 5]
Current measurement accuracy:	±[(0.05%)*(Current_reading)+3 mA] [1, 4, 5]	±[(0.05%)*(Current_reading)+3 mA*N] [1, 3, 4, 5]

Note 1: Specifications are valid for 1 group of channels operating in parallel or 1 individual channel sourcing/sinking at a time with an inlet air temperature of Tchan ±5 °C, where Tchan is the channel alignment temperature. The reported expanded uncertainty is based on a standard uncertainty multiplied by a coverage factor k = 2, providing a level of confidence of approximately 95 %.

Note 2: Voltage Power Adder - When multiple channels or groups of channels in a module are sourcing/sinking current an additional spec adder must be applied. Add (0.001 * Ipeak^2) % of reading additional error, where I peak is the maximum current being measured on any other individual channel in that module. For cell groups, I peak is the total cell Ireading / N, or the maximum current being measured on any other individual channel in that module, whichever value is greater.

Note 3: Current Power Adder - When multiple channels or groups of channels in a module are sinking/sourcing current an additional spec adder must be applied. Add (0.004 * Ipeak^2) % of reading additional error, where I peak is the maximum current being measured on any other individual channel in that module. For cell groups, I peak is the total cell Ireading / N, or the maximum current being measured on any other individual channel in that module, whichever value is greater.

Note 4: Temperature Adder - For inlet air temperature outside of ±5 °C from the calibration temperature, the following must be applied. For voltage, add (0.001 * T)% reading additional error. For current, add (0.01 * T) % reading additional error. T is the amount in degree C that the inlet air temperature is outside of Tchan ±5 °C and Tchan is outside of Tref ±5 °C, where Tref is the reference calibration temperature and Tchan is the channel temperature.

Note 5: Specifications are valid for the following conditions:
Reference calibration performed within 1 year and channel alignment performed within past 7 days.
Channel alignment must be performed on all modules whenever any module is added or removed from the mainframe.
For channel alignment intervals greater than 7 days, add the following error terms
8 days to 31 days: Current Accuracy + 0.2% of reading, Voltage Accuracy: +0.01% of reading
32 to 180 days: Current Accuracy: +0.3% of reading, Voltage Accuracy: + 0.02% of reading
181 to 365 days: Current Accuracy +0.4% of readings, Voltage Accuracy: +0.03% of reading

BT2205A Charge-Discharge Specifications

Specifications are valid 20 seconds after starting a charge/discharge step.

BT2205A Parameter	Individual Channels	Paralleled Channels where N = the number of channels
Number of channels per module:	2	2, 4, 6, or 8
Voltage range for charging:	0 V to +6 V	0 V to +6 V
Voltage range for discharging	+6 V to +1.9 V (@ 100 A) +6 V to +1.2 V (@ 0 A)	+6 V to +1.9 V (@ 100 A * N) +6 V to +1.2 V (@ 0 A)
Current range:	-100 A to +100 A	(-100 A * N) to (+100 A * N)
Voltage measurement accuracy:	±[(0.06%)*(Voltage_reading)+1 mV] [1, 2, 3]	±[(0.06%)*(Voltage_reading)+1 mV] [1, 2, 3]
Current measurement accuracy:	±[(0.2%)*(Current_reading)+50 mA] [1, 2, 3]	±[(0.2%)*(Current_reading)+50 mA*N] [1, 2, 3]

Note 1: Specifications are valid for 1 group of channels operating in parallel or 1 individual channel sourcing/sinking at a time with an inlet air temperature of Tchan ±5 °C, where Tchan is the channel alignment temperature. The reported expanded uncertainty is based on a standard uncertainty multiplied by a coverage factor k = 2, providing a level of confidence of approximately 95 %.

Note 2: Temperature Adder - For inlet air temperature outside of ±5 °C from the calibration temperature, the following must be applied. For voltage, add (0.001 * T)% reading additional error. For current, add (0.01 * T) % reading additional error. T is the amount in degree C that the inlet air temperature is outside of Tchan ±5 °C and Tchan is outside of Tref ±5 °C, where Tref is the reference calibration temperature and Tchan is the channel temperature.

Note 3: Specifications are valid for the following conditions:
Reference calibration performed within 1 year and channel alignment performed within past 7 days.
Channel alignment must be performed on all modules whenever any module is added or removed from the mainframe.
For channel alignment intervals greater than 7 days, add the following error terms
8 days to 31 days: Current Accuracy + 0.2% of reading, Voltage Accuracy: +0.01% of reading
32 to 180 days: Current Accuracy: +0.3% of reading, Voltage Accuracy: + 0.02% of reading
181 to 365 days: Current Accuracy +0.4% of readings, Voltage Accuracy: +0.03% of reading

BT2204A/BT2204B Charge-Discharge Characteristics

BT2204A/B Parameter	Individual Channels	Paralleled Channels where N = the number of channels
Voltage programming accuracy[1]:	±[(0.02%)*(Voltage_reading)+1 mV]	±[(0.02%)*(Voltage_reading)+1 mV]
Current programming accuracy[1]:	±[(0.05%)*(Current_reading)+3 mA]	±[(0.05%)*(Current_reading)+3 mA*N]
Voltage measurement & programming resolution:	200 µV	200 µV
Current measurement & programming resolution:	200 µA	200 µA * N
Sampling interval for all measurements:	1 second	1 second
DCIR measurement accuracy[2]:	$\pm\left[(0.26\%) * (\mathrm{DCIR}) + \frac{\mathrm{DCIR} * \lvert\mathrm{I\_after}\rvert}{120\mathrm{kA}} + 160\mu\Omega\right]$	$\pm\left[(0.26\%) * (\mathrm{DCIR}) + \frac{\mathrm{DCIR} * \lvert\mathrm{I\_after}\rvert}{\mathrm{N} * 120\mathrm{kA}} + \frac{160\mu\Omega}{\mathrm{N}}\right]$

Note 1: Programming accuracy is a closed-loop function of the measurement accuracy. It is equivalent to the measurement accuracy described in the previous table, less the programming resolution. Notes 1 - 5 in the previous table also apply.
Note 2: A minimum of 20% full scale current is required for the characteristic.

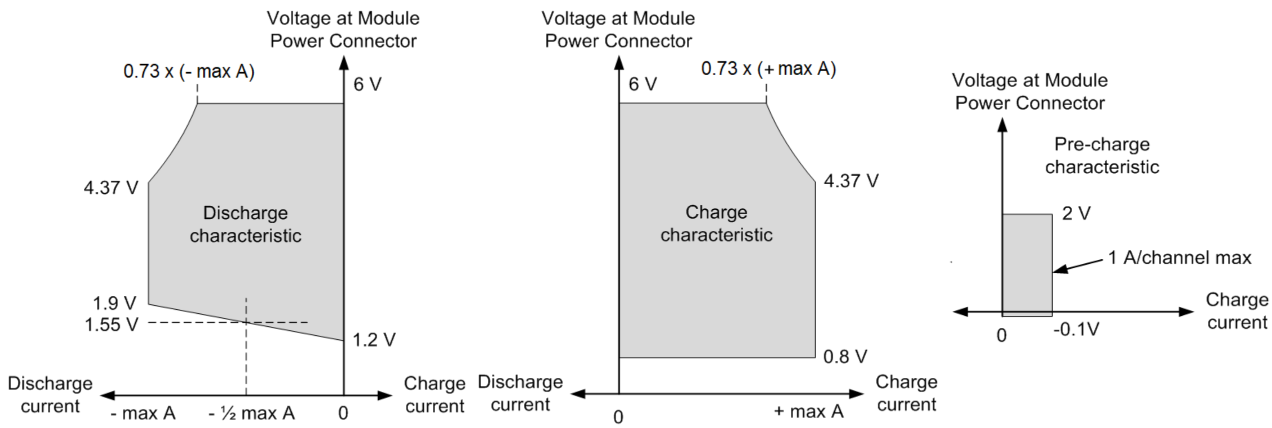
BT2205A Charge-Discharge Characteristics

BT2205A Parameter	Individual Channels	Paralleled Channels where N = the number of channels
Voltage programming accuracy[1]:	±[(0.06%)*(Voltage_reading)+1 mV]	±[(0.06%)*(Voltage_reading)+1 mV)
Current programming accuracy[1]:	±[(0.2%)*(Current_reading)+50 mA]	±[(0.2%)*(Current_reading)+50 mA*N]
Voltage measurement & programming resolution:	200 µV	200 µV
Current measurement & programming resolution:	3.2 mA	3.2 mA * N
Sampling interval for all measurements:	1 second	1 second
DCIR measurement accuracy[2]:	$\pm\left[(0.26\%) * (\mathrm{DCIR}) + \frac{\mathrm{DCIR} * \lvert\mathrm{I\_after}\rvert}{7.5\mathrm{kA}} + 10\mu\Omega\right]$	$\pm\left[(0.26\%) * (\mathrm{DCIR}) + \frac{\mathrm{DCIR} * \lvert\mathrm{I\_after}\rvert}{\mathrm{N} * 7.5\mathrm{kA}} + \frac{10\mu\Omega}{\mathrm{N}}\right]$

Note 1: Programming accuracy is a closed-loop function of the measurement accuracy. It equivalent to the measurement accuracy described in the previous table, less the programming resolution. Notes 1 - 3 in the previous table also apply.
Note 2: A minimum of 20% full scale current is required for the characteristic. The characteristic is valid from 0 Ω to 50 mΩ .

Power Module Operating Quadrants

The following graphs illustrate the operating quadrants of the CDS with the following configurations:



Configurations with BT2204A/BT2204B modules installed

Max user-defined cells per chassis	Max current per channel	# of paralleled channels per cell	Max power per user-defined cell
256	± 6.25 A	No channels paralleled	27.34 W
64	± 25 A	4	109.38 W
32	± 50 A	8	218.75 W
16	± 100 A	16	437.5 W
8	± 200 A	32	875.0 W

Configurations with BT2205A modules installed

You cannot mix Keysight BT2205A modules with Keysight BT2204A/B modules in the same mainframe.

Max user-defined cells per chassis	Max current per channel	# of paralleled channels per cell	Max power per user-defined cell
16	± 100 A	No channels paralleled	437.5 W
8	± 200 A	2	875.0 W
4	± 400 A	4	1,750 W
2	± 600 A	6	2,625 W
2	± 800 A	8	3,500 W

BT2202A/BT2203A/B Mainframe Specifications

Parameter	Specification
Voltage measurement accuracy [1]:	±[(0.018%)*(Voltage_reading) + 0.6 mV]
Current measurement accuracy [1]:	±[(0.050%)*(Current_reading) + 1.6 mA]

Note 1: Temperature Adder - For inlet air temperature outside of ±5 °C from the calibration temperature, the following must be applied. For voltage, add (0.001 * T)% reading additional error. For current, add (0.01 * T) % reading additional error. T is the amount in degree C that the inlet air temperature is outside of Tref ±5 °C, where Tref is the reference calibration temperature.

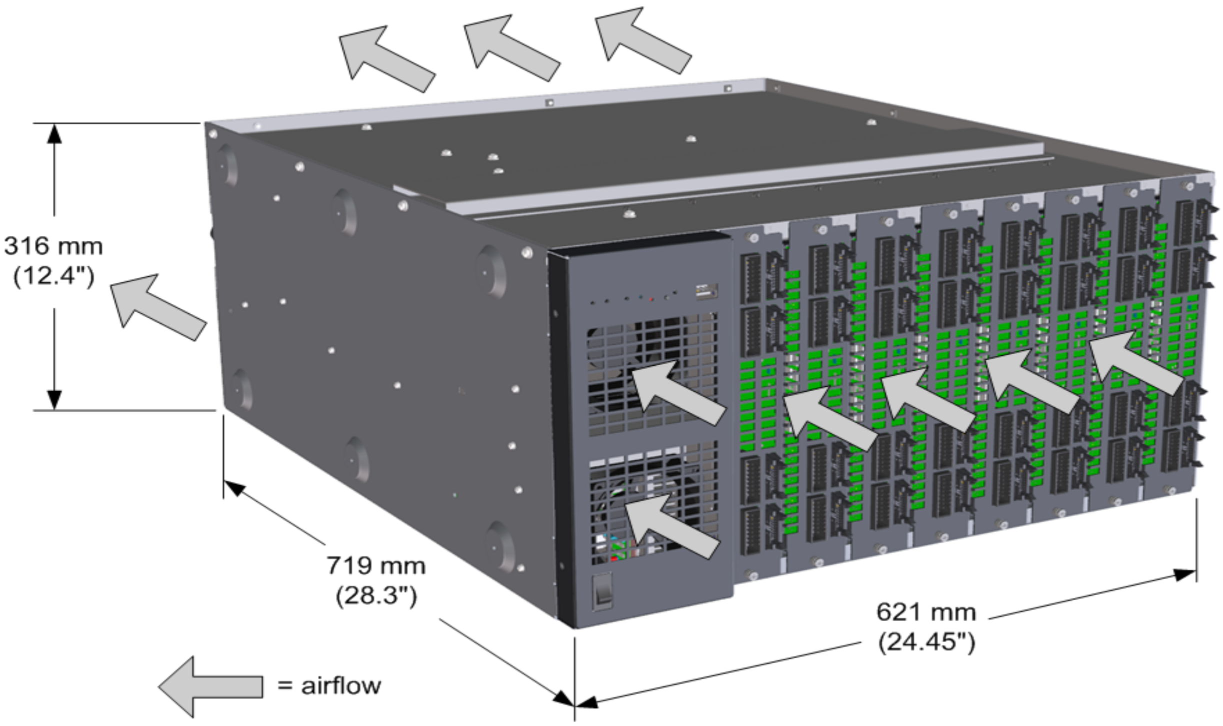
BT2202A/BT2203A/B Mainframe Characteristics

Parameter	BT2202A	BT2203A/BT2203B
Charge power limit:	7 kW (256 channels @ 6.25 A, 4.375 V)	7 kW (256 channels @ 6.25 A, 4.375 V)
Discharge power limit:	7 kW (256 channels @ 6.25 A, 4.375 V)	7 kW (256 channels @ 6.25 A, 4.375 V)
Fixed power dissipation of chassis:	350 W (add 15 W per C/D module)	350 W (add 15 W per C/D module)
Charging efficiency @1 A, 4.2 V excluding fixed dissipation: @6 A, 4.2 V excluding fixed dissipation:	 90% 80%	 90% 80%
Discharging efficiency: @1 A, 4.2 V excluding fixed dissipation: @6 A, 4.2 V excluding fixed dissipation:	 80% 75%	 80% 75%
AC input phase and range:	3 phase; 400 VAC nominal +10%/-15% 3 phase; 480 VAC nominal ±10%	3 phase; 200 VAC nominal ±10% 3 phase; 208 VAC nominal ±10%
Input VA:	11.5 kVA	11.5 kVA
Input current per phase:	19 A	39 A
Power factor:	0.99 at nominal input and rated power	0.99 at nominal input and rated power

Parameter	Common Characteristics
Computer Interfaces	
LXI:	LXI Core 2011 compliant
LAN:	10 Mb, 100 Mb, 1 Gb LAN
USB:	USB 2.0 (USB-TMC488 protocol
Digital Port	
Max voltage rating:	+16.5 VDC/- 5 VDC between pins
Digital Pins 1 & 2 as FLT:	Maximum low-level output voltage = 0.5 V @ 4 mA Maximum low-level sink current = 4 mA Typical high-level leakage current = 1 mA @ 16.5 VDC
Digital Pins 1-23 as outputs:	Maximum low-level output voltage = 0.5 V @ 4 mA; 1 V @ 50 mA; 1.75 V @ 100 mA Maximum low-level sink current = 100 mA Typical high-level leakage current = 1 mA @ 16.5 VDC
Digital Pins 1-23 as inputs:	Maximum low-level input voltage = 0.8 V Minimum high-level input voltage = 2 V Typical low-level current = -2 mA @ 0 V (internal 2.2k pull-up) Typical high-level leakage current = 1 mA @ 16.5 VDC
Common pins	Internally connected to chassis ground On 8-pin connector = pin 8 On 25 pin connector = pins 1, 6, 11, 13, 14,19, 24
Environmental conditions: Operating environment: Ambient air temperature range: Relative humidity: Altitude: Storage temperature:	Indoor use, installation category II, pollution degree 2 20°C to 35°C Up to 80% (non-condensing) Up to 2000 meters -30°C to 70°C
Regulatory Compliance	
EMC only[1]:	BT2202A/BT2204B/BT2205A comply with European EMC Directive for test and measurement products, and carry the CE mark BT2202A/BT2204B/BT2205A comply with Australian standard, and carry the RCM mark BT2202A/BT2204B/BT2205A comply with the South Korean EMC requirements BT2202A/BT2204B/BT2205A comply with Canadian ICES-001 standard BT2202A/BT2204B/BT2205A est conforme à la norme NMB-001 du Canada
Safety:	All models comply with European Low Voltage and carry the CE mark. All models conform to US and Canadian safety regulations. Declarations of Conformity for this product may be downloaded from the Web. Go to http://www.keysight.com/go/conformity and click on “Declarations of Conformity.”
Acoustic statement (European Machinery Directive)	Acoustic noise emission LpA 73 dB at Bystander position Normal operation mode per ISO 7779
Weight	BT2202A/BT2203A/B mainframes without modules: 28 kg (62 lbs) Each installed module adds 1.8 kg (4 lbs) to the mainframe's weight.

Note 1: Models BT2203A/B and BT2204A do not comply with IEC 61326-1 (part of the EMC regulatory compliance stated above)

Dimensions and Airflow



- Airflow is in from the front of the unit and out of the back of the unit.
- Fan speed control is automatic and has low and high settings. Fan speeds increase when the system determines that additional cooling is needed.
- The front and rear air vents require a minimum of 12 inches (30 cm) clearance. Inlet air temperature must be within the temperature range of 20°C to 35°C.
- The instrument should not be installed in a pressurized rack or enclosure.

Command Quick Reference

Common Commands

ABORt	Aborts the sequence in progress
*CAL <*channels*>	Runs channel alignment on the specified channels
*CLS	Clears status
*ESE <*value*>	Event status enable command and query
*ESR?	Event status event query
*IDN?	Returns instrument identification
*OPC	Sets the OPC (operation complete) bit in the standard event register
*RST	Resets the instrument
*STB?	Status byte query
*TST?	Self-test query
*WAI	Pauses command processing until all pending operations are complete

CALibration

:AUTO <*channels*>	Runs channel alignment on the specified channels
:STATus? <*error*>, <*run state*>, <*status*>, <*% complete*>, <*module*>, <*channel*>, <*elapsed*>	Returns the status of the channel alignment
:STARt	Initiates calibration
:STEP <*step*>	Steps through the different calibration processes
:STORe	Stores the cal constants in the EEPROM
:STRing <target>, <"*string*">, 1|2	Stores a message in calibration memory
:VALue? <*step*>, <*value*>	Sends the calibration measurement to the instrument

CELL

:ABORt (@<cell_list>)	Aborts any running cell sequence
:CLEar (@<cell_list>)	Ungroups a paralleled cell into individual channels
:DEFine <cell_id>, (@<chan_list>)	Defines a paralleled group of channels into a cell
:QUICk <cell_size>	Defines cells across all charge-discharge modules
:ENABle (@<cell_list>), <seq_id>	Assigns a sequence to a cell
:FSETtle 0|OFF|1|ON	Enables fast settling time for all cells
:INITiate (@<cell_list>)	Initiates the specified cells to start their sequence
:PAUSe (@<cell_list>)	Pauses the cell's execution in a sequence
:RESume (@<cell_list>)	Resumes the cell's execution in a sequence
:STEP	
:DCIR? (@<cell_list>)	Returns the DCIR measurement per cell
:NEXT (@<cell_list>)	Forces the cell to advance to the next step

:TIME? (@<cell_list>)	Returns the time elapsed in the current step
:TIME? (@<seq_id>)	Returns the time elapsed during the sequence
:TRANsition	
[:MODE] IMMediate|RESTart	Enables step transitions without requiring restart

DATA

:LOG	
[:CHANnel]	
[:READ]?	Returns up to 7 records from the datalog buffer
:RECords	
[:AVAIlable]?	Returns the number of records available in the buffer
MISSed?	Returns the number of records that are no longer available in the buffer
:CLEar	Clears all the data from the buffer

DIGital

:CABort <pin>, (@<cell_list>)	Associates a cell-abort list to a digital IO pin
:FUNCtion <pin>, <*function*>	Specifies the pin function of the 23 pins
:POLarity <pin>, POSitive|NEGative	Sets the pin polarity of the 23 pins
:CHANs?	Returns the number of digital IO pins in the mainframe
:INPut	
:DATA?	Reads the state of the digital control port
:OUTPut	
:DATA <*value*>	Sets the state of the digital control port
:PIN<1-7>	*These 2 legacy commands only apply to BT2203A*
:FUNCtion <*function*>	Specifies the pin function
:POLarity POSitive|NEGative	Specifies the pin polarity

LXI

:IDENtify	Turns the front panel LXI identify indicator on or off
:STATe 0|OFF|1|ON	
:MDNS	
:ENABle 0|OFF|1|ON	Enables the multicast Domain Name System (mDNS)
:HNAMe	
:RESolved?	Returns the current hostname
:SNAMe	
:DESired <"*name*">	Sets the desired service name
:RESolved?	Returns the current service name
:RESet	Resets all network settings to their factory settings
:RESTart	Resets all LAN settings

MEASure

:CAPacity	
:AHR? (@<chan_list)	Returns the amp-hour capacity per channel
:WHR? (@<chan_list)	Returns the watt-hour capacity per channel
:CELL	
:CAPacity	
:AHR? (@<cell_list>)	Returns the amp-hour capacity per cell
:WHR? (@<cell_list>)	Returns the watt-hour capacity per cell
:CURRent? (@<cell_list>)	Returns the current per cell
:DCIR? (@<cell_list>)	Returns the DCIR measurement per cell
:POWer? (@<cell_list>)	Returns the power per cell
:RESet (@<cell_list>)	Clears the watt-hour and amp-hour measurement per cell
:VOLTage? (@<cell_list>)	Returns the remote-sensed voltage per cell
:CURRent? (@<chan_list>)	Returns the current per channel
:POWer? (@<chan_list>)	Returns the power per channel
:RESet (@<chan_list>)	Clears the watt-hour and amp-hour measurement per channel
:VOLTage? (@<chan_list>)	Returns the remote-sensed voltage per channel

OUTPut

:PROTection	
:CLEar	Resets any protection events that have occurred

ROOT

:WATChdog	
:ENABle 0|OFF|1|ON	Enables the watchdog timer
:TOUT <*value*>	Sets the watchdog delay time
:RESet	Resets the watchdog timer

SEQuence

:CATalog?	Returns which sequences are valid
:CLEar <seq_id>	Clears the specified sequence
:STEP	
:COUNt? <seq_id>	Returns the defined steps
:CPOWer	
:DEFine <seq_id>, <step_id>, <mode>, <duration>, <CC>, <CV>, <CP>	Defines a constant power step
:DEFine <seq_id>, <step_id>, <mode>, <duration>, <CC>, <CV>	Defines a step in a sequence
:DEFine? <seq_id>, <step_id>	Queries a step in a sequence
:DCIR	Defines a step in a sequence

:DEFine <seq_id>, <step_id>, <maxVoltLimit>, <minVoltLimit>, <pauseBeforeFirstPulse>, <firstPulseLevel>, <firstPulseWidth> [,<pauseAfter-FirstPulse>, <secondPulseLevel>, <secondPulseWidth>, <pauseAfterSecondPulse>]	Defines a DCIR step in a sequence
:DEFine? <seq_id>, <step_id>	Queries a DCIR step in a sequence
:TEST	
:COUNt? <seq_id>, <step_id>	Returns the defined tests
:DEFine <seq_id>, <step_id>, <test_id>, <test_type>, <value>, <time_type>, <time_limit>, <test_action>	Defines a sequence test
:DEFine? <seq_id>, <step_id>, <test_id>	Queries a sequence test
:DCIR	Defines a step in a sequence
:DEFine <seq_id>, <step_id>, <test_id>, <test_type>, <value>, <test_ action>	Defines a DCIR test in a sequence
:DEFine? <seq_id>, <step_id>, <test_id>	Queries a DCIR sequence test

STATus

:CELL	
:PROBe? (@<cell_list>)	Returns the latest probe check result
:REPort? (@<cell_list>)	Returns the status of a cell
:RUN	
:COUNt?	Returns how many cells are still running a sequence
:STEP? <step_id>, <cell>	Returns the completion state of a step in the sequence
:VERBose? <cell>	Returns a summary of the current state of the cell
:OPERation	
[:EVENt]?	Queries the operation event register
:CONDition?	Queries the operation condition register
:ENABle <*value*>	Sets the operation enable register

SYSTem

:CARD	
:DETect	
:BOOT? <card>	Returns module cards detected at bootup
:NOW? <card>	Returns module cards detected now
:COMMunicate	
:LAN	
:DHCP 0|OFF|1|ON	Enables or disables DHCP
:DOMain?	Returns the domain name
:GATeway "<*address*>"	Assigns a default gateway address
:HOSTname "<*name*>"	Assigns a hostname

:IPADdress "<*name*>"	Assigns a static IP address
:MAC?	Returns the instrument's MAC address
:SMASk "<*mask*>"	Assigns a subnet mask
:TELNet	
:PROMpt "<*string*>"	Sets the command prompt for Telnet
:WMESsage "<*string*>"	Sets the welcome message for Telnet
:UPDate	Saves any changes made to the LAN settings
:ERRor?	Reads and clears one error from the error queue
:PROBecheck	
:LIMit <*value*>, 0	Sets the probe check upper limit
:REBoot	
:SYSTem	Reboots the entire CDS including all installed cards
:TEST	
:ALL	Tests the entire charge-discharge system
:CHANnel <@chan_list>	Tests the specified channel
:MAINframe	Tests the mainframe only
:UPTime?	The time the CDS has been running since its last power-on

2
Installing the Charge-Discharge System

WARNING Heavy Weight

Danger to hands and feet. To avoid personal injury and damage to the instrument, always use a sturdy cart or other suitable device to move the instrument. Do not lift the instrument alone; always use two or more people to lift the instrument.

Before Installation or Use

Inspecting the Unit

When you receive your Keysight BT2200 Series Charge-Discharge System, inspect it for any obvious damage that may have occurred during shipment. If there is damage, notify the shipping carrier and nearest Keysight Sales and Support Office immediately. Refer to www.keysight.com/find/assist.

Returning the Unit

Until you have checked out the unit, save the shipping carton and packing materials in case the unit has to be returned.

NOTE

Important - Always use the original shipping cartons to return the mainframe and modules. *Charge/discharge modules require their own shipping carton*. Equipment damage may result if mainframes are shipped with the modules installed.

Check for Items Supplied

Before getting started, check the following list and verify that you have received these items.

BT2202A/BT2203A/BT2203B Items	Description	Keysight Part Number
Bumper Foot Kit	Stick-on feet for mainframe installation (optional)	5188-9572
Firmware Addendum	Firmware and Software Notification	5190-1894
RoHS Addendum	China RoHS Addendum for Power Supply-DC	9320-6686
Finding product manuals	Includes information on finding product manuals	9320-6794
Safety booklet	Includes safety information	9320-6797
Calibration certificate	Calibration certificate referenced to serial number	None
BT2204A/BT2204B/BT2205A Items	**Description**	**Keysight Part Number**
RoHS Addendum	China RoHS Addendum for Power Supply-DC	9320-6686
Safety booklet	Includes safety information	9320-6794
Inductor Core (BT2205A only)	Inductor-Core-Ferrite-Fixed 425 Ohm - Qty 2	9170-2721
Connection kit (BT2205A only)	Cover and Bus Bar Connection Kit includes the following: - Machine Screw M8x1.25 22mm Long - Qty 4 - Hex Nut M8x1.25 - Qty 4 - Split Washer - Qty 4 - Flat Metallic Washer - Qty 8 - Safety Cover - Qty 4 (2-pair) - Cable Tie self-locking - Qty 2	BT2205-60004 0515-6007 0535-0002 2190-1273 3050-2573 BT2205-00105 1400-0507

Refer to the box packing list for any additional items that may be included with your shipment. If anything is missing, please contact your nearest Keysight Sales and Support Office.

Customer-Supplied Items

The following items are customer-supplied. Recommended manufacturer part numbers are provided.

Items	Description	Part Number
LAN cable	LAN interface cable	Keysight 8121-3010; L-COM TRD815OR-7
Digital connector	8-pin connector for the digital port	Keysight 1253-6408; Phoenix Contact 1840421
Calibration connector	Hardware required for calibration connections	see Calibration Connections
Power connectors	Hardware required for power connections	see Power Connections for BT2204B, BT2205A
Sense connectors	Hardware required for power connections	see Sense Connections for BT2204B, BT2205A
Cover plate	Only required if less than eight mainframe slots are used	Keysight BT2206A

Review Safety Information

This instrument is a Safety Class 1 instrument, which means it has a protective earth terminal. That terminal must be connected to earth ground through a power source equipped with an earth ground. Refer to the Safety Notices page for general safety information. Before installation or operation, check the instrument and review this guide for safety warnings and instructions. Safety warnings for specific procedures are located at appropriate places throughout this guide.

Observe Environmental Conditions

WARNING Do not operate the instrument in the presence of flammable gases or fumes.

The environmental conditions of the instrument are documented under Common Characteristics. Basically, the unit should only be operated indoors in a controlled environment. Do not operate the unit in areas where the ambient temperature is outside the ambient temperature range. This applies for rack-mounting as well as for bench use.

Provide Adequate Air Flow

CAUTION Do not block the air intake at the front, or the exhaust at the rear of the instrument.

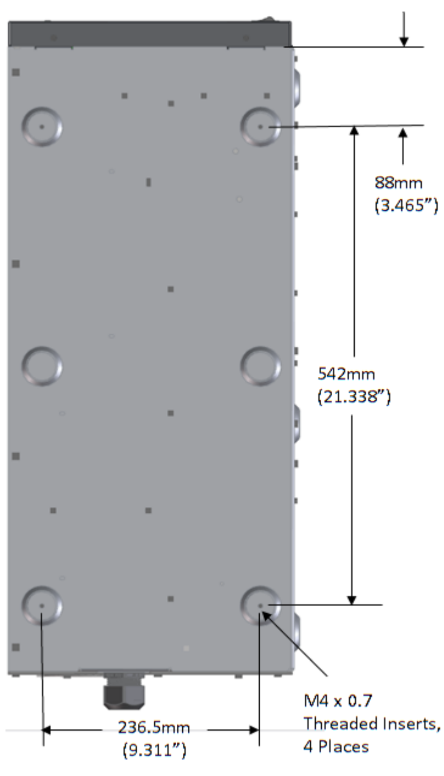
The dimensions of your instrument as well as an outline diagram are given under Dimensions. Fans cool the unit by drawing air through the front and exhausting it out the back. The unit must be installed in a location that allows sufficient space of at least 12 inches (35 cm) at the front and back of the unit for adequate air circulation.

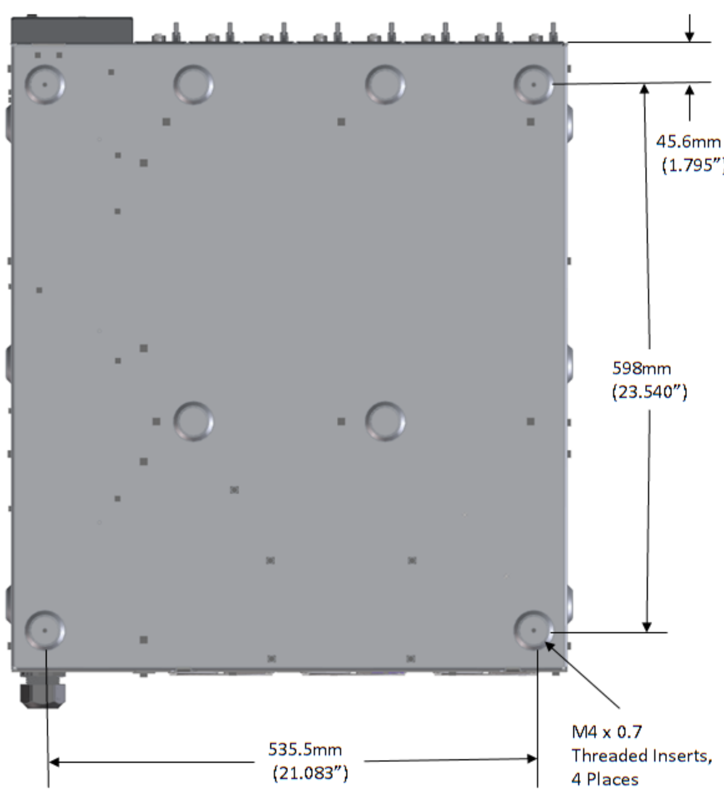
Instrument Orientation

CAUTION Keysight BT2200 series mainframes are not designed to be installed in standard EIA rack cabinets. The instrument is designed to be permanently installed in the vicinity of the cell-forming fixture/station. Attachment points are located on the chassis.

Your Keysight BT2200 series mainframe may be installed in either a horizontal or vertical orientation. Orient the instrument only as shown in the following figures.

The embosses on the bottom and side of the unit include M4 x 0.7 threaded nuts for attaching mounting screws. Attach the mounting screws on all four attachment points - either the front or side attachment points. Note that left and right side dimensions are identical.





You also have the option of installing stick-on feet either on the bottom or side of the instrument. Attach the stick-on feet to the embosses.

Because of the additional weight of the mainframe after the modules are installed, it is recommended that you install the charge-discharge modules **after** the mainframe has been placed in its operating location.

CAUTION

Fully loaded Keysight BT2200 series mainframes weigh as much as 95 lbs. (43 kg). Two or more people are required for installation. Do not lift or move the unit alone. Avoid moving the unit by hand. If unavoidable, lift only the unit's chassis; do not lift the unit using any cable connectors.

Do not block the air intake at the front, or the exhaust at the rear of the instrument.

Module Installation

This section describes how to install the Keysight BT2204A/B Charge-Discharge Modules. Because of the additional weight of the mainframe after the modules are installed, it is recommended that you install the charge-discharge modules **after** the mainframe has been placed in its operating location.

Installing the Module

WARNING Possible Sharp Edges - The BT2204A/B modules may potentially have sharp edges that require careful handling. Exercise caution when touching the edges around the perimeter of the module and the solder points on the bottom of the module.

Hot Surface - When removing modules after operation, the heatsink surface may be very hot. Exercise due caution when removing modules.

CAUTION Electrostatic-discharge sensitive device
Observe all precautions for handling electrostatic discharge sensitive devices when installing the charge-discharge module.

CAUTION You cannot mix Keysight BT2205A modules with Keysight BT2204A/B modules in the same mainframe. Keysight BT2205A modules require their own dedicated mainframe.

NOTE The BT2204A module installs in the BT2203A chassis. The BT2204B module installs in the BT2202A or BT2203B chassis. The BT2205A module installs in the BT2202A or BT2203B chassis.

1. Install the modules in the front of the instrument starting with slot location 1.
   Modules must be installed next to one another, starting with slot 1. Do not leave any empty slots between modules. Unused slots must have cover plates installed for safety and proper airflow. Do not install cover plates between power modules.
2. Use either a slot-head or #2 Pozi driver and tighten the two screws on the module.
3. Run Channel Alignment after installing the charge/discharge modules.
   All charge/discharge modules use a common calibration reference, which is sourced from the mainframe in which they are installed. When a module is installed in a mainframe for the first time, or switched to a different mainframe, channel alignment must be performed so that the module is synchronized to the calibration reference of that mainframe.

Power Cable Connections

Cable Current Ratings

Power Cord Installation

Regenerative Operation

Cable Current Ratings

An AC mains power cable is not provided with the unit.
Refer to the following table for the maximum current capacity requirements for each cable conductor. If required by local electrical codes, install a fuse or circuit breaker between the AC mains and the unit. Refer to the following table for current ratings.

Keep the AC mains cables as short as possible. The longer the cable, the greater the voltage loss due to cable resistance.

WARNING

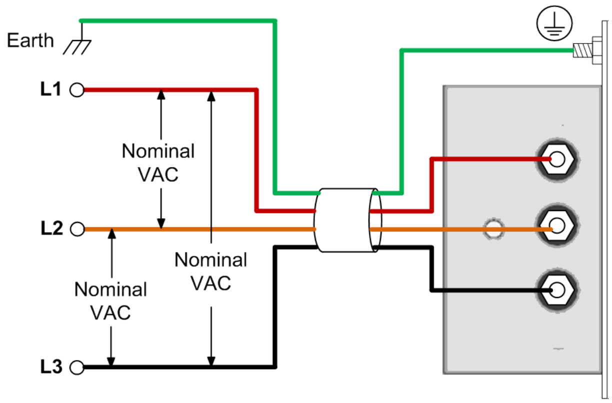
The cable cross-section must be suitable for the maximum input current of the instrument. The ground cable must have the same cross-section as the phase cable.

NOTE

Safety agency requirements dictate that there must be a way to physically disconnect the AC mains cable from the unit. A disconnect device, either a switch or circuit breaker must be provided in the final installation. The disconnect device must be close to the equipment, be easily accessible, and be marked as the disconnect device for this equipment. It must meet the input ratings requirements listed in the following table.

Nominal Unit Rating	L1 I_{max}	L2 I_{max}	L3 I_{max}
BT2203A/BT2203B - 10 kW - 200/208 VAC	39 A	39 A	39 A
BT2202A - 10 kW - 400/480 VAC	19 A	19 A	19 A

Either a delta-type or a Y-type AC mains distribution can be used, provided that the correct line-to-line voltage is applied (see above). **Do not connect the neutral wire on Y-type AC mains distribution**. An earth-ground to chassis-ground connection through a separate conductor must always be provided. The following figure illustrates the 3-phase AC mains connections.



Power Cord Installation

WARNING

SHOCK HAZARD The instrument requires a chassis ground connection through a separate conductor. The AC mains must include an earth ground connection.

AC mains connections must be made by a qualified electrician who knows about 3-phase mains circuits and all applicable safety standards and requirements.

In cases were the unit is not hardwired to the electrical system, a locking connector scheme should be used such as UL 498, IEC 60309, or equivalent. Consult a local electrician for the connector scheme appropriate for your region.

208V/30A examples:

https://www.grainger.com/product/HUBBELL-WIRING-DEVICE-KELLEMS-30-Amp-Industrial-Grade-Locking-6C549

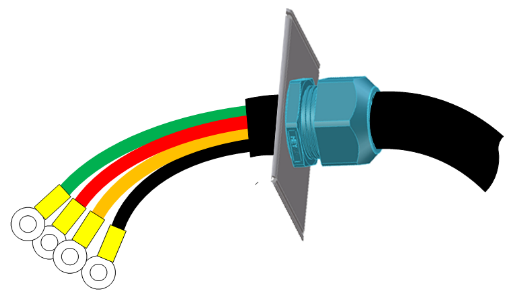
480V/30A examples:

https://www.grainger.com/product/HUBBELL-WIRING-DEVICE-KELLEMS-30-Amp-Industrial-Grade-Locking-6C549

1. Remove the AC input panel from the unit. Remove and save the five screws that attach the panel.

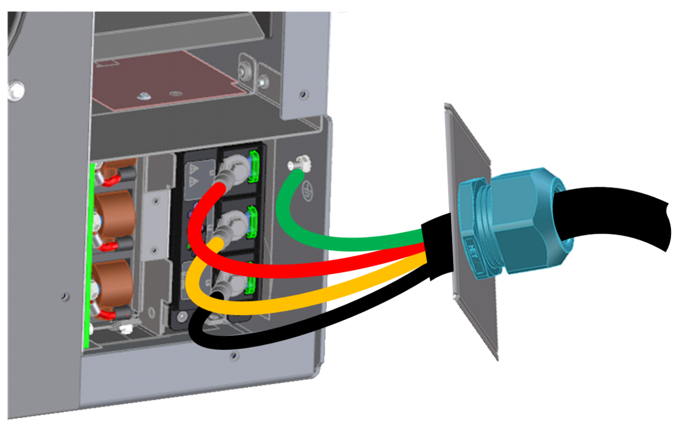
2. Connect ring terminals to the ends of the line wires. The minimum ring hole diameter is 0.2 in (5 mm).

3. Insert the terminated ends of the power cord through the strain relief on the AC input cover panel. The strain relief is designed to accommodate both a wire cable, or individual wires.



4. Do not tighten the strain relief until all wire connections are complete.

5. Attach the ring-terminated line wires to the AC mains terminals (U.S. color code shown). Place the ring terminals between the star washers. Connect the ground wire to the chassis stud *next to* the AC line filter assembly. **If one is provided, do not connect the neutral wire.**



6. Tighten the terminals to 23 in-lb (2.6 Nm).

7. Reattach the AC input panel to the unit and tighten the strain relief.

Regenerative Operation

NOTE Compliance to all regulations for the operation of and connection to the public grid of energy back-feeding equipment is required. Connections must be made by a qualified electrician who knows about energy back-freeding equipment to ensure that all applicable safety requirements have been applied and all necessary conditions have been met.

To achieve improvements in energy efficiency, the CDS can re-use cell discharge energy to supplement the energy required to charge other cells in the mainframe. This is possible because of the bi-directional power transfer capability between charging and discharging cells when connected to a common power bus. To take advantage of this energy transfer requires that some cells in the mainframe must be operating in discharge mode at the same time that other cells are operating in charging mode.

When the total discharge energy in the mainframe exceeds the charging energy, the mainframe will direct the excess energy back to the AC mains through the power cord.

In case of an AC mains power failure, the unit will automatically disconnect from the AC mains. This occurs even when the unit is directing power back to the AC mains. Any charging and discharging activity will stop, and the current sequence, test data, and programmed settings will be lost.

Interface Connections

If you have not already done so, install the Keysight IO Libraries Suite, which can be found at www.keysight.com/find/iolib. Always install the latest version of the Keysight IO Libraries Suite.

NOTE For detailed information about USB and LAN interface connections, refer to the documentation included with the Keysight IO Libraries Suite.

LAN Connections

NOTE LAN cable lengths must be less than 30 meters.
To guarantee the most reliable LAN connection, Keysight recommends turning DHCP off and use static IP addressing.

1. Connect the instrument to the site LAN or to your computer using a customer-supplied LAN cable.

2. The as-shipped LAN settings are configured to automatically obtain an IP address from the network using a DHCP server (DHCP is set On). The DHCP server will register the instrument's hostname with the dynamic DNS server. The hostname as well as the IP address can then be used to communicate with the instrument. If you are using a private LAN, you can leave all LAN settings as they are. Most Keysight products and most computers will 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 will come on when the LAN port has been configured.

3. Use the Connection Expert utility of the Keysight IO Libraries Suite to add the instrument and verify a connection. To add the instrument, you can request the Connection Expert to discover the instrument. If the instrument cannot be found, add the instrument using the instrument’s hostname or IP address.

4. You can now use Interactive IO within the Connection Expert to communicate with your instrument, or you can program your instrument directly using the applicable SCPI commands..

USB Connections

1. Connect the instrument to the USB port on your computer using a customer-supplied USB cable. .

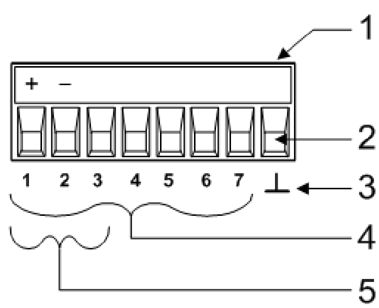
2. With the Connection Expert utility of the Keysight IO Libraries Suite running, the computer will automatically recognize the instrument. This may take several seconds. When the instrument is recognized, your computer will display the VISA alias, IDN string, and VISA address. This information is located in the USB folder.

3. You can now use Interactive IO within the Connection Expert to communicate with your instrument, or you can program your instrument directly using the applicable SCPI commands.

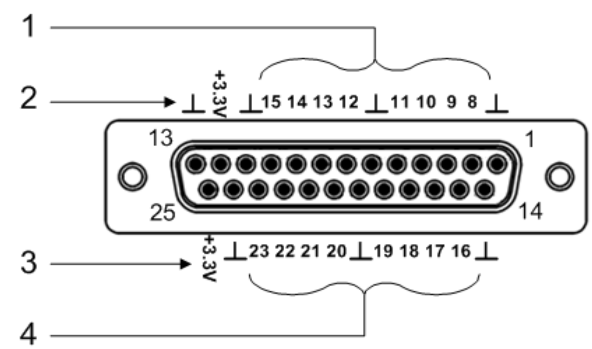
Digital Port Connections

NOTE It is good engineering practice to twist or shield all signal wires to and from the digital connector. If shielded wire is used, connect only one end of the shield to chassis ground to prevent ground loops.

Information on using the digital port is found under Using the Digital Port. The electrical characteristics are described under Common Characteristics.



1. Turn to tighten wires
2. Insert wires here
3. Signal common pin
4. Digital IO-configurable pins (pins 1-7)
5. Fault/Inhibit configurable pins (pins 1-3)



1. Digital IO-configurable pins (pins 8-15)
2. Signal common pins (7 pins available)
3. +3.3 V reference (2 pins available)
4. Digital IO-configurable pins (pins 16-23)

8-pin connector

An 8-pin connector and a quick-disconnect connector plug are provided for accessing the digital port functions. Disconnect the connector plug to make your wire connections. The connector plug accepts wires sizes from AWG 14 (1.5 mm^2) to AWG 28 (0.14 mm^2). Wire sizes smaller than AWG 24 (0.25 mm^2) are not recommended. Strip wire insulation back 7 mm.

25-pin connector (not available on Keysight BT2203A mainframes)

A 25-pin connector is provided for digital pins 8-23. A mating connector must be used to make the wire connections. The following mating connector is recommended:

Description: 25-pin D-sub plug, male pins, solder termination

Manufacturer: Amphenol p/n DB25P064TXLF

Digi-Key part number: 609-1518-ND

The following table describes the digital pin assignments of the 25 pin connector:

25-pin connector top row (right to left)	Digital pin assignment	25-pin connector bottom row (right to left)	Digital pin assignment
1	common	14	common
2	DIO 8	15	DIO 16
3	DIO 9	16	DIO 17
4	DIO 10	17	DIO 18
5	DIO 11	18	DIO 19
6	common	19	common
7	DIO 12	20	DIO 20
8	DIO 13	21	DIO 21
9	DIO 14	22	DIO 22
10	DIO 15	23	DIO 23
11	common	24	common
12	+3.3 V	25	+3.3 V
13	common		

Cell Wiring Connections

This section describes how to make and connect the power and sense wires on the Keysight BT2204A/B 32- Channel Charge-Discharge Modules.

To optimize performance and minimize the possibility of output instability and output noise, please observe the following guidelines:

- It is good engineering practice to either twist or shield the sense and power wires.
- Twist the power wires together and keep them as short as possible.
- Twist the sense wires together but do not twist them together with the power wires.
- Extend the wire twists as far as possible before connecting to the cell.
- If possible, shield the sense wires. Connect the shield to the case.
- Keep the total cable length as short as possible.
- Use low resistance fixture contacts.

BT2204A/B Power and Sense Wiring

Power Wiring

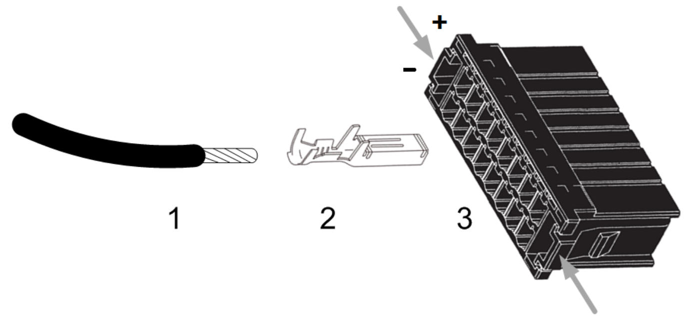
The recommended mating connector and parts for the power wires are as follows:

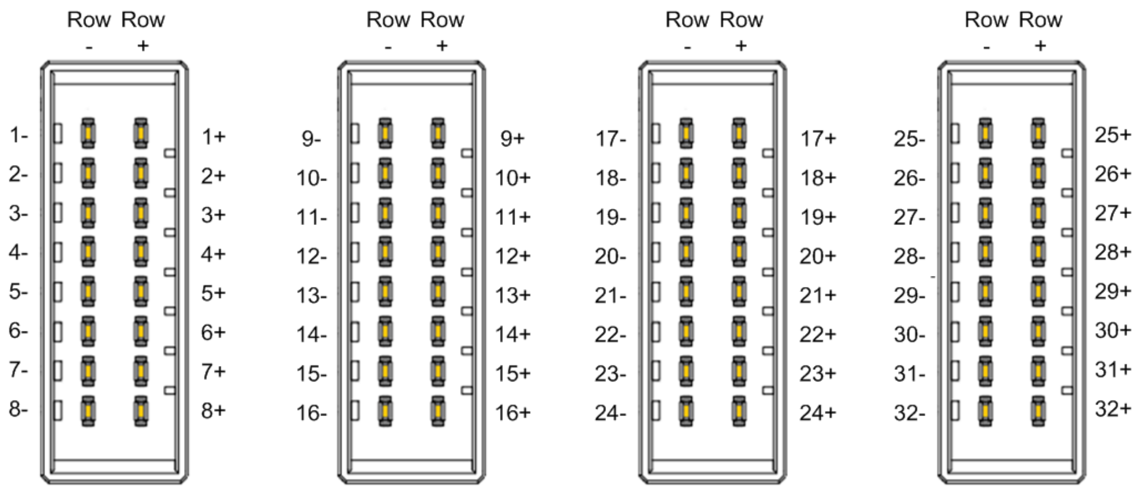
Power Connector Items	Description	Part Number
Power mating connector	16-pin mating connector	TE Connectivity: 178289-7
Power contact pins	Pins for mating connector (accepts wires sizes AWG 14 and AWG 16)	TE Connectivity: 353717-2
Crimping tool	Crimping tool for power contact pins	TE Connectivity: 91561-1

The mating connector pin assignments are as follows when viewed from the front of the connector. Each pin pair (+ and -) connects to one channel.

Connect the power wires into the mating connector as shown.

1. Insert the wire (1) into the contact pin (2).
2. Crimp the contact pin using the appropriate crimping tool.
3. Insert the pins into the connector (3).
4. Insert the connector plug into the power connector of the module. (To remove the connector plug, squeeze the latches together as shown by the arrows.)





Sense Wiring for ribbon cables and discrete wires

The sense connections provide remote sense capability at the cell test fixture. Remote sensing allows the cell voltage to be sensed at the cell, thus allowing for proper measurement of cell voltage regardless of the voltage drop in the power lines due to losses in the wiring. Note also that the CDS channel voltage can be up to 6 volts to compensate for any voltage drop caused by resistance in the wiring or in the connections between the power connector and the cells.

NOTE

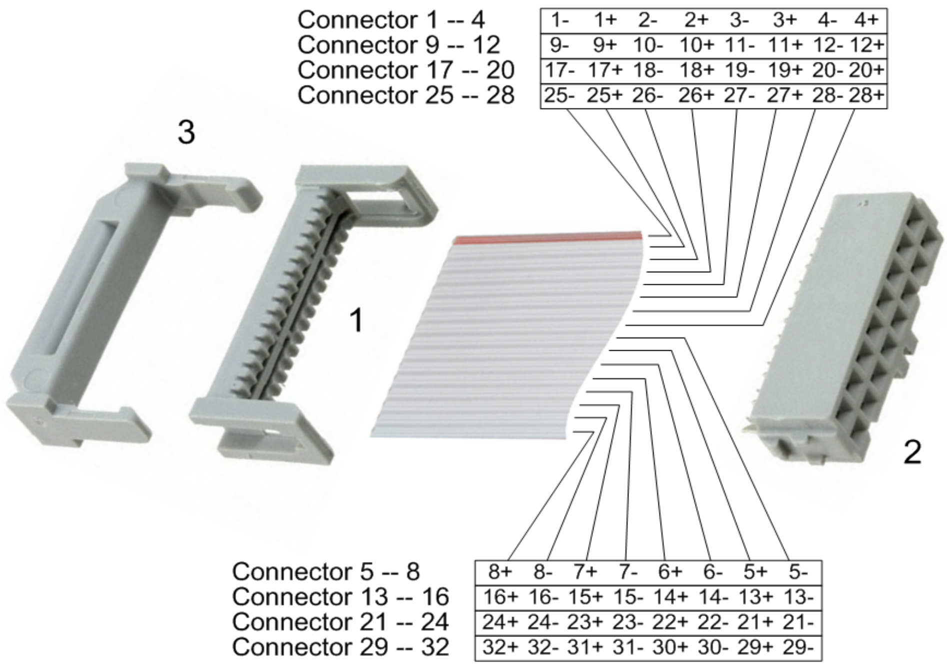
Charge-discharge systems with the latest firmware will only require one channel's sense pins to be connected for each configured cell. The connected sense channel must be the first (or lowest) channel number that is part of the cell group. The remaining sense connections for the other channels assigned to that cell can remain open. Sense connections on previously configured systems do not need to be rewired.

The mating connector for the ribbon cable sense wires is as follows:

Cell Connector Items	Description	Part Number
Sense mating connector	16-pin mating connector	3M: 89116-0103
Twisted ribbon cable for sense connector	16-wire ribbon cable for sense connector (AWG 28, 100 ft length)	Harting: 09180167006

Connect the ribbon cable into the mating receptacle as shown.

1. Place the ribbon cable against the connector base (1). Note the color of the stripe at the lowest channel number.
2. Press the connector plug (2) against the ribbon cable in the base.
3. Insert the strain relief (3).
4. Insert the connector plug into the sense connector of the module.



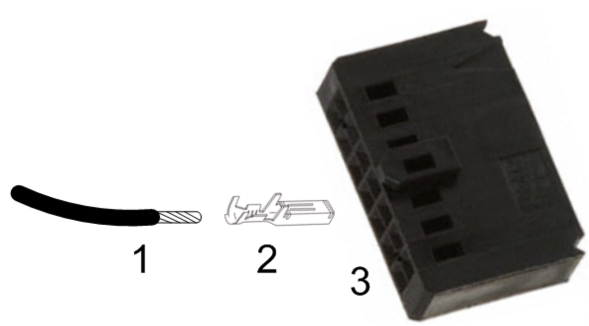
The mating connector for the discrete sense wires is as follows:

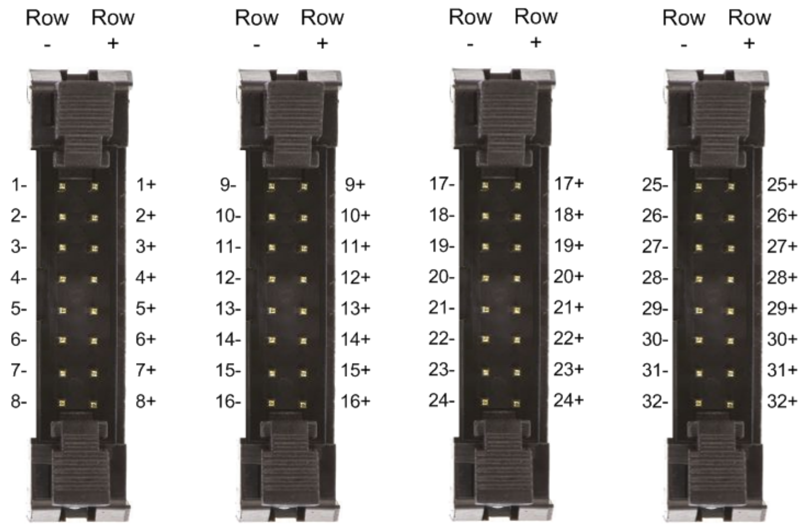
Cell Connector Items	Description	Part Number
Sense mating connector	16-pin mating connector	Digi-Key: A25903-ND
Contact pins	Pins for mating connector (accepts wires sizes AWG 22 to AWG 26)	TE Connectivity: 102128-1
Crimping tool	Crimping tool for sense contact pins	TE Connectivity: 91517-1

The mating connector pin assignments are as follows when viewed from the front of the connector. Each pin pair (+ and -) connects to one channel.

Connect the sense wires into the mating connector as shown.

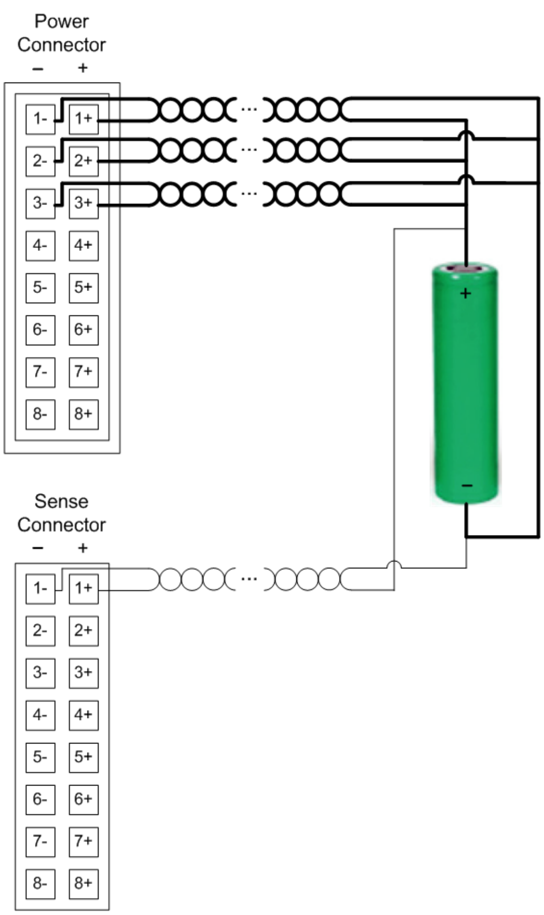
1. Insert the wire (1) into the contact pin (2).
2. Crimp the contact pin using the appropriate crimping tool.
3. Insert the pins into the connector (3).
4. Insert the connector plug into the sense connector of the module.





Wiring Example

The following example Illustrates the connections for a cell paralleled to channels 1 to 3. Note that both the power wires and sense wires for each channel are twisted pairs.



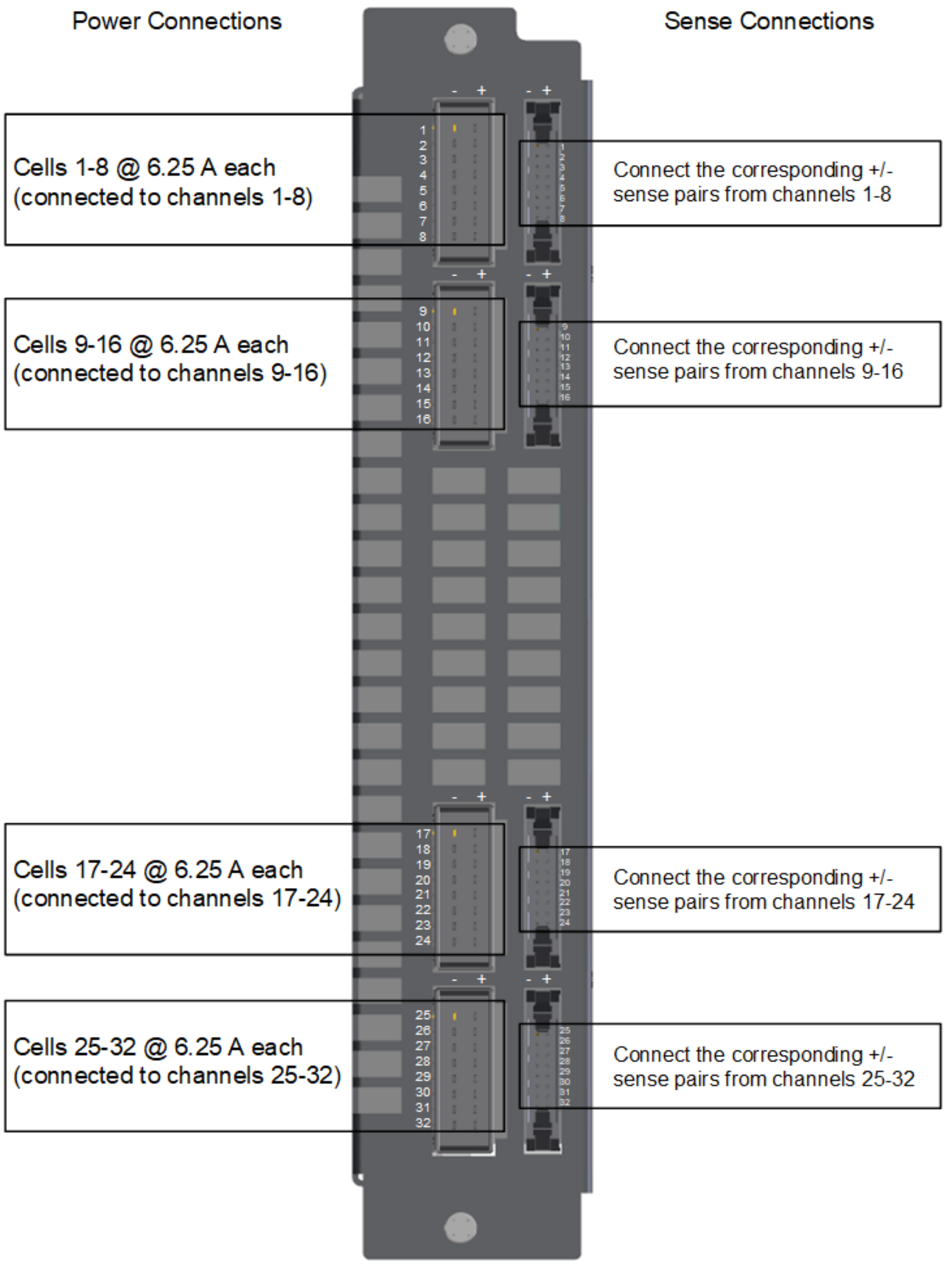
BT2204A/B Cell Configurations

The following diagrams illustrate a variety of cell configurations The following constraints apply:

- Charge-discharge current per cell is configurable from 6.25 A up to 200 A maximum.
- Each channel can produce 4.5 V measured at the cell, which allows for a 1.5 V drop in wiring.
- All parallel configurations are restricted to ONE module; you cannot parallel cells across modules.

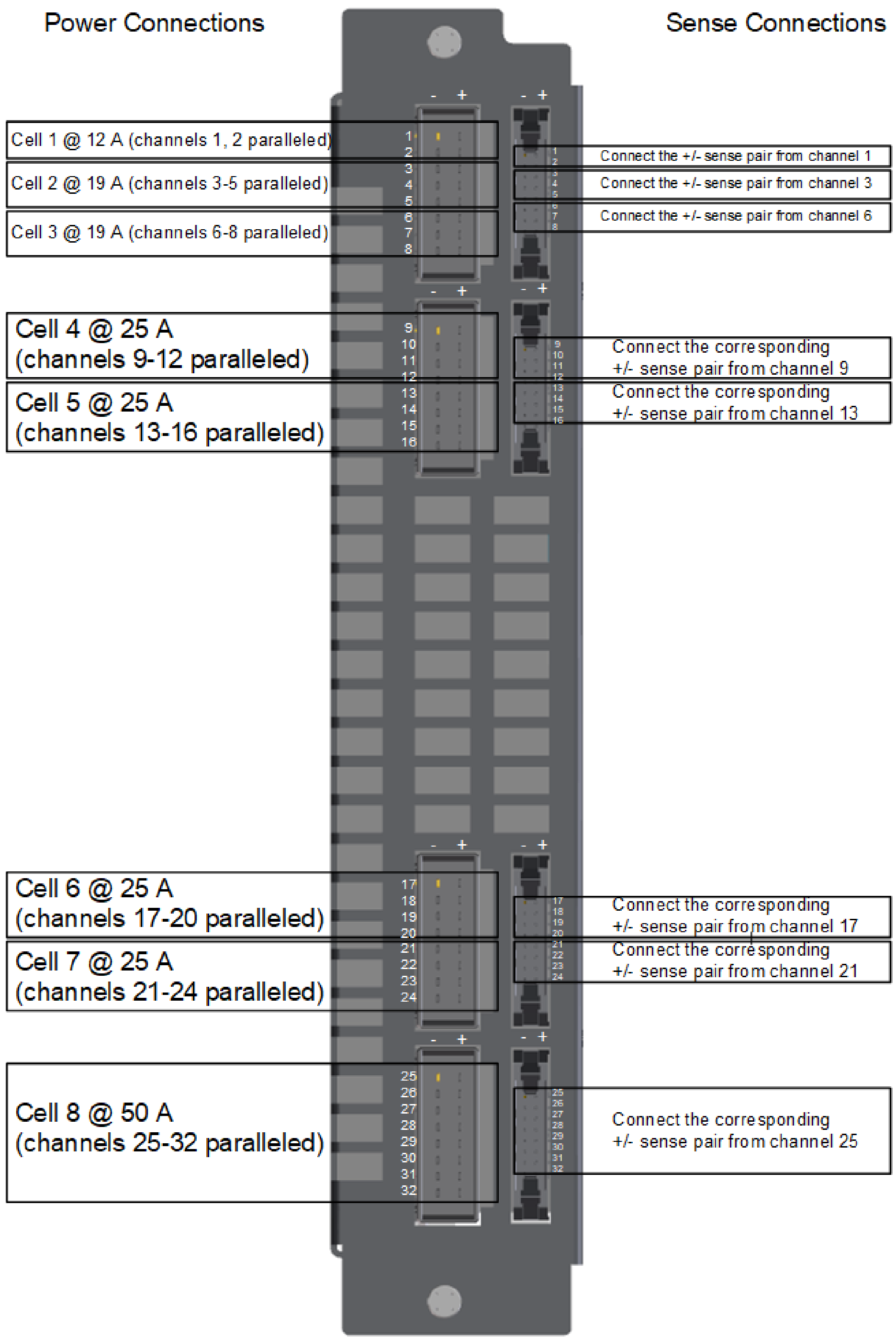
Example 1

This diagram illustrates the as-shipped cell configurations. Each channel controls one cell, up to 32 cells per module. Each cell connection is rated at 6.25 A max. In this 32 cell example, each sense pair connects to its corresponding power channel.



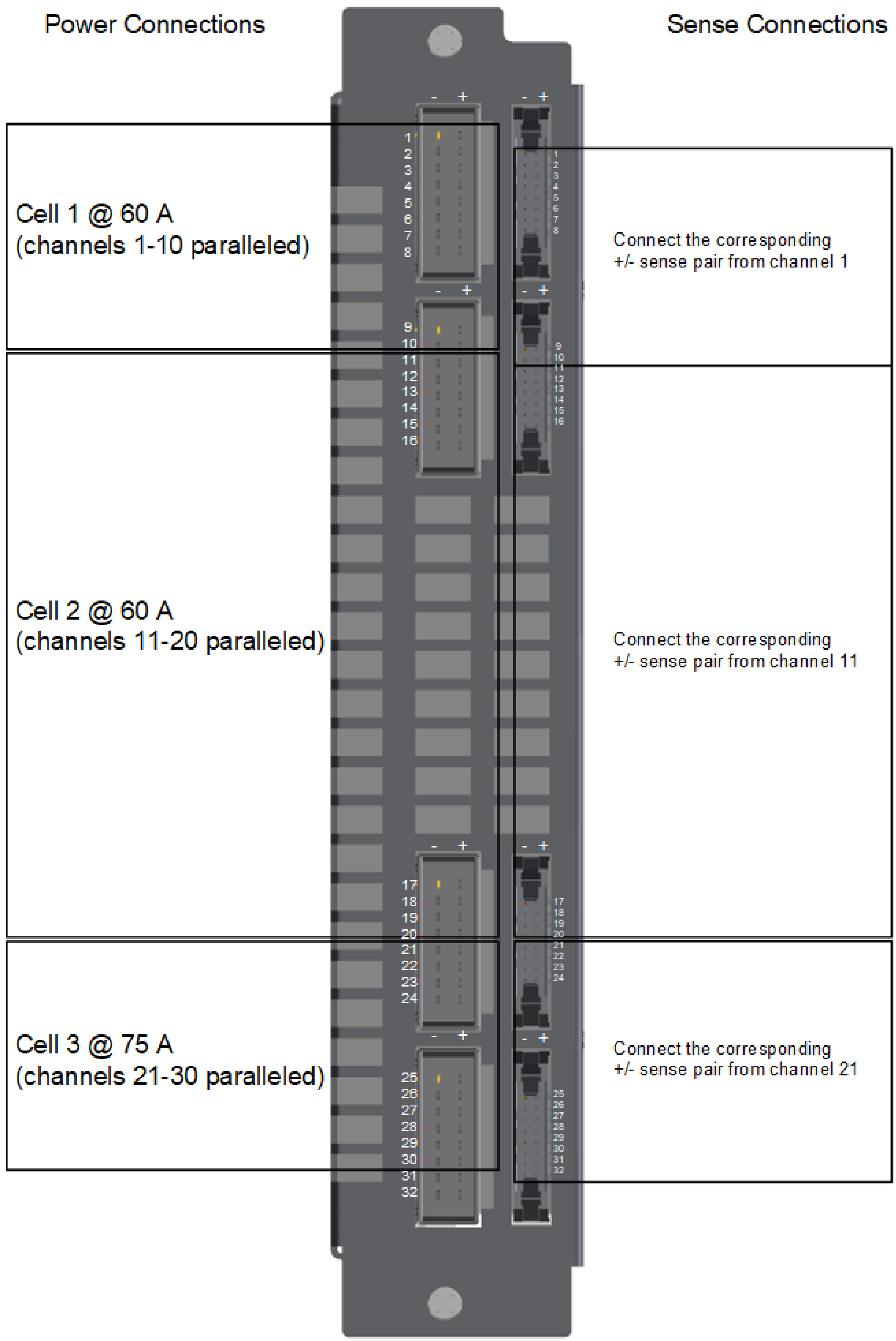
Example 2

This diagram illustrates eight cell configurations. Channels one and two are paralleled and control one cell, which is rated at 12 A max. The sense pair must be connected to channel one. Channels three through five are paralleled and control one cell, which is rated at 19 A max. The sense pair must be connected to channel three. Channels nine through 12 are paralleled and control one cell, which is rated at 25 A max. The sense pair must be connected to channel nine. Channels 25 through 32 are paralleled and control one cell, which is rated at 50 A max. The sense pair must be connected to channel 25.



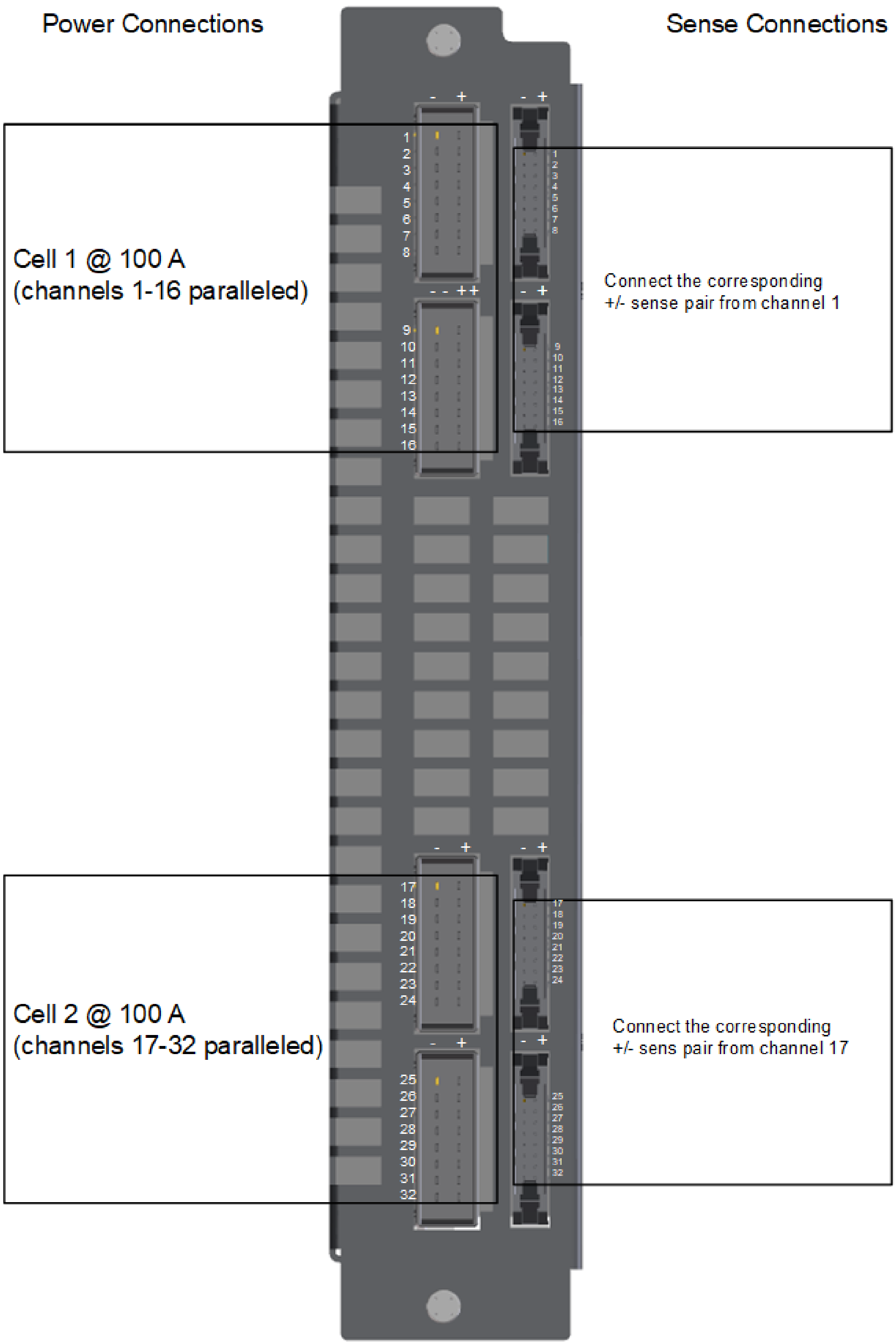
Example 3

This diagram illustrates higher-current cell configurations, from 60 A to 75 A. Channels one through ten are paralleled and control one cell, which is rated at 60 A max. The sense pair must be connected to channel one. Channels 11 through 20 are paralleled and control one cell, also rated at 60 A max. The sense pair must be connected to channel 11. Channels 21 through 32 are paralleled and control one cell, which is rated at 75 A max. The sense pair must be connected to channel 21.



Example 4

This diagram illustrates two cells, each rated at 100 A max. Channels one through 16 are paralleled and control one cell. The sense pair must be connected to channel one. Channels 17 through 32 are paralleled and control the second cell. The sense pair must be connected to channel 17.



BT2205A Power and Sense Wiring

Wire Size

The following table describes the recommended AWG (American Wire Gauge) copper wire.

AWG	Equivalent mm^2	Nearest Metric size	Ampacity (Note 1)	Resistance (Note 2)
2	33.6	35 mm^2	up to 140 A	0.156 Ω

Note 1 Ampacity is based on a single conductor **in free air**, 26-30 °C ambient temperature with the conductor rated at 60 °C. Ampacity decreases at higher temperatures.
Note 2 Resistance is in ohms/1000 feet, at 20 °C wire temperature.

Power Connections

When multiple channels are paralleled, the wires from each cell should be connected to a common termination point. the Individual cell wires should be as short as possible; therefore the common termination point should be close to the mainframe.

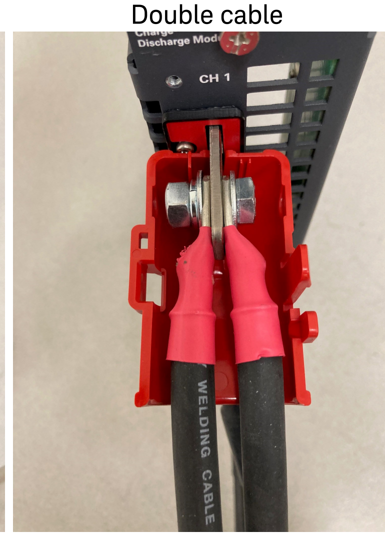
1. Terminate all power wires with the wire terminal lugs securely attached.

2. Attach the wire lugs to the bus bars using the supplied M8 hardware as shown. (Note that the bottom half of the safety cover is shown.)

   CAUTION Tightening torque cannot exceed 10.8 Nm (8 lb-ft).

Single cable

Double cable



Next, connect the safety cover and ferrite core to complete the connections. The safety cover and ferrite core are only required to be installed on the positive cable.

1. Attach the top half of the safety cover as shown.

2. Use the supplied cable tie to secure both halves of the safety cover.

   ⚠ The safety cover must be installed before operating the instrument.

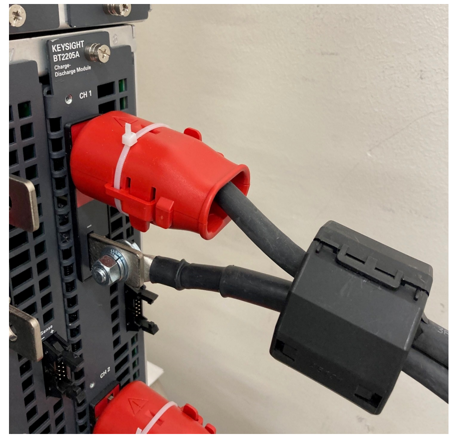
Install the ferrite core as follows:

1. Install the supplied ferrite core on the output cable(s) as shown to ensure EMC compliance. Place the core as close as possible to the + output terminal. For a single + cable, loop the wire once through the core to hold the core in place.

   You can also loop both + and – cables through a single core as a common-mode configuration. Simply snap the core in place over both cables.

+ cable only

+ and - cables



2. To fully ensure EMC compliance and reduce electromagnetic radiation/susceptibility, twist the two output cables together for four complete turns within one meter when measured from the back of the unit.

Sense Connections for ribbon cables and discrete wires

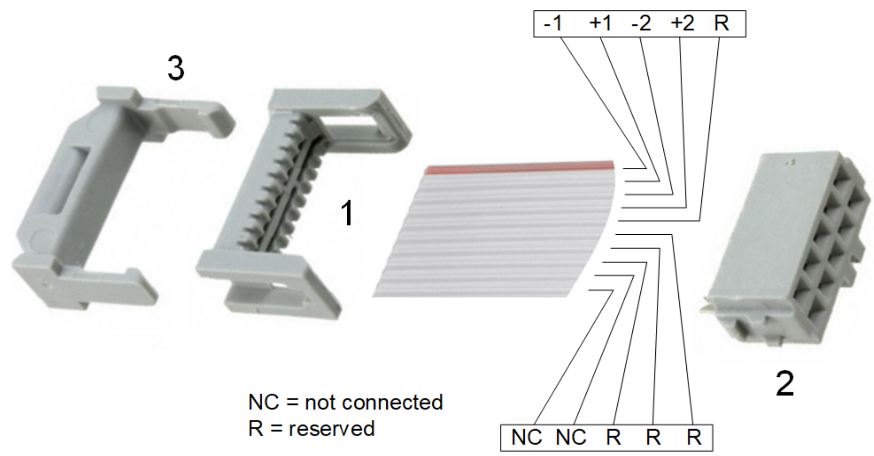
NOTE In examples 5-8, the connected sense channel must be the first (or lowest) channel number on the first (or lowest) module that is part of the cell group. The remaining sense connections for the other channels assigned to that cell can remain open.

The mating connector for the ribbon cable sense wiring is as follows:

Cell Connector Items	Description	Part Number
Sense mating connector	10 Position Rectangular Receptacle Connector IDC Gold 26-28 AWG	3M: 3473-6610
Flat ribbon cable	10 Conductors 0.050" (1.27mm) Flat Cable 500.0' (152.40m)	3M: 3365/10

Connect the ribbon cable into the mating receptacle as shown.

1. Place the ribbon cable against the connector base (1). Note the color of the stripe at the lowest channel number.
2. Press the connector plug (2) against the ribbon cable in the base.
3. Insert the strain relief (3).
4. Insert the connector plug into the sense connector of the module.

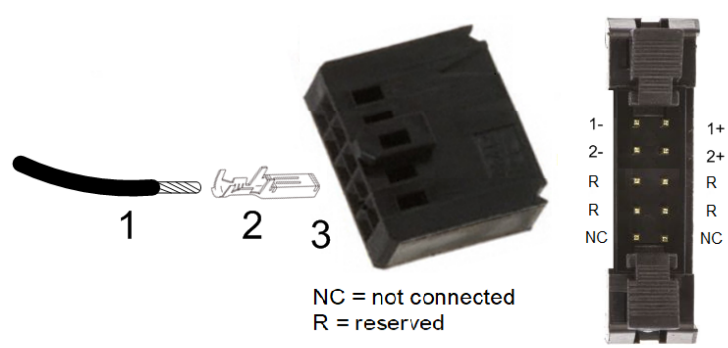


The mating connector for the discrete sense wires is as follows:

Cell Connector Items	Description	Part Number
Sense mating connector	10-pin mating connector	TE Connectivity 102387-1
Contact pins	Pins for mating connector (accepts wires sizes AWG 22 to AWG 26)	TE Connectivity: 102128-1
Crimping tool	Crimping tool for sense contact pins	TE Connectivity: 91517-1

Connect the sense wires into the mating connector as shown.

1. Insert the wire (1) into the contact pin (2).
2. Crimp the contact pin using the appropriate crimping tool.
3. Insert the pins into the connector (3).
4. Insert the connector plug into the sense connector of the module.



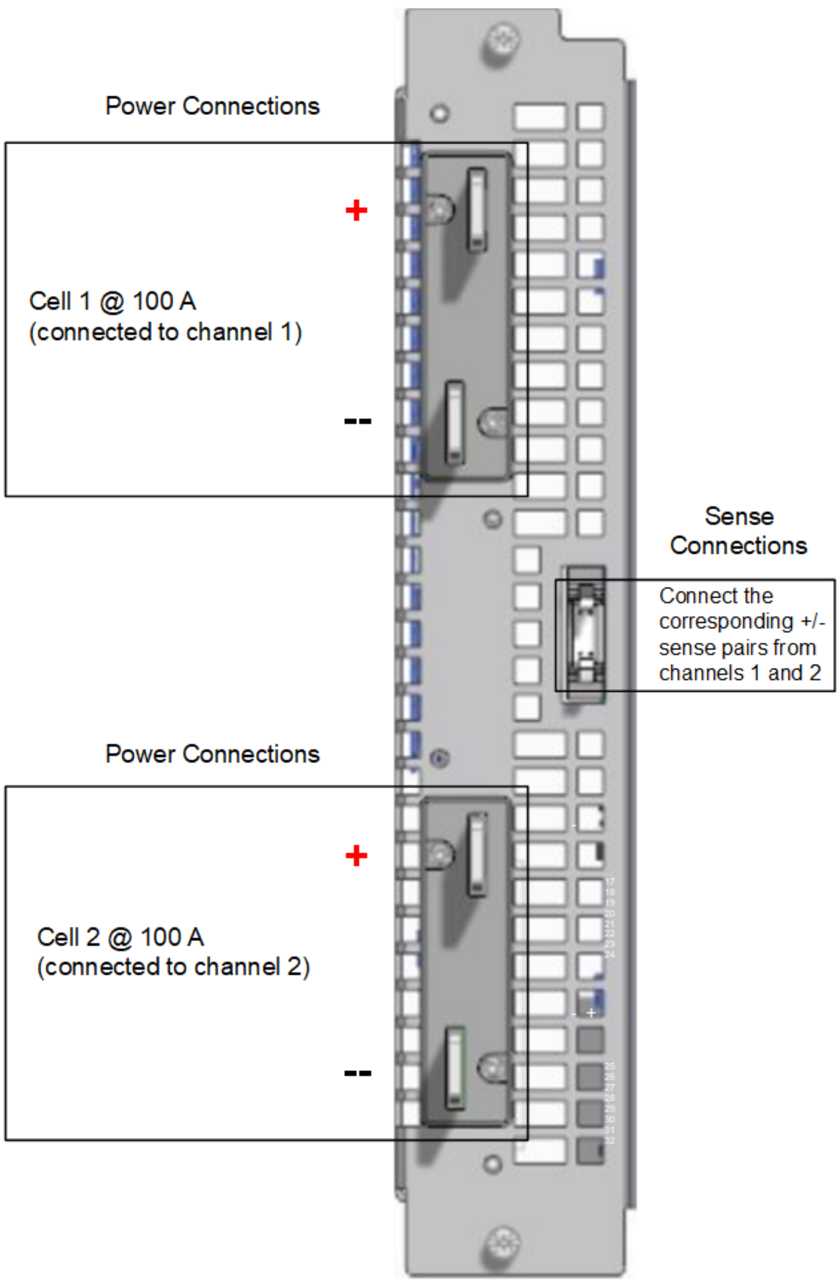
BT2205A Cell Configurations

CAUTION Keysight BT2204A/B and BT2205A modules cannot be combined in the same mainframe.

Unlike BT2204A/B modules, BT2205A channels can be paralleled across modules, within the same mainframe. Any paralleled modules must be physically contiguous. Refer to Defining Channel Addresses and Cells for BT2205A for information about cell addressing.

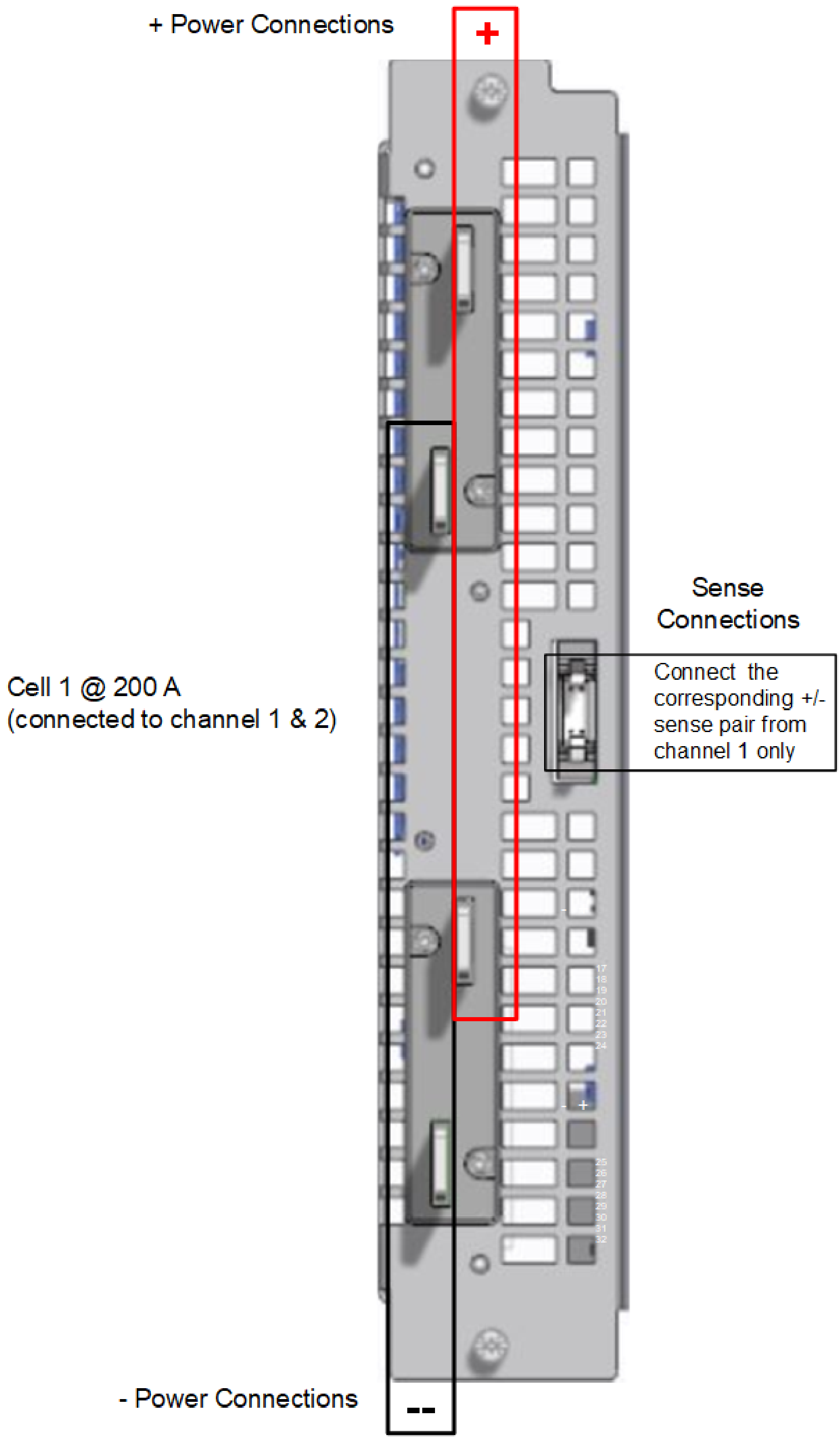
Example 5

This diagram illustrates the as-shipped cell configurations. Each channel controls one cell, with up to two cells per module, each rated at 100 A max. The (+) bus baris on top, the (-) bus bar is below.



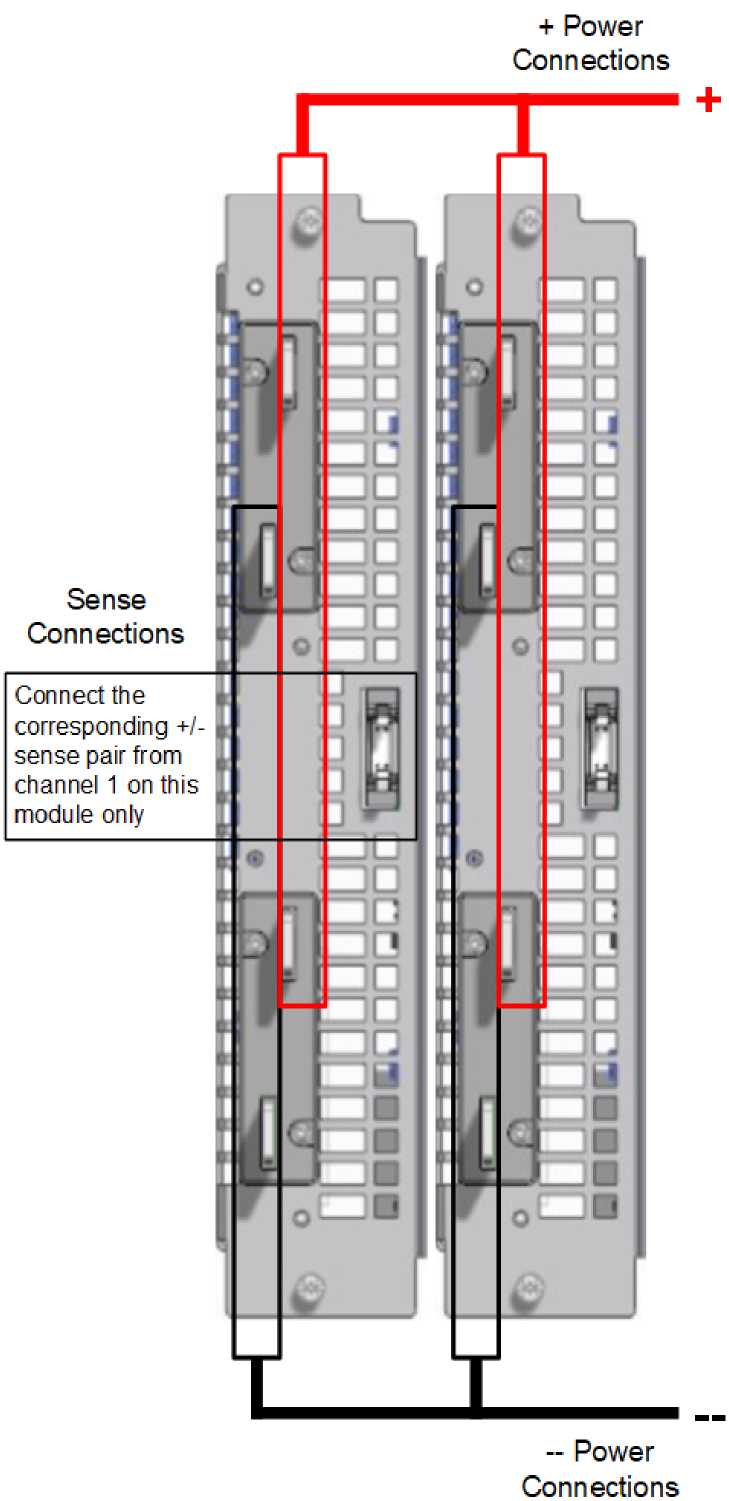
Example 6

This diagram illustrates one cell connection, rated at 200 A max. Channels one and two are paralleled and control one cell.



Example 7

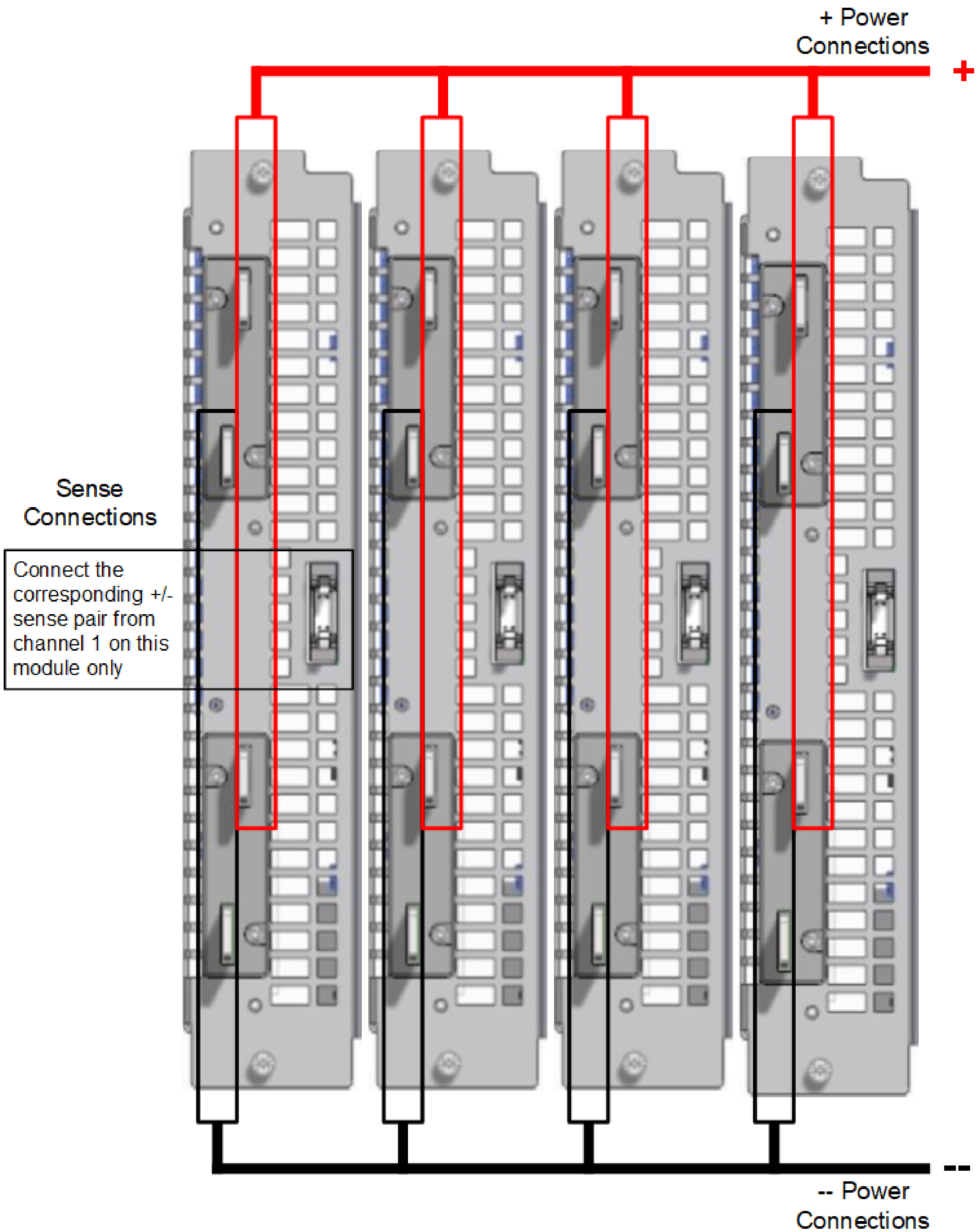
This diagram illustrates one cell connection, rated at 400 A max. The positive and negative connections of channels one and two of each module are paralleled across all modules and control one cell.



Example 8

This diagram illustrates one cell connection, rated at 800 A max. The positive and negative connections of channels one and two of each module are paralleled across all modules and control one cell.

Removing the 4th module on the right will illustrate a cell connection rated at 600 A.



3
Operating the Charge-Discharge System

KEYSIGHT TECHNOLOGIES

Understanding Channels and Cells

What is the Difference Between Channels and Cells?

Channels - simply put, the term channels refers to the hardware channels of the charge-discharge module. Each module has 32 channels. So, depending on the number of modules that are installed in your mainframe, you can have up to 256 available channels. Each channel is rated at +5V, ±6.25 A. Use the <channel> or <chanlist> parameter to program the channels.

Cells - refers to the lithium ion cells that are connected to the hardware channels. If none of the cells in your application are greater than +6.25 A, you can connect up to 256 lithium ion cells to a fully loaded mainframe. In this configuration, there are the same number of channels as there are cells.

In many configurations however, the rating of the cells exceed the channel rating of +6.25 A. In that case, multiple channels need to be paralleled to match the current rating of the cell (see Cell Cable Connections). You can no longer use the <chanlist> parameter to program the cells. Instead, you must define each cell using the CELL:DEFine command, and use the <Cell_ID> or <cell_list> parameter to program the corresponding cells. Refer to Cell Examples for cell ID address examples.

NOTE Cell charge-discharge sequences can only be run on cells, not channels. To participate in a sequence, each channel or channel-list must be assigned cell-IDs.

Defining Channel Addresses and Cells for BT2204A/B

Defining Addresses

The following table illustrates the channel addressing scheme used for the BT2204A/B modules.

Mainframe Slot	Connector 1	Connector 2	Connector 3	Connector 4	Channel Addresses
1	1 - 8	9 - 16	17 - 24	25 - 32	101 - 132
2	1 - 8	9 - 16	17 - 24	25 - 32	201 - 232
3	1 - 8	9 - 16	17 - 24	25 - 32	301 - 332
4	1 - 8	9 - 16	17 - 24	25 - 32	401 - 432
5	1 - 8	9 - 16	17 - 24	25 - 32	501 - 532
6	1 - 8	9 - 16	17 - 24	25 - 32	601 - 632
7	1 - 8	9 - 16	17 - 24	25 - 32	701 - 732
8	1 - 8	9 - 16	17 - 24	25 - 32	801 - 832

Defining Cells

The following table illustrates a typical cell-addressing scheme for the BT2204A/B modules where the first digit of each ID references the charge-discharge module slot to which it is connected. However, you can assign any value from 1000 to 8032 to any cell, as long as you keep track of where it is connected.

Recommendation: Use the first digit in the cell ID to indicate the slot where the cell is located. (ex: 1000+ is in slot 1; 5000+ is in slot 5). Otherwise you would have no way of easily identifying to which slot the cell is connected.

Mainframe Slot	Typical Cell ID range per Module	Mainframe Slot	Typical Cell ID range per Module
1	1001 to 1032	5	5001 to 5032
2	2001 to 2032	6	6001 to 6032
3	3001 to 3032	7	7001 to 7032
4	4001 to 4032	8	8001 to 8032

Cell Examples

The following table gives an example of cell IDs that can be assigned to the typical cell configuration example discussed previously in Example 2. Note that each example is assigned to a different charge-discharge module. The values in the columns show the syntax used in the CELL:DEFine command.

Example	Cell IDs per Module	Channel IDs per Cell
1 (Module 1)	1001 to 1032	(@101:132)
2 (Module 2)	2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008	(@201:202) (@203:205) (@206:208) (@209:212) (@213:216) (@217:220) (@221:224) (@225:232)
3 (Module 3)	3001, 3002, 3003	(@301:310) (@311:320) (@321:330)
4 (Module 4)	4001, 4002	(@401:416) (@417:432)

The following SCPI examples define cells 4 and 5 in Module 1 as shown in connection Example 2.

```
CELL:DEFine 2004,(@209:212)
CELL:DEFine 2005,(@213:216)
```

Refer to Introduction to the SCPI Language for cell addressing examples.

Defining Channel Addresses and Cells for BT2205A

CAUTION Keysight BT2204A/B and BT2205A modules cannot be combined in the same mainframe.

Each Keysight BT2205A module has 2 channels. So, depending on the number of installed modules, you can have up to 16 available channels. Each channel is rated at +6V, ±100 A.

In many configurations, the rating of the cells exceed the channel rating of +100 A. In that case, multiple channels need to be paralleled to match the current rating of the cell (see BT2205A Cell Cable Connections). You can no longer use the <chanlist> parameter to program the cells. Instead, you must define each cell using the CELL:DEFine:QUICk command, and use the <Cell_ID> parameter to program the corresponding cells. Refer to the CELL:DEFine:QUICk command for cell ID address examples.

The following table lists the allowable cell ID's for up to eight BT2205A modules in a mainframe based on the number of channels assigned to a cell. Note that output currents greater than 800 A only allow you to configure one cell (>800 A max to ≤1600 A max).

Channels Per Cell <cell_size>	Amperes per Cell	Cells per mainframe (with 8 modules)	Cell IDs assigned
1	up to 100	16	1001, 1002, 2001, 2002, 3001, 3002, 4001, 4002, 5001, 5002, 6001, 6002, 7001, 7002, 8001, 8002
2	up to 200	8	1001, 2001, 3001, 4001, 5001, 6001, 7001, 8001
4	up to 400	4	1001, 3001, 5001, 7001
6	up to 600	2	1001, 5001
8	up to 800	2	1001, 5001

Understanding Sequences

Sequence Basics

The primary function of a channel in the CDS is to form battery cells using a charge-discharge process. The forming process is comprised of a sequence of precharge, charge, discharge, and rest steps. This section provides a sequence example, and describes how to configure a sequence.

The system can contain up to 256 unique sequences of up to 50 steps each. Each sequence step can define up to 24 test conditions. Tests are used to verify that the cells are performing properly and to control the transition to the next step according to the test outcome.

Sequence Example

The following table describes a sequence composed of four steps (charge, rest, discharge, rest) with a few tests defined for the charge and discharge steps.

Function	Step	Step Action/ Test type	Voltage	Current	Time	Test Action
Set Seq Step	1	Charge at	4.0 V	20 A	for 1200 s	
Set Seq Test	1	Voltage ≥	3.6 V		before 300 s	Fail (cell connection at high impedance)
Set Seq Test	1	Current ≤		1 A	after 300 s	Next step (cell rest)
Set Seq Step	2	Rest			for 300 s	
Set Seq Step	3	Discharge at	3.0 V	20 A	for 900 s	
Set Seq Test	3	Voltage ≤	3.0 V		before 300 s	Fail (cell connection at high impedance)
Set Seq Test	3	Voltage ≤	3.0 V		after 300 s	Next step (cell rest)
Set Seq Test	3	Voltage ≥	3.0 V		at 900 s	Fail (cell connection at high impedance)
Set Seq Step	4	Rest			for 300 s	Sequence complete

Sequence Steps

A sequence is built using steps. There are three primary steps in the charge/discharge sequence: charge, discharge, and rest. The charge and discharge steps require you to specify a time duration, a constant current limit (CC), and a constant voltage limit (CV). A rest step only requires a time duration. A precharge step is also available, which is used to lightly charge cells that are at a very low initial voltage.

The SEQuence:STEP:DEFine command defines a step and adds it to a sequence. The first parameter is an identification, referring to the sequence in which steps are defined. The second parameter is the step number being defined. The third through the sixth parameter is the mode type, the duration in seconds, the CC limit and the CV limit. The following SCPI example shows the commands needed to define the steps in the previous sequence example. The sequence ID is "1", consisting of steps numbered from "1" to "4".

```
SEQ:STEP:DEF 1, 1, CHARGE, 1200, 20A, 4.0V
SEQ:STEP:DEF 1, 2, REST, 300
SEQ:STEP:DEF 1, 3, DISCHARGE, 900, 20A, 3.0V
SEQ:STEP:DEF 1, 4, REST, 300
```

There is an additional step that can also be programmed if you wish to include a constant power limit component as part of the sequence. To specify a power limit, use SEQuence:STEP:CPOWer:DEFine. The following example shows how to include a power limit of 80 W for a charge step.

```
SEQ:STEP:CPOW:DEF 1, 1, CHARGE, 1200, 20A, 4.0V, 70W
```

Step Setup

At the beginning of each charge and discharge step, the instrument performs a number of setup procedures, which complete in approximately 15 seconds and include the following:

- Disables the output
- Matches the cell voltage
- Checks if the cell is reversed or outside the sense limits (< 0.8 V; > 6.7 V)
- Sets the current limit and output voltage to minimize any rapid rise or drop in current
- Execute any BEFORE_START sequence tests
- Enables the output to start current flow
- Ramps the voltage and current to prevent voltage or current overshoots
- Checks the cell voltage against the target voltage and if it is already at target, proceeds to the next step

Precharge Step

An optional precharge step is also available for the sequence. It is used *before* the charge step, at the beginning of a sequence. This step addresses a special situation of a cell that initially is at a very low voltage (less than 800 mV). Normally, this low voltage would cause a cell to fail early in the sequence because there is a minimum voltage requirement of 800 mV. The precharge step has a lower sense limit of -0.1 V to prevent an early cell failure.

The precharge step lightly charges a cell so that it meets the minimum voltage requirement of 800 mV of a charge step. It enforces a target voltage between 1 and 2 volts, and a time duration of 900 seconds (15 minutes) or less. You may use multiple precharge steps if more than 900 seconds of precharge is desired. Refer to SEQuence:STEP:DEFine. Continuous probe checks (both power and sense) are not performed during the precharge step.

Note that at the beginning of each precharge step, the instrument performs a number of setup procedures, which complete in approximately 5 seconds.

In the following SCPI example, the precharge step runs for 900 seconds with a light current limit of 0.5 A and a voltage limit of 1.5 V. CELL:TRANsition IMMediate enables a seamless precharge transition. CELL:FSETtle ON decreases the turn-on time of the following charge/discharge steps to be the same as precharge (~ 5 seconds).

Note that in this example, a power limit is also included in the precharge, charge, and discharge steps.

```
CELL:TRAN IMM
CELL:FSET ON
SEQ:STEP:CPOW:DEF 1, 1, PRECHARGE, 900, 0.5A, 1.5V, 0.5W
SEQ:STEP:CPOW:DEF 1, 2, CHARGE, 1200, 20A, 4.0V, 70W
SEQ:STEP:DEF 1, 3, REST, 300
SEQ:STEP:CPOW:DEF 1, 4, DISCHARGE, 900, 20A, 3.0V, 50W
SEQ:STEP:DEF 1, 5, REST, 300
```

DCIR Step

The Internal resistance of a cell (DCIR) can be measured by programming short positive and negative pulses to the cell which will not affect the cell's charge or discharge state. A separate DCIR step has been defined to generate the pulses that allow the internal cell resistance to be measured. Refer to Cell Resistance Measurements for more information

Sequence Tests

Each step in the sequence can have up to 32 associated tests, as defined by the SEQuence:TEST:DEFine command. The tests are used to monitor and verify that the cell is operating within limits. Each test has five attributes (or parameters): the test type, the test limit, the time type, the time limit, and what action to take if the test condition is true.

The first two parameters - test type and test limit, describe the basis of the test. There are quite a few combinations of test types and limits; refer to SEQ:TEST:DEF for a full list of supported test types. For example: Voltage ≥ 3.0, Current ≤ 0.292, and AmpHours ≥ 1.2 are some of the supported test bases.

The next two parameters - the time type and time limit, specify the time interval of the test. Valid values for the time type are AT, AFTER, BEFORE, or BEFORE_START. The time type along with the time limit let you specify when the test will be active. The time limit is relative to the start of the step. For example, if the time type and time limit were ‘AFTER 300’, the test would be inactive during the first 300 seconds (5 minutes) of the step, and then become active from 5 minutes to the end of the step.

The final parameter specifies what action to take if the test condition is met. The two options are NEXT or FAIL. NEXT means the cell can continue to the next step in the sequence when the cell satisfies the conditions defined by the NEXT parameter. FAIL means that the test has satisfied the conditions defined by the FAIL parameter. The cell connections open into a high impedance state, the sequence moves to the rest state, and the cell doesn't participate in any subsequent steps.

The following SCPI example shows the commands needed to define the tests shown in the sequence example. The first three arguments to the SEQ:TEST:DEF are the seq_Id, step_Id, and test_Id.

```
SEQ:TEST:DEF 1, 1, 1, VOLT_GE, 3.6, BEFORE, 300, FAIL
SEQ:TEST:DEF 1, 1, 2, CURR_LE, 1, AFTER, 300, NEXT
SEQ:TEST:DEF 1, 3, 1, VOLT_LE, 3.0, BEFORE, 300, FAIL
SEQ:TEST:DEF 1, 3, 2, VOLT_LE, 3.0, AFTER, 300, NEXT
SEQ:TEST:DEF 1, 3, 3, VOLT_GE, 3.0, AT, 900, FAIL
```

DCIR Test

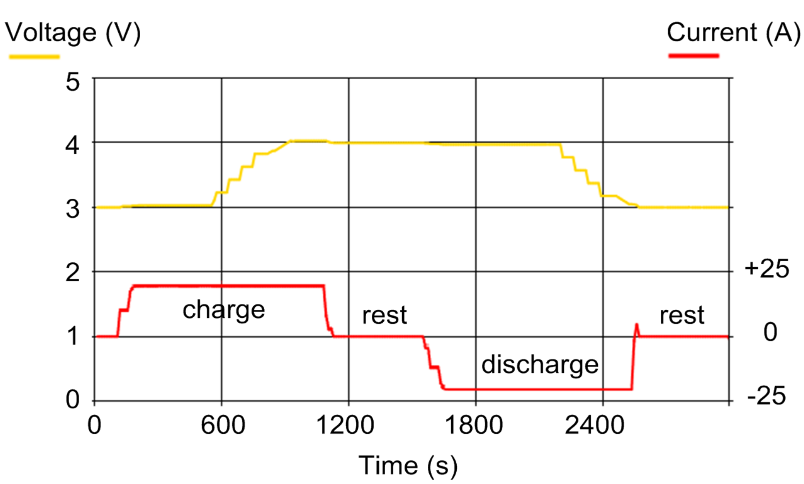
The following DCIR tests define the conditions to verify that the internal resistance is within the acceptable limits. The tests will transition to the next step based on cell performance. The first three arguments to the SEQ:TEST:DCIR:DEF are the seq_Id, step_Id, and test_Id. The resistance values that are specified are based on the expected internal resistance value of the cell.

```
SEQ:TEST:DCIR:DEF 1, 1, 1, DCIR1_GE, 0.6, FAIL
SEQ:TEST:DCIR:DEF 1, 1, 2, DCIR1_LE, 0.5, NEXT
SEQ:TEST:DCIR:DEF 1, 1, 3, DCIR2_GE, 0.6, FAIL
SEQ:TEST:DCIR:DEF 1, 1, 4, DCIR2_LE, 0.5, NEXT
```

Note that the internal resistance value of the cell can be measured by using the SEQuence:STEP:DCIR:DEFine command followed by the MEASure:CELL:DCIR? query.

Putting it all together - defining cells, sequences, and tests

The following figure describes a successful cell-forming sequence based on the previous sequence example. The connections are shown in Example 2, cells 4 and 5 are used in this example.



```
# Clear any initial setups
CELL:ABOR 0
CELL:CLE 0
SEQ:CLE 0

# Define two paralleled cells of 4 channels each
CELL:DEF 2004,(@209:212)
CELL:DEF 2005,(@213:216)

# Define a small sequence (seq 1) with 4 steps and 5 tests
# Define charge step 1
SEQ:STEP:DEF 1, 1, CHARGE, 1200, 20, 4.0
# Define a fail test
SEQ:TEST:DEF 1, 1, 1, VOLT_GE, 3.6, BEFORE, 300, FAIL
# Define a pass test
SEQ:TEST:DEF 1, 1, 2, CURR_LE, 1, AFTER, 300, NEXT

# Define rest step 2
SEQ:STEP:DEF 1, 2, REST, 300

# Define discharge step 3
SEQ:STEP:DEF 1, 3, DISCHARGE, 900, 20, 3.0
# Define a fail test
SEQ:TEST:DEF 1, 3, 1, VOLT_LE, 3.0, BEFORE, 300, FAIL
# Define a pass test
SEQ:TEST:DEF 1, 3, 2, VOLT_LE, 3.0, AFTER, 300, NEXT
# Define a fail test
SEQ:TEST:DEF 1, 3, 3, VOLT_GE, 3.0, AT, 900, FAIL

# Define rest step 4
SEQ:STEP:DEF 1, 4, REST, 300

# Assign the cells to run sequence 1
CELL:ENAB (@2004,2005),1
# Start the sequence on both cells defined above
CELL:INIT (@2004,2005)
```

In Step 1, all cells are set to charge at a constant current of 20 amperes until the voltage reaches 4 volts. Cell charging continues at the 4 volt limit, however the charging current now starts decreasing from its 20 ampere limit setting. The cell continues charging until the cell current falls to 1 ampere. When this occurs, the cell passes the test and goes to the rest step. A cell fails the test if it reaches the 3.8 volt setting in less than 300 seconds. This indicates that the cell is charging too rapidly.

In Step 2, all cells rest for at least 5 minutes with no stimulus applied to their outputs. The rest step can be used to move a cell into a resting state if you do not want the present stimulus settings to be applied to the cell after it has satisfied the test criteria, or if you do not want it to proceed to the next step before any of the other cells have completed the present step.

In step 3, all cells are set to discharge at a constant current of 20 amperes until the voltage falls to 3 volts. This voltage is referred to as the end of discharge voltage. If the voltage drops to 3 volts after five minutes has elapsed, the cell passes the test and goes to the rest step. The maximum time limit for the discharge step is 15 minutes. A cell fails the test if its voltage drops to 3 volts before 5 minutes has elapsed. A cell also fails the test if the voltage does not fall below 3 volts after 15 minutes. This indicates that the cell is discharging too slowly, possibly a problem with the test fixture or the wiring.

Step 4 is a five minute rest step, which is only included in this example as a buffer between the previous discharge step and any other step that may follow in the sequence. Because cells can be independently paced, you do not have to use rest steps in this manner.

Charge, Discharge, and Precharge Details

This section describes the differences in Charge, Discharge, and Precharge operation when using the default settings of the CDS, and when using the CELL:FSETtle ON and the CELL:TRANsition IMMediate command settings.

Charge Start/End Differences

Example 1: The following waveforms illustrate the start and end of a charge step using the default settings. Before the start of this step, the cell is at rest. CELL:INIT starts the charge. Safety checks occur during the first 15 seconds of the programmed start step before the full charge current of 6.25 A is reached.

There is a rest step at the end of the charge step in this example. At the end of the programmed charge step, but before the rest step, the waveform takes another two seconds to fully end. The first second is shown by the lower current level. Another second is required at the end of the lower current level to fully end the charge step.

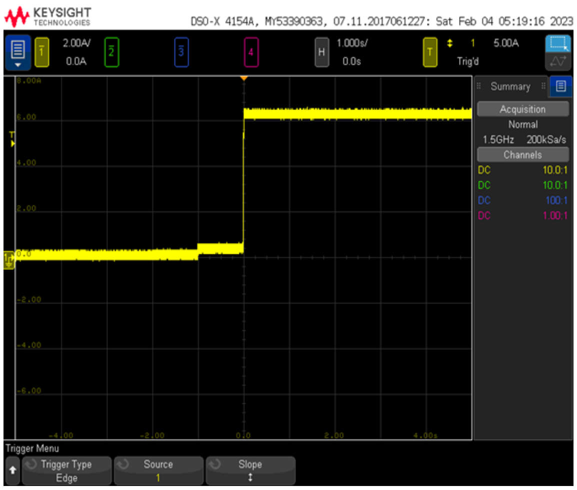
This charge-end time may be less than 1 to 2 seconds with charge currents under 6.25 A. Also, the additional end time is not part of the programmed charge time, but actually *shortens* the programmed time of the of the next charge or discharge step after the first 15 seconds have elapsed.

Charge-start waveform

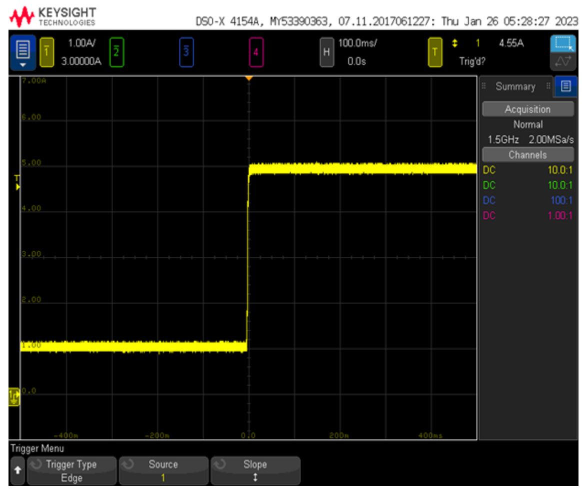
Charge-end waveform

Example 2: In the following example, programming CELL:FSETtle ON (fast settle) ensures that the time required after programming CELL:INIT for the target charge current of 6.25 A to be reached is reduced from 15 seconds to 5 seconds.

When a precharge step is included, programming CELL:TRANsition IMMediate ensures that the transition from precharge to charge is immediate, with no 5 second delay. The 5 A charge starts immediately after 1 A precharge. This is because the safety checks are done during precharge.



Charge-start with CELL:FSET ON



Charge-start with CELL:TRAN IMM

Discharge Start/End Differences

Example 1: The following waveforms illustrate the start and end of a discharge step using the default settings. CELL:INIT occurs 15 seconds before the full discharge current of 6.25 A is reached.

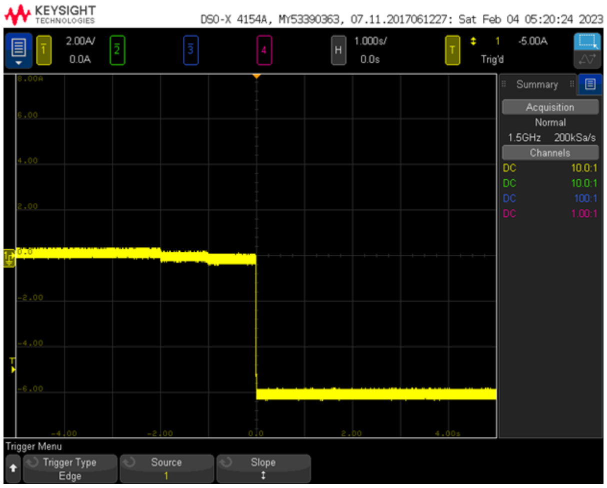
At the end of the programmed discharge step, the waveform takes another two seconds to fully end. The first second is shown by the lower discharge level. Another second is required at the end of the lower discharge level to fully end the discharge step.

This discharge-end time may be less than 1 to 2 seconds with discharge currents under 6.25 A. Also, the additional end time is not part of the programmed discharge time, but actually *shortens* the programmed time of the of the **next** charge or discharge step after the first 15 seconds have elapsed.

Discharge-start waveform

Discharge-end waveform

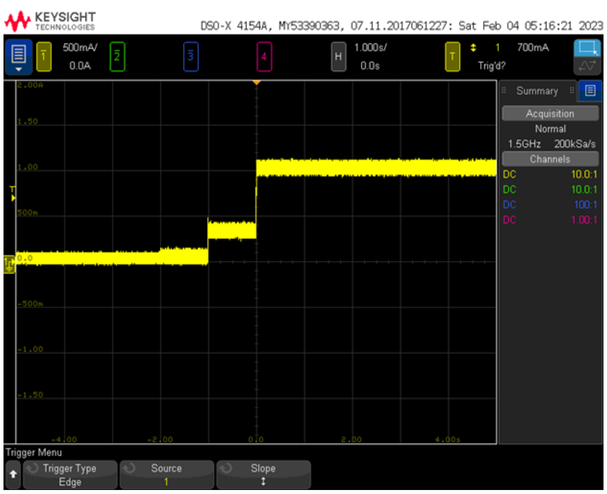
Example 2: Programming a discharge step with **CELL:FSETtle ON** (fast settle) ensures that the time required after CELL:INIT for the target discharge current to be reached is reduced from 15 seconds to 5 seconds. This effect is the same as for the charge step. The CELL:TRANsition IMMediate command has no effect on discharge steps.



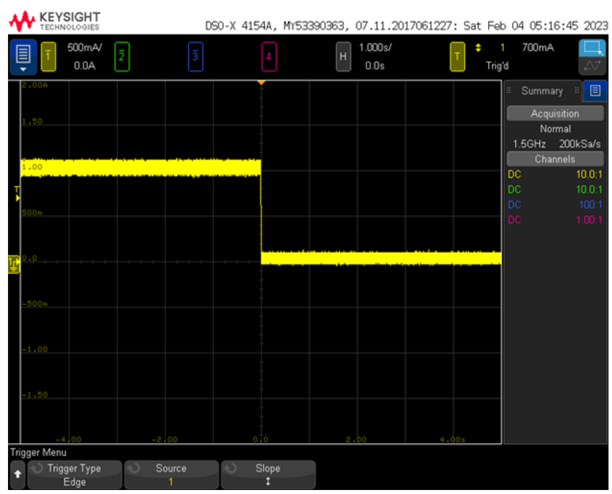
Discharge-start with CELL:FSET ON

Precharge Start/End Details

The following waveforms illustrate a precharge step. **CELL:INIT** occurs 5 seconds before the precharge target current of 1 A is reached. The CELL:FSETtle ON and CELL:TRANsition IMMediate commands have no effect on precharge steps. No additional time is needed at the end of the programmed precharge step.



Precharge Start waveform



Precharge End waveform

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Understanding Measurements

Voltage and Current Measurements

Voltage Measurements

The Keysight BT2200 Series Charge-Discharge System measures the voltage of each channel using a calibrated internal measurement circuit. The voltage is measured at the end of the remote sense leads. The remote sense leads must be connected to the cell so that the actual voltage of the cell will be measured. Any voltage drops in the load leads will not affect the measurement.

NOTE If the sense leads are not connected, a probe check error will be generated.

Current Measurements

The CDS measures actual current in the output current path for each channel using a calibrated internal measurement circuit.

Capacity Measurements

Ampere-Hour Capacity

The CDS determines amp-hour cell capacity by making calculations based on continuous current measurements.

During charge, every time the CDS makes a measurement, it calculates the actual incremental amp-hours put into the cell during each sampling interval by multiplying the measured current times the sampling interval. It then adds this incremental amount to the accumulated amp-hour value to determine the total amp-hours delivered into the cell. Amp-hour capacity will be positive during charge. Thus, accurate amp-hour capacity measurements can be made even when charge current is not constant, such as during constant voltage charging.

During discharge, every time the CDS makes a measurement, it calculates the actual incremental amp-hours taken out of the cell by multiplying the measured current times the sampling interval. It then adds this incremental amount to the accumulated amp-hour value to determine the total amp-hours removed from the cell. Amp-hour capacity will be negative during discharge. Thus, accurate amp-hour capacity measurements can be made even when discharge current is not constant.

Amp-hour capacity measurements are reset to zero at the beginning of each step.

Watt-Hour Capacity

The CDS determines watt-hour cell capacity by making calculations based on continuous current and voltage measurements.

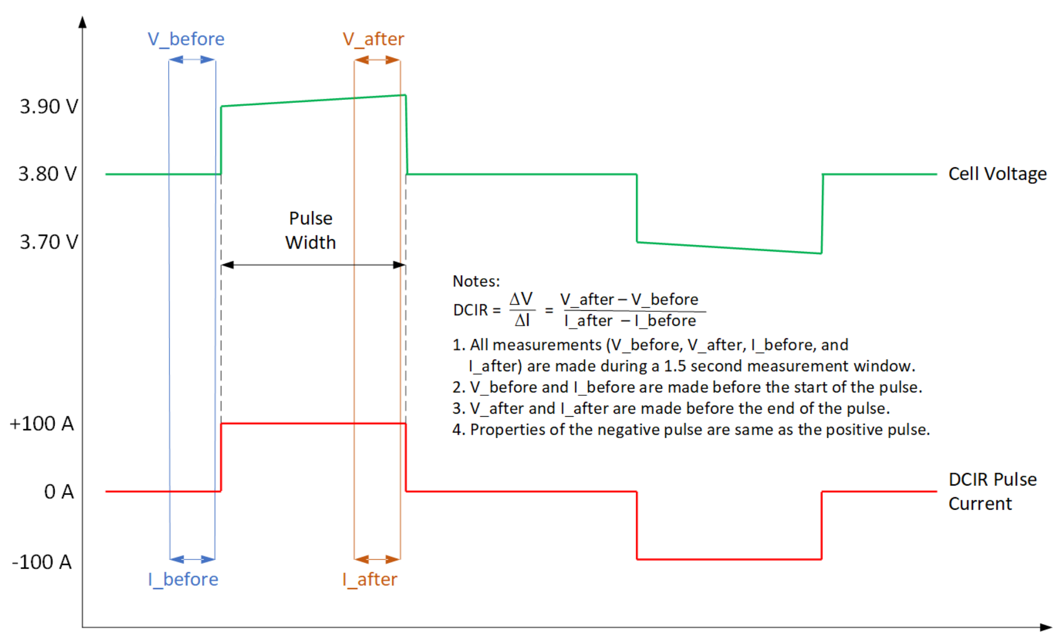
During charge, every time the CDS makes a measurement, it calculates the actual incremental watt-hours put into the cell during each sampling interval by multiplying the measured current times the measured voltage times the sampling interval. It then adds this incremental amount to the accumulated watt-hour value to determine the total watt-hours delivered into the cell. Watt-hour capacity will be positive during charge. Thus, accurate watt-hour capacity measurements can be made even when charge current and voltage is varying.

During discharge, every time the CDS makes a measurement, it calculates the actual incremental watt-hours taken from the cell during each sampling interval by multiplying the measured current times the measured voltage times the sampling interval. It then adds this incremental amount to the accumulated watt-hour value to determine the total watt-hours taken from the cell. Watt-hour capacity will be negative during discharge. Thus, accurate watt-hour capacity measurements can be made even when discharge current and voltage is varying.

Watt-hour capacity measurements are reset to zero at the beginning of each step.

Cell Resistance Measurements

The following figure describes how cell resistance measurements (DCIR) are obtained in the BT2200 Series Charge-Discharge System. It illustrates a positive and a negative pulse that has been programmed by the DCIR step. Note that the step pulses should be symmetrical, meaning that the positive and negative pulses are identical with reverse polarity. This ensures that the DCIR measurement does not change the cell's state of charge. Also, since the voltage change due to charging/discharging process is usually very slow, the impact to this voltage change can be kept to a minimum by applying short pulses (e.g. 3 seconds minimum).



The DCIR measurement is made during the 1.5 second window shown above. The window is open up to 0.1 second ***before*** the leading and trailing edges of the pulses. In the following SCPI example, the DCIR step defines the positive and negative pulses shown in the figure.

```
SEQ:STEP:DCIR:DEF 1, 1, 3.9, 3.8, 3, 100, 3, 5, -100, 3, 3
```

After the SEQuence:STEP:DCIR:DEFine command completes, use the MEASure:CELL:DCIR? query to return the resistance measurements. Then calculate the percent of error for the DCIR measurement as follows (refer to BT2205A Characteristics):

Assume that the DCIR measurement returned is 5 mΩ at -100 A on a single BT2205A channel:
5mΩ ± [0.26% * 5mΩ + 5mΩ * |-100A| / (1 * 7500A) + 10µΩ / 1], or
5mΩ ± [13µΩ + 66.7µΩ + 10µΩ], or
5mΩ± 89.7µΩ

Probe Resistance Measurements

Probe resistance is continually checked while the sequence is running. Refer to Understanding Probe Checks for more information.

Understanding Probe Checks

Continuous Probe Checks

Power and sense probe checking continuously monitors the probes to ensure that they are working properly while a sequence is running. Probes are checked against a limit. If the measurements are within the limit, the sequence continues. If they are outside the limit, then that particular cell fails the sequence and is turned off. Power and sense probe checking occurs every second throughout the charge and discharge steps. It does not occur during rest and precharge steps.

Power Probe Check

The power probe check uses the sense lines to read the difference between the voltage at the cell (as sensed by the sense lines) and the voltage at the power connector. It uses the internal current measurement along with voltage difference between power and sense probes to calculate the total resistance in the power probes.

- The power probe check is initiated 5 seconds after the channel enters a charge or discharge step, and continues once per second for the duration of the step.
- The probe check limit is set at 500 milliohms, which includes the outbound and return wires along with any contact resistance. This limit is programmed by SYSTem:PROBecheck:LIMit.
- When a power probe failure is detected, the channel is marked as failed (in the cell status register) and is exited from the sequence.
- The power probe check is done on each channel individually even if channels are paralleled. If a channel fails, then all of the channels that are in the paralleled group are considered failed.

Sense Probe Check

The sense probe check does not measure the resistance value of the sense probe wires because it is acceptable to have high resistance wiring in the sense probe path - as no current flows through the sense probes. Instead, the sense inputs are fully differential with a 1 MΩ input resistance from +sense to -sense. If either the positive or negative sense lead opens, the 1 MΩ input resistance causes the differential voltage to go to approximately 0 V. Any differential voltage measured on the sense inputs less than 0.8 V will generate a sense probe failure and cause the cell to be removed from the sequence.

- The sense probe check is initiated 5 seconds after the channel enters a charge or discharge step, and continues once per second for the duration of the step.
- When a sense probe failure is detected, the channel is marked as failed (in the cell status register) and is exited from the sequence.
- The sense probe check is done on each channel individually even if channels are paralleled. If a channel fails, then all of the channels that are in the paralleled group are considered failed.

Understanding System Protection

The CDS provides extensive capability to protect both the hardware and the individual cells being formed from catastrophic damage. The CDS can also communicate its protection status to other parts of the manufacturing system for more sophisticated forms of protection.

Protection Faults

When a protection fault occurs, the front panel **Error** indicator turns red.

Any running sequences abort their operation and cannot be resumed until the protection fault is cleared. When a sequence is aborted, the power connections open into a high impedance state.

When a SCPI error occurs, the instrument will continue to operate with the errors present in the Error queue. Reading the Error queue clears it.

There is no front panel control to clear protection faults. Clearing the protection faults can only be done using the test program (see Clearing Protection Events and Errors). Once the test program clears the protection fault, the Error LED turns off.

Internal Protection Features

There are internal solid-state switches in the channel and sense paths of the charge-discharge modules. These switches protect the CDS from over-voltage and under-voltage conditions on the output/sense paths. They also protect the CDS if an external fault condition is detected.

Power circuits include several features to protect the cell from failures in the hardware. Internal circuits connected in series with each channel protect the system from reverse cell polarity, cell failure, and regulator failure. Internal thermal sensors check for maximum heat rise to avoid failures due to excessive temperature excursions. Fans keep the internal temperature at an acceptable level

Lastly, the CDS has an extra level of safety - a built-in hardware watchdog timer. The hardware watchdog timer is independent of CPU, software, or firmware activities. If, due to some internal firmware or software fault, the CPU in the CDS should stop functioning for the specified watchdog setting, the hardware watchdog timer will reset the CDS to the power-on state. When this occurs, all cell connections open into a high impedance state.

NOTE

Overvoltage and overcurrent tests can be included as part of a test sequence to implement overvoltage and overcurrent protection.

Digital IO Protection Features

Digital IO pins 1 and 2 can be configured as a fault-output pair. The Fault Output function enables a fault condition to generate a protection fault signal on the digital port.

Digital Pin 3 can be configured as a remote inhibit input. The Inhibit input function lets an external input signal abort the sequence. The Inhibit input is level triggered. Pin 8 is the common for pin 3.

The digital IO can also be used as general purpose IO. As a general purpose IO, the input or output signals on the digital connector are directly controlled with SCPI commands over the interface.

On Keysight BT2202A and BT2203B mainframes only, dgital IO pins 1-23 can be configured to abort a test in response to an external signal. Cell-abort lists can be assigned to any of the digital IO pins. When a cell-abort signal occurs on the pin, the cells in the abort list will be aborted.

More information on using the digital port is found under Understanding the Digital Port.

AC Power-fail Protection

Should the AC line fail, the CPU in the CDS will shut down. Any charging and discharging activity will stop, and the sequence, test data, and programmed settings will be lost. To provide for safety, the cell connections open into a high impedance state, and any further charging and discharging stops.

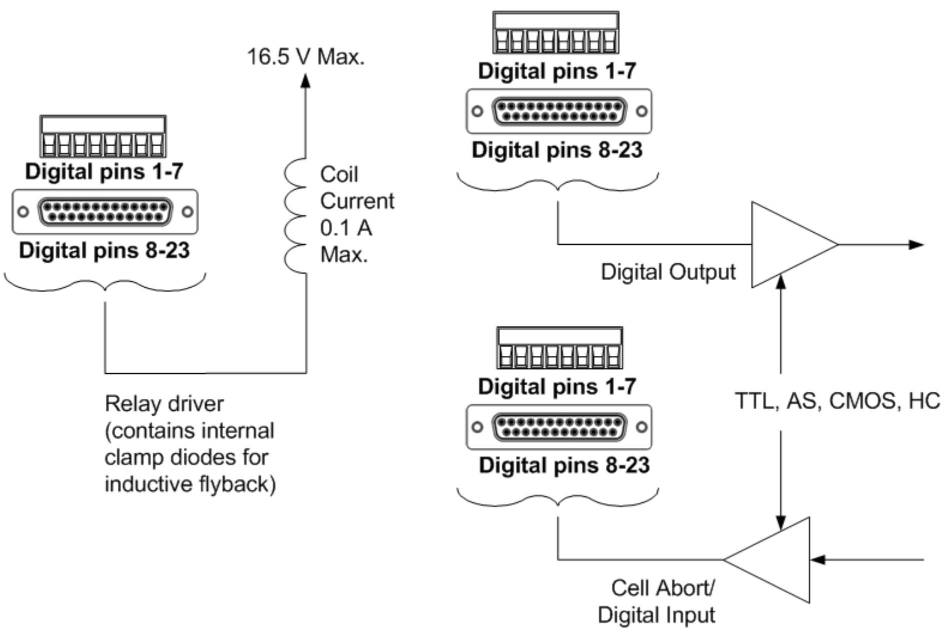
Understanding the Digital Port

Digital Port Operation

Keysight BT2202A and BT2203B mainframes have two digital port connectors consisting of a total 23 digital IO pins that support various control functions. Each digital pin is user-configurable.

Keysight BT2203A mainframes have one 8-pin digital port connector that supports various control functions. This connector is compatible with other instruments such as DC power supplies.

The digital pins can be used to control both relay circuits as well as digital interface circuits. The following figure illustrates typical relay and digital circuit connections using the digital pin functions.



The following table describes the possible pin configurations for the digital port(s). For a complete description of the electrical characteristics of the digital port, refer to Common Characteristics.

Function	Description
CABort	Cell Abort mode. Applies to all pins. Assigns a cell-abort list to a digital pin. When a cell-abort signal occurs on the pin, the sequence running on the cells in the abort list will be aborted.
DIO	General-purpose ground-referenced digital input/output function. Applies to all pins. The output can be set with DIGital:OUTPut:DATA.
DINPut	Digital input-only mode. Applies to all pins. The digital output data of the pin is ignored.
FAULt	Applies only to pins 1 and 2. Pin 1 functions as an isolated fault output. Pin 2 is the isolated common for pin 1. The fault signal is true when a fault occurs on the instrument.

INHibit	Applies only to pin 3. A logic true signal at the Inhibit pin aborts all sequences.
Common	Applies to pin 8 on the 8-pin connector, and to pins 1, 6, 11, 13, 14,19, and 24 on the 25-pin connector. Connected to ground.

In addition to the configurable pin functions, the signal polarity for each pin is also configurable. Positive indicates a high level voltage at the pin. Negative indicates a low level voltage at the pin.

Cell Abort Input

Each of the 23 pins can be configured as a cell-abort input pin. The polarity of the pins can also be configured. The cell-abort input is level triggered. The signal latency is 250 milliseconds. A signal common connection is required for the cell abort pins.

A cell-abort list must be also assigned to the designated pin. Whenever the cell abort pin receives an abort signal, the cells designated in the abort list will be aborted. If a CELL:INITiate command is received while a digital pin is in the abort state, any cells associated with that pin will be aborted.

To configure pins 8-10 for cell abort:

```
DIG:FUNC 8,CAB
DIG:FUNC 9,CAB
DIG:FUNC 10,CAB        \\ sets the function of pins 8-10 to cell abort
DIG:POL 8,POS
DIG:POL 9,POS
DIG:POL 10,POS         \\ sets the polarity of pins 8-10 to positive -
                       \\ aborts the sequence when pins are pulled high
DIG:CAB 8,(@2004:2010) \\ assigns an abort cell list to pin 8
DIG:CAB 9,(@3004:3010) \\ assigns an abort cell list to pin 9
DIG:CAB 10,(@4004:4010)\\ assigns an abort cell list to pin 10
```

Note that *RST resets all digital pin functions to Digital Input and Positive polarity.

Bi-Directional Digital IO

Each of the 23 pins can be configured as general purpose bi-directional digital inputs and outputs. The polarity of the pins can also be configured. A signal common connection is required for the digital IO pins. Data is programmed according to the following bit assignments:

Pin	1	2	3	4	5	6	7	. . .	20	21	22	23
Bit Weight	0 (lsb)	1	2	3	4	5	6	. . .	19	20	21	22 (msb)

To configure pins 1-3 for digital IO:

```
DIG:FUNC 1,DIO
DIG:FUNC 2,DIO
DIG:FUNC 3,DIO     \\ sets the function of pins 1-3 to digital IO
DIG:POL 1,POS
DIG:POL 2,POS
DIG:POL 3,POS      \\ sets the polarity of pins 1-3 to positive
DIG:OUTP:DATA 5    \\ configures pins 1-3 as "101"
```

Digital Input

Each of the 23 pins can be configured as digital input only. The polarity of the pins can also be configured. A signal common connection is required for the digital input pins. The pin status reflects the true condition of the external signal that is applied to the pin. The pin state is not affected by the setting of DIGital:OUTPut:DATA.

To configure the pins 11-13 for digital input only:

```
DIG:FUNC 11,DINP
DIG:FUNC 12,DINP
DIG:FUNC 13,DINP    \\ sets the function of pins 11-13 to digital in
DIG:POL 11,POS
DIG:POL 12,POS
DIG:POL 13,POS      \\ sets the polarity of pins 11-13 to positive
DIG:INP:DATA?       \\ reads the data on the pins
```

Fault Output

Only pins 1 and 2 can be configured as a fault-output pair. The Fault Output function enables a fault condition to generate a protection fault signal on the digital port.

Both pins 1 and 2 are dedicated to this function. Pin 1 is the Fault output; pin 2 is the common for pin 1. This provides for an optically-isolated output. The polarity of pin 1 can also be configured. When the pin polarity is positive, a fault condition causes the isolated output to conduct. The Fault output signal remains latched until the fault condition is removed and the protection circuit is cleared using OUTPut:PROTection:CLEar.

NOTE Do not program pin 2. Connect pin 2 to the ground of the external circuit.

To configure the Fault Output function:

```
DIG:FUNC 1,FAUL  \\ sets the function for pin 1 to fault output
DIG:POL 1,POS    \\ sets the function for pin 1 to positive
```

Inhibit Input

Only pin 3 can be configured as a remote inhibit input. Asserting a logic true on this input aborts all sequences, which puts the Channel/Cell connections into a high impedance state. The Inhibit input is level triggered. The signal latency is 5 microseconds. Pin 8 is common for pin 3. Whenever the Inhibit function is active, the mode will be latching, and must be cleared using OUTPut:PROTection:CLEar.

To configure the Inhibit Input function:

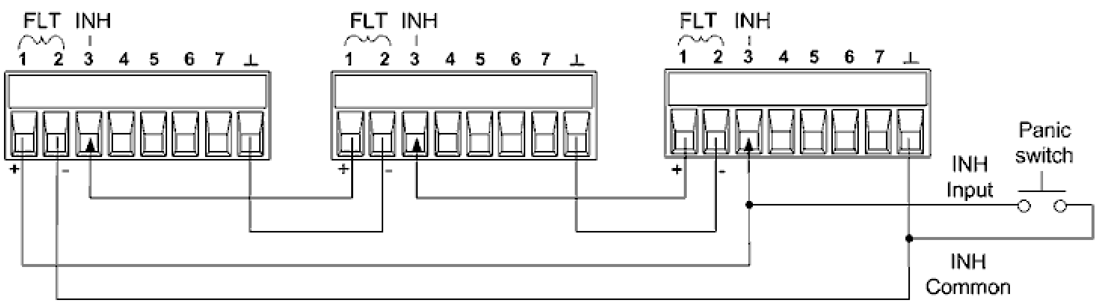
```
DIG:FUNC 3,INH      \\ sets the function for pin 3 to inhibit input
DIG:POL 3,POS       \\ sets the polarity for pin 3 to positive
```

Fault/Inhibit System Protection

This function applies to Keysight BT2202A, BT2203A, and BT2203B mainframes. It is used when multiple mainframes are connected together. This function can only be configured on the 8-pin digital connector.

As shown in the following figure, when the Fault outputs and Inhibit inputs of several instruments are daisy-chained, an internal fault condition in one of the units will disconnect all channels without intervention by either the controller or external circuitry. Note that when using the Fault/Inhibit signals in this manner, both signals must be set to the same polarity.

Also, as shown in the figure, you can also connect the Inhibit input to a manual switch or external control signal that will short the Inhibit pin to common whenever it is necessary to disconnect all channels. Negative polarity must be programmed for all pins in this case. You can also use the Fault output to drive an external relay circuit or signal other devices whenever a protection fault occurs.



Note that *RST resets all digital pin functions to Digital Input and Positive polarity.

Clearing a System Protection Fault

To restore all instruments to a normal operating condition when a fault condition occurs on the daisy-chained system protection configuration, two fault conditions must be removed:

1. **The initial protection fault or external Inhibit signal.**
2. **The subsequent daisy-chained fault signal (which is sourced by the Inhibit signal).**

NOTE Even when the initial fault condition or external signal is removed, the fault signal is still active and will continue to disconnect the channels of all the units.

To clear the daisy-chained fault signal, turn off the Inhibit input on ALL units individually. To re-enable the chain, re-program the Inhibit input on each unit to Latched mode.

4
Programming Reference

KEYSIGHT TECHNOLOGIES

Introduction to the SCPI Language

Command Types

SCPI (Standard Commands for Programmable Instruments) is an ASCII-based instrument command language designed for test and measurement instruments. SCPI has two types of commands, common and subsystem.

Common commands are defined by the IEEE 488.2 standard to perform common interface functions such as reset, status, and synchronization. All common commands consist of a three-letter mnemonic preceded by an asterisk: *RST, *IDN?

Subsystem commands perform specific instrument functions. They can be a single command or a group of commands. The groups are comprised of commands that extend one or more levels below the root. Subsystem commands are arranged alphabetically according to the function they perform. The following figure shows a portion of a subsystem command tree, from which you access the commands located along the various paths.

```
MEASure
    :CELL
        :CURRent? <cell_ID>
```

Keywords

Keywords, also referred to as headers, are instructions recognized by the instrument. MEASure is the root keyword, CELL is a second-level keyword, CURRent is a third-level keyword. Colons (:) separate the keyword levels. Common commands are also keywords.

The command syntax shows most commands (and some parameters) as a mixture of upper- and lower-case letters. The upper-case letters indicate the abbreviated spelling for the command. For shorter program lines, you can send the abbreviated form. For better program readability, you can send the long form.

In the previous examples, MEASure and MEAS are both acceptable forms. You can use upper- or lower-case letters. Therefore, MEASure, meas, and Meas are all acceptable. Other forms such as MEASur, are not valid and will generate an error.

Queries

Following a keyword with a question mark (**?**) turns it into a query. If a query contains parameters, place the query indicator at the end of the last keyword, before the parameters. Insert a space between the query indicator and the first parameter.

You can query the programmed value of most parameters. For example, you can query the programmed sequence step values by sending:

```
SEQuence:STEP:DEFine? <seq_ID>, <step_ID>
```

You must read back all the results of a query before sending another command to the instrument. Otherwise, a *Query Interrupted* error will occur and the unreturned data will be lost.

Syntax Conventions

- Colons (:) separate keyword levels. Blank spaces must be used to separate command parameters from their corresponding keyword. Note the space between STATe and the *RST parameter. If a command requires more than one parameter, use a comma to separate adjacent parameters. In the following calibration command, the <step> and <measured> value parameters must be separated with a comma.

```
CALibration:VALue <step>, <measured>
```

- Triangle brackets (**< >**) indicate that you must specify a value for the enclosed parameter. In the example above, the <*voltage*> parameter is enclosed in triangle brackets. The brackets are not sent with the command string. You must specify a value for the parameter.
- A vertical bar (**|**) separates multiple parameter choices for a given command string.
- Square brackets (**[ ]**) enclose some syntax elements - nodes and parameters for example. This indicates that the element is optional and can be omitted. The brackets are not sent with the command string. Any keyword enclosed in brackets is optional and can be omitted. However, if you are combining several commands within the same message string, you must include the optional commands to place the command parser at the correct level in the hierarchy.

Parameter Types

The SCPI language defines several data formats to be used in commands and queries.

Parameters

SCPI parameters appear with a short name in angle brackets i.e. <*parameter*>. The angle brackets and the name itself are to be substituted with a numeric or enumeration parameter, and are never actually sent in a SCPI command. By convention, many SCPI commands accept 0 to specify ‘all’ valid channels or cells (see Channel ID and Cell ID). If the <cell_id> parameter is omitted, a 0 will be passed in.

Channel ID

NOTE

IMPORTANT You cannot program Keysight BT2205A models using channel IDs. Use CELL:DEFine to assign the channels in a BT2205A module to a cell ID.

The channel Id refers to a 3-digit channel identifier. Channel ID's are encoded as SCC. That is a 1-digit slot number followed by a 2-digit channel number. For example 101 refers to slot 1 channel 1. A slot number with a 00 channel number (ex: 200) will accept 00 to mean all channels in a slot. Note that a channel Id of 0 (zero) addresses ALL channels in the CDS.

A channel list <chan_list> is required to address one or more specific cell channels. Each slot contains 32 channels; therefore, cell channels in any slot are always numbered from 1 to 32. It has the following syntax for the range of the first 16 channels in slot 1:

```
(@101,102,103,104,105,106,107,108,109,110,111,112,113,114,115,116)
or
(@101:116)
```

You can specify any combination of channels in a slot, provided the channels are in ascending order:

```
(@101:108,110,112,114,116,118,120:132)
```

To program channels in multiple slots, simply identify the slot using the first digit of the channel identifier. The following examples address all of the cells in a mainframe with 8 slots:

```
(@101:132,201:232,301:332,401:432,501:532,601:632,701:732,801:832)
or (@0)
```

The channel list, shown as <chan_list> throughout this document, must be preceded with the @ symbol and must be enclosed in parentheses (). Query results are channel list order-sensitive. Results are returned in the order they are specified in the list.

When adding a channel list parameter to a query, you must include a space character between the query indicator (?) and the channel list parameter. Otherwise error –103, Invalid separator will occur.

Cell ID

The cell ID is similar to the channel ID except it refers to a group of channels that are paralleled together using the CELL:DEFine command. The cell Id is a number from 1000 to 8032 inclusive.

A cell list <cell_list> is required to address one or more defined cells. This is similar to the <chan_list> except that it refers to the paralleled cell groups. The following examples are equivalent, assuming that only four cell groups have been defined:

```
(@1001,1002,1003,1004)
or
(@1001:1004)
```

In the range form, the <cell_list> must be increasing. Also, only defined and valid cell ID's will be included in the command. For example if cell ID 2001 wasn't defined, the comma-separated form would report an error that 2001 is not defined, whereas the range form of the command would skip over the undefined cell ID. Note that a cell Id of 0 (zero) addresses ALL defined cells in the CDS.

The following examples address all of the defined cells in a mainframe with 8 slots - provided that each channel has been defined as a cell:

```
(@1001:1256)
or (@0)
```

The following example addresses eight paralleled channels across four BT2205A models located in mainframe slots 1 through 4. These paralleled modules are connected to a single cell, and can provide up to 800 A maximum current to the connected cell. This assumes that each of the eight channels in a mainframe have been assigned to a channel ID for that mainframe. For example, the eight channels in the mainframe located in slot 1 through 4 (channels 11, 12, 21, 22, 31, 32, 41, and 42) would need to be assigned to cell ID 1001. Refer to Defining Channel Addresses and Cells for BT2205A for a description of the allowable cell ID's for up to eight BT2205A modules in a mainframe.

```
(@1001)
```

More Cell ID and Channel ID Examples

Note that gaps in the range of cell lists are allowed; however, the two endpoints of the cell range must reference actual defined locations. This also applies to channels. Here are some examples to illustrate the concept.

The following set defines four cells located in two different card slots named 1001,1004, 2001 and 2002 with channels defined for each cell. The cells in slot 1 have a gap.

```
CELL:DEFine 1001,(@101);DEFine 1004,(@116:120);DEFine 2001,
(@121:122);DEFine 2002,(@123)
```

To return the voltage of a single cell:

```
MEASure:CELL:VOLTage? (@1001)
```

To return the voltage for all four cells (all you need are the endpoints separated by a colon):

```
MEASure:CELL:VOLTage? (@1001:2002)
```

To return the voltage for the two cells that are separated by the cell 1004:

```
MEASure:CELL:VOLTage? (@1002:2001)
```

The following commands generate error messages because they include cell ID's that have not been defined or are outside the endpoints of the cells (cell ID's 1002 and 2003 are invalid):

```
MEASure:CELL:VOLTage? (@1002:1004)
MEASure:CELL:VOLTage? (@1001:2003)
```

The following commands are channel list examples. Note that channel queries function independently of defined cells. They will return values from any channel in the CDS regardless if it has been or has not been defined as part of a cell.

To return the voltage for all channels on cards slots 1 and 2:

```
MEASure:VOLTage? (@101:232)
```

To return the voltage for the first 16 channels on card slots 1 and 2:

```
MEASure:VOLTage? (@101:116,201:216)
```

To return the voltage on channels 101 and 117 on card slot 1, and all channels on card slot 2:

```
MEASure:VOLTage? ((@101,117,201:232)
```

The following commands generate error messages because they include illegal channel parameters, or are outside the channel range on a card slot:

```
MEASure:VOLTage? (@1002:1004)
MEASure:VOLTage? (@101:133)
```

Numeric Parameters

Commands that require numeric parameters will accept all commonly used decimal representations of numbers including optional signs, decimal points, and scientific notation. If a command accepts only certain specific values, the instrument will automatically round the input numeric parameters to the accepted values. The following command requires a numeric parameter to enable bits 0 through 3 in the Standard Operation Register (1+2+4+8=15):

```
STATus:OPERation:ENABle 15
```

Note that special values for numeric parameters such as MINimum, MAXimum, and INFinity are also accepted. Instead of selecting a specific value for the voltage parameter, you can substitute MIN to set the voltage to its minimum allowable value, MAX to set it to its maximum allowable value.

You can also send engineering unit suffixes with numeric parameters (e.g., V for volts, A for amperes, W for Watts). All parameters values are in base units.

Boolean Parameters

Boolean parameters represent a single binary condition that is either true or false. For a false condition, the instrument will accept "OFF" or "0". For a true condition, the instrument will accept "ON" or "1". When you query a Boolean setting, the instrument will always return "0" or "1". The following command requires a Boolean parameter:

```
SYSTem:COMMunicate:LAN:DHCP OFF|0|ON|1
```

ASCII String Parameters

String parameters can contain virtually any set of ASCII characters. A string must begin and end with matching quotes; either with a single quote or a double quote. You can include the quote delimiter as part of the string by typing it twice without any characters in between. The following command uses a string parameter:

```
SYSTem:COMMunicate:LAN:DNS "198.105.232.4"
```

Device Clear

Device Clear is an IEEE-488 low-level bus message that you can use to return the instrument to a responsive state. Different programming languages and IEEE-488 interface cards provide access to this capability through their own unique commands. The status registers, the error queue, and all configuration states are left unchanged when a Device Clear message is received. Device Clear performs the following actions:

- If a sequence or any background calibration is in progress, it is aborted.
- The instrument's input and output buffers are cleared.
- The instrument is prepared to accept a new command string.

NOTE The ABORt command is the recommended way to terminate an instrument operation.

Programming Samples

Defining and Starting a Sequence

The process for starting a sequence is to setup the cells, setup the sequence steps and tests, assign the sequence to cells, and command the cell to start sequencing. All cells run independently from each other, and can be in different steps of the same sequence. Multiple cell's can share the same sequence. However, a cell can have only one sequence assigned to it at a time.

The SCPI code below shows the steps needed to parallel channels, define a small sequence, assign the channels to the sequence, and to start the sequence.

```
# Clear any initial setups
CELL:ABOR 0
CELL:CLE 0
SEQ:CLE 0
# Define parallel cells of 4 channels
CELL:DEF 1001,(@101:104)
CELL:DEF 2001,(@201:204)
# Define seq 1 as a small example sequence (no sequence tests)
SEQ:STEP:DEF 1,1,CHARGE, 600,24,4.2
# Insert any tests for step 1 here
SEQ:STEP:DEF 1,2,REST, 600
SEQ:STEP:DEF 1,3,DISCHARGE,600,24,3.0
# Insert any tests for step 3 here
SEQ:STEP:DEF 1,4,REST, 600
# Assign the cells to run sequence no. 1
CELL:ENAB (@1001,2001),1
# Start the sequence on both cells defined above
CELL:INIT (@1001,2001)
```

Querying the State of a Cell

Once a cell is running a sequence, use CELL:STEP:TIME? to query the present step number and the time elapsed into the step. Use CELL:TIME? to query the total time elapsed into the sequence. Use STATus:CELL:VERBose? to return a more complete state of the cell. This returns whether the cell is idle or running a sequence, the sequence ID and step ID, the voltage and current measurement, and the status of the step (ok, fail, or abort). If a test fails, it returns the test ID of the failure, the time of the failure from the start of the step, the test type, the expected test limit, and the measured test limit.

```
# Query the sequence elapsed time and step time elapsed in the step
CELL:TIME? 1001
# Query result:
<600
CELL:STEP:TIME? 1001
# Query result:
<3,100
# Query the status of the cell
# Returns IDLE|RUNNING,<seq>,<step>,<Vsense>,<Imon>,
# NONE|OK|FAIL|ABORTED,
# <testId>,<testType>,<expected limit>,<measured limit>
STAT:CELL:VERBose? 1001
# Query result:
<RUNNING,1,3, 3.30151200E+00, 1.95000000E-01, OK, 0, NONE,
0.00000000E+00, 0.00000000E+00
# Query the result of a completed step
# Returns <step completion time>,<Vsense>,<Imon>,<step completion status>
# <testId>,<testType>,<expected limit>,<measured limit>
STAT:CELL:STEP? 1,1001
# Query result:
<500,3.99999999E+00,1.99999999E-02,NEXT,2,CURR_LE,2.00000000E-02,
1.99999999E-02
```

Stopping/Aborting a Sequence

Because things can go wrong during a test sequence, it may be necessary to stop the sequence to debug or fix a problem like a damaged fixture. Send the Abort command to stop a sequence. When a sequence is aborted, the power connections open into a high impedance state.

```
ABORt
```

If the host computer is located in another building in a distributed factory environment, stopping the sequence from a program may not be practical. The Inhibit input pin on the digital IO connector can be used to immediately stop a test. Again, the power and sense connections open into a high impedance state. This will safely stop the test without losing test data or the test configuration. Refer to Using the Digital Port for more information.

You can also configure specific pins on the digital connector to abort a test on specific cells only. The SCPI code below shows the steps needed to configure one digital pin to provide the output signal to stop a test, ad another digital pin as the cell-abort input for the specified cells. In this example, digital pins 4 and 5 are connected together.

```
# Clear any initial setups
CELL:ABOR 0
CELL:CLE 0
SEQ:CLE 0
# Define a cell of 4 channels that will be connected to the abort pin
CELL:DEF 1001,(@101:104)
# Define pin 4 as the output for the cell abort signal
```

```
DIG:FUNC 4,DIO
# Define pin 5 as the cell-abort input for pin 4
DIG:FUNC 5,CAB
# Set the polarities of pins 4 an 5 to positive
DIG:POL 4,POS
DIG:POL 5,POS
# Set up Cell 1001 to be aborted when pin 4 is driven high
DIG:CAB 4,(@1001)
# Assign the cell to run sequence no. 1
CELL:ENAB (@1001),1
# Start the sequence on the cell
CELL:INIT (@1001)
# Drive pin 4 high to generate a cell abort signal to pin 5
DIG:OUTP:DATA 5
# Verify that the sequence has aborted
STATus:CELL:REPort? (@1001)
<3
```

Clearing Protection Events and Errors

Protection events occur due to one of the following fault conditions:

- Hardware fault
- Watchdog timeout
- Card detection failure
- Temperature out of range
- Fan failure
- AC Input supply temperature out of range

The front panel Error light indicates that a fault has occurred. The unit latches off and cannot be operated until the fault is cleared. To clear the fault, first remove the cause of the fault, then clear the protection status. Faults are part of the Event Status Group. To query if a fault has occurred, send:

```
STATus:OPERation:EVENt?
```

The value returned indicates the type of protection event (see Standard Operation Group) The command reads and clears the fault when it is sent to the instrument. To determine if the fault still exists, send STATus:OPERation:EVENt? again. If a value other than zero is returned, the fault is still present and must be removed.

Errors occur due to a variety of command processing errors, such as failing to read back the result from a query. The unit will continue to operate with errors present. To read and clear error codes send:

```
SYSTem:ERRor?
```

Each time this command is sent, one error is removed from the Error queue. When the query returns a zero, all error have been removed from the queue.

Commands by Subsystem

IEEE-488 Common Commands

ABORt

Aborts the sequence or any background calibration that is in progress. When a sequence is aborted, the power connections open into a high impedance state.

Parameter	Typical Return
(none)	(none)
Abort the sequence in progress: ABOR	

*CAL <*channels*>
*CAL? <*channels*>

Runs channel alignment on the specified channels, but does not wait for alignment to complete. Same as CAL:AUTO. This allows for execution of other commands.

The query also runs channel alignment, but waits for channel alignment to complete. Returns a 0 (zero) when successful, and a +1 when a channel failed.

NOTE IMPORTANT Remove all connections from the CAL connector on the front panel of the CDS before performing channel alignment.

Parameter	Typical Return
<channels> 0 | XX00 | XXYY, where 0 calibrates all 256 channels; XX00 calibrates all channels in a specific slot (XX) from 01 to 08; XXYY calibrates a specific channel (YY) from 01 to 32 in the specific slot (XX)	0 | 1
Start channel alignment on all channels: *CAL 0 Start channel alignment on all channels and wait for calibration to complete: *CAL? 0	

- *CAL also resets the digital IO configuration of the instrument.

*CLS

Clear Status Command. Clears the event registers in all register groups. Also clears the Status Byte and Error Queue. If *CLS immediately follows a program message terminator (<NL>), then the Output Queue and the MAV bit are also cleared. Refer to Status Tutorial for more information.

Parameter	Typical Return
(none)	(none)
Clear Event register bits, Status byte, and Error queue: *CLS	

*ESE <*value*>
*ESE?

Event Status Enable Command and Query. Sets the value in the enable register for the Standard Operation Group. Each set bit of the register enables a corresponding event. All enabled events are logically ORed into the ESB bit of the status byte.

The query reads the enable register. Refer to Status Tutorial for more information.

Parameter	Typical Return
A decimal value that corresponds to the binary-weighted sum of the bits in the register.	<bit value>
Enable bits 3 and 4 in the enable register: *ESE 24	

- Returns the binary-weighted sum of all enabled bits in the register. For example, to enable bit 2 (value = 4) and bit 4 (value = 16), the corresponding decimal value would be 20 (4 + 16).
- Any or all conditions can be reported to the ESB bit through the enable register. To set the enable register mask, write a decimal value to the register using *ESE.
- *CLS does not clear the enable register, but does clear the event register.

*ESR?

Event Status Event Query. Reads and clears the event register for the Standard Operation Group. The event register latches all standard events. Refer to Status Tutorial for more information.

Parameter	Typical Return
(none)	<bit value>
Read event status enable register: *ESR?	

- Returns the binary-weighted sum of all enabled bits in the register.
- Any or all conditions can be reported to the ESB bit through the enable register. To set the enable register mask, write a decimal value to the register using *ESE.
- Once a bit is set, it remains set until cleared by this query or *CLS.

*IDN?

Identification Query. Returns the instrument’s identification string, which contains the following fields:

> “manufacturer, product number, serial number, firmware revision(build id) - major.minor card rev (card build id) - major.minor fpga rev - cardFpgaRev - boardId - cardBoardId - #of DigitalPins".

For example:

> Keysight Technologies,BT2203A,MY58000517,05.36(2672)-02.01(0525)-00.24-07-02-02-1590985-07

Parameter	Typical Return
(none)	<ASCII string with comma-separated fields>
Return the instrument's identification string: *IDN?	

*OPC
*OPC?

Operation Complete Command and Query. *OPC Sets the OPC (operation complete) bit in the *standard event register* when the instrument has completed all pending operations sent before *OPC. This occurs at the completion of the current operation.

The query returns a 1 to the *output buffer* when all pending operations complete. The response is delayed until updated data has been received from all connected channels.

Parameter	Typical Return
(none)	1
Return a 1 when data is returned: *OPC?	

- **The purpose of this command is to synchronize your application with the instrument.**
- **Other commands may be executed before the operation complete bit is set.**

*RST

Reset Command. Resets the instrument to pre-defined values that are either typical or safe. These settings are described under Reset Settings.

Parameter	Typical Return
(none)	(none)
Reset the instrument: *RST	

- ***RST forces the ABORt command. This cancels any measurement actions presently occurring.**
- **Allow at least 4 seconds for the *RST to complete. Set the IO timeout to >4 seconds.**

*STB?

Status byte query. Reads the Status Byte Register, which contains the status summary bits and the Output Queue MAV bit. The Status Byte is a read-only register and the bits are not cleared when it is read. Refer to Status Tutorial for more information.

Parameter	Typical Return
(none)	<bit value>
Read status byte: *STB?	

*TST?

SelfTest Query. Performs an instrument self-test. A 0 (zero) indicates the instrument passed self-test. If self-test fails, one or more error messages will provide additional information. Use **SYSTem:ERRor?** to read the error queue. See **SCPI Error Messages** for more information. Note that *TST? is more abbreviated than SYST:TEST:ALL? and takes about 70 seconds.

Parameter	Typical Return
(none)	0 or 1
Perform self-test: *TST?	

- *TST? also forces an *RST command.

*WAI

Pauses additional command processing until updated data has been received from all connected channels.

Parameter	Typical Return
(none)	(none)
Wait until all data is returned. *WAI	

- *WAI can only be aborted by sending the instrument a Device Clear command.

Calibration Commands

NOTE Read the Calibration section before calibrating. Improper calibration can reduce accuracy and reliability.

CALibration:AUTO <*channels*>
CALibration:AUTO? <*channels*>

Runs channel alignment on the specified channels, but does not wait for alignment to complete. Same as *CAL. This allows for execution of other commands.

The query also runs channel alignment, but waits for channel alignment to complete. The command returns a 0 (zero) when successful, and a +1 when a channel failed.

During channel alignment, each individual channel is sequentially connected to the internal reference and gain and offset corrections are calculated and stored in non-volatile memory.

NOTE **IMPORTANT** Remove all connections from the **CAL** connector on the front panel of the CDS before performing channel alignment.

Parameter	Typical Return
<channels> 0 | XX00 | XXYY | XY, where 0 calibrates all channels; XX00 calibrates all channels in a specific slot (XX) from 01 to 08; BT2204A/B: XXYY calibrates a specific channel (YY) from 01 to 32 in the specific slot (XX); BT2205A: XY calibrates a specific channel (Y) from 1 to 2 in the specific slot (X) from 1 to 8	0 | 1
Start channel alignment on all channels: CAL:AUTO 0 Start channel alignment on all channels and wait for alignment to complete: CAL:AUTO? 0	

- **CAL:AUTO also resets the digital IO configuration of the instrument.**

CALibration:AUTO:STATus? <*error*>, <*run state*>, <*status*>, <*% complete*>, <*module*>, <*channel*>, <*elapsed*>

Returns the completion status of channel alignment after CAL:AUTO is programmed. The query returns the defined values.

<error> - returns +0 if no errors; +! if an error occurred.

<run state> - returns the following run states: IDLE or RUNNING.

<status> - returns the status: NONE, OK, FAILED, or ABORTED. NONE means that no status is returned (i.e. the run state is IDLE). OK means that channel alignment is complete (i.e. the run state is IDLE).

<% complete> - returns the percent of channel alignment that has completed.

<module> - returns the module that is running channel alignment.

<channel> – returns the channel that is running channel alignment.

<elapsed> – returns the time in seconds of channel alignment that has elapsed since the start

Parameter		Typical Return
<error> +0 or +1 <run state> IDLE or RUNNING <status> NONE, OK, FAILED, or ABORTED <% complete> 0 - 100%	<module> 1-8 <channel> 1 - 32 <elapsed> time in seconds	+0,RUNNING,OK,100%, Module 1,Channel 1, 30s
Defines step number 1 in sequence 1: SEQ:STEP:DEF 1, 1, CHARGE, 60, 20, 4.0		

CALibration:STARt

Initiates the calibration procedure.

Parameter	Typical Return
(none)	(none)
Start calibration: CAL:STAR	

CALibration:STEP <*step*>

Steps through the different calibration processes; executes a reset after the command is sent. The query returns 0 (zero) if no step is sent.

Step	Calibrating:	Step	Calibrating:
1	1 V value	4	4 A value
2	4 V value	5	-1 A value
3	1 A value	6	-4 A value

Parameter	Typical Return
<step> number from 1- 6	1-6
Execute calibration step 1: CAL:STEP 1	

CALibration:STORe

Calculates and stores the calibration constants in the EEPROM if they are within reasonable limits. This step overwrites the previous calibration constants.

Parameter	Typical Return
(none)	(none)
Store the calibration constants: CAL:STOR	

CALibration:STRing <target>, <"*string*">, 1| 2
CALibration:STRing? <target> ,1|2

Stores a message in calibration memory. Common messages include the last calibration date, calibration due date, or calibration contact information. You can save calibrations strings for the mainframe as well as the charge/discharge modules. An index value, which is required for the charge/discharge modules, lets you save up to two string per target.

Parameter	Typical Return
<target> 0 for mainframe, or 1 - 8 for modules	none
<"string"> a quoted string of up to 128 characters	"Calibrated on 4/2018"
1|2 the index value for saving up to two strings (this is only optional if the target = 0)	none
To store one cal string for module 1: `CAL:STR 1,"Calibrated on 4/2018.", 1` To store a second cal string for module 1: `CAL:STR 1,"Next calibration due 4/2021.", 2`	

CALibration:VALue? <*step*>, <*value*>

Sends the valid calibration measurement to the instrument. Values are either in volts or amps depending on the step. The command returns a 0 (zero) when successful, and a +1 otherwise.

Parameter	Typical Return
<step> number from 1- 6 <value> the measured value in volts or amps	0 | 1
Send the calibration measurement for step 1: `CAL:VAL? 1, 1.04`	

Cell Commands

Cell commands program a group of channels that have been paralleled together using the CELL:DEFine command. Use the <cell_ID> or <cell_list> parameter to send commands to multiple cells. Refer to Cell ID for more information.

CELL:ABORt (@<cell_list>)

Aborts specific cells that may be running a sequence. After this command the cell connections open into a high impedance state, and the sequence moves to the rest state. The parameter specifies which cells to abort. If the parameter is omitted (or 0), all running cells will abort. This is the same as ABORt.

Parameter	Typical Return
<cell_list> cells to abort	(none)
Aborts all cells: CELL:ABOR	

CELL:CLEar (@<cell_list>)

Ungroups a paralleled cell into its constituent channels. If the parameter is omitted (or 0), all paralleled cells will ungroup.

Parameter	Typical Return
<cell_list> cells to ungroup	(none)
Ungroups the channels associated with cell ID 2000: CELL:CLE (@2000)	

- Clearing a cell that is currently running a sequence will abort the sequence, then clear the cell.

CELL:DEFine <cell_id>, (@<chan_list>)
CELL:DEFine? <cell_id>

Defines a paralleled group of channels into a cell. The <cell_id> assigned using this command can be used in other SCPI commands that accept a <cell_list> parameter to send commands to the cell.

Parameter	Typical Return
<cell_id> from 1000 to 8032 The leading number usually identifies the slot <chan_list> the paralleled channels assigned to this cell	201, 202, 203, 204 (for 4 channels)
Defines cell ID 2001 in slot 2 with four channels: CELL:DEF 2001, (@201,202,203,204)	

- Specifying a cell that is already defined is prohibited, and will return an error.
- Specifying a channel that is already in a cell is prohibited and will return an error.
- For the BT2205A, refer to CELL:DEFine:QUICk for the allowable channels (in parentheses) that can be defined for each Cell ID listed.

CELL:DEFine:QUICk <cell_size>

Automatically defines cells of size <cell_size> across all charge-discharge modules. This parallels multiple channels to match the desired current rating of a cell. This is useful only if ALL batteries connected to the CDS are of the same type, having the same maximum current limit.

As cell charge-discharge sequences can only be run on cells, not channels, this command provides a quick way to define cells of a certain size without sending many CELL:DEFine commands. Cells are defined for all modules installed in the mainframe.

- Each cell ID is assigned based on the module (slot) to which it is connected, keyed off of the first channel in the cell.
- If the <cell_size> does not divide evenly into 32 channels on a module, the leftover channels will not be included in a cell.
- Examples of cells (paralleled channels) are as follows:

Channels per cell <cell_size>	Amperes per cell	Cells per module	Cells allowed per mainframe (with 8 modules)	Cell IDs assigned per module using module 1 as an example. The 4-digit number identifies the module or slot location. For the BT2205A, the numbers in parentheses identify the slot and channel assigned to the 4-digit Cell ID (i.e. module#/channel#).
1	6.25	32	256	1001 to 1032
4	25	8	64	1001, 1005, 1009, 1013, 1017, 1021, 1025, 1029
8	50	4	32	1001, 1009, 1017, 1025
14	87.5	2	16	1001, 1015 (four channels are unused)
30	187.5	1	8	1001 (two channels are unused)
Keysight BT2205A power modules				
1	up to 100	2	16	1001(11), 1002(12), 2001(21), 2002(22),3001(31), 3002(32), 4001(41), 4002(42), 5001(51), 5002(52), 6001(61), 6002(62), 7001(71), 7002(72), 8001(81), 8002(82)
2	up to 200	1	8	1001(11,12), 2001(21,22), 3001(31,32), 4001(41,42), 5001(51,52), 6001(61,62), 7001(71,72), 8001(81,82)
3	up to 300	N/A	4	1001(11,12,21), 3001(31,32,41), 5001(51,52,61), 7001(71,72,81)
4	up to 400	N/A	4	1001(11,12,21,22), 3001(31,32,41,42), 5001(51,52,61,62), 7001(71,72,81,82)
5	up to 500	N/A	2	1001(11,12,21,22,31), 5001(51,52,61,62,71)
6	up to 600	N/A	2	1001(11,12,21,22,31,32), 5001(51,52,61,62,71,72)
7	up to 700	N/A	2	1001(11,12,21,22,31,32,41), 5001(51,52,61,62,71,72,81)
8	up to 800	N/A	2	1001(11,12,21,22,31,32,41,42), 5001(51,52,61,62,71,72,81,82)

Parameter	Typical Return
<cell_size> from 1 to 30 (1 to 8 for BT 2205A)	(none)
Defines cells consisting of eight paralleled channels each: `CELL:DEF:QUIC 8`	

CELL:ENABle (@<cell_list>), <seq_id>
CELL:ENABle? (@<cell_list>)

Assigns a sequence to a cell list, enabling it to participate in a sequence. The first parameter specifies which cells are being enabled. The second <seq_id> parameter specifies which sequence to assign to the cells. If the <seq_id> parameter is from 1 to 8, it is assigning a sequence to the cell. If the parameter is 0, then the cell list is removed from the sequence.

Parameter	Typical Return
<cell_list> the cells assigned to the sequence <seq_id> 0-8	2001, 2002, 2003, 2004 (for 4 cells)
Assigns four cells to a sequence with ID=8: CELL:ENAB (@2001:2004), 8	

- Modifying a cell that is currently running a sequence is prohibited, and will return an error.

CELL:FSETtle 0|OFF|1|ON
CELL:FSETtle?

CELL:FSEtle (fast settle) decreases the turn-on time of charge and discharge steps to be the same as that of the precharge step. The turn-on time for all steps is reduced from 15 seconds to 5 seconds. This global setting applies to all cells and applies to both charge and discharge steps.

Parameter	Typical Return
0|OFF|1|ON, default OFF	0 or 1
To enable fast settling time for all cells: CELL:FSET ON	

- Use this command in conjunction with CELL:TRANsient IMM to provide the best performance.
- No sequence can already be running on any cells when this command is executed.

CELL:INITiate (@<cell_list>)

Initiates the specified cells to start their sequence. All cells listed or included in the cell list must be valid cells and must have been assigned a valid sequence.

Parameter	Typical Return
<cell_list> cells to initiate	(none)
Initiate cells 2001 to 2004: CELL:INIT (@2001:2004)	

- No sequence can already be running on any of the specified cells when this command is executed.
- For a Precharge step, CELL:INIT enforces a cell current limit of ≤ (#ofParalleledChannels * 1A).

CELL:PAUSe (@<cell_list>)

Pauses a cell's execution in a sequence and disconnects the cell (or cells) from the channel output. The designated cell enters a rest state where no current is flowing in the channel. This is a safety procedure intended to pause the sequence. For example - if a door to a cell forming station is accidentally opened. This command is not intended to be used during normal sequence operation.

Parameter	Typical Return
<cell_list> cells to pause	(none)
Pauses cells 2001 to 2004: CELL:PAUSE (@2001:2004)	

CELL:RESume (@<cell_list>)

Resumes the paused cell's execution in a sequence. The cell (or cells) is reconnected to the channel output and resumes it's programmed state.

Parameter	Typical Return
<cell_list> cells to resume	(none)
Resumes cells 2001 to 2004: CELL:RESume (@2001:2004)	

CELL:STEP:NEXT (@<cell_list>)

Forces the cell to advance to the next step. If it is on the last step of the sequence, then the sequence ends.

Parameter	Typical Return
<cell_list> cells to advance	(none)
Advances cells 2001 to 2004 to the next step: CELL:STEP:NEXT (@2001:2004)	

CELL:STEP:TIME? (@<cell_list>)

Returns the step number and the time elapsed in seconds in the current step for the specified cells.

Parameter	Typical Return
<cell_list> cells to query	2, 8.0000, 2, 8.0000, 2, 8.0000, 2, 8.0000
Returns the step time for cells 2001 to 2004: CELL:STEP:TIME? (@2001:2004)	

CELL:TIME? (@<cell_list>)

Returns the time that the sequence has been running on the specified cells in seconds. The time is returned regardless of whether the indicated cells are running the same or different sequences.

Parameter	Typical Return
<cell_list> cells to query	18, 12, 20, 31 (for 4 cells)
Returns the sequence time for cells 2001 to 2004: CELL:TIME? (@2001:2004)	

CELL:TRANsition[:MODE] IMMediate|RESTart
CELL:TRANsition[:MODE]?

Allows for seamless transitions **between** precharge-to-charge steps, charge- to-charge steps, or discharge-to-discharge steps. This eliminates the set-up procedure for the second step, which can take up to 15 seconds. This bypasses setup checks which have already passed (like voltage matching, cell reversal, current limit, etc).

Note that immediate transitions between charge to discharge steps, or discharge-to-charge steps, are not supported and will require a starting waveform in between the two steps.

IMMediate - enables seamless transitions between steps.
RESTart - allows the step setup procedure to restart each step.

Parameter	Typical Return
IMMediate|RESTart *RST RESTart	RESTart
Initiate immediate transition for all cells: CELL:TRAN IMM	

- Use this command in conjunction with CELL:FSETtle ON to provide the best performance.
- No sequence can already be running on any of the specified cells when this command is executed.

Datalog Commands

Datalog commands facilitate getting uninterrupted data out of the BT2200 Series Charge-Discharge System. Data returned includes voltage, current, cell ID, and sequence state for all 256 channels. Data is collected every second and stored in a 60-second internal FIFO buffer. Therefore the data must be read out every 60 seconds or the buffer overflows with the oldest records being discarded.

DATA:LOG[:CHANnel][:READ]?

Returns up to 4 records from datalog buffer. The maximum number of records in the buffer is 60. If no records are available then the query returns #14<0000>.

As there are up to 60 records available, up to 15 queries are needed to return all 60 records. It is recommended to allow for some time (about 15 seconds) before the completion of the 60 second buffer, to allow the 15 queries to complete fetching all 60 data records before the buffer overflows.

Parameter	Typical Return
(none)	<Binary Block Format>
Return up to 4 records from datalog buffer: DATA:LOG?	

Binary Block Format Examples

Data type	Description
1 32-bit integer	This is the number of records of binary data. The value will be between 0 and 4 inclusive.
Subsequently, for each record in the binary block, the following is returned:	
1 64-bit unsigned integer	This is a time-stamp of the number of milliseconds since boot-up
256* 32-bit float	IMon. Returns current information for every channel.
256* 32-bit float	VSense. Returns Voltage Sense information for every channel.
256* 32-bit float	VLocal. Returns Voltage Local information for every channel.
256* 32-bit float	DCIR1. Returns DCIR1 information for every channel.
256* 32-bit float	DCIR2. Returns DCIR2 information for every channel.
256* uint16	Cell ID values. Returns what cell ID is loaded for every channel.
256* int16	Sequence step values. Returns what sequence step a channel is running. Positive sequence steps indicate that channel is running and is executing that step number. If a sequence step is not running, the query returns values less than or equal to 0, to indicate the sequence stopped state as described as follows:

0	Idle. The channel is idle. A state has not been run on the channel
-2	Done. The channel has completed a forming sequence successfully.
-4	Aborting. The channel is in the process of aborting a sequence.
-5	Aborted. The channel has aborted a sequence.
-6	Chan Exit. The sequence is currently exiting under an error condition such as probe failure or limit failure.
-7	HW Fail. There was a hardware failure on the module running a sequence

*A value of 0 identifies channel 1 of the module in slot 1; a value of 255 identifies channel 32 of the module in slot 8.

Example 1 – returns no record of data

```
#14«x00»«x00»«x00»«x00»<NL>
```

is start of the block.
1 indicates the number of digits in the block size that follows.
4 indicates the number of bytes in the block.
«x00»«x00»«x00»«x00» is the 4-byte integer data in the block that represents a 32 byte integer showing zero records of data in the block.

Example 2 – returns one record of data

```
#46156«x01»«x00»«x00»«x00» <Binary Data for Record 1><NL>
```

is the start of the block.
4 indicates the number of digits in the block size that follows.
6156 indicates the number of bytes in the block.
«x01»«x00»«x00»«x00» is the 4-byte 32-bit integer in Little Endian format that represents 1 record.
<Binary Data For Record 1> contains 1 record of data described in rows 3 – 10 in the previous table.

Example 3 – returns four records of data

```
#524612«x04»«x00»«x00»«x00»<Binary Data For Record 1><Binary Data For
Record 2><Binary Data For Record 3><Binary Data For Record 4><NL>
```

is the start of the block.
5 indicates the number of digits in the block size that follows.
24612 indicates the number of bytes in the block.
«x07»«x00»«x00»«x00» is the 4-byte 32-bit integer in Little Endian format that represents 7 records.
<Binary Data For Record 1> ... <Binary Data For Record 7> are the 7 records of data that map to rows 3 – 10 in the previous table.

DATA:LOG[:CHANnel]:CLEar

Clears all data from the datalog buffer and also clears the number of records that have been missed.

Parameter	Typical Return
(none)	(none)
Clears the datalog buffer: DATA:LOG:CLE	

DATA:LOG[:CHANnel]:RECords[:AVAIlable]?

Returns the number of records available in the buffer. This query returns a number between 0 and 60.

Parameter	Typical Return
(none)	0 - 60
Returns the number of available records: DATA:LOG:REC?	

DATA:LOG[:CHANnel]:RECords:MISsed?

Returns the number of data records that did not get read out of the buffer and are no longer available. This applies since turn-on, the last *RST, or the last DATA:LOG:CHANnel:CLEar command.

Parameter	Typical Return
(none)	0 - 60
Returns the number of missed records: DATA:LOG:REC:MIS?	

Digital Commands

Digital commands program the digital control ports on the rear panel of the instrument.

For Keysight BT2202A and BT2203B, the digital commands program the 23 digital IO pins located on both the 8-pin and the 25-pin digital connectors.

For Keysight BT2203A, the digital commands program the 7 digital IO pins located on the 8-pin digital connector.

DIGital:CABort <pin>, (@<cell_list>)
DIGital:CABort? <pin>

Assigns a cell-abort list to a digital IO pin. Whenever the digital pin receives an abort signal (logic true), the sequences running on the cells assigned to that pin will be aborted. The signal logic is set by the DIGital:POLarity command.When a sequence is aborted, the power connections open into a high impedance state. If a CELL:INIT is executed while a pin is in the Abort state, none of the cells assigned to that digital pin will be initiated.

Parameter	Typical Return
<pin> a pin number from 1-23 (BT2202A/BT2203B) <pin> a pin number from 1-7 (BT2203A)	<the pin number>
<cell_list> cells to abort	(none)
Sets pin 1 to CABort mode for cells 1001-1004: DIG:CAB 1, (@1001:1004)	

DIGital:CHANs?

Returns the number of digital IO pins available in the mainframe.

Parameter	Typical Return
(none)	7 | 23
Returns the number of digital pins: DIG:CHAN?	

DIGital:FUNCtion <pin>, <*function*>
DIGital:FUNCtion? <pin>

Specifies the pin function.
CABort - Cell abort mode - applies to all pins
DIO - Digital input/output mode - applies to all pins
DINPut - Digital input-only mode - applies to all pins
FAULt - Pin 1 functions as an isolated fault output; pin 2 is common for pin 1
INHibit - Pin 3 functions as an inhibit input

Parameter	Typical Return
<pin> a pin number from 1-23 (BT2202A/BT2203B) <pin> a pin number from 1-7 (BT2203A)	<the pin number>
DIO | DINPut | FAULt | INHibit, *RST DINPut	CAB, DIO, DINP, FAUL, INH
Sets pin 1 to FAULt mode: DIG:FUNC 1, FAUL	

DIGital:INPut:DATA?

Reads the state of the digital control port. For the BT2202A/BT2203B, it returns the binary-weighted value of the state of pins 1 through 23 in bits 0 through 22 respectively. For BT2203A, returns the binary-weighted value of the state of pins 1 through 7 in bits 0 through 6 respectively.

Parameter	Typical Return
(none)	<bit value>
Reads the state of the digital control port: DIG:INP:DATA?	

DIGital:OUTPut:DATA <*value*>
DIGital:OUTPut:DATA?

Sets the state of the digital control port. This only affects the pins whose function has been set to Digital IO operation. For the BT2202A/BT2203B the ports have 23 signal pins and up to 8 common (ground) pins. For the BT2203A, the ports have seven signal pins and one common (ground) pin. In the binary-weighted value that is written to the port, the pins are controlled according to the following bit assignments:

Pin	1	2	3	4	5	6	7	8	9	10	11	12	13
Bit number BT2202A/BT2203B	0	1	2	3	4	5	6	7	8	9	10	11	12
Bit number BT2203A	0	1	2	3	4	5	6						
Decimal value	1	2	4	8	16	32	64	128	256	512	1024	2048	4096

Pin	14	15	16	17	18	19	20	21	22	23
Bit number BT2202A/BT2203B	13	14	15	16	17	18	19	20	21	22
Decimal value	8192	16384	32768	65536	131072	262144	524288	1048576	2097152	4194,304

Bit values corresponding to digital port pins that are not configured as DIO are ignored.

Parameter	Typical Return
0 – 4,194,304, *RST 0	<bit value>
Programs pins 1, 3, and 15 on: DIG:OUTP:DATA 16389	

DIGital:POLarity <pin>, POSitive|NEGative
DIGital:POLarity? <pin>

Sets the pin polarity. **POSitive** means a logical true signal is a voltage high at the pin. **NEGative** means a logical true signal is a voltage low at the pin.

Parameter	Typical Return
<pin> a pin number from 1-23 (BT2202A/BT2203B) <pin> a pin number from 1-7 (BT2203A)	<the pin number>
POSitive|NEGative, *RST POSitive	POS or NEG
Sets pin 1 to POSitive polarity: DIG:POL 1, POS	

DIGital:PIN<1-7>:FUNCtion <*function*>
DIGital:PIN<1-7>:FUNCtion?

NOTE This command is for backward compatibility. It only applies to Keysight BT2203A.

Sets the pin function.
DIO - Digital input/output mode
DINPut - Digital input-only mode
FAULt - Pin 1 functions as an isolated fault output; pin 2 is common for pin 1
INHibit - Pin 3 functions as an inhibit input

Parameter	Typical Return
DIO | DINPut | FAULt | INHibit, *RST DINPut	DIO, DINP, FAUL, INH
Sets pin 1 to FAULt mode: DIG:PIN1:FUNC FAUL	

DIGital:PIN<1-7>:POLarity POSitive|NEGative
DIGital:PIN<1-7>:POLarity?

NOTE This command is for backward compatibility. It only applies to Keysight BT2203A.

Sets the pin polarity. **POSitive** means a logical true signal is a voltage high at the pin. **NEGative** means a logical true signal is a voltage low at the pin.

Parameter	Typical Return
POSitive|NEGative, *RST POSitive	POS or NEG
Sets pin 1 to POSitive polarity: DIG:PIN1:POL POS	

LXI Commands

LXI commands program the LXI functions of the instrument.

LXI:IDENtify:STATe 0|OFF|1|ON
LXI:IDENtify:STATe?

Turns the front panel LXI identify indicator on or off. When turned on, the "LAN" status indicator on the front panel blinks on and off to identify the instrument that is being addressed.

Parameter	Typical Return
0|OFF|1|ON	0 or 1
To blink the front panel LXI indicator: LXI:IDEN:STAT ON	

LXI:MDNS:ENABle 0|OFF|1|ON
LXI:MDNS:ENABle?

Enables or disables the multicast Domain Name System (mDNS),which provides the capabilities of a DNS server for service discovery in a small network without a DNS server. This setting is non-volatile.

Parameter	Typical Return
0|OFF|1|ON , default ON	0 or 1
To disable mDNS: LXI:MDNS:ENAB OFF	

LXI:MDNS:HNAMe:RESolved?

Returns the resolved (unique) mDNS hostname in the form K-<model number>-<serial>, where <serial> is the last 5 digits of the instrument's serial number.

Parameter	Typical Return
(none)	"K-BT2202A-12345"
To return the resolved mDNS hostname: LXI:MDNS:HNAM:RES?	

LXI:MDNS:SNAMe:DESired <"*name*">
LXI:MDNS:SNAMe:DESired?

Sets the desired mDNS service name. Enter any ASCII string up to 63 characters. This setting is non-volatile.

Parameter	Typical Return
<"name"> a quoted string of up to 63 characters.	<service name>
To set a service name: LXI:MDNS:SNAMe:DESired "BT2202A-system"	

LXI:MDNS:SNAMe:RESolved?

The resolved mDNS service name will be the desired service name.

Parameter	Typical Return
(none)	"BT2202A-system"
To return the resolved service name: LXI:MDNS:SNAM:RES?	

LXI:RESet

Resets all network settings to their factory settings. Refer to Reset Settings.

Parameter	Typical Return
(none)	(none)
Resets the network settings: :LXI:RES	

- **Depending on your network, the LAN interface may take several seconds to restart after this command is sent.**

LXI:RESTart

Resets the LAN to the settings specified by the SYSTem:COMMunicate:LAN commands.

Parameter	Typical Return
(none)	(none)
Resets the LAN settings: LXI:REST	

- **Depending on your network, the LAN interface may take several seconds to restart after this command is sent.**

Measure Commands

Measure commands return measurements from the specified channel or cell. Refer to What is the Difference Between Channels and Cells? for more information.

MEASure:CAPacity:AHR? (@<chan_list>)
MEASure:CELL:CAPacity:AHR? (@<cell_list>)

Returns the accumulated ampere-hour capacity of the specified channels (or cells).

Parameter	Typical Return
<chan_list> or <cell_list>	<comma-separated AHR values>
Returns the ampere-hour capacity of a channel list MEAS:CAP:AHR? (@201,202,203,204) Returns the ampere-hour capacity of a cell list MEAS:CELL:CAP:AHR? (@2001:2004)	

MEASure:CAPacity:WHR? (@<chan_list>)
MEASure:CELL:CAPacity:WHR? (@<cell_list>)

Returns the accumulated watt-hour capacity of the specified channels (or cells).

Parameter	Typical Return
<chan_list> or <cell_list>	<comma-separated WHR values>
Returns the watt-hour capacity of a channel list MEAS:CAP:WHR? (@201,202,203,204) Returns the watt-hour capacity of a cell list MEAS:CELL:CAP:WHR? (@2001:2004)	

MEASure:CELL:DCIR? (@<cell_list>)

Returns the measured DCIR of the specified cell in ohms as well as the voltage and current measurements from which the resistance was calculated. The start (1) and ending (2) voltage and current values of the DCIR pulse are returned. The calculation is as follows:

DCIR = (V2-V1)/(I2-I1)

Values are returned in the following commas separated order: V1, I1, V2, I2, DCIR. When a double pulse is defined for the cell being queried (depending on the DCIR step definition), then the values of the second pulse are appended to the values of the first pulse.

Parameter	Typical Return
<cell_list> cells to measure DCIR	From one pulse: 3.4995,0.0000,3.5861,6.2267,0.0139 From two pulses: 3.4995,0.0000,3.4119,-6.2960,0.0139,3.4995,0.0000,3.5861,6.2267,0.0139
Returns the resistance values of a pulse applied to a cell MEAS:CELL:DCIR? (@1001 A total of ten resistance values will be returned for two pulsed defined for a cell MEAS:CELL:DCIR? (@1002)	

MEASure:CURRent? (@<chan_list>)
MEASure:CELL:CURRent? (@<cell_list>)

Returns the measured current of the specified channels (or cells) in amperes.

Parameter	Typical Return
<chan_list> or <cell_list>	<comma-separated current values>
Returns the measured current of a channel list MEAS:CURR? (@201,202,203,204) Returns the measured current of a cell list MEAS:CELL:CURR? (@2001:2004)	

MEASure:POWer? (@<chan_list>)
MEASure:CELL:POWer? (@<cell_list>)

Returns the measured power of the specified channels (or cells) in Watts.

Parameter	Typical Return
<chan_list> or <cell_list>	<comma-separated power values>
Returns the measured power of a channel list MEAS:POW? (@201,202,203,204) Returns the measured power of a cell list MEAS:CELL:POW? (@2001:2004)	

MEASure:RESet (@<chan_list>)
MEASure:CELL:RESet (@<cell_list>)

Clears the ampere-hour and watt-hour capacity measurement of the specified channels (or cells).

Parameter	Typical Return
<chan_list> or <cell_list>	(none)
Clears the AHR of a channel list MEAS:RES (@201,202,203,204) Clears the AHR of a cell list MEAS:CELL:RES (@2001:2004)	

MEASure:VOLTage? (@<chan_list>)
MEASure:CELL:VOLTage? (@<cell_list>)

Returns the measured remote-sensed voltage at the specified channels (or cells) in volts.

Parameter	Typical Return
<chan_list> or <cell_list>	<comma-separated voltage values>
Returns the measured voltage of a channel list MEAS:VOLT? (@201,202,203,204) Returns the measured voltage of a cell list MEAS:CELL:VOLT? (@2001:2004)	

Output Commands

OUTPut:PROTection:CLEar

Resets any protection events that have occurred.

Parameter	Typical Return
(none)	(none)
Clear output protection: `OUTP:PROT:CLE`	

ROOT Commands

Root commands program the watchdog timer (see Internal Protection).

ROOT:WATChdog:ENABle 0|OFF|1|ON
ROOT:WATChdog:ENABle?

Enables/disables the IO watchdog timer. When enabled, the sequence is aborted if there is no IO activity on any remote interface within the time period specified by ROOT:WATChdog:TOUT.

When a sequence is aborted, the power connections open into a high impedance state.

Parameter	Typical Return
0|OFF|1|ON	0 or 1
Enable the watchdog timer: ROOT:WATC:ENAB ON	

ROOT:WATChdog:TOUT <*value*>
ROOT:WATChdog:TOUT?

Sets the watchdog delay time. When the watchdog timer is enabled, the sequence is aborted if there is no IO activity on any remote interface within the time period specified by the delay time. Programmed values can range from 1 to 3600 seconds in 1 second increments.

Parameter	Typical Return
<value> from 1 to 3600 seconds	3600
Sets the watchdog timer to 10 minutes: ROOT:WATC:TOUT 600	

ROOT:WATChdog:RESet

Resets the watchdog timer to the specified delay time (TOUT), which restarts the watchdog countdown. Any other SCPI command will also reset the timer.

Parameter	Typical Return
(none)	(none)
Resets the watchdog timer: ROOT:WATC:RES	

Sequence Commands

Sequence commands define the forming process, which incudes charge, discharge, and rest steps.

SEQuence:CATalog?

Returns which sequences are valid. A valid sequence must have at least one step defined.

Parameter	Typical Return
(none)	1, 2, 3, 4, 5, 6, 7, 8
Return the sequence catalog: SEQ:CAT?	

SEQuence:CLEar [<seq_id>]

Clears the specified sequence. Omitting the optional <seq_id> clears all sequences. Note that even after clearing, some cells may remain assigned until they are re-assigned to another sequence.

Parameter	Typical Return
<seq_id> from 1 to 256 (optional)	(none)
Clear the specified sequence: SEQ:CLE 8	

- Clearing a sequence that is in use by a channel will return an error.

SEQuence:STEP:COUNt? <seq_id>

Returns how many valid steps are defined in the sequence specified by <seq_id>. A valid sequence must have at least one step defined at <step_id> 1.

Parameter	Typical Return
<seq_id> from 1 to 256	4 (for 4 steps)
Queries the steps in the specified sequence: SEQ:STEP:COUN? 6	

- If a sequence has missing steps, the step count stops at the missing step. For example, if a sequence has steps 1, 2, and 4 defined (missing step 3), then the step count is 2.

SEQuence:STEP:CPOWer:DEFine <seq_id>, <step_id>, <mode>, <duration>, <CC>, <CV>, <CP>
SEQuence:STEP:CPOWer:DEFine? <seq_id>, <step_id>

Defines a step in a sequence. The query returns the defined values.

<seq_id> – specifies the sequence to which the step is added. Sequences are numbered from 1 to 256.

<step_id> – specifies which step number is being added. Steps are numbered from 1 to 50. A missing or unspecified step will cause the sequence to end and exit to the Rest state at the missing step.

<mode> specified as PRECHARGE, CHARGE or DISCHARGE mode. This specifies whether the channel is sinking or sourcing current.

<duration> is the maximum allowable step time in seconds. Values range from 1 to 2147483647. Note that the step can terminate earlier than the duration due to a test condition being met.

<CC> is the current limit for the step. The channel will limit the current to this value. In charge mode <CC> refers to the current source limit. In discharge mode, the <CC> refers to the current sink limit. For BT2204A/B: the minimum lower limit to this parameter is determined by the number of channels paralleled together such that MinCC is ≥ (#ofParalleledChannels * 0.01A). The maximum upper limit to this parameter is determined by the number of channels paralleled together such that MaxCC is ≤ (#ofParalleledChannels * 6.25A). For a Precharge step, the MaxCC is ≤ (#ofParalleledChannels * 1A). For BT2205A: the minimum lower limit to this parameter is determined by the number of channels paralleled together such that MinCC is ≥ (#ofParalleledChannels * 0. 16A). The maximum upper limit to this parameter is determined by the number of channels paralleled together such that MaxCC is ≤ (#ofParalleledChannels * 100A). For a Precharge step, the MaxCC is ≤ (#ofParalleledChannels * 16A).

<CV> is the voltage limit for the step. The channel will limit the voltage to this value. Values range from 2.0 V to 4.5 V. For a Precharge step, the cell voltage range is fro 1.0 V to 2.0 V.

<CP> is the power limit for the step. The channel will limit the power (product of voltage and current) to this value. The units are Watts (W).

Parameter		Typical Return
<seq_id> from 1 to 256 <step_id> from 1 to 50 <mode> PRECHARGE, CHARGE, or DISCHARGE <duration> step duration in seconds	<CC> the constant current limit <CV> the constant voltage limit <CR> the constant power limit	CHARGE, 60, 20, 4.0, 70
Defines step number 1 in sequence 1: SEQ:STEP:CPOW:DEF 1, 1, CHARGE, 60, 20, 4.0, 70		

SEQuence:STEP:DEFine <seq_id>, <step_id>, <mode>, <duration>, <CC>, <CV>
SEQuence:STEP:DEFine? <seq_id>, <step_id>

Defines a step in a sequence. The query returns the defined values.

<seq_id> – specifies the sequence to which the step is added. Sequences are numbered from 1 to 256.

<step_id> – specifies which step number is being added. Steps are numbered from 1 to 50. A missing or unspecified step will cause the sequence to end and exit to the Rest state at the missing step.

<mode> specified as PRECHARGE, CHARGE, DISCHARGE, or REST mode. This specifies whether the channel is sinking current, sourcing current, or resting with the output disconnected.

<duration> is the maximum allowable step time in seconds. Values range from 1 to 2147483647. Note that the step can terminate earlier than the duration due to a test condition being met. For a Precharge step, the maximum allowable step time is limited to 900 seconds (15 minutes). You can use multiple Precharge steps if more than 15 minutes of precharge is desired.

<CC> is the current limit for the step. The channel will limit the current to this value. In charge mode <CC> refers to the current source limit. In discharge mode, the <CC> refers to the current sink limit.
For BT2204A/B: the minimum lower limit to this parameter is determined by the number of channels paralleled together such that MinCC is ≥ (#ofParalleledChannels * 0.01A). The maximum upper limit to this parameter is determined by the number of channels paralleled together such that MaxCC is ≤ (#ofParalleledChannels * 6.25A). For a Precharge step, the MaxCC is ≤ (#ofParalleledChannels * 1A).
For BT2205A: the minimum lower limit to this parameter is determined by the number of channels paralleled together such that MinCC is ≥ (#ofParalleledChannels * 0. 16A). The maximum upper limit to this parameter is determined by the number of channels paralleled together such that MaxCC is ≤ (#ofParalleledChannels * 100A). For a Precharge step, the MaxCC is ≤ (#ofParalleledChannels * 16A).

<CV> is the voltage limit for the step. The channel will limit the voltage to this value. Values range from 2.0 V to 4.5 V. For a Precharge step, the cell voltage range is fro 1.0 V to 2.0 V.

Parameter		Typical Return
<seq_id> from 1 to 256 <step_id> from 1 to 50 <mode> PRECHARGE, CHARGE, DISCHARGE, or REST	<duration> step duration in seconds <CC> the constant current limit <CV> the constant voltage limit	CHARGE, 60, 20, 4.0
Defines step number 1 in sequence 1: SEQ:STEP:DEF 1, 1, CHARGE, 60, 20, 4.0		

SEQuence:STEP:DCIR:DEFine <seq_id>, <step_id>, <maxVoltLimit>, <minVoltLimit>, <pauseBeforeFirstPulse>, <firstPulseLevel>, <firstPulseWidth> [,<pauseAfterFirstPulse>, <secondPulseLevel>, <secondPulseWidth>, <pauseAfterSecondPulse>]
SEQuence:STEP:DCIR:DEFine? <seq_id>, <step_id>

Defines a DCIR step in a sequence. The step can consist of one or two pulses. Each pulse can be either positive or negative polarity. The query returns the defined values.

<seq_id> - specifies the sequence to which the step is added. Sequences are numbered from 1 to 256.

<step_id> - specifies which step number is being added. Steps are numbered from 1 to 50. A missing or unspecified step will cause the sequence to end and exit to the Rest state at the missing step.

<maxVoltLimit> - specifies the upper voltage limit in volts. The power supply disconnects the DUT if the DUT voltage is higher than this voltage at any time during the pulse test.

<minVoltLimit> - specifies the lower voltage limit in volts. The power supply disconnects the DUT if the DUT voltage is lower than this voltage at any time during the pulse test.

<pauseBeforeFirstPulse> - specifies the pause in seconds before the first pulse. The range is from 0 to 3,600 with 1- second resolution.

<firstPulseLevel> - specifies the current level of the first pulse in amperes. These limits are the same as the ± cell definition limits for current. The range is as follows:
For BT2204A/B: -6.25 A/channel to -10 mA/channel, or 10 mA/channel to 6.25 A/channel
For BT2205A: -100 A/channel to -160 mA/channel, or 160 mA/channel to 100 A/channel

<firstPulseWidth> – specifies the duration of the first current pulse in seconds. The range is from 3 to 30 with 1- second resolution.

[<pauseAfterFirstPulse>] – optionally specifies the pause in seconds between first and second pulse if a second pulse is defined. The range is from 3 to 3,600 with 1- second resolution.

[<secondPulseLevel>] – optionally specifies the current level of the second pulse in amperes. These limits are the same as the ± cell definition limits for current. The range is as follows:
For BT2204A/B: -6.25 A/channel to -10 mA/channel, or 10 mA/channel to 6.25 A/channel
For BT2205A: -100 A/channel to -160 mA/channel, or 160 mA/channel to 100 A/channel

[<secondPulseWidth>] – optionally specifies the duration of the second current pulse in seconds. The range is from 3 to 30 with 1- second resolution.

[<pauseAfterSecondPulse>] – optionally specifies the pause in seconds after the second pulse. The range is from 3 to 3,600 with 1- second resolution.

Parameter		Typical Return
<seq_id> from 1 to 256 <step_id> from 1 to 50 <maxVoltLimit> from 4.5 V down to 2 V <minVoltLimit> 2 V up to 4.5 V <pauseBeforeFirstPulse> from 0 to 3,600 <firstPulseLevel> see description above	<firstPulseWidth> from 3 to 30 [<pauseAfterFirstPulse>] from 3 to 3,600 [<secondPulseLevel>] see description above [<secondPulseWidth>] from 3 to 30 [<pauseAfterSecondPulse>] from 3 to 3,600	4.2,3.4,3,100,3,5,-100,3,3
Generate a 1st and 2nd pulse to measure DCIR: SEQ:STEP:DCIR:DEF 1,1,3.9,3.8,3,100,3,5,-100,3,3		

- Using the **minimum** Pulse Width values has the least impact on the charge/discharge state of the cell when the DCIR measurement is made.

SEQuence:TEST:COUNt? <seq_id>, <step_id>

Returns a count of how many sequence tests are defined for the step given by <seq_id>,<step_id>.

Parameter	Typical Return
<seq_id> from 1 to 256 <step_id> from 1 to 50	12 (for 12 tests)
Queries the tests in the step: SEQ:TEST:COUN? 1, 1	

SEQuence:TEST:DEFine <seq_id>, <step_id>, <test_id>, <test_type>, <value>, <time_type>, <time_limit>, <test_action>
SEQuence:TEST:DEFine? <seq_id>, <step_id>, <test_id>

Defines a test that will monitor during a particular step. Tests define conditions to verify that cells are performing properly, and will transition to the next step based on cell performance. Up to 24 tests can be defined per step. Tests are not active during Rest steps. The query returns the defined values.

<seq_id> – specifies the sequence to which the step is added. Sequences are numbered from 1 to 256.

<step_id> – specifies which step number is being added. Steps are numbered from 1 to 50. A missing or unspecified step will cause the sequence to end and exit to the Rest state at the missing step.

<test_id> – specifies which test is being added to the step. Tests are numbered from 1 to 24.

<test_type> – specifies one of the following test types:

Test type	Description
NONE	Value when the test is undefined; also returned when the test result is within test limits
VOLT_GE	The cell voltage that is greater than or equal to the programmed <value>
VOLT_LE	The cell voltage that is less than or equal to the programmed <value>
CURR_GE	The cell current that is greater than or equal to the programmed <value>
CURR_LE	The cell current that is less than or equal to the programmed <value>
POWER_GE	The absolute value of cell power in Watts (cell voltage x cell current) that is greater than or equal to the programmed <value>
POWER_LE	The absolute value of cell power in Watts (cell voltage x cell current) that is less than or equal to the programmed <value>
AMPH_GE	The absolute value of cell capacity in Ampere-hours that is greater than or equal to the programmed <value>
AMPH_LE	The absolute value of cell capacity in Ampere-hours that is less than or equal to the programmed <value>
WATTH_GE	The absolute value of cell capacity in Watt-hours that is greater than or equal to the programmed <value>
WATTH_LE	The absolute value of cell capacity in Watt-hours that is less than or equal to the programmed <value>
POS_DVDT_GE	The change in voltage during the 1-second sampling interval that is positive and greater than or equal to the programmed <value>
POS_DVDT_LE	The change in voltage during the 1-second sampling interval that is positive and less than or equal to the programmed <value>
NEG_DVDT_GE	The change in voltage during the 1-second sampling interval that is negative, and the magnitude of the change is greater than or equal to the programmed <value>
NEG_DVDT_LE	The change in voltage during the 1-second sampling interval that is negative, and the magnitude of the change is less than or equal to the programmed <value>
POS_DIDT_GE	The change in the magnitude of current during the 1-second sampling interval that is positive and greater than or equal to the programmed <value>
POS_DIDT_LE	The change in the magnitude of current during the 1-second sampling interval that is positive and less than or equal to the programmed limit
NEG_DIDT_GE	The change in the magnitude of current during the 1-second sampling interval that is negative, and the magnitude of the change is greater than or equal to the programmed limit
NEG_DIDT_LE	The change in the magnitude of current during the 1-second sampling interval that is negative, and the magnitude of the change is less than or equal to the programmed <value>
DVMAX_GE	The magnitude of the difference between the voltage and the maximum voltage observed during the step that is greater than or equal to the programmed <value>
DVMAX_LE	The magnitude of the difference between the voltage and the maximum voltage observed during the step that is less than or equal to the programmed <value>
DVMIN_GE	The magnitude of the difference between the voltage and the minimum voltage observed during the step that is greater than or equal to the programmed <value>

Test type	Description
DVMIN_LE	The magnitude of the difference between the voltage and the minimum voltage observed during the step that is less than or equal to the programmed <value>
DIMAX_GE	The magnitude of the difference between the absolute value of current and the maximum absolute value of current observed during the step that is greater than or equal to the programmed <value>
DIMAX_LE	The magnitude of the difference between the absolute value of current and the maximum absolute value of current observed during the step that is less than or equal to the programmed <value>
DIMIN_GE	The magnitude of the difference between the absolute value of current and the minimum absolute value of current observed during the step that is greater than or equal to the programmed <value>
DIMIN_LE	The magnitude of the difference between the absolute value of current and the minimum absolute value of current observed during the step that is less than or equal to the programmed <value>

<value> – specifies the programmed value of the test type above. All values are in whole units.

<time_type> – specifies one of the following time types:

Time type	Description
AT	The test is evaluated once at the <time limit>
AFTER	The test is evaluated continuously from the <time_limit> until the step is finished
BEFORE	The test is evaluated continuously from the start of the step until the <time limit>
BEFORE_START	The test is evaluated before starting the associated step. This test is performed during the step setup procedure when only the voltage sense lines are connected to the cell.

<time_limit> – specifies a time limit for the step. Values range from 20 to 2147483647 seconds. A minimum of 20 seconds is required for the step to complete the initial setup procedure. The AT, AFTER, and BEFORE <time_types> are performed after the **step setup** procedure completes.

<test_action> – specifies one of the following test actions:

Test action	Description
FAIL	When met, the test action indicates the test failed.
NEXT	When met, the test action indicates the test passed and the sequence proceeds to the next step

Parameter		Typical Return
<seq_id> from 1 to 256 <step_id> from 1 to 50 <test_id> from 1 to 24 <test_type> see description above	<value> the value of the test type <time_type> AT | AFTER | BEFORE | BEFORE_START <time_limit> from 20 to 2147483647 <test_action>FAIL | NEXT	VOLT_GE, 3.8, BEFORE, 300, FAIL
Defines test number 1 in step number 1 in sequence 1: `SEQ:TEST:DEF 1, 1, 1, VOLT_GE, 3.8, BEFORE, 300, FAIL`		

SEQuence:TEST:DCIR:DEFine <seq_id>, <step_id>, <test_id>, <test_type>, <value>, <test_action>
SEQuence:TEST:DCIR:DEFine? <seq_id>, <step_id>, <test_id>

Defines the tests for the DCIR step. Tests define the conditions to verify that cells are performing properly, and will transition to the next step based on cell performance. Up to 32 tests can be defined per step. Tests are not active during Rest steps. The query returns the defined values.

<seq_id> – specifies the sequence to which the step is added. Sequences are numbered from 1 to 256.

<step_id> – specifies which step number is being added. Steps are numbered from 1 to 50. A missing or unspecified step will cause the sequence to end and exit to the Rest state at the missing step.

<test_id> – specifies which test is being added to the step. Tests are numbered from 1 to 24.

<test_type> – specifies one of the following test types:

Time type	Description
DCIR1_GE	The DCIR pulse 1 value is greater than or equal to the programmed <value>
DCIR1_LE	The DCIR pulse 1 value is less than or equal to the programmed <value>
DCIR2_GE	The DCIR pulse 2 value is greater than or equal to the programmed <value>
DCIR2_LE	The DCIR pulse 2 value is less than or equal to the programmed <value>

<value> – specifies the programmed value of the test type in ohms.

<test_action> – specifies one of the following test actions:

Test action	Description
FAIL	When met, the test action indicates the test failed.
NEXT	When met, the test action indicates the test passed and the sequence proceeds to the next step

Parameter		Typical Return
<seq_id> from 1 to 256 <step_id> from 1 to 50 <test_id> from 1 to 24	<test_type> see description above <value> the value of the test type <test_action>FAIL | NEXT	DCIR1_GE, 0.8, NEXT
Defines test number 1 in step number 1 in sequence 1: SEQ:TEST:DCIR:DEF 1, 1, 1, DCIR1_GE, 0.5, NEXT		

Status Commands

Status commands let you determine the operating condition of the instrument at any time. Refer to Status Tutorial for more information.

STATus:CELL:PROBe? (@<cell_list>)

Returns the latest probe check result. If a sequence is active, it reports the latest result from probe check which runs continuously. If a sequence was completed, it will report the probe check result from the end of the sequence. A 1 is returned if probe check failed; otherwise a 0 (zero) is returned, indicating success. A zero is also returned if no probe check measurements have ever been done.

Parameter	Typical Return
<cell_list> from 1000 to 8032	0, 0, 0, 0 (for 4 cells)
Queries the probe check result of cells 1001to1004: STAT:CELL:PROB? (@1001:1004)	

STATus:CELL:REPort? (@<cell_list>)

Returns a status report for the specified cells. The following values can be returned:

0 = NONE is returned if the cell has not run a sequence.
1 = RUNNING indicates the cell is running a sequence and has no failures.
2 = FAIL indicates a test has failed.
3 = ABORT indicates the sequence has been aborted.
4 = OK indicates the cell has completed a sequence with no failures.

Parameter	Typical Return
<cell_list> from 1000 to 8032	1, 1, 1, 1
Returns the results of a status report for cells 1001 to 1004: STAT:CELL:REP? (@1001:1004)	

STATus:CELL:RUN:COUNt?

Returns how many cells are still running a sequence. The count is returned regardless of whether the cells are running the same or different sequences. The return value will be an integer from 0 to 256.

Parameter	Typical Return
(none)	256
Return the number of cells still running a sequence: STAT:CELL:RUN:COUN?	

STATus:CELL:STEP? <step_id>, <cell>

Returns information about a completed step in the sequence. The query only returns a valid response *after* a step has completed - otherwise a string of zeroes is returned. The return parameters are:

Return parameters	Description
<compTime>	Returns the completion time (how long the step ran) in seconds
<volts>	Returns the last measured voltage of the step
<amps>	Returns the last measured current of the step
<cellStat>	Returns the cell state: NONE | OK | FAIL | ABORTED | NEXT
<testId>	Returns the test ID of the first test that met its conditions and caused the step to move NEXT or FAIL
<testType>	Returns the test type as defined by SEQuence:TEST:DEFine
<expLim>	Returns the expected step limit
<measLim>	Returns the measured step limit

Parameter	Typical Return
<step_id> from 1 to 256 <cell> from 1000 to 8032	500, 3.9999E+00, 1.9999E-02, NEXT, 2, CURR_LE, 2.0000E-02, 1.9999E-02
Queries the state of step 2 for cell 1001: STAT:CELL:STEP? 2, 1001	

- In addition to the test types defined by SEQuence:TEST:DEFine, the following charge and discharge tests can also be returned. The testId for these tests is zero:
  PROBE - checks the sense and power probes
  CELLREV - checks if a cell is reversed, or outside the sense limits of 0.8 V to 6.7 V
  AT-TARGET - checks if a cell is already charged or discharged to the target voltage
  HARDLIMIT_VMAX - checks that the cell voltage is less than 6.7 V
  HARDLIMIT_VMIN - checks that the cell voltage is greater than -1.0 V
  HARDLIMIT_IPOS - checks that the charge current is less than 6.5 A
  HARDLIMIT_INEG - checks that the discharge current is less than 6.5 A (in magnitude)
  VOLT_COMP_AT_TERM - checks for excessive voltage drop on load leads
- The following precharge tests can also be returned. Note that power and sense probe checks are not performed during precharge. The testId for these tests is also zero:
  CELLREV - checks if a cell is reversed, or outside the sense limits of -0.1 V to 6.7 V
  AT-TARGET - checks if a cell is already charged to the target voltage
  HARDLIMIT_VMAX - checks that the cell voltage is less than 6.7 V
  HARDLIMIT_VMIN - checks that the cell voltage is greater than -1.0 V
  HARDLIMIT_IPOS - checks that the charge current is less than 6.5 A

STATus:CELL:VERBose? <cell>

Returns a summary of the current state or "snapshot" of the cell. The return parameters are:

Return parameters	Description
<runState>	Returns either IDLE or RUNNING specifying whether the cell is currently running a sequence or is idle
<seqId>	Returns the latest sequence the cell has executed. Returns 0 (zero) if the cell has never run a sequence
<stepId>	Returns the latest step the cell has executed. Returns 0 (zero) if the cell has never run a sequence
<volts>	Returns the last measured sense voltage
<amps>	Returns the last measured cell current
<cellStat>	Returns the last status of the cell: NONE is returned if the cell has not run a sequence. OK indicates the cell is either running or has completed the sequence with no failures (see <run_state>). FAIL indicates a test has failed. ABORTED indicates the test has been aborted. NEXT indicates the cell has moved to the next step in the sequence.
<testId>	Returns the test ID. Only returns an ID if the test has failed; otherwise returns 0 (zero)
<testType>	Returns the test type. Only returns a test type if the test has failed; otherwise returns NONE
<expLim>	Returns the expected limit. Only returns the limit if the test has failed; otherwise returns 0 (zero)
<measLim>	Returns the measured limit. Only returns the limit if the test has failed; otherwise returns 0 (zero)

Parameter	Typical Return
<cell> from 1000 to 8032	RUNNING,1,3, 3.1000E+00, 1.9500E-01, OK, 0, NONE, 0.0000E+00, 0.0000E+00
Queries the state of cell 1001: STAT:CELL:VERB? 1001	

- In addition to the test types defined by SEQuence:TEST:DEFine, system tests can also be returned. Refer to STATus:CELL:STEP? for details.

STATus:OPERation[:EVENt]?

Returns the sum of the bits in the event register for the Standard Operation Register group. An event register is a read-only register that latches events from the condition register. While an event bit is set, subsequent events corresponding to that bit are ignored. The register bits are cleared when you read the register.

Parameter	Typical Return
(none)	<bit value>
Read the operation event status register: STAT:OPER?	

- Once a bit is set, it remains set until cleared by reading the event register or by sending *CLS (clear status).
- Returns the binary-weighted sum of all enabled bits in the register.

STATus:OPERation:CONDition?

Returns the sum of the bits in the condition register for the Standard Operation Register group. This register is read-only; bits are not cleared when read.

Parameter	Typical Return
(none)	<bit value>
Read the operation status condition register: `STAT:OPER:COND?`	

- The condition register bits reflect the current condition. If a condition goes away, the corresponding bit is cleared.
- Returns the binary-weighted sum of all enabled bits in the register.

STATus:OPERation:ENABle <*value*>
STATus:OPERation:ENABle?

Sets and queries bits in the enable register for the Standard Operation Register group. The enable register is a mask for enabling specific bits from the Operation Event register to set the OPER (operation summary) bit of the Status Byte register. STATus:PRESet clears all bits in the enable register.

Note that *CLS does not clear the enable register, but does clear the event register.

Parameter	Typical Return
A decimal value that corresponds to the binary-weighted sum of the bits in the register.	+16 (bit 4 set)
Enable bit 4 in the enable register: `STAT:OPER:ENAB 16`	

System Commands

SYSTem:CARD:DETect:BOOT? <card>
SYSTem:CARD:DETect:NOW? <card>

Returns what module cards are detected. SYSTem:CARD:DETect:BOOT? returns the cards detected at bootup. SYSTem:CARD:DETect:NOW? returns the cards detected at present.

Parameter	Typical Return
<card> = 0 for all cards, or 1 - 8,	0,1,1,1,0,0,0,1 or 1 | 0
Detect if a card is in slot 6 now: SYST:CARD:DET:NOW? 6	

SYSTem:COMMunicate:LAN:DHCP 0|OFF|1|ON
SYSTem:COMMunicate:LAN:DHCP?

Disables or enables instrument's use of DHCP. DHCP stands for Dynamic Host Configuration Protocol, a protocol for assigning dynamic IP addresses to networked devices. With dynamic addressing, a device can have a different IP address every time it connects to the network.

ON - the instrument tries to obtain an IP address from a DHCP server. If a DHCP server is found, it assigns a dynamic IP address, Subnet Mask, and Default Gateway to the instrument.

OFF or DHCP unavailable - the instrument uses the static IP address, Subnet Mask, and Default Gateway during power-on.

Parameter	Typical Return
0|OFF|1|ON, Default: ON	0 or 1
Disable DHCP: SYST:COMM:LAN:DHCP OFF	

- If a DHCP LAN address is not assigned by a DHCP server, then an Auto-IP address is obtained after approximately 2 minutes. An Auto-IP address has the form 169.254.nnn.nnn.
- The DHCP setting is stored in non-volatile memory.
- You must send SYSTem:COMMunicate:LAN:UPDate to activate the new setting.

SYSTem:COMMunicate:LAN:DOMain?

Returns the domain name assigned to the instrument.

Parameter	Typical Return
(none)	"example.com"
Return the domain name used by the instrument: SYST:COMM:LAN:DOM?	

- If Dynamic Domain Name System (DNS) is available on your network and your instrument uses DHCP, the domain name is assigned by the Dynamic DNS service at power-on.
- A null string ("") indicates that no domain name is assigned.

SYSTem:COMMunicate:LAN:GATeway "<*address*>"
SYSTem:COMMunicate:LAN:GATeway? [CURRent|STATic|PENDing]

Assigns a default gateway for the instrument. The specified IP Address sets the default gateway, which allows the instrument to communicate with systems that are not on the local subnet. Thus, this is the default gateway where packets are sent that are destined for a device not on the local subnet, as determined by the Subnet Mask setting. Contact your LAN administrator for details.

The optional **CURRent** query returns the address currently being used. The optional **STATic** returns the static address from non-volatile memory. This address is used if DHCP is disabled or unavailable. Optional **PENDing** returns the value sent, but is not yet committed to non-volatile memory.

Parameter	Typical Return
Command: "nnn.nnn.nnn.nnn". Default: "0.0.0.0".	(none)
Query: [CURRent|STATic|PENDing]. Default: CURRent	"198.105.232.1"
To set a static Gateway address: SYST:COMM:LAN:GAT "198.105.232.1"	

- If DHCP is enabled (SYSTem:COMMunicate:LAN:DHCP ON), the specified default gateway is not used.
- The gateway address is stored in non-volatile memory.
- You must send SYSTem:COMMunicate:LAN:UPDate to activate the new setting.

SYSTem:COMMunicate:LAN:HOSTname "<*name*>"
SYSTem:COMMunicate:LAN:HOSTname? [CURRent|STATic|PENDing]

Assigns a hostname to the instrument. A hostname is the host portion of the domain name, which is translated into an IP address. If Dynamic Domain Name System (Dynamic DNS) is available on your network and your instrument uses DHCP, the hostname is registered with the Dynamic DNS service at power-on. If DHCP is enabled, the DHCP server can change the specified hostname. Contact your LAN administrator for details.

The optional **CURRent** query returns the name currently being used. The optional **STATic** returns the name from non-volatile memory. This may not be the actual name used by the instrument if DHCP is enabled. Optional **PENDing** returns the value sent, but is not yet committed to non-volatile memory.

Parameter	Typical Return
String of up to 15 characters. Must start with letter (A-Z) May contain letters, numbers (0-9), or dashes ("-").	(none)
Query: [CURRent|STATic|PENDing]. Default: CURRent	"KeysightBT2202A"
To define a hostname: SYST:COMM:LAN:HOST "KeysightBT2202A "	

- If no hostname exists, the query returns a null string ("").
- The hostname is stored in non-volatile memory.
- You must send SYSTem:COMMunicate:LAN:UPDate to activate the new setting.

SYSTem:COMMunicate:LAN:IPADdress "<*address*>"
SYSTem:COMMunicate:LAN:IPADdress? [CURRent|STATic|PENDing]

Assigns a static Internet Protocol (IP) address for the instrument. If DHCP is enabled, the specified static IP address is not used. Contact your LAN administrator for details.

The optional CURRent query returns the address currently being used. The optional STATic returns the static address from non-volatile memory. This address may not be the actual address used by the instrument if DHCP is enabled. Optional PENDing returns the value sent, but is not yet committed to non-volatile memory.

Parameter	Typical Return
Command: "nnn.nnn.nnn.nnn".	(none)
Query: [CURRent|STATic|PENDing]. Default: CURRent	"169.254.149.35"
To set a static IP address: SYST:COMM:LAN:IPAD "169.254.149.35"	

- If DHCP is enabled (SYSTem:COMMunicate:LAN:DHCP ON), the specified IP address is not used. However, if the DHCP server fails to assign a valid IP address, the instrument uses an Auto-IP address.
- The IP address is stored in non-volatile memory.
- You must send SYSTem:COMMunicate:LAN:UPDate to activate the new setting.

SYSTem:COMMunicate:LAN:MAC?

Returns the instrument's Media Access Control (MAC) address as an ASCII string of 12 hexadecimal characters (0-9 and A-F) enclosed in quotation marks.

Parameter	Typical Return
(none)	"0030D3001041"
To return the MAC address: SYST:COMM:LAN:MAC?	

- The MAC address is also known as the link-layer address, the Ethernet (station) address, LANIC ID or Hardware Address. This is an unchangeable 48-bit address assigned by the manufacturer to each unique Internet device.
- Your LAN administrator may need the MAC address to assign a static IP address

SYSTem:COMMunicate:LAN:SMASk "<*mask*>"
SYSTem:COMMunicate:LAN:SMASk? [CURRent|STATic|PENDing]

Assigns a subnet mask for the instrument to use in determining whether a client IP address is on the same local subnet. When a client IP address is on a different subnet, all packets must be sent to the Default Gateway. Contact your LAN administrator for details.

The optional **CURRent** query returns the address currently being used. The optional **STATic** returns the static address from non-volatile memory. Optional **PENDing** returns the value sent, but is not yet committed to non-volatile memory.

Parameter	Typical Return
Command: "nnn.nnn.nnn.nnn". Default: "255.255.0.0".	(none)
Query: [CURRent|STATic|PENDing]. Default: CURRent	"255.255.0.0"
To set a static subnet mask: SYST:COMM:LAN:SMAS "255.255.0.0"	

- If DHCP is enabled (SYSTem:COMMunicate:LAN:DHCP ON), the specified subnet mask is not used. However, if the DHCP server fails to assign a valid IP address, the instrument uses the Auto-IP subnet mask.
- A value of "0.0.0.0" or "255.255.255.255" indicates that subnetting is not being used.
- The subnet mask setting is stored in non-volatile memory.
- You must send SYSTem:COMMunicate:LAN:UPDate to activate the new setting.

SYSTem:COMMunicate:LAN:TELNet:PROMpt "<*string*>"
SYSTem:COMMunicate:LAN:TELNet:PROMpt?

Specifies the command prompt seen when communicating with the instrument via Telnet.

Parameter	Typical Return
Quoted string of up to 15 characters.	"BT2202A"
To set a command prompt: SYST:COMM:LAN:TELN:PROM "BT2202A"	

- The instrument uses LAN port 5024 for SCPI Telnet sessions and port 5025 for SCPI Socket sessions.
- Telnet sessions are typically started from a host computer shell (telnet <IP_address> <port>). For example: telnet 169.254.4.10 5024. To exit a Telnet session, press <Ctrl-D>.
- This setting is stored in non-volatile memory.
- You must send SYSTem:COMMunicate:LAN:UPDate to activate the new setting.

SYSTem:COMMunicate:LAN:TELNet:WMESsage "<*string*>"
SYSTem:COMMunicate:LAN:TELNet:WMESsage?

Specifies the welcome message seen when communicating with the instrument via Telnet.

Parameter	Typical Return
Quoted string of up to 63 characters.	"Welcome to the Telnet Session"
To set a command prompt: SYST:COMM:LAN:TELN:WMES "Welcome to the Telnet Session"	

- The instrument uses LAN port 5024 for SCPI Telnet sessions and port 5025 for SCPI Socket sessions.
- This setting is stored in non-volatile memory.
- You must send SYSTem:COMMunicate:LAN:UPDate to activate the new setting.

SYSTem:COMMunicate:LAN:UPDate

Stores any changes made to the LAN settings into non-volatile memory and restarts the LAN driver with the updated settings.

Parameter	Typical Return
(none)	(none)
The following configures the instrument to use statically assigned LAN settings: SYST:COMM:LAN:DHCP OFF SYST:COMM:LAN:IPAD "198.105.232.101" SYST:COMM:LAN:GAT "198.105.232.1" SYST:COMM:LAN:SMAS "255.255.255.0" SYST:COMM:LAN:UPD The following configures the instrument back to use DHCP: SYST:COMM:LAN:DHCP ON SYST:COMM:LAN:UPD	

- This command must be sent after changing the settings for any LAN setting: DHCP, gateway, host-name, IP address, subnet mask, Telnet prompt or Telnet welcome message.
- The IP address, gateway, and subnet mask, must be consistent with each other and meet networking requirements.
- It is possible to change the static IP address settings without disabling DHCP.
- The command will result in the LAN driver being restarted and may result in the loss of connectivity.

SYSTem:ERRor?

Reads and clears one error from the error queue.

Parameter	Typical Return
(none)	+0,"No error"
Reads and clears the first error in error queue: SYST:ERR?	

- Error retrieval is first-in-first-out (FIFO), and errors are cleared as you read them.
- If more have accumulated than the queue can hold, the last error stored in the queue (the most recent error) is replaced with -350,"Error queue overflow". No additional errors are stored until you remove errors from the queue. If no errors are in the error queue, the instrument responds with +0,"No error".
- The error queue is cleared when power is cycled. It is not cleared by a *RST.
- Errors have the following format (the error string may contain up to 80 characters). <*error code*>,<*error string*> For a list of error codes and message strings, see SCPI Error Messages.

SYSTem:PROBecheck:LIMit <*value*>, 0

Sets the upper limit for the probe check for all channels in ohms. It has a maximum value of 10 Ω. The default is 0.5 Ω. The lower limit is 0.001 Ω. The zero following the value must be included as a placeholder for the channel list, otherwise an error will be generated.

Parameter	Typical Return
<value> from 0.001 to 10, *RST 0.5	0.5
Sets the resistance of the probe check to 1 ohm: SYST:PROB:LIM 1, 0	

- The following commands restore the limit to its default value: *RST, *TST, SYSTEM:TEST:ALL?, SYSTEM:TEST:MAINframe?, SYSTEM:TEST:CHANnel?.

SYSTem:REBoot:SYSTem

Reboots the entire charge/discharge system including all installed cards.

Parameter	Typical Return
(none)	(none)
Reboots the charge/discharge syatem: SYST:REB:SYST	

SYSTem:TEST:ALL?

Tests the entire charge/discharge system, including modules. If 0 (zero) is returned, no errors found. If 1 is returned, errors have occurred. Use SYSTem:ERRor? to return the error.

Note that SYSTem:TEST:ALL? is more extensive than *TST? and takes about 130 seconds to complete.

Parameter	Typical Return
(none)	0 or 1
Tests the entire charge-discharge : SYST:TEST:ALL?	

SYSTem:TEST:CHANnel? (@<chan_list>)

Tests the specified channel(s). If 0 (zero) is returned, no errors found. If 1 is returned, errors have occurred. Use SYSTem:ERRor? to return the error. Approximate test times are indicated below.

Parameter	Typical Return
<chan_list> XX00 | XXYY | XY, where XX00 tests all channels in a specific slot (XX) from 01 to 08; BT2204A/B: XXYY tests a specific channel (YY) from 01 to 32 in the specific slot (XX); BT2205A: XY tests a specific channel (Y) from 1 to 2 in the specific slot (X) from 1 to 8	0 | 1
Tests 4 channels in slot 2 for a BT2204B: SYST:TEST:CHAN? (@201,202,203,204) Tests 6 channels in slots 1, 2, and 3 for a BT2205A: SYST:TEST:CHAN? (@11, 12, 21, 22, 31, 32)	

- XX00 tests all channels of the specified module (XX) and takes about 40 seconds.
- XX01 tests only one channel of the specified module and takes about 20 seconds.

SYSTem:TEST:MAINframe?

Tests the charge-discharge system mainframe. If 0 (zero) is returned, no errors found. If 1 is returned, errors have occurred. Use SYSTem:ERRor? to return the error. SYST:TEST:MAIN? takes about 15 seconds.

Parameter	Typical Return
(none)	0 or 1
Tests the charge-discharge mainframe: SYST:TEST:MAIN?	

SYSTem:UPTime?

Returns the time that the CDS has been running since its last power-on. The returned values indicate days, hours, minutes, and seconds, respectively.

Parameter	Typical Return
(none)	+2,+8,+13,+50 (2 days, 8 hours, 13 minutes, 50 seconds)
Return time that the instrument has been running: SYST:UPT?	

- This command is typically used to verify that the instrument is warmed up sufficiently before calibration.

Status Tutorial

This section provides a detailed description of the individual registers and register groups. The status diagram at the end of this topic shows how the status registers and groups are interconnected.

Status Registers

The Standard Operation group uses three different type of registers to track qualify, flag, and enable instrument events.

- A Condition register continuously monitors the state of the instrument. The bits in the condition register are updated in real time and the bits are not latched or buffered.
- An Event register latches the various events from the condition register. There is no buffering in this register; while an event bit is set, subsequent events corresponding to that bit are ignored. This is a read-only register.
- An Enable register defines which bits in the event register will be reported to the Status Byte register group. You can write to or read from an enable register.

To program individual bits in any register group, you must send a value that corresponds to the binary-weighted value of all the bits that you wish to enable. For example, to enable bit 2 (value = 4) and bit 4 (value = 16), the corresponding decimal value would be 20 (4 + 16).Similarly, any register queries return the binary-weighted value of the bits that have been set. For example, with bit 3 (value 8) and bit 5 (value 32) being set, the query returns +40.

Standard Operation Group

These register groups record signals that indicate the present operating status of the instrument. The group consists of a condition, event, and enable register. The Standard Operation event register latches events relating to the operation of the unit. It is a read-only register that is cleared when read. When enabled, the outputs of the Standard Operation enable register are logically-ORed into the OPERation bit (7) of the Status Byte register.

The following table describes the bit assignments.

Bit	Bit Name	Decimal Value	Definition
0	CAL	1	Calibrating
1	FAU	2	Hardware fault
2	WDG	4	Watchdog timeout
3	CRD	8	Card detection failure
4	TMP	16	Temperature out of range
5	FAN	32	Fan failure
6	PFC	64	AC input supply (PFC) temperature out of range
7	INH	128	The inhibit signal has disconnected all channels from the cells
8-15	not used	not used	0 is returned

Status Byte Register

This register summarizes the information from all other status groups as defined in the IEEE 488.2 Standard Digital Interface for Programmable Instrumentation. The following table describes the bit assignments.

Bit	Bit Name	Decimal Value	Definition
0, 1	not used	not used	0 is returned
2	Error Queue	4	One or more errors in the Error Queue. SYSTem:ERRor? reads and deletes errors.
3	not used	not used	0 is returned
4	Message Available	16	Data is available in the instrument output buffer.
5	not used	not used	0 is returned
6	Master Status Summary	64	One or more bits are set in the Status Byte Register and may generate a Service Request. Bits must be enabled, see *SRE.
7	Operation Status Summary	128	One or more bits are set in the Operation Status Register. Bits must be enabled, see STATus:OPERation:ENABle.

MSS Bit

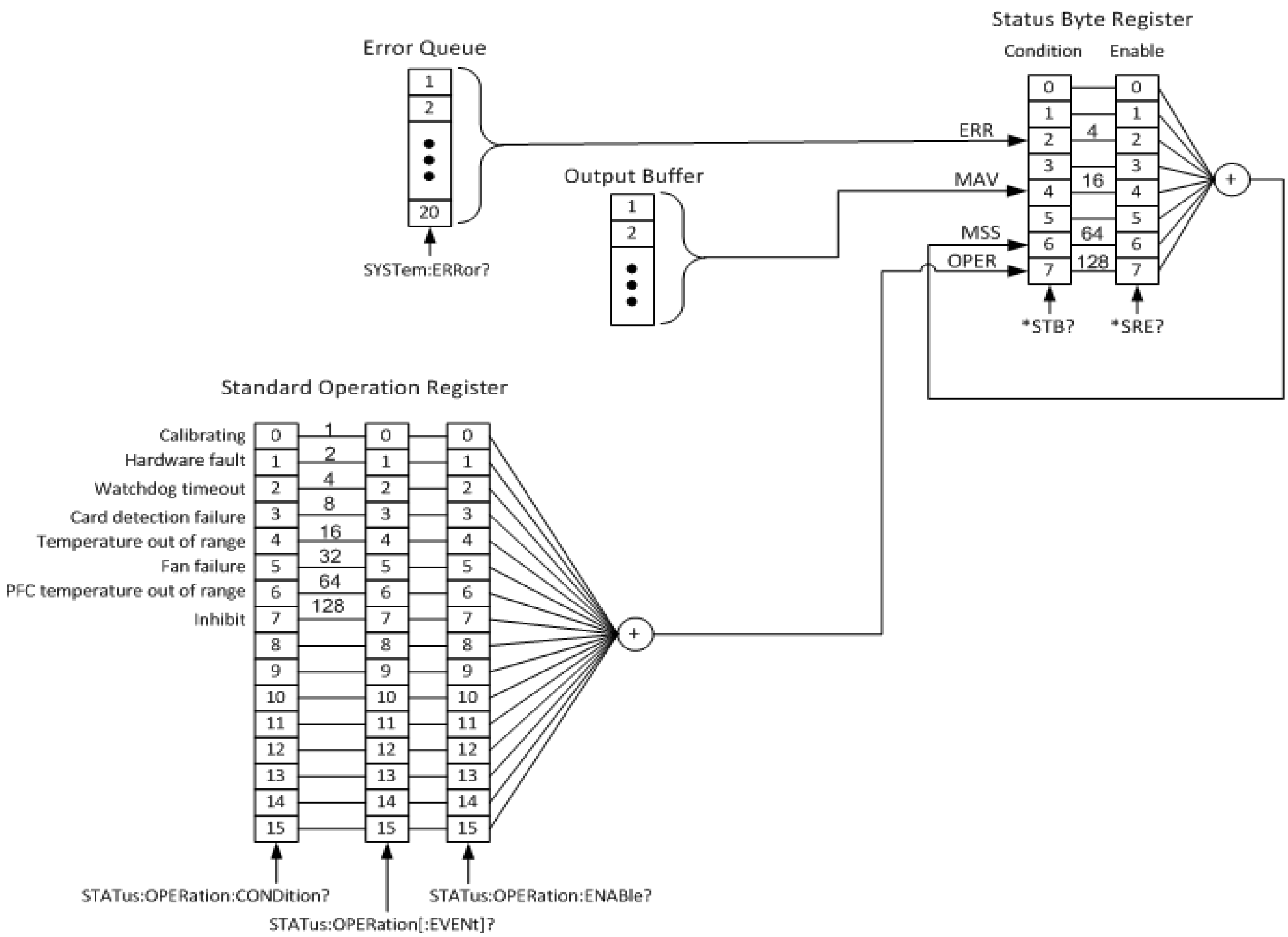
MSS is a real-time (unlatched) summary of all Status Byte register bits that are enabled by the Service Request Enable register. MSS is set whenever the instrument has one or more reasons for requesting service. *STB? reads the bits in the Status Byte register but does not clear them.

Error and Output Queues

The Error Queue is a first-in, first-out (FIFO) data register that stores numerical and textual description of an error or event. Error messages are stored until they are read with SYSTem:ERRor? If the queue overflows, the last error/event in the queue is replaced with error -350,"Queue overflow".

The Output Queue is a first-in, first-out (FIFO) data register that stores instrument-to-controller messages until the controller reads them. Whenever the queue holds messages, it sets the MAV bit (4) of the Status Byte register.

Status Diagram



Reset (*RST) and Interface Settings

Reset State settings are set when the unit is reset.

Parameter	Setting
Sequences	All sequences are aborted
Outputs	All outputs are disabled
Steps	All steps are cleared
Tests	All test definitions are cleared
Probe check resistance	0.5 Ω
Calibration mode	Calibration mode is exited; all calibration parameters are reloaded from NV storage
LXI Lan identification	LXI Lan Identification state is set to false
Output inhibit mode	Off
Digital pin function	Digital input
Digital pin polarity	Positive
Digital output data	0 (zero)
Cell fast settle	Off
Cell transitions	Restart

Interface Settings are the default factory settings.

Parameter	Setting
LAN interface:	enabled
USB interface:	enabled
DHCP:	On
Auto IP:	On
IP Address:	169.254.4.61
Subnet Mask:	255.255.0.0
Default Gateway:	0.0.0.0
DNS Server:	0.0.0.0
Host Name:	K-BT2202A-nnnnn (where nnnnn is last 5 digits of the serial number)
LAN Services:	All enabled
Telnet prompt:	"BT2202A> "
IP addresses of Windows Internet Name System	0.0.0.0

Power must cycled for interface enable or LAN service changes to take effect.
LAN settings changes require a LAN restart. From SCPI you must cycle power.

SCPI Error Messages

- Up to 20 errors can be stored in the error queue.
- A global error queue holds all power-on and hardware-related errors (example: over-temperature).
- Error retrieval is first-in-first-out (FIFO), and errors are cleared as you read them. Once you have read all interface-specific errors, the errors in the global error queue are retrieved.
- If more than 20 errors have occurred, the last error stored in the queue (the most recent error) is replaced with -350,"Error queue overflow". No additional errors are stored until you remove errors from the queue. If no errors have occurred when read, the instrument responds with +0,"No error".
- Interface-specific error queues are cleared by power cycles. The error queue is not cleared by *RST.
- The SYSTem:ERRor? query reads and clears one error from the error queue. Errors have the following format -113,"Undefined header". The error string may contain up to 255 characters.

Error List

Device-dependent Errors

308, "Not allowed while sequence is running",

309, "Cell has no sequence enabled",

310, "Seq current exceeds cell capacity",

311, "Cell is running a sequence",

312,"Seq current exceeds limit for precharge step",

313, "Cell init error, inhibit is latched",

314, "Seq current does not meet minimum channel requirements",

315, "Invalid Sequence Step",

316, "Sequencer Call Failed",

400, "System Monitor: Cell Enable Line Asserted. Hardware Panic Detected.",

401, "System Monitor: Temperature Out of Range.",

402, "System Monitor: Fan Speed Out of Range.",

403, "System Monitor: PFC Temperature Out of Range.",

500, "Output Protection Asserted",

513, "LAN invalid IP address",

514,"LAN duplicate IP address",

515,"LAN failed to renew DHCP lease",

516,"LAN failed to configure",

517,"LAN failed to initialize",

518, "LAN VXI-11 fault",

544, "Backplane ID doesn't match expected ID for model number",

609,"System ADC test failed",

610, "Fan test failed",

611, "EEPROM load failed",

612, "EEPROM checksum failed",

613, "EEPROM save failed",

614, "Invalid serial number",

615, "Invalid MAC address",

900, "Firmware update failed",

901, "Fgpa update start failed",

-1000, "Cell Add Error",

-1001, "Invalid Cell Id",

-1002, "FW update: invalid data size!",

-1003, "Unable to get CAN send lock!",

-1004, "Sequences aborted due to watchdog timeout",

-1005, "Card Error Detected!",

-1006, "Timeout.",

-1007, "Lan Settings Error! Send SYST:ERR? for details.",

-1008, "CRC Error",

-1009, "FW update No Ack from Card",

-1010, "Interface Card Cal Corrupted!",

-1011, "Sequencer Locked.",

-1012, "Brownout Condition Detected.",

-1013, "Model Number does not match PFC dipswitch setting, Fets Locked!",

-1014, "Calibration Step Missing!",

-1015, "Calculated Calibration Constants outside of expected limits.",

Command Errors

-100, "Command error",

-101, "Invalid character",

-102, "Syntax error",

-103, "Invalid separator",

-104, "Data type error",

-105, "GET not allowed",

-108, "Parameter not allowed",

-109, "Missing parameter",

-110, "Command header error",

-111, "Header separator error",

-112, "Program mnemonic too long",

-113, "Undefined header",

-114, "Header suffix out of range",

-120, "Numeric data error",

-121, "Invalid character in number",

-123, "Exponent too large",

-124, "Too many digits",

-128, "Numeric data not allowed",

-130, "Suffix error",

-131, "Invalid suffix",

-134, "Suffix too long",

-138, "Suffix not allowed",

-140, "Character data error",

-141, "Invalid character data",

-144, "Character data too long",

-148, "Character data not allowed",

-150, "String data error",

-151, "Invalid string data",

-158, "String data not allowed",

-160, "Block data error",

-161, "Invalid block data",

-168, "Block data not allowed",

-170, "Expression error",

-171, "Invalid expression",

-178, "Expression data not allowed",

Execution Errors

-222, "Data out of range",

-223, "Too much data",

-224, "Illegal parameter value",

-225, "Out of memory",

-226, "Command msg invalid",

-227, "CAN aborted",

-228, "CAN send failed",

-229, "Invalid card and/or channel param",

-231, "Output buffer overflow",

-234, "Data corrupt or stale",

-241, "Hardware missing",

Internal Errors

-310, "System error",

-311, "Memory error",

-313, "Calibration memory lost",

-321, "Out of memory",

-330, "Self-test failed",

-350, "Queue overflow",

-363, "Input buffer overrun",

Query Errors

-400, "Query error",

-410, "Query INTERRUPTED",

-420, "Query UNTERMINATED",

-430, "Query DEADLOCKED",

-440, "Query UNTERMINATED after indefinite response",

5
Verification and Calibration

Verification Procedure

Introduction

Verification consists of using the SYSTem:TEST commands to verify the proper operation of both mainframe and modules. Mainframe verification verifies the operation of the BT2200 series mainframes. Channel verification verifies the operation of the charge-discharge modules.

You do not have to disconnect any cabling to perform verification.

CAUTION Initiating verification while a sequence is running or if calibration is in progress will generate an error.

Mainframe Verification

Mainframe verification checks the internal communication of the chassis, as well as the fan speed and internal temperature. It also tests the bias, EEPROM, and SDRAM. To run mainframe verification send:

SYSTem:TEST:MAINframe?

Channel Verification

Channel verification checks the following functions on the charge-discharge modules:

- Sourcing current on all channels
- Sinking current on all channels
- Voltage on all channels
- Sensing function on all channels

To run channel verification send:

SYSTem:TEST:CHANnel?

NOTE The SYSTem:TEST:ALL? and *TST? commands test the entire charge-discharge system, including modules.

Reference Calibration

Introduction

The instrument features closed-case electronic calibration; no internal mechanical adjustments are required. The instrument calculates correction factors based on reference values that you enter and stores correction factors in non-volatile memory until the next calibration is performed.

Calibration Interval

The instrument should be calibrated on a regular interval determined by the accuracy requirements of the application.

- **Reference Calibration** - Perform annually (once per year)
- **Channel Alignment** - Perform weekly (once per week)
  Channel alignment must be performed on all modules whenever any module is added or removed from the mainframe. Refer to the last note under Module Specifications for information about longer channel alignment intervals.

Calibration Environment

The calibration ambient temperature is stable and between 20 °C and 35 °C, ideally 23 °C ±2 °C. Relative humidity is <80%.

Calibration Equipment

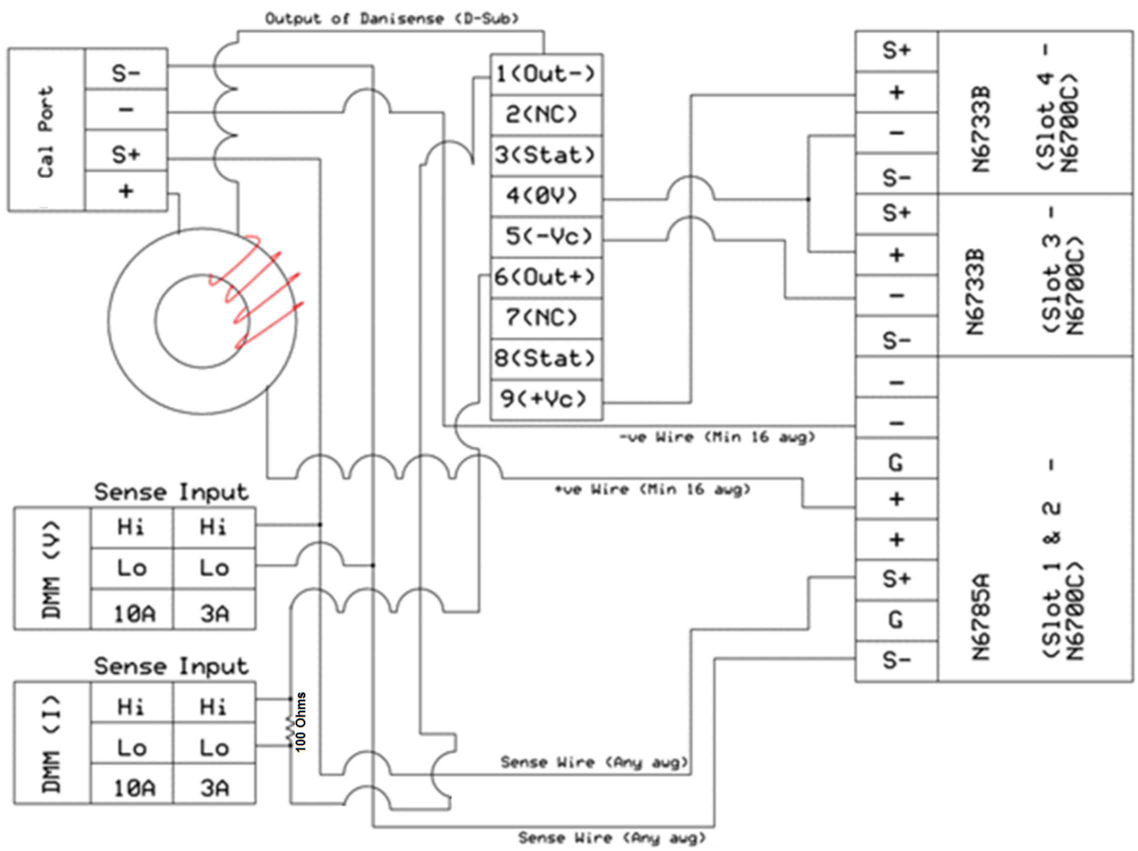
The following equipment is recommended for calibration:

Calibration Items	Description	Part Number
Calibration connector	4- pin plug connects to Cal port on the BT2200A mainframe	Housing: TE AMP 770849-4 Pins (qty 4): 770476-2 Wire: AWG 18 -24
Current transducer	200 A current transducer *	Danisense DS200IDSA
Transducer cable	Power and signal cable for current transducer	Danisense 1412100001
Current burden resistor	RES 100 Ω, 0.01% 0.2ppm/C *	Vishay Y0706100R000T9L
Power supply	3 output power supply +/-15 VDC and 6V/5A	Keysight N6700B with Keysight N6733B (qty 2) Keysight N6785A
DMM	Voltage and current DMM (qty 2) *	Keysight 34460A or equivalent (qty 2)
Banana plugs	Two-wire banana plugs for DMM connections (as required)	None

* This equipment must be in calibration

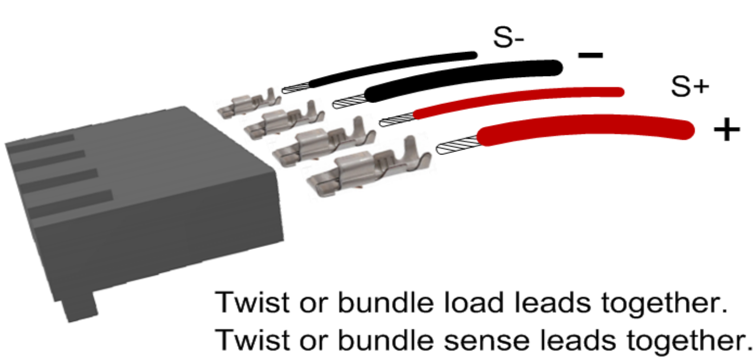
Calibration Connections

The following schematic details the calibration connections:



Calibration Cable

The calibration cable is built using the TE AMP housing (refer to the part numbers under Calibration equipment). The following figure shows the wire connections to the calibration housing, which plugs into the CAL port on the front of the BT2200 series mainframe.

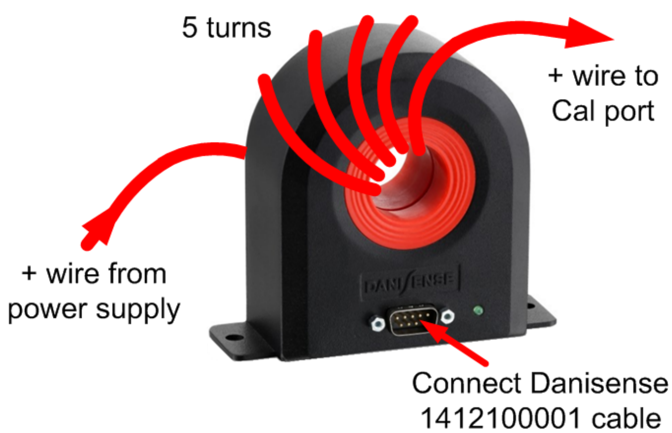


- The positive lead loops through the Current Transducer and connects to the + output of the N6785A.
- The negative lead connects to the – output of the N6785A.
- The S+ and S- leads connect to the Hi and Lo inputs of the voltage DMM .

Current Transducer Wiring

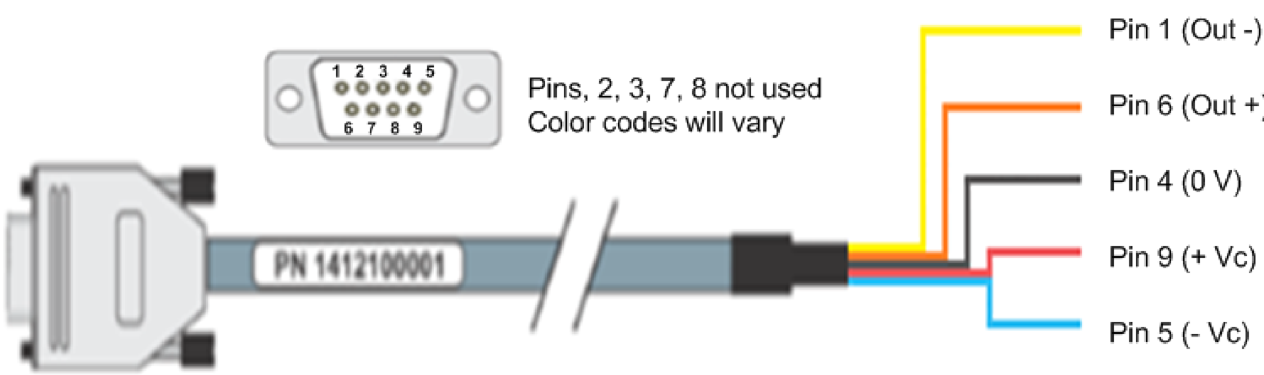
Using Danisense 1412100001 Signal and Power Cable or equivalent connect Danisense +15V to the plus output of one of the N6733B. Connect Danisense –15V to the minus output of the other N6733B. Connect the unused plus/minus of the two N6733B to each other (see figure 6) and to the ground/0V pin of the Danisense. This will provide the + - 15 V to power Danisense. Set both power supplies to 15 V and when ready to use turn on the output. Alternatively use Danisense DSSIU-6 or a dual output power supply.

Connect the Danisense signal outputs to the 100 Ohm burden resistor and connect to the matching polarity of the VOLTAGE input of the other DMM this will be the current DMM. (see figures 3 and 7) and note the resistor across the input connections.



- The positive lead from the N6785A power supply must be looped 5 turns through the Current Transducer following the positive current arrow.

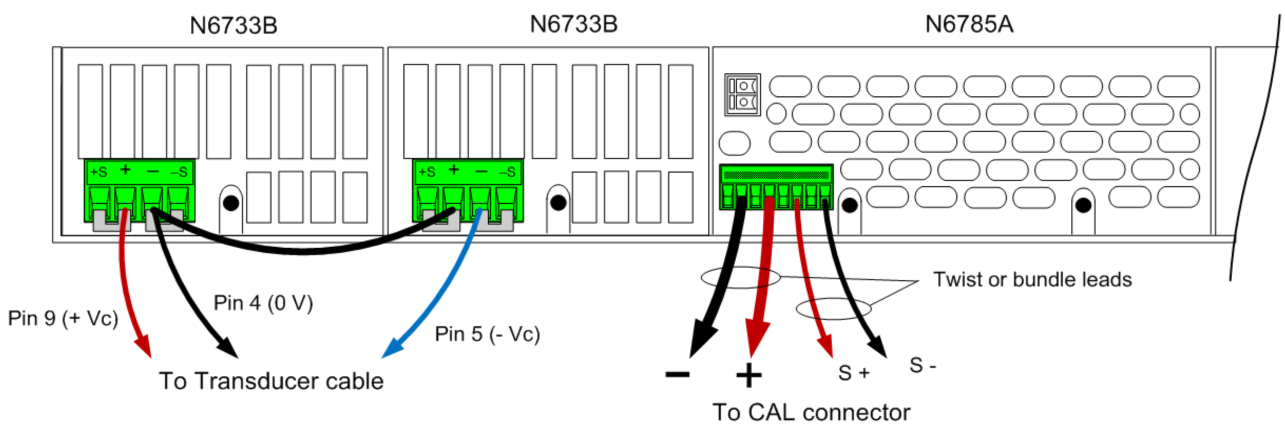
Use the Danisense 1412100001 Signal and Power Cable to connect to the current DMM and N6733A power supplies. You must cut one of the connectors at the end of the cable and connect the individual pin wires identified below.



- The wires from pins 1 and 6 are connected to the Hi and Lo inputs of the current DMM. The 100 Ohm burden resistor is connected across the DMM inputs.
- The wires from pins 4, 5, and 9 are connected to the outputs of the paralleled N6733B power supplies.

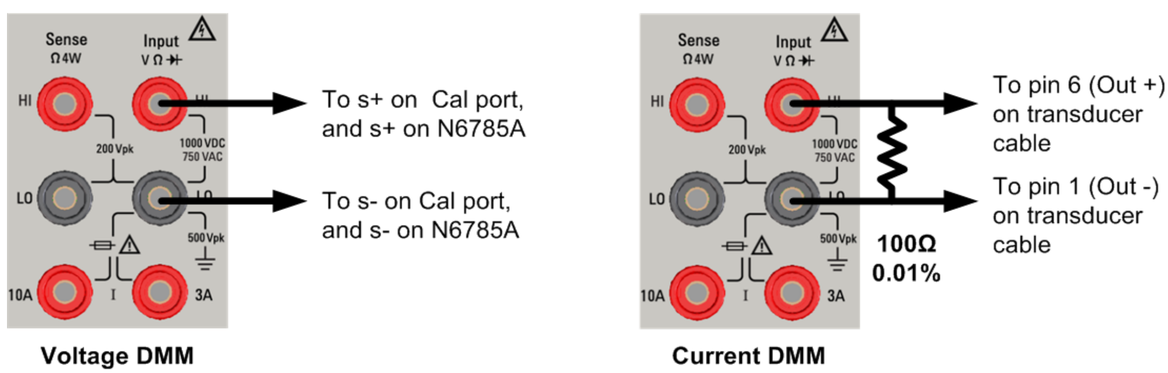
Power Supply Connections

The power supplies provide the +/- 15V bias for the Current Transducer, and a reference current for the BT2200 series mainframe.



- The pins 4, 5, and 9 wires are part of the Danisense 1412100001 Signal and Power Cable. Color codes will vary.
- The positive lead (+) from the N6785A power supply must be looped 5 turns through the Current Transducer.

DMM Connections



- You can use the same DMM for both voltage and current calibration, but you must add the 100 Ohm burden resistor to the current DMM.
- Use two-wire banana plugs for the DMM connections as needed.

Calibration Procedure

The following SCPI command starts the calibration. It aborts any other instrument process that is running and prepares the instrument for calibration. You can calibrate any of the six calibrations steps independently of the other steps and store those results. The other values will not be affected.

Start the Calibration

Send CAL:STARt

Calibrate the Reference Voltage

Connect the Voltage DMM as previously shown under "DMM Connections". Put the DMM in voltage measurement mode, in AUTO range, with a minimum of 10 NPLC averaging.

Step 1. Start the 1 V calibration. Send CAL:STEP 1

Step 2. Measure the DC voltage with the DMM.

Cal Step 1	Expected Value
Begins 1 V calibration	1 V

Step 3. Send the measurement to the instrument. Send CAL:VALue? 1, <value>

Step 4. Start the 4 V calibration. Send CAL:STEP 2

Step 5. Measure the DC voltage with the DMM.

Cal Step 2	Expected Value
Begins 4 V calibration	4 V

Step 6. Send the valid measurement to the instrument. Send CAL:VALue? 2, <value>

Calibrate the Reference Current

Connect the Current DMM as previously shown under "DMM Connections". Also connect the burden resistor. Put the DMM in voltage measurement mode, in AUTO range, with a minimum of 10 NPLC averaging.

The voltage read from the DMM must be converted to current using the following:

Current = ((Volts / Rburden) * CT_TurnsInteral) / Loops through transducer

where:
Volts = the voltage measured by the DMM
Rburden = 100. This is the calibrated burden resistor value.
CT_TurnsInteral = 500. This is the number of turn in the Danisense current transducer.
Loops through transducer = 5
Example: Current = (4V/100)*500/5 = 4 A

Step 1. Measure the DC voltage with the DMM (expected value = 0 V).

Step 2. Convert the voltage measurement to current using the above formula.

Step 3. Record the current value as the OffsetCurrent for future use.

Step 4. Program the N6785A power supply to 3 V/6 A, and enable the output.

Step 5. Start the 1 A calibration. Send CAL:STEP 3

Cal Step 3	Expected Value
Begins 1 A calibration	1 V

Step 6. Measure the DC voltage with the DMM.

Step 7. Convert the voltage measurement to current using the above formula. This is the MeasuredCurrent.

Step 8. Calculate the actual current: ActualCurrent = MeasuredCurrent - OffsetCurrent.

Step 9. Send the ActualCurrent value to the instrument. Send CAL:VALue? 3, <value>

Step 10. Start the 4 A calibration. Send CAL:STEP 4

Cal Step 4	Expected Value
Begins 4 A calibration	4 V

Step 11. Repeat steps 6 through 8.

Step 12. Send the ActualCurrent value to the instrument. Send CAL:VALue? 4, <value>.

Step 13. Start the -1 A calibration. Send CAL:STEP 5

Cal Step 5	Expected Value
Begins low -1 A calibration	-1 V

Step 14. Repeat steps 6 through 8.

Step 15. Send the ActualCurrent value to the instrument. Send CAL:VALue? 5, <value>

Step 16. Start the -4 A calibration. Send CAL:STEP 6

Cal Step 6	Expected Value
Begins -4 A calibration	-4 V

Step 17 Repeat steps 6 through 8.

Step 18. Send the ActualCurrent value to the instrument. Send CAL:VALue? 6, <value>

Store the Results and End Calibration

Step 1. Calculate and store the calibration results. This step overwrites the previous calibration constants. Send CAL:STORe

Step 2. Disconnect the DMM from the instrument.

Apply the Calibration Constants to the Channels

Refer to Channel Alignment.

Channel Alignment

NOTE **IMPORTANT** Remove all connections from the **CAL** connector on the front panel of the CDS before performing the channel alignment.

During channel alignment, each individual channel is sequentially connected to the mainframe's calibration reference, and gain and offset corrections are calculated and stored in the module's non-volatile memory.

Prerequisites

- The unit must pass self-test, which is run at the start of channel alignment. If self-test (*TST) does not pass, channel alignment (i.e. CAL:AUTO?) will abort.
- The unit must stay within its temperature limits. If the unit exceeds the limits, CAL:AUTO? will abort.

Running Channel Alignment

Send CAL:AUTO? <channels>

Channel alignment is automatic and takes up to 45 minutes, or less if the mainframe has fewer than 8 modules installed. The command returns a +0 (zero) when successful, and a +1 when a channel failed.

The **Test** indicator flashes orange when channel alignment is running. The Test indicator turns off when alignment is complete.

If Problems Occur with Channel Alignment

If the alignment value of a specific channel is out of the accepted tolerance, that channel will fail. The remaining channels will continue to alignment with the results being stored when alignment completes.

An error will be placed in the error queue with the channel number that failed, along with measurement information detailing the issue. Use SYSTem:ERRor? to read the error queue. See SCPI Error Messages for more information.

Aborting Channel Alignment

If you need to abort channel alignment, either press the **Abort** button on the front panel for one second, or send a device clear.

The Test indicator turns off when channel alignment stops.

NOTE You can also query the status register via a different connection and check when the cal bit returns to 0. If you are using the LAN interface for example, you can query the status register using the USB interface.

Maintenance

Firmware Updates

Keysight recommends that you always install the latest firmware. To view your current firmware version, refer to *IDN?.

You can obtain the latest firmware updates at https://www.keysight.com

Supporting documentation for installing the firmware is also available.

Calibration

No additional maintenance other than calibration is required. See Calibration Interval.

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