Product Manual

VOLT Series

VOLT 108 and VOLT 116
GRANITE Measurement Modules

RELIABLE
SINCE 1974
MONITORING

CAMPBELL SCIENTIFIC

Guarantee

This equipment is guaranteed against defects in materials and workmanship. We will repair or replace products which prove to be defective during the guarantee period as detailed on your invoice, provided they are returned to us prepaid. The guarantee will not apply to:

- Equipment which has been modified or altered in any way without the written permission of Campbell Scientific

- Batteries

- Any product which has been subjected to misuse, neglect, acts of God or damage in transit.

Campbell Scientific will return guaranteed equipment by surface carrier prepaid. Campbell Scientific will not reimburse the claimant for costs incurred in removing and/or reinstalling equipment. This guarantee and the Company's obligation thereunder is in lieu of all other guarantees, expressed or implied, including those of suitability and fitness for a particular purpose. Campbell Scientific is not liable for consequential damage.

Please inform us before returning equipment and obtain a Repair Reference Number whether the repair is under guarantee or not. Please state the faults as clearly as possible, and if the product is out of the guarantee period it should be accompanied by a purchase order. Quotations for repairs can be given on request. It is the policy of Campbell Scientific to protect the health of its employees and provide a safe working environment, in support of this policy a "Declaration of Hazardous Material and Decontamination" form will be issued for completion.

When returning equipment, the Repair Reference Number must be clearly marked on the outside of the package. Complete the "Declaration of Hazardous Material and Decontamination" form and ensure a completed copy is returned with your goods. Please note your Repair may not be processed if you do not include a copy of this form and Campbell Scientific Ltd reserves the right to return goods at the customers' expense.

Note that goods sent air freight are subject to Customs clearance fees which Campbell Scientific will charge to customers. In many cases, these charges are greater than the cost of the repair.

About this manual

Please note that this manual was originally produced by Campbell Scientific Inc. primarily for the North American market. Some spellings, weights and measures may reflect this origin.

Some useful conversion factors:

Area: 1 in^2 (square inch) = 645 mm^2

Length: 1 in. (inch) = 25.4 mm
1 ft (foot) = 304.8 mm
1 yard = 0.914 m
1 mile = 1.609 km

Mass: 1 oz. (ounce) = 28.35 g
1 lb (pound weight) = 0.454 kg

Pressure: 1 psi (lb/in^2) = 68.95 mb

Volume: 1 UK pint = 568.3 ml
1 UK gallon = 4.546 litres
1 US gallon = 3.785 litres

In addition, while most of the information in the manual is correct for all countries, certain information is specific to the North American market and so may not be applicable to European users.

Differences include the U.S standard external power supply details where some information (for example the AC transformer input voltage) will not be applicable for British/European use. *Please note, however, that when a power supply adapter is ordered it will be suitable for use in your country.*

Reference to some radio transmitters, digital cell phones and aerials may also not be applicable according to your locality.

Some brackets, shields and enclosure options, including wiring, are not sold as standard items in the European market; in some cases alternatives are offered. Details of the alternatives will be covered in separate manuals.

Part numbers prefixed with a "#" symbol are special order parts for use with non-EU variants or for special installations. Please quote the full part number with the # when ordering.

Recycling information

At the end of this product's life it should not be put in commercial or domestic refuse but sent for recycling. Any batteries contained within the product or used during the products life should be removed from the product and also be sent to an appropriate recycling facility.

Campbell Scientific Ltd can advise on the recycling of the equipment and in some cases arrange collection and the correct disposal of it, although charges may apply for some items or territories.

For further advice or support, please contact Campbell Scientific Ltd, or your local agent.

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WHEN MEASUREMENTS MATTER

Safety

DANGER — MANY HAZARDS ARE ASSOCIATED WITH INSTALLING, USING, MAINTAINING, AND WORKING ON OR AROUND **TRIPODS, TOWERS, AND ANY ATTACHMENTS TO TRIPODS AND TOWERS SUCH AS SENSORS, CROSSARMS, ENCLOSURES, ANTENNAS, ETC**. FAILURE TO PROPERLY AND COMPLETELY ASSEMBLE, INSTALL, OPERATE, USE, AND MAINTAIN TRIPODS, TOWERS, AND ATTACHMENTS, AND FAILURE TO HEED WARNINGS, INCREASES THE RISK OF DEATH, ACCIDENT, SERIOUS INJURY, PROPERTY DAMAGE, AND PRODUCT FAILURE. TAKE ALL REASONABLE PRECAUTIONS TO AVOID THESE HAZARDS. CHECK WITH YOUR ORGANIZATION'S SAFETY COORDINATOR (OR POLICY) FOR PROCEDURES AND REQUIRED PROTECTIVE EQUIPMENT PRIOR TO PERFORMING ANY WORK.

Use tripods, towers, and attachments to tripods and towers only for purposes for which they are designed. Do not exceed design limits. Be familiar and comply with all instructions provided in product manuals. Manuals are available at www.campbellsci.eu or by telephoning +44(0) 1509 828 888 (UK). You are responsible for conformance with governing codes and regulations, including safety regulations, and the integrity and location of structures or land to which towers, tripods, and any attachments are attached. Installation sites should be evaluated and approved by a qualified engineer. If questions or concerns arise regarding installation, use, or maintenance of tripods, towers, attachments, or electrical connections, consult with a licensed and qualified engineer or electrician.

General
- Prior to performing site or installation work, obtain required approvals and permits. Comply with all governing structure-height regulations, such as those of the FAA in the USA.
- Use only qualified personnel for installation, use, and maintenance of tripods and towers, and any attachments to tripods and towers. The use of licensed and qualified contractors is highly recommended.
- Read all applicable instructions carefully and understand procedures thoroughly before beginning work.
- Wear a **hardhat** and **eye protection**, and take **other appropriate safety precautions** while working on or around tripods and towers.
- **Do not climb** tripods or towers at any time, and prohibit climbing by other persons. Take reasonable precautions to secure tripod and tower sites from trespassers.
- Use only manufacturer recommended parts, materials, and tools.

Utility and Electrical
- **You can be killed** or sustain serious bodily injury if the tripod, tower, or attachments you are installing, constructing, using, or maintaining, or a tool, stake, or anchor, come in **contact with overhead or underground utility lines**.
- Maintain a distance of at least one-and-one-half times structure height, or 20 feet, or the distance required by applicable law, **whichever is greater**, between overhead utility lines and the structure (tripod, tower, attachments, or tools).
- Prior to performing site or installation work, inform all utility companies and have all underground utilities marked.
- Comply with all electrical codes. Electrical equipment and related grounding devices should be installed by a licensed and qualified electrician.

Elevated Work and Weather
- Exercise extreme caution when performing elevated work.
- Use appropriate equipment and safety practices.
- During installation and maintenance, keep tower and tripod sites clear of un-trained or non-essential personnel. Take precautions to prevent elevated tools and objects from dropping.
- Do not perform any work in inclement weather, including wind, rain, snow, lightning, etc.

Maintenance
- Periodically (at least yearly) check for wear and damage, including corrosion, stress cracks, frayed cables, loose cable clamps, cable tightness, etc. and take necessary corrective actions.
- Periodically (at least yearly) check electrical ground connections.

WHILE EVERY ATTEMPT IS MADE TO EMBODY THE HIGHEST DEGREE OF SAFETY IN ALL CAMPBELL SCIENTIFIC PRODUCTS, THE CUSTOMER ASSUMES ALL RISK FROM ANY INJURY RESULTING FROM IMPROPER INSTALLATION, USE, OR MAINTENANCE OF TRIPODS, TOWERS, OR ATTACHMENTS TO TRIPODS AND TOWERS SUCH AS SENSORS, CROSSARMS, ENCLOSURES, ANTENNAS, ETC.

Table of contents

1. Introduction

The VOLT 108 and VOLT 116 are 24-bit analogue input modules that significantly increase the number of analogue channels in a data logger system. The VOLT 108 has eight differential channels and the VOLT 116 has 16 differential channels.

The VOLT 108 and VOLT 116 feature a 24-bit analogue-to-digital converter and a low-noise, analogue front-end to provide superior analogue measurements. They also support period average measurements and include both current and voltage excitation channels.

Use the CPI calculator at www.campbellsci.eu/downloads/cpi-calculator ⬈ to estimate the usage and capacity of a CPI network. Select a CDM-A108 for a VOLT 108 and a CDM-A116 when using a VOLT 116.

Throughout this manual, any reference to the VOLT 100 series applies to both the VOLT 108 and VOLT 116, unless specifically noted.

2. Precautions

- READ AND UNDERSTAND the Safety section at the front of this manual.
- WARNING:
    - Protect from over-voltage
    - Protect from water
    - Protect from ESD (electrostatic discharge)
- IMPORTANT: Maintain a level of calibration appropriate to the application. Campbell Scientific recommends factory recalibration of the VOLT 100 series every three years.

3. Initial inspection

- Inspect the packaging and contents for damage immediately. File damage claims with the shipping company.

- Check packaging materials for all products. Check model numbers, part numbers, product descriptions, and cable lengths against shipping documents. Model or part numbers are found on each product. Cable numbers are normally found at the end of the cable that connects to the measurement device. Check that expected cable lengths were received. Contact Campbell Scientific immediately if you find any discrepancies.

- Check the operating system version in the VOLT 100 series, and the data logger. Update as needed. See Operating systems (p. 22).

- For more information on accessing the calibration certificate watch a video at www.campbellsci.eu/videos/calibration-certs. ▶

4. Measurement quickstart using *SURVEYOR*

Campbell Scientific *SURVEYOR* software is an easy way to quickly see measurement results and store data from the VOLT 100 series. The module configuration can be saved on the computer or exported as a CRBasic data logger program. *SURVEYOR* is available as a download from www.campbellsci.com/cs-surveyor ⬀. A video tutorial is available at www.campbellsci.com/videos/surveyor ▶.

This section will guide you through reading a differential Type-T thermocouple on a VOLT 100 series. With minor changes, these steps can apply to other compatible measurements.

1. Open *SURVEYOR* 👁.

2. Connect a USB cable between your computer and the VOLT 100 series **USB** port.

3. Apply 9.6 to 32 VDC external power using the green **Power** connector on the side of the VOLT 100 series.

4. Select **Connect Now** 🔗 CONNECT NOW .

5. Select the communications port, it will be labelled similar to **VOLT 100 series (COM3)**.

6. Make selections for **Speed or Noise Rejection** and **CAN enabled**. See the *SURVEYOR* help ℹ for more information on all settings.

7. Click **Apply**.

8. Select a **Sample Rate**. For this exercise, select **10 Hz**. (1/2 Hz is typical for thermocouple measurements.)

9. **Add Measurement**(s). For this exercise, add a Type-T differential thermocouple on **DIFF1**.
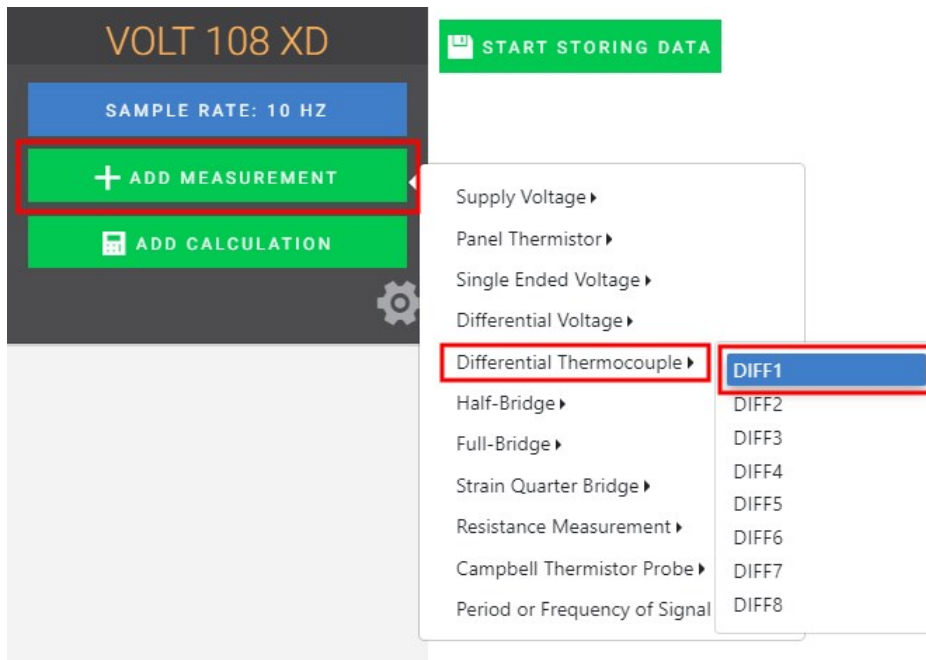
10. Wire the sensor according to the given wiring diagram.

11. Complete the rest of the form and **Apply** to save the configuration.

12. Check the resulting measurements in the numeric and graphic displays.
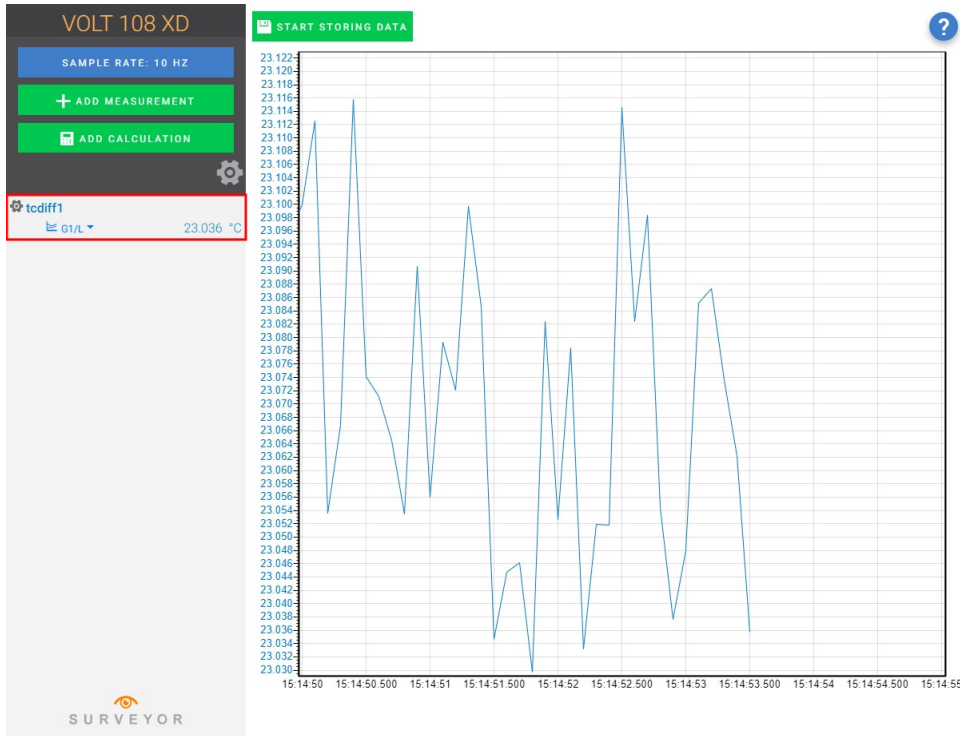
13. Click **Start Storing Data** ![Start Storing Data button]. While data is being stored the options to stop and pause data storage become available.

5. Programming quickstart using *SURVEYOR*

Campbell Scientific *SURVEYOR* is an easy way to generate a simple CRBasic program for your VOLT 100 series Campbell Scientific data acquisition system.

1. Configure the VOLT 100 series for measurements, see Measurement quickstart using SURVEYOR (p. 2).

2. Select **File** > **Export Datalogger Program** then select the data logger you will be connecting the VOLT 100 series to. For this example, we'll select GRANITE 6.
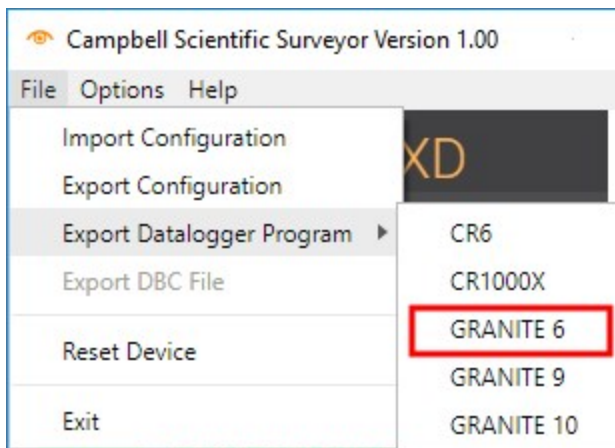
3. By default, the CRBasic program will be saved in C:\Users*username*\Documents\SURVEYOR.

6. Programming quickstart using *Short Cut*

Short Cut is another easy way to program a Campbell Scientific data acquisition system to measure a sensor and assign wiring terminals. *Short Cut* is available as a download from www.campbellsci.eu/shortcut.   It is also included in installations of *LoggerNet*, *RTDAQ*, and *PC400*.

The following procedure shows using *Short Cut* to program the data logger to measure a type-T thermocouple on a VOLT 100 series.

1. Open *Short Cut* and click **Create New Program**.

2. Double-click your data logger.

3. In the **Available Sensors and Devices** box, start typing GRANITE. You can also locate it in the **Devices** folder. Double click the GRANITE Measurement Module you are working with. Type the serial number located on the VOLT 100 series label. Optionally, type a name in the **Module ID String** if you want the module to have an ID. This is useful when multiple VOLT 100 series modules are connected to the data logger.
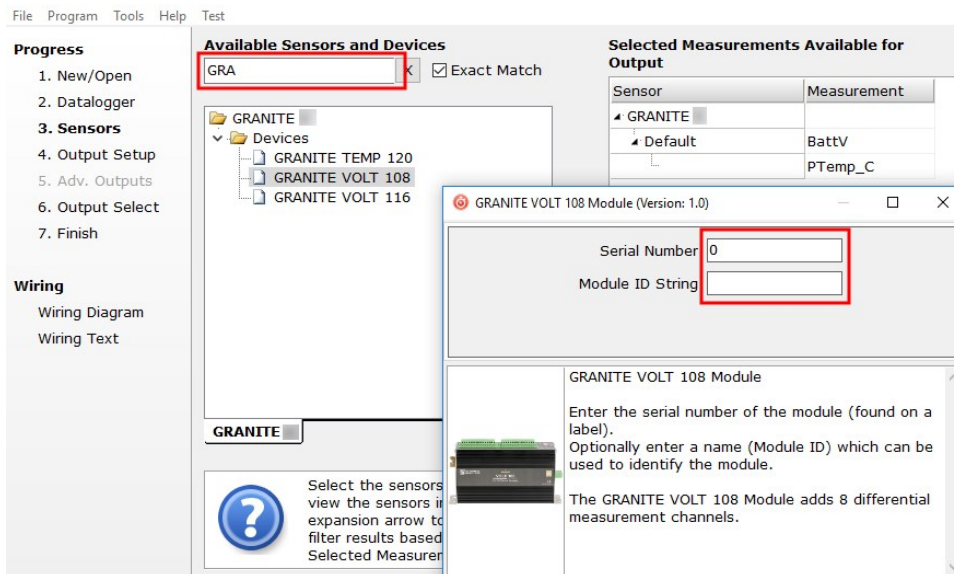
4. In the **Available Sensors and Devices** box, type Type T. You can also locate the thermocouple in the **Sensors** > **Temperature** folder. Double click **Type T Thermocouple**. Type the number of type T thermocouples connected to the VOLT 100 series. The temperature defaults to degree C. This can be changed by clicking the **Temperature** units box and selecting one of the other options.
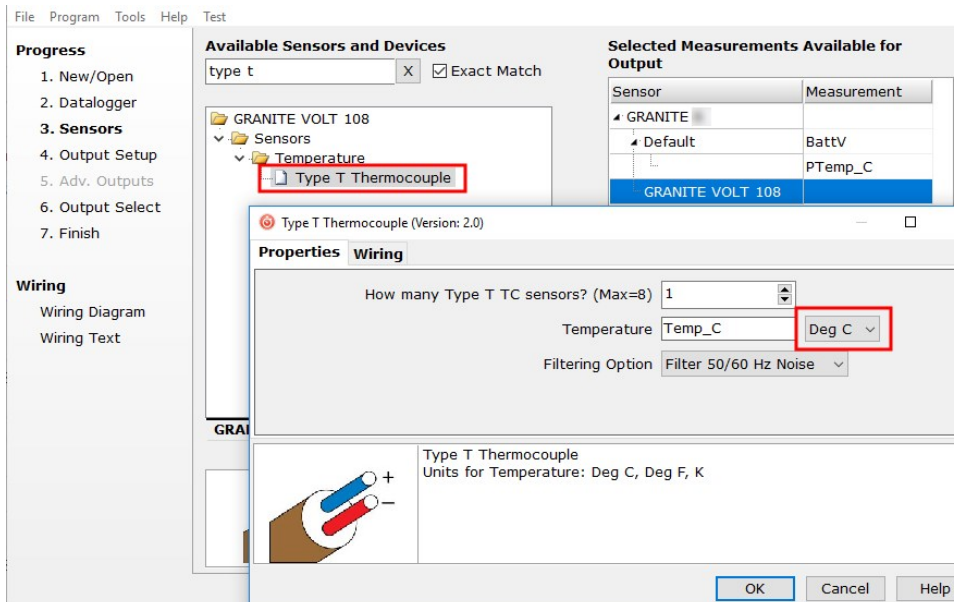
5. Click on the **Wiring** tab to see how the sensor is to be wired to the VOLT 100 series. Click **OK** after wiring the thermocouple.
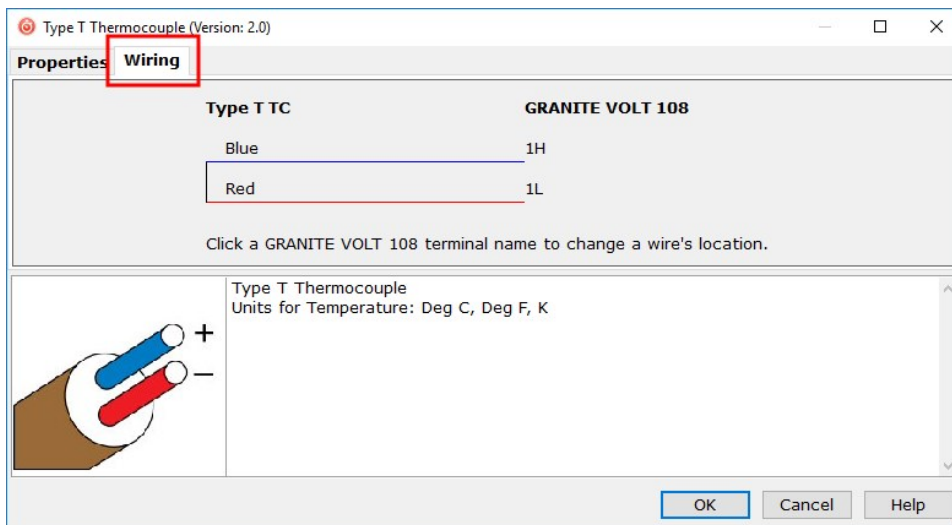
6. Repeat steps four and five for other sensors you want to measure. Click **Next**.

7. In **Output Setup**, type the scan rate, a meaningful table name, and the **Data Output Storage Interval**.
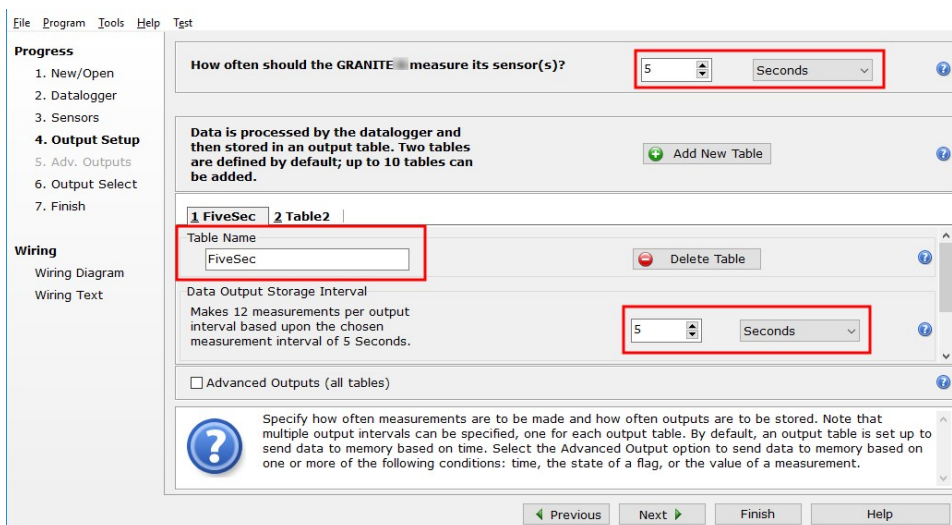
8. Select the measurement and its associated output option.
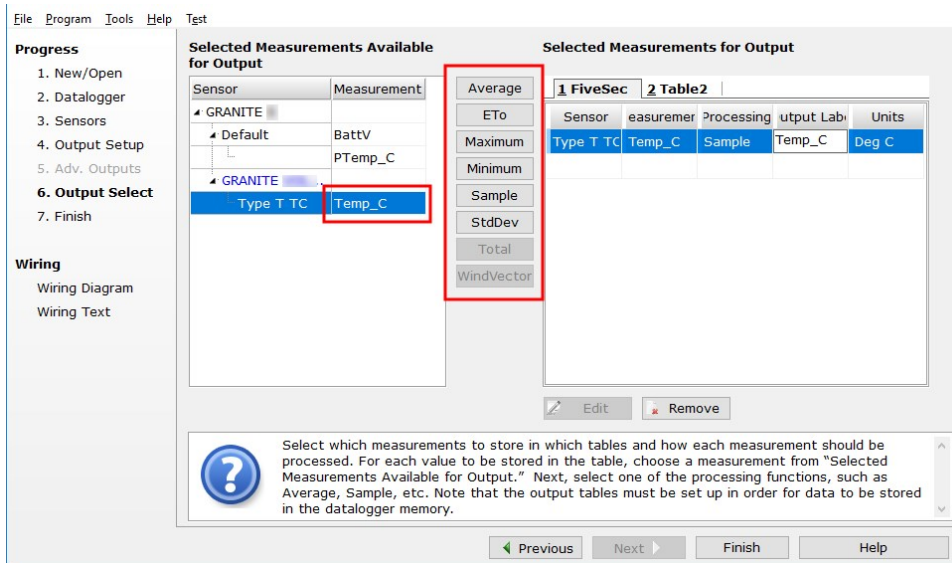
9. Click **Finish** and save the program. Send the program just created to the data logger if it is connected to the computer.

10. If the thermocouple is connected to the VOLT 100 series, check the output of the thermocouple in the data display of *LoggerNet*, *RTDAQ*, or *PC400* to make sure it is making reasonable measurements.

7. Overview

The VOLT 100 series expands the number of analogue measurement terminals and increases the measurement-speed potential in a data logger system. GRANITE Measurement Modules operate through a data logger program and communicate using the CAN peripheral interface (CPI). A single data logger can operate multiple GRANITE Measurement Modules. Use the CPI calculator at www.campbellsci.eu/downloads/cpi-calculator to estimate the usage and capacity of a CPI network. Select a CDM-A108 for a VOLT 108 and a CDM-A116 when using a VOLT 116.

The VOLT 100 series is compatible with the following data loggers:

- GRANITE 10
- GRANITE 9
- GRANITE 6
- CR6
- CR1000X

7.1 Wiring panel overview

> **CAUTION:**
> To avoid damage to sensors and devices, ensure that each removable wiring-terminal strip is connected to the VOLT 108 and VOLT 116 in the proper location before applying power. Each strip is keyed identically.
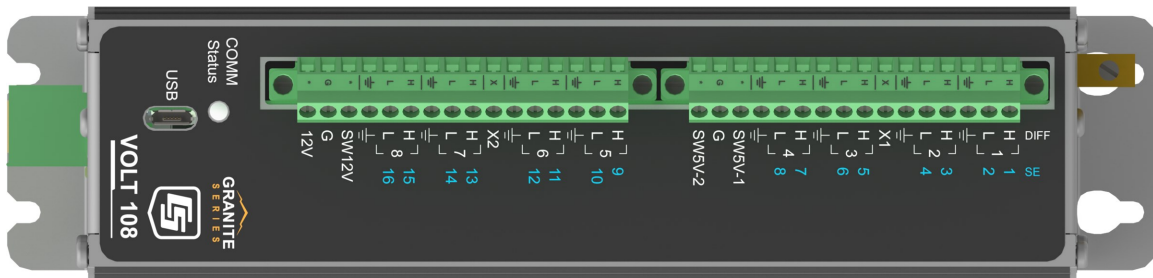
FIGURE 7-1. VOLT 108 Wiring panel
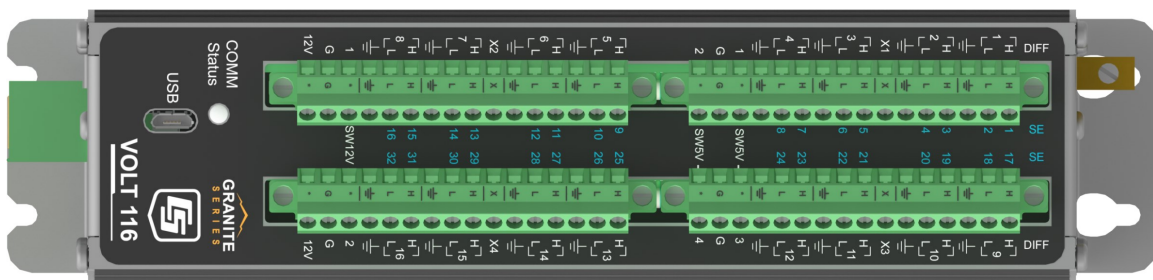
FIGURE 7-2. VOLT 116 Wiring panel
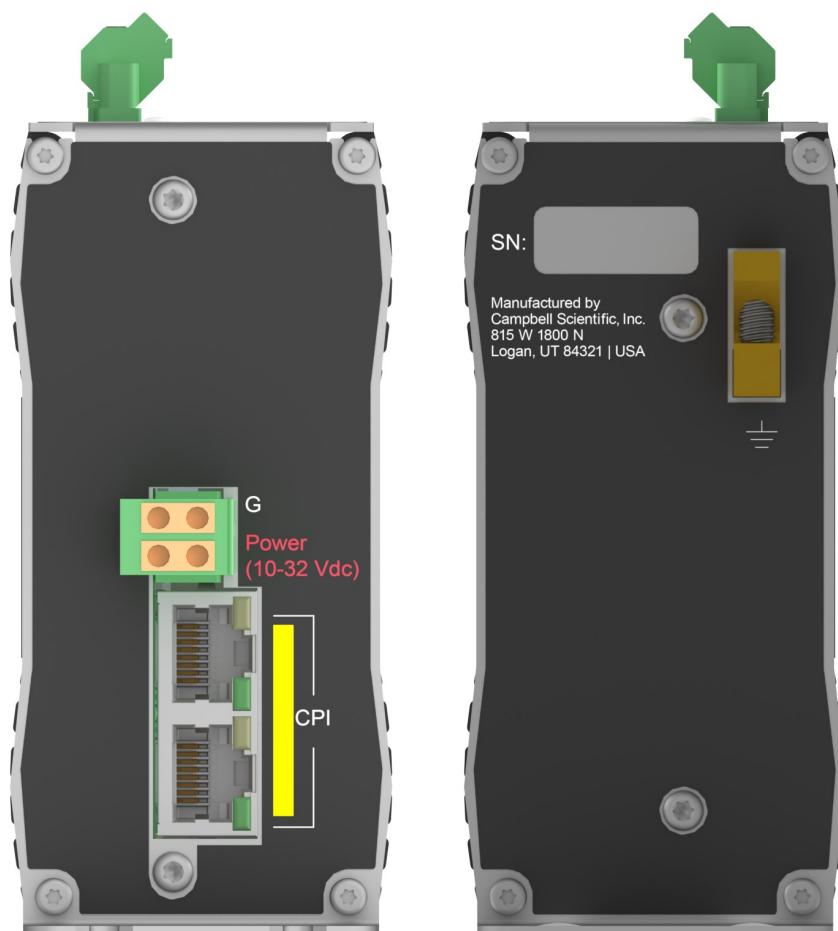
FIGURE 7-3. Power and CPI ports view (left) and ground lug view (right)

7.1.1 Analogue input

Analogue sensors output a continuous voltage or current signal that varies with the phenomena measured. Sensors compatible with the VOLT 100 series output a voltage. Current output can be made compatible with a resistive shunt. Sensor output is measured with the appropriate CRBasic measurement instruction. Measurement types are described the following sections.

Sensor connection is to **H/L** terminals configurable for differential (**DIFF**), single-ended (**SE**), or period-average inputs. For example, differential channel **1** is comprised of terminals **1H** and **1L**, with **1H** as high and **1L** as low.

7.1.1.1 Single-ended measurements

A single-ended measurement measures the difference in voltage between the terminal configured for single-ended input and the reference ground. Single-ended terminals are labelled in blue. The VOLT 108 has 16 **SE** terminals, and the VOLT 116 has 32. For example, single-ended channel 1 is comprised of terminals **1** and ⏚.

7.1.1.2 Differential measurements

A differential measurement measures the difference in voltage between two input terminals. Use a differential measurement to measure current by using external resistors to convert current to voltage. The VOLT 108 has 8 **H/L** differential terminals, and the VOLT 116 has 16.

7.1.1.3 Period averaging

Single-ended terminals on the VOLT 100 series are also configurable for measuring the period of an analogue signal.

7.1.2 Voltage and current excitation

X terminals supply switched voltage or current to sensors. The VOLT 108 has two **X** terminals, and the VOLT 116 has four.

- Voltage Excitation (switched-analogue output) – **X** terminals, configured for voltage excitation output, supply precise voltage in the range of ±5000 mV. These terminals are regularly used with resistive-bridge measurements.

- Current Excitation (switched-analogue output) – **X** terminals, configured for current excitation output, supply precise current in the range of ±2.5 mA. These terminals are regularly used with resistive-bridge measurements.

7.1.3 Switched voltage output

SW5V and **SW12V** terminals supply voltage and control for sensors. The VOLT 108 includes two **SW5V** and one **SW12V** terminals. The VOLT 116 includes four **SW5V** and two **SW12V** terminals.

7.1.4 Grounding terminals

Proper grounding lends stability and protection to a data acquisition system. It is the easiest and least expensive insurance against data loss. The following terminals are provided for sensor and VOLT 100 series ground connections:

- Signal Ground (⏚) – reference for single-ended analogue inputs, excitation returns, and as a ground for sensor shield wires. Current-loop sensors, however, should be grounded to power ground.

- Power Ground (**G**) – return for 5V, 12V, and current-loop sensors. Use of G grounds for these outputs minimizes potentially large current flow through the analogue-voltage-measurement section of the wiring panel, which can cause single-ended voltage measurement errors.

- Earth Ground Lug (⏚) – connection point for a heavy-gauge earth-ground wire. A good earth connection is necessary to secure the ground potential of the VOLT 100 series and shunt transients away from electronics. 14 AWG wire, minimum, is recommended.

> **NOTE:**
> Several ground wires can be connected to the same ground terminal.

7.1.5 Power terminals

7.1.5.1 Power in

The removable **Power** connector is the connection point for external power supply components. The power supply must be in the range of 9.6 to 32 VDC.

7.1.5.2 Power out

The VOLT 100 series can be used as a power source for sensors. The following voltage terminals are available:

- **12V** and **SW12V** – Regulated 12 VDC when the supply voltage is 14.5 to 32 VDC. Below 14.5 VDC, the voltage tracks the power supply. Current output is limited to 200 mA.
- **SW5V** – See Switched 5 VDC (p. 19) for information on voltage and current sourcing limits.

7.1.6 Communications ports

One micro-B **USB** port, labelled **USB**, is for communicating with a computer through *SURVEYOR* or *Device Configuration Utility* software.

CPI is a proprietary protocol that supports GRANITE Measurement Modules. Two RJ45 ports labelled **CPI** enable communications with a Campbell Scientific data logger and other GRANITE Measurement Modules.

7.1.7 LED indicators

7.1.7.1 COMM status

When the VOLT 100 series has successfully been configured by a data logger, the **COMM Status** LED will flash green. For scan rates 500 ms or slower, it will flash at the scan rate. For faster scan rates, the LED will flash green every few scans. See Table 12-2 (p. 39).

7.1.7.2 CPI port

When the VOLT 100 series has successfully been configured by a data logger, the green LED on the **CPI** port will flash. For scan rates 500 ms or slower, it will flash at the scan rate. For faster scan rates, the green LED will flash every few scans. A flashing orange LED indicates bus activity. A solid orange LED indicates a bus error. See Table 12-3 (p. 39).

8. Specifications

All Standard Duty (SD) VOLT 100 series units meet electrical specifications in a temperature range of -40 to 70 °C, non-condensing environment. Extended Duty (XD) units are tested over an extended temperature range of -55 to 85 °C. Recommended calibration interval is every three years.

8.1 Voltage measurements

Voltage measurements use a 24-bit Analogue-to-Digital (A-to-D) converter. One channel at a time is measured in numeric succession. Differential and single-ended channels can be mixed.

Terminals

  Differential configuration

VOLT 108:	DIFF 1H/1L – 8H/8L
VOLT 116:	DIFF 1H/1L – 16H/16L

  Single-ended configuration

VOLT 108:	SE 1 – 16
VOLT 116:	SE 1 – 32

Range:	±5000, ±1000, ±250 mV. See Table B-1 (p. 42)
Accuracy[1]	
0 to 40 °C:	±(0.04% of Reading + Offset[2])
–40 to 70 °C:	±(0.06% of Reading + Offset[2])
–55 to 85 °C:	±(0.08% of Reading + Offset[2])
Resolution:	See Table B-1 (p. 42)
Speed:	See Table 8-2 (p. 15)
	See also Fast measurements (p. 32)

Input resistance:	>20 GΩ
Input limits:	±5 VDC
Maximum input voltage:	±20 VDC
DC common-mode rejection:	>120 dB with input reversal
	≥86 dB without input reversal
Normal-mode rejection:	>70 dB at 60 Hz
Input current:	±3 nA typical at 25 °C
	±12 nA maximum at 50 °C
	±100 nA maximum at 85 °C

[1] Accuracy specification does not include sensor error or measurement noise.

[2] See

Table 8-1: Analogue voltage measurement accuracy offsets

Range (mV)	Differential with input reversal (µV)	Differential or single-ended without input reversal (µV)
±5000	±4	±40
±1000	±2	±10
±200	±1	±3

Table 8-2: Analogue voltage measurement speed[1]

f_{N1} (Hz)	Multiplexed[2] measurement			
	With input reversal		Without input reversal	
	Time (ms)	Rate (Hz)	Time (ms)	Rate (Hz)
30000	1.46	698.49	0.75	1394.05
15000	1.53	667.41	0.78	1332.15
7500	1.66	612.87	0.85	1223.49
3750	1.93	526.78	0.98	1051.89

| f_{N1} (Hz) | Multiplexed[2] measurement | | | |
| | With input reversal | | Without input reversal | |
	Time (ms)	Rate (Hz)	Time (ms)	Rate (Hz)
2000	2.40	422.83	1.22	844.59
1000	3.40	297.18	1.72	593.82
500	5.40	186.39	2.72	372.58
100	21.40	46.81	10.72	93.60
60	34.73	28.82	17.38	57.63
50	41.40	24.18	20.72	48.35
30	68.06	14.70	34.05	29.40
25	81.40	12.29	40.72	24.58
15	134.73	7.42	67.38	14.85
10	201.40	4.97	100.72	9.93
5	401.40	2.49	200.72	4.98
2.5	801.40	1.25	400.72	2.50

Table 8-2: Analogue voltage measurement speed[1]

[1] Default settling time of 500 μs.

[2] Refers to multiplexing circuitry internal to the VOLT 108/116.

8.2 Resistance measurements

Resistance measurements for four- and six-wire full-bridge and two-, three-, and four-wire half-bridge using voltage excitation or direct resistance measurements using current excitation. Excitation polarity reversal minimizes DC error.

Terminals

VOLT 108:   SE terminals **1 – 16**

DIFF terminals **1H/1L – 8H/8L**

Excitation terminals **X1 – X2**

VOLT 116:	SE terminals **1 – 32**
	DIFF terminals **1H/1L – 16H/16L**
	Excitation terminals **X1 – X4**

Accuracy[1,2]

0 to 40 °C:	±(0.02% of voltage measurement + offset)
–40 to 70 °C:	±(0.025% of voltage measurement + offset)
–55 to 85 °C:	±(0.03% of voltage measurement + offset)

[1] Assumes input reversal for differential measurements and excitation reversal for excitation voltage <1000 mV and excitation current <1 mA, not including bridge resistor errors and sensor and measurement noise.

[2] See GRANITE 6 Data logger Manual for help estimating measurement accuracy for ratiometric measurements. For `Resistance()` instruction, the excitation current is internally measured across an internal resistor (200 Ω, ±0.005% @ 25 °C, 2 ppm/°C TCR) with sensor resistance determined as Vs/Ix, where Ix is the measured excitation current and Vs is the returned sensor signal.

8.3 Voltage and current excitation

Two terminals on the VOLT 108 and four terminals on the VOLT 116 can be configured for voltage or current excitation using a 12-bit D-to-A converter. When used for ratiometric-resistance measurement, excitation is active only during measurement.

Terminals

VOLT 108:	X1 – X2
VOLT 116:	X1 – X4

Voltage excitation

Range:	±5000 mV

Accuracy[1]

0 to 40 °C:	±(0.05% of setting + 2.5 mV)
–40 to 70 °C:	±(0.08% of setting + 2.5 mV)
–55 to 85 °C:	±(0.1% of setting + 2.5 mV)
Resolution:	1.25 mV
Maximum source or sink current:	±50 mA

Current excitation

Range:	±2.5 mA

Accuracy[1]

0 to 40 °C:	±(0.05% of setting + 2.5 µA)
–40 to 70 °C:	±(0.08% of setting + 2.5 µA)
–55 to 85 °C:	±(0.1% of setting + 2.5 µA)
Resolution:	638 nA
Compliance voltage[2]:	±5000 mV

[1] Note that ratiometric accuracy, rather than absolute accuracy, determines overall measurement accuracy of ratiometric-resistance measurements.

[2] Current excitation meets specified accuracy when voltage at the port remains within the compliance voltage.

8.4 Period averaging

Terminals

VOLT 108:	SE 1 – 16
VOLT 116:	SE 1 – 32
Range:	See Table 8-3 (p. 18)
Accuracy:	±(0.01% of reading + resolution)
Resolution:	130 ns ÷ number of cycles

Table 8-3: Period average ranges

Voltage gain	Minimum peak-to-peak Signal[1,2] (mV)	Minimum pulse width (µs)	Maximum frequency (kHz)
1	500	2.4	200
3.8	50	8	50
19	10	50	8
67	2	80	5
[1] With signal centered around VOLT 108/116 ground.			
[2] Maximum period average signal amplitude = 20 V peak-to-peak.			

8.5 Voltage output

8.5.1 Continuous 12 VDC

Terminals

VOLT 108:	12V
VOLT 116:	12V

Voltage output[1]: 12.5 ± 0.5 VDC

Current sourcing limit (each): 200 mA typical, 180 mA minimum

[1] Unregulated below 14.5 V.

8.5.2 Switched 12 VDC

Terminals

VOLT 108:	SW12V-1
VOLT 116:	SW12V-1-2

Voltage output[1]: 12.5 ± 0.5 VDC

Current sourcing limit (each): 200 mA typical, 180 mA minimum

[1] Unregulated below 14.5 V.

8.5.3 Switched 5 VDC

Terminals

VOLT 108:	SW5V-1-2
VOLT 116:	SW5V-1-4

Voltage output

On, no load:	4.75 ± 0.25 VDC
Off:	<0.1 VDC

Output resistance: 30 Ω

Current sourcing limit: See FIGURE 8-1 (p. 20)
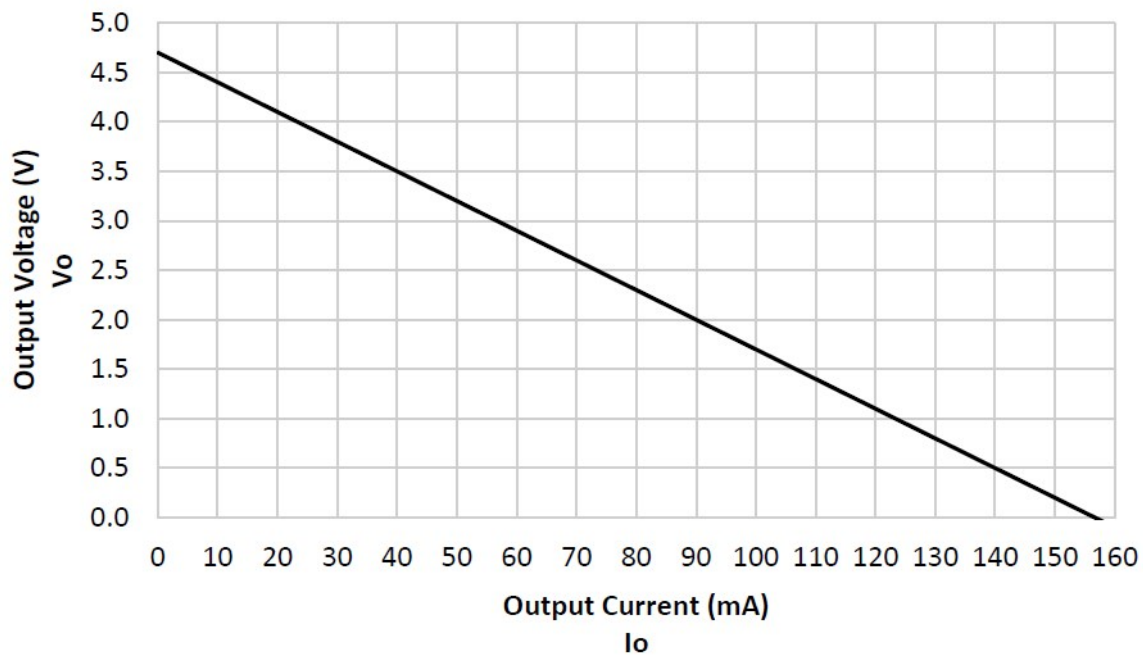
FIGURE 8-1. Current sourcing on SW5V terminals

8.6 Module

8.6.1 Communications

CPI:	RJ45 interface to Campbell Scientific data loggers, sensors, and GRANITE Measurement Modules.
USB:	USB micro-B device only, 2.0 full-speed 12 Mbps, for computer connection.

8.6.2 System

Processor:	Renesas RX63N (32-bit with hardware FPU, running at 96 MHz)
Memory:	2 MB SRAM

8.6.3 Power requirements

Voltage:	9.6 to 32 VDC
Typical Current Drain	(Sensor excitation or switched power loads are additive to the active values.)
Sleep:	<1 mA

Active 1 Hz Scan[1]:	2 mA, estimated
Active 20 Hz Scan[1]:	20 mA
Active 1 kHz Scan[2]:	67 mA

[1] Assumes one single-ended measurement with the first notch frequency (f_{N1}) at 30 kHz.

[2] Assumes one differential measurement with the first notch frequency (f_{N1}) at 30 kHz.

8.6.4 Compliance

View EU Declarations of Conformity at www.campbellsci.eu/volt108 ↗ and www.campbellsci.eu/volt116. ↗

8.6.5 Physical attributes

Dimensions:	20.3 x 12.7 x 5.1 cm (8.0 x 5.0 x 2.0 in); additional clearance required for cables and wires
Weight	
VOLT 108:	0.8 kg (1.75 lb)
VOLT 116:	0.9 kg (1.95 lb)
Operating Temperature	
Standard Duty (SD):	–40 to 70 °C
Extended Duty (XD):	–55 to 85 °C

9. Installation

Preconfigure and test stations in an indoor location before doing the field installation.

After installing a field station, wait long enough to confirm that good measurements are being made, that data is collected by the data logger, and that data from the data logger can be copied to a computer.

9.1 Install driver for computer connection

SURVEYOR automatically installs the required drivers. See: Measurement quickstart using SURVEYOR (p. 2). When *SURVEYOR* is not used, the device driver must be installed before connecting to the VOLT 100 series via USB for the first time.

To install the device driver using the *Device Configuration Utility*, select **GRANITE** > **VOLT 100 series**. Click the **Install the USB** driver link and follow the prompts.

> **TIP:**
> Driver installation is optional for computers running Windows 10 and later.

9.2 Operating systems

Campbell Scientific posts operating system (OS) updates at www.campbellsci.eu/downloads [↗] when they become available. Before deploying instruments, check OS versions and update as needed to the most recent version. Use the *Device Configuration Utility* and follow the procedures on the **Send OS** tab.

> **NOTE:**
> For best performance, use the most recent OS for each device.

9.3 Configuring VOLT 100 series

The VOLT 100 series arrives ready to be connected to a system. Device configuration is only required when multiple GRANITE Measurement Modules are connected to a single data logger. Each module must have a unique CPI address. Set a unique device name for further distinction between GRANITE Measurement Modules.

Configure the VOLT 100 series using one of four methods: through *SURVEYOR*, the `CPIAddModule()` program instruction, *Device Configuration Utility* software, or the **CPIStatus** table.

9.3.1 Configuring with *SURVEYOR*

Modules are automatically configured when connected to **SURVEYOR**. **SURVEYOR** sets the module CPI address to 1 and uses the device type and serial number to generate and assign a device name such as 'VOLT108-1234'.

For more information see Measurement quickstart using SURVEYOR (p. 2)

9.3.2 Configuring with the CPIAddModule() instruction

To configure a VOLT 100 series within a program, use the `CPIAddModule()` instruction. A separate instruction is used for each device. The `CPIAddModule()` instruction overrides settings entered by other means, such as *Device Configuration Utility* or the **CPIStatus** table.

```
CPIAddModule(CDMType, CDMSerialNo, CDMDeviceName, CPIAddress)
```

The data logger creates an internal list of CPI modules from each `CPIAddModule()` instruction. Modules added to the CPI bus will be checked against this list and reconfigured accordingly. See a programming example: Configuring GRANITE Measurement Module with CPIAddModule() (p. 45).

> **NOTE:**
> The `CPIAddModule()` instruction overrides changes made through *SURVEYOR*, *Device Configuration Utility* or the **CPIStatus** table.

9.3.3 Configuring with *Device Configuration Utility*

Install the device driver before connecting the VOLT 100 series to a computer. This is optional for Windows 10, or later, operating systems.

1. Open *Device Configuration Utility*.

2. Under **Device Type**, select **GRANITE** > **VOLT 100 series**.

3. Carefully review the Connect Instructions text provided on the right.

4. With the USB device driver installation complete, connect the supplied USB cable between the USB port on your computer and the **USB** port on the VOLT 100 series.

5. Apply 9.6 to 32 VDC to the power terminals on the device.

6. Click the browse button next to **Communication Port**.

7. Select the port labelled **VOLT 100 series**.

8. Click **OK**.

9. Click **Connect** then **OK** to avoid conflicts.

10. Set the **Device Name** (optional) and the **CPI Address**.

    a. **Device Name** is a user-editable field to set a unique name to the VOLT 100 series. The default name is **VOLT 100**.

    b. **CPI Address** specifies the address of the VOLT 100 series. Each GRANITE Measurement Module connected to the same data logger must have a unique address. By default, the VOLT 100 series uses a CPI address of 1. Allowable addresses are 1 through 120.

11. Click **Apply** to save your changes.

9.3.4 Configuring with CPIStatus table

When a GRANITE Measurement Module is used in a program, the data logger adds a **CPIStatus** table to display current CPI information. View the **CPIStatus** table in the *LoggerNet* Connect screen, or *Device Configuration Utility* **Data Monitor** tab. Information about each module included in the data logger program or connected to the CPI bus appears in the **CPIStatus** table within the **ModuleInfo()** array. Information is shown in the following order:

```
GRANITE Measurement Module Type, Serial Number, Device Name, CPI Address, Activity,
CDM OS Version
```

> **NOTE:**
> CDM OS version will be the last element in the **ModuleInfo()** array for VOLT 100 series modules with OS version 7 or newer.

Within the **ModuleInfo()** array index string, the Device Name and CPI Address fields can be edited. This provides a way to rename and readdress a VOLT 100 series through Campbell Scientific software without editing the CRBasic program or connecting directly to the **USB** port.

See CPIStatus table (p. 38) for additional information.

9.4 Data logger programming

Short Cut is the best source for up-to-date data logger programming code. Programming code is needed when:

- Creating a program for a new data logger installation
- Adding sensors to an existing data logger program

If your data acquisition requirements are simple, you can likely create and maintain a data logger program exclusively with *Short Cut*. If your data acquisition needs are more complex, the files that

Short Cut creates are a great source for programming code to start a new program or add to an existing custom program.

> **NOTE:**
> *Short Cut* cannot edit programs after they are imported and edited in *CRBasic Editor*.

See Programming quickstart using Short Cut (p. 6) for a *Short Cut* tutorial. If you wish to import *Short Cut* code into *CRBasic Editor* to create or add to a customized program, follow the procedure in Importing Short Cut code into CRBasic Editor (p. 41). Complete program examples can be found in: Example programs (p. 45).

9.4.1 Scan buffers

When VOLT 100 series instructions are included in a program, Campbell Scientific recommends setting the `BufferOption` of the `Scan()` instruction to a value greater than or equal to two seconds' worth of scans. For example, if the scan rate is 50 ms (.05 s), set the `BufferOption` to **40** (2 s ÷ .05 s = 40). At a minimum, the `BufferOption` should be set to **3**.

The data logger processes the data from the VOLT 100 series in batches according to frame syncs received from the VOLT 100 series. Upon receiving a batch of data, the data logger puts it into a processing queue. Processing the data may take more time than is available in a single scan. The `BufferOption` allows the data logger to balance its task load by processing the data from the VOLT 100 series during subsequent scans while maintaining correct data time stamps. If a `BufferOption` is not set, the data logger will attempt to process all of the data during the scan it is received, which can result in skipped scans. Scan buffers are only used when the data logger is running in pipeline mode.

9.4.2 GRANITE Measurement Module instructions

For the most current information on data logger instructions, refer to the CRBasic Editor Help⤢.

The first two parameters for each CDM instruction are the **CDMType** and **CPI_Addr**. **CDMType** refers to the GRANITE Measurement Model used. Valid entries are **VOLT108** and **VOLT116**. **CPI_ Addr** is the address of the VOLT 100 series. Wire sensors to the terminals specified within the corresponding measurement instructions. The following program example shows the use of the `CDM_VoltSE()` instruction.

```
'Program Example: Measuring a single-ended voltage
Public SEVolt
BeginProg
   Scan(5,Sec,3,0)
     'Measure Single-Ended Voltage on VOLT 108, CPI address 1
     CDM_VoltSe(VOLT108,1,SEVolt,1,mV5000,1,True,500,60,1,0)
   NextScan
EndProg
```

9.5 Data logger connection

VOLT 100 series devices communicate with a data logger through a **CPI** port. Each VOLT 100 series ships with a 6-inch RJ45 cable for this connection, though any CAT5e, or better, RJ45 cable can be used. To allow daisy-chaining, two **CPI** ports are available on the VOLT 100 series. Either **CPI** port on the VOLT 100 series connects directly to the **CPI** port on a GRANITE 10, GRANITE 9, GRANITE 6, CR6, or CR1000X data logger.

9.6 Connecting multiple GRANITE Measurement Modules

The CPI bus, which handles the communications between the data logger and GRANITE Measurement Modules, can accept addresses **1 to 120**. Multiple GRANITE Measurement Modules may be connected to a single data logger using a daisy-chain or star topology. In both network configurations, as total cable length increases, the maximum possible bit rate decreases. Therefore, in networks with long cable lengths, it may be necessary to use the **CPISpeed()** instruction to decrease the CPI network bit rate from its default 250 kbps. Limitations on cable length and bit rate are discussed further in CPI network bit rate (p. 35) and listed in Table 10-2 (p. 36).

Use the CPI calculator at www.campbellsci.eu/downloads/cpi-calculator to estimate the usage and capacity of a CPI network. Select a CDM-A108 for a VOLT 108 and a CDM-A116 when using a VOLT 116.

9.6.1 Daisy-chain topology

In a daisy-chain topology, GRANITE Measurement Modules are connected one after another, as shown in FIGURE 9-1 (p. 27).
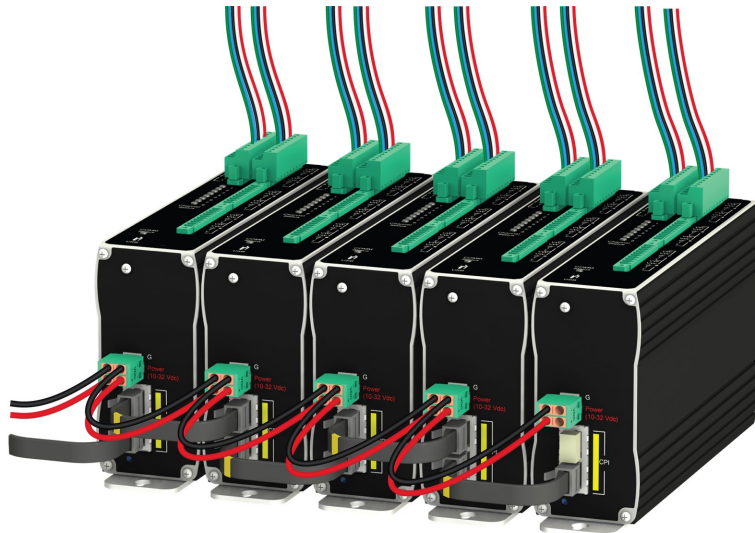
FIGURE 9-1. Multiple GRANITE Measurement Modules connected in a daisy-chain topology

For best performance, a CPI terminator (supplied in a CPI Network Kit) is installed in the open **CPI** port at the end of a daisy-chain network. For more information see: https://s.campbellsci.eu/documents/us/technical-papers/cpi-bus.pdf

9.6.2 Star topology

A star topology uses a passive RJ45 hub, such as the HUB-CPI, to connect multiple GRANITE Measurement Modules. An illustration of this is shown in .

> **NOTE:**
> Do not use a CPI terminator with this configuration.
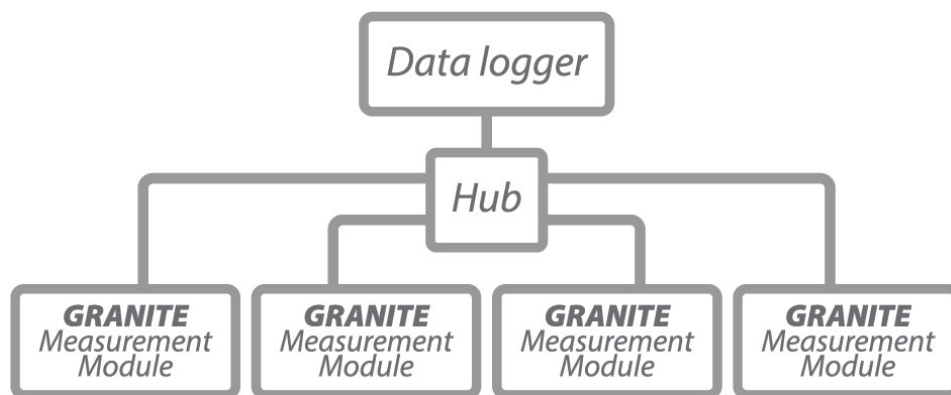
FIGURE 9-2. Multiple GRANITE Measurement Modules connected in a star topology

9.7 Power connection

Connect the power supply to the removable **Power** connector on the side of the VOLT 100 series. Power supplies providing voltages from 9.6 to 32 VDC may be used.

- While the input power requirements of Campbell Scientific instruments vary, there is one constant – they all run on 12 VDC. To keep things simple, we only discuss the use of 12 VDC power supplies in this manual.
- Do not connect energized wires to an instrument. All connections discussed assume de-energized wires. Switch off power supplies before making connections.
- Double check the polarity of connections before switching on power supplies.

> **NOTE:**
> When the supply voltage is below 14.5 VDC, the voltage on the **12V** and **SW12V** terminals track the power supply. Voltage on these terminals is regulated to 12.5 ± 0.5 VDC when the supply voltage is 14.5 to 32 VDC.

Open the power connector by inserting a screwdriver into the slots shown in FIGURE 9-3 (p. 28). When the screwdriver is pushed in far enough, the orange terminals will open and remain open until the screwdriver is removed. The power connector includes two positive (+VDC) terminals and two negative (–VDC) terminals to allow for daisy-chaining power supplies. Terminals of the same type open and close together. Insert the positive wire from the power supply into a +VDC terminal, and insert the negative wire into a –VDC terminal.

FIGURE 9-3. Opening the power connector terminals

9.7.1 Power-up sequence

Best practice is to start all instruments in a station simultaneously from a single power supply. If this is not possible, first turn on VOLT 100 seriess, then the data logger. This procedure will reduce the time required to synchronize the CPI bus.

See COMM status LED (p. 39) for more information.

9.8 Earth ground connection

Earth grounding provides protection from static discharge, transients, and power surges. A ground lug is provided on the VOLT 100 series for connection to earth ground, see Power and CPI ports view (left) and ground lug view (right) (p. 11). Minimum 14 AWG ground wire is recommended. The earth side of the connection should be to a grounding rod or other grounded device.

9.9 Mounting in an enclosure

Campbell Scientific data loggers and GRANITE Measurement Module brackets have mounting holes through which small screws are inserted into nylon anchors in an enclosure backplate.
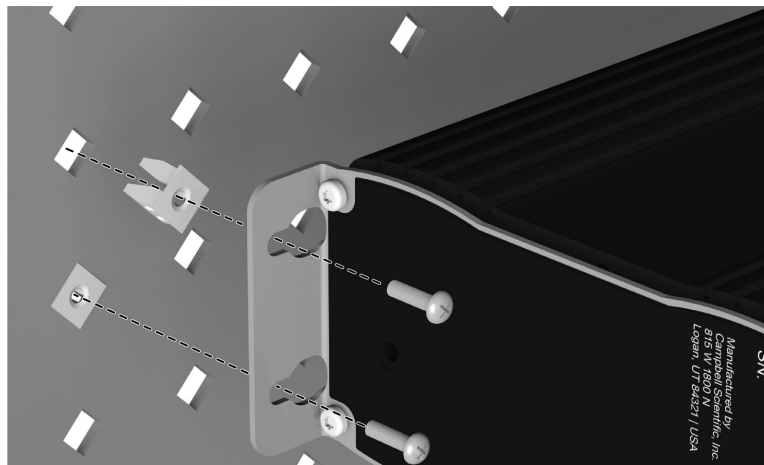
FIGURE 9-4. Enclosure backplate mounting

If mounting to a DIN rail, use the GRANITE-series DIN-Rail Kit as shown in the following images.
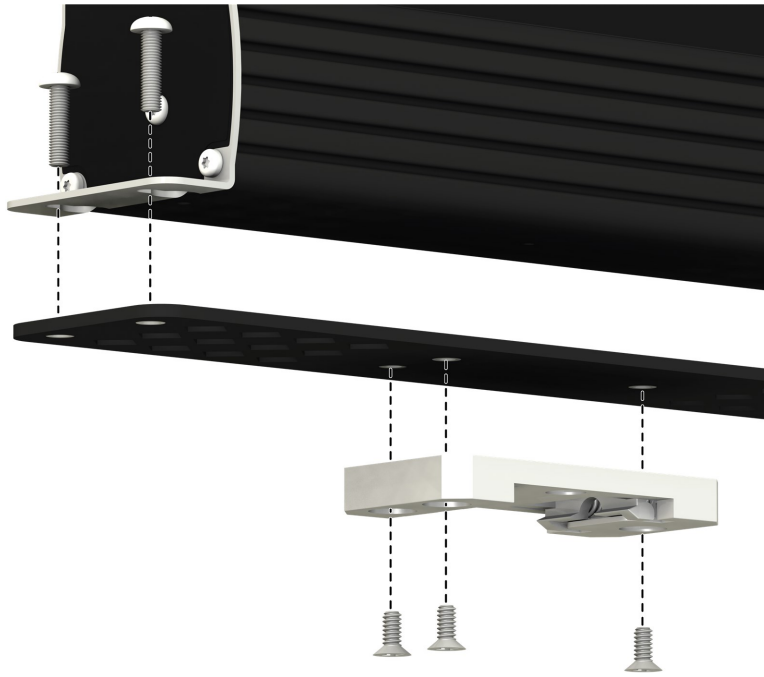
FIGURE 9-5. GRANITE DIN-Rail Mounting Kit

FIGURE 9-6. DIN rail mounting

10. Operation

The VOLT 100 series makes analogue measurements either under the direction of **SURVEYOR** or the data logger.

10.1 **SURVEYOR** control

SURVEYOR sets up the VOLT 100 series to start making measurements, display data, and store that data to a computer. For more information, see

10.2 Data logger control

Upon compiling the program, the data logger sends information to each VOLT 100 series about every relevant sequence, scan, and measurement. The data logger uses a data sync to initiate measurements on the VOLT 100 series. Because measurements can be made in multiple scans, slow sequences, sub-scans, and subroutines, the data logger firsts sends a message to the modules indicating which measurements are to be made upon the next data sync.

When the VOLT 100 series receives a sync signal, it begins making measurements. The measurement order on the VOLT 100 series follows the sequence of the instructions addressed to it within the current active scan of the data logger program. After the measurements are completed, it sends the data to the data logger for processing.

10.3 Measurements

Because the VOLT 100 series makes measurements similar to the GRANITE 6 series data logger, refer to the GRANITE 6 Measurement and Control System⬈ manual for in-depth measurement details. Information specific to the VOLT 100 series is provided in the subsequent sections.

10.3.1 First notch frequency

The first notch frequency (f_{N1}) determines the lowest frequency that will be eliminated, or notched out, by a sinc filter. This filter notches out frequencies at integer multiples of f_{N1} by averaging for a time equal to 1/f_{N1}. Thus, lower first notch frequencies result in longer measurement times. Any value between 2.5 Hz and 30 kHz can be entered, but the value will be rounded to the closest of 16 frequency options, with the midway point rounding up. The options for the first notch frequency are shown in Table 8-2 (p. 15).

Common options for filtering noise are:

- 30000 – Performs a 0.0333 millisecond integration (for fast measurements)
- 60 – Performs a 16.67 millisecond integration (filters 60 Hz noise)
- 50 – Performs a 20 millisecond integration (filters 50 Hz noise)

10.3.2 Panel temperature

Each terminal strip has a panel temperature thermistor (Measurement Specialties 10K3A1A) located just under its centre-point. The VOLT 108 includes two panel-temperature thermistors, and the VOLT 116 includes four. The thermistor has an interchangeability specification of 0.1 °C for temperatures between 0 and 70 °C. Below freezing and at higher temperatures, this specification is degraded. Combined with possible errors in the completion-resistor measurement and the Steinhart and Hart equation used to calculate the temperature from

resistance, the accuracy of panel temperature is estimated at ±0.1 °C over 0 to 40 °C, ±0.3 °C from –25 to 50 °C, and ±0.8 °C from –55 to 85 °C.

The panel temperature can be measured with the `CDM_PanelTemp()` instruction, where each thermistor is numbered as shown in the following figure. In thermocouple measurements, using the panel temperature for the thermocouple-wiring strip will result in more accurate measurements.
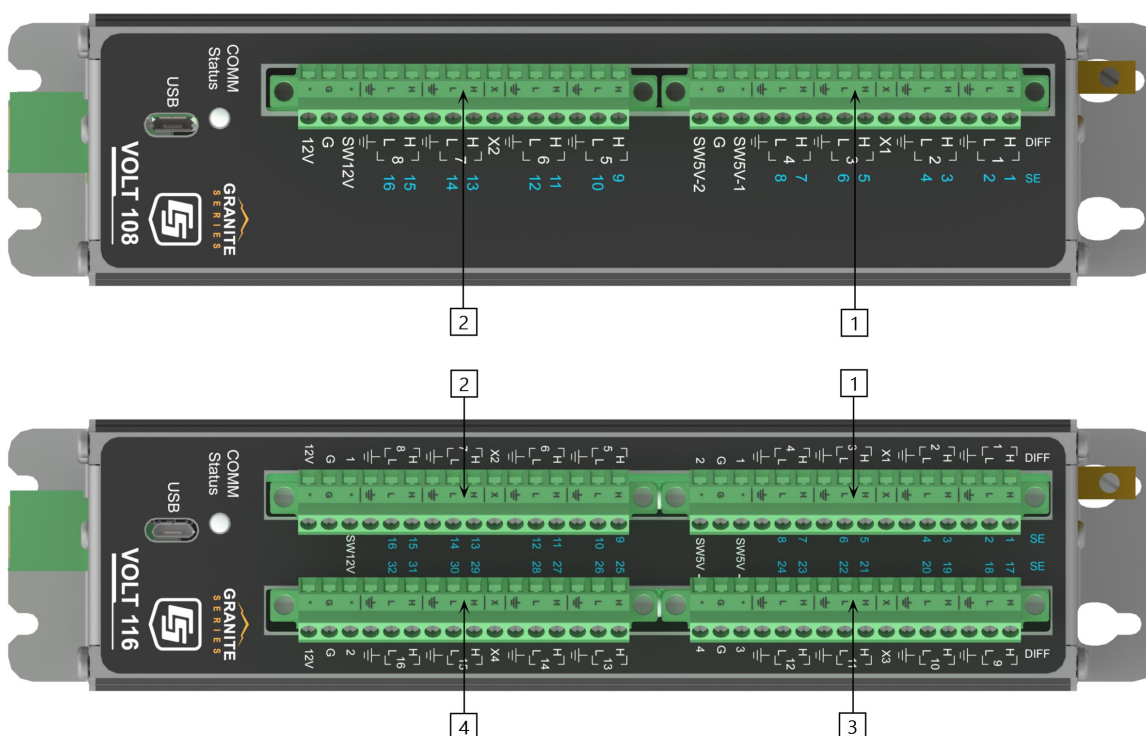
FIGURE 10-1. Wiring panel thermistor locations on VOLT 108 (top) and VOLT 116 (bottom)

10.4 Fast measurements

Use the following steps when designing fast-measurement networks:

1. Calculate the time the VOLT 100 series will take to make all of the measurements (See Measurement speed (p. 33)).

2. Calculate the CPI bit rate necessary to keep up with the sum of data generated by all devices (CPI network bit rate (p. 35)).

3. Determine if the physical layout of your network will allow for the calculated CPI bit rate (See Table 10-2 (p. 36)).

Use the CPI calculator at www.campbellsci.eu/downloads/cpi-calculator ⬈ to estimate the usage and capacity of a CPI network. Select a CDM-A108 for a VOLT 108 and a CDM-A116 when using a VOLT 116.

Also, see Calculating network restrictions (p. 50) for complete examples.

10.4.1 Measurement speed

Use the equations in Table 10-1 (p. 33) to ensure that the VOLT 100 series is able to make measurements at the speed required. Compare that speed with the scan rate options for the data logger to determine if the VOLT 100 series measurements can be done within the main scan or if they need to be performed in a sub-scan or burst. The Sample Rate refers to the rate at which the VOLT 100 series makes measurements when the **Reps** parameter is greater than 1.

These equations show that smaller notch frequencies increase measurement time. At the same time, larger notch frequencies result in lower measurement resolution. Consider this trade-off when designing your system.

Table 10-1: Multiplexed analogue voltage measurement speed[1,2,3]		
Without input or excitation reversal	Measurement time (µs)	$\mathbf{repetitions} \bullet \left(T_{settle} + \frac{10^6 \; \mu s/s}{f_{N1}} + 184 \; \mu s \right) + 31 \; \mu s$
	Sample rate (Hz)	$10^6 \bullet \; \left(T_{settle} + \frac{10^6 \; \mu s/s}{f_{N1}} + 184 \; \mu s \right)^{-1}$
With input or excitation reversal	Measurement time (µs)	$\mathbf{repetitions} \bullet \left[2 \bullet \left(T_{settle} + \frac{10^6 \; \mu s/s}{f_{N1}} + 180 \; \mu s \right) + 5 \; \mu s \right] + 31 \; \mu s$
	Sample rate (Hz)	$10^6 \bullet \; \left[2 \bullet \left(T_{settle} + \frac{10^6 \; \mu s/s}{f_{N1}} + 180 \; \mu s \right) + 5 \; \mu s \right]^{-1}$
With input and excitation reversal	Measurement time (µs)	$\mathbf{repetitions} \bullet \left[4 \bullet \left(T_{settle} + \frac{10^6 \; \mu s/s}{f_{N1}} + 180 \; \mu s \right) + 8 \; \mu s \right] + 31 \; \mu s$
	Sample Rate (Hz)	$10^6 \bullet \; \left[4 \bullet \left(T_{settle} + \frac{10^6 \; \mu s/s}{f_{N1}} + 180 \; \mu s \right) + 8 \; \mu s \right]^{-1}$
Burst measurement	Measurement Time (µs)	$\mathbf{repetitions} \bullet \frac{10^6 \; \mu s/s}{f_{N1}} + T_{settle} + 215 \; \mu s$
	Sample Rate (Hz)	f_{N1}

[1] If the instruction uses excitation, calculate the measurement time separately and add 46 µs for each excitation terminal used. Refer to Example 3 in Calculating network restrictions.

[2] Refers to multiplexing circuitry internal to the VOLT 100 series series.

[3] Default settling time, Tsettle, is 500 µs, minimum 100 µs.

> **NOTE:**
> The VOLT 100 series auto-calibrates to compensate for changes caused by changing temperature and aging. This calibration occurs during downtime for the measurement hardware. A time-consuming program may prevent background calibration if there is insufficient downtime.

10.4.1.1 Sub-scans

To measure at rates faster than the maximum scan rate of the data logger, the **SubScan()/NextSubScan** instruction pair is added within the data logger scan. Using this method, the measurement speed is dictated by the **SubInterval** and **Units** parameters.

The following program makes 20 **CDM_VoltSE()** measurements on **SE 1** at 200 Hz. Note that the notch frequency chosen must accommodate the SubScan rate. In this example, f_{N1} must be 500 or greater to allow for a single-ended measurement in a 5 ms SubScan. Refer to Table 8-2 (p. 15) for analogue voltage measurement speeds associated with f_{N1} options.

CRBasic Example 2: Measuring VoltSE() in a sub-scan

```
'Program Example: Measuring VoltSE() in a Sub-Scan
Public FastSE(20)
Dim i 'index counter

DataTable(FastSETable,True,-1)
  Sample (20,FastSE(),FP2)
EndTable

BeginProg
  Scan(1,sec,10,0)
    i=1 'initialize index counter
    SubScan(5,msec,20) 'repeat the 200 Hz measurement 20 times
      CDM_VoltSe(VOLT108,1,FastSE(i),1,mV5000,1,False,150,500,1,0)
      i = i + 1 'increment index counter after each measurement
    NextSubScan
    CallTable FastSETable
  NextScan
EndProg
```

10.4.1.2 Burst measurements

To measure at rates greater than the maximum sub-scan rate of the data logger, switch the measurement into burst mode by negating the measurement channel parameter. In burst mode, the measurement dwells on a single channel and measures it at rates up to 30 kHz, as

demonstrated in the following CRBasic example. Burst measurements do not allow offset measurement, input reversal, or excitation reversal.

The measurement rate is determined by the notch frequency (f_{N1}). With f_{N1} set to 15000, the measurement is made at 15 kHz. User-entered notch frequencies will be rounded to the nearest notch-frequency option (see Table 8-2 (p. 15) or the CRBasic Editor Help⬀ for a full list of frequency options). The destination parameter must be an array sized to the total number of measurements to be made. Refer to the CRBasic Help for more information. The following program makes 1,735 **CDM_VoltSE()** measurements on **SE 1** at a rate of 15 kHz.

CRBasic Example 3: Measuring VoltSE() in burst mode

```
Public BurstSE(1735)

DataTable(BurstSETable,True,-1)
  Sample (1735,BurstSE(),FP2)
EndTable

BeginProg
  Scan(1,sec,10,0)
    'Negate the measurement channel to make a burst measurement
    CDM_VoltSe(VOLT108,1,BurstSE(),1735,mV5000,-1,False,150,15000,1,0)
    CallTable BurstSETable
  NextScan
EndProg
```

10.4.2 CPI network bit rate

A CPI network is capable of operating at 1000, 500, 250, 125, or 50 kbps, depending on your network configuration (see Connecting multiple GRANITE Measurement Modules (p. 26)). This is the rate that data are transferred from the GRANITE Measurement Module to the data logger. When multiple GRANITE Measurement Modules are making measurements faster than 1 Hz, it is important to ensure that the CPI network bit rate is higher than the rate that data is generated by the GRANITE Measurement Modules within the network.

To calculate how many kilobits per second (kbps) will be generated, use the following **equation** for each GRANITE Measurement Module in your network:

Kilobits per second = (number of measurements) × (measurement frequency) × (0.064 kilobits per measurement)

The network topology and cable length affect the maximum allowable CPI network bit rate. Refer to Table 10-2 (p. 36) for the maximum cable length allowed for the topology and bit rate your network requires. The bit rate of the network defaults to 250 kbps and can be changed by using the **CPISpeed()** instruction in the data logger program.

Table 10-2: Network topology, bit rate, and cable length			
Bit Rate[1] (kbps)	Maximum total cable length (ft)		
	Daisy-chain topology		Star topology
	Full termination	Half termination	No termination
1000	50	1	not viable
500	200	200	100
250	500	400	400
125	1200	1000	1000
50	2800	2400	2400

[1] Default Bit Rate is 250 kbps. Change with `CPISpeed()` instruction.

10.5 Multiple devices

Multiple GRANITE Measurement Modules may be connected to a single data logger using a daisy-chain or star topology (see Connecting multiple GRANITE Measurement Modules (p. 26)). In both network configurations, as total cable length increases, the maximum possible bit rate decreases. Limitations on cable length and baud rate are examined in the document Designing Physical Network Layouts for the CPI Bus ⬈.

When including two or more VOLT 100 series devices in the program, the processing mode of the data logger affects the measurement timing of each VOLT 100 series. In sequential mode, the VOLT 100 series devices make measurements one after the other, following the order of their instructions within the program. Conversely, in pipeline mode, the devices start their measurements simultaneously. Pipeline mode is recommended.

> **NOTE:**
> In either mode, measurements that require excitation MUST be made on the same VOLT 100 series that provides the excitation voltage or current.

10.6 Switched voltage output

An **SW5V** terminal is normally used to operate an external relay-driver circuit because the port itself has limited drive capacity. Drive capacity is determined by the 5 VDC supply, a Schottky diode, and a 30 Ω output resistance. It is expressed as:

$V_0 = 5\ V - 0.3\ V - (30\ \Omega) \times I_0$

Where V_0 is the drive limit, and I_0 is the current required by the external device. shows the relationship between supply voltage and current load.

The **SW12V** terminals are used to power devices such as sensors that require 12 VDC during measurement. Current sourcing must be limited to 200 mA or less on each channel. When the supply voltage is below 14.5 VDC, the voltage on the **SW12V** terminals track the power supply. Voltage on these terminals is regulated to 12.5 ± 0.5 VDC when the supply voltage is 14.5 to 32 VDC.

11. Maintenance and calibration

- Protect the VOLT 100 series from humidity and moisture.
- Send to Campbell Scientific for factory calibration every three years.

If sending the VOLT 100 series to Campbell Scientific for calibration or repair, consult first with a Campbell Scientific representative. If the VOLT 100 series is malfunctioning, be prepared to perform some troubleshooting procedures with Campbell Scientific. Many problems can be resolved with a conversation. If calibration or repair is needed, the procedure shown in Assistance should be followed when sending the product.

12. Troubleshooting

1. Check the voltage of the power source at the **Power** connector. It should be between 9.6 and 32 VDC.

2. Check wires and cables for the following:

    - Loose connection points

    - Faulty connectors

    - Cut wires

    - Damaged insulation, which allows water to migrate into the cable. Water, whether or not it comes in contact with wire, can cause system failure. Water may increase the dielectric constant of the cable sufficiently to impede sensor signals, or it may migrate into the sensor, which will damage sensor electronics.

3. Check the CRBasic program. Create a simplified version of the program, or break it up into multiple smaller units to test individually. For example, if a sensor signal-to-data conversion is faulty, create a program that only measures that sensor and stores the data, absent from all other inputs and data. Write these mini-programs before going to the field, if possible.

4. Verify that each VOLT 100 series in the network has a unique CPI address.

5. Check the data logger and VOLT 100 series operating system and update them as needed.

6. Check that the scan rate is long enough for the measurement time. (See Measurement speed (p. 33).) The data logger compiler often catches scan rates that are too fast.

7. Ensure that the CPI network bit rate is fast enough for the data generated and that it can accommodate the cable lengths in use. (See CPI network bit rate (p. 35).)

12.1 CPIStatus table

Information in the **CPIStatus** table, located in the data logger, helps in troubleshooting. The **ModuleInfo()** array shows the following information:

CDM Type, Serial Number, Device Name, CPI Address, Activity

The last entry in the **ModuleInfo()** index shows the activity of the module. Possible entries and their meanings are shown in the following table.

Table 12-1: CPIStatus activity	
Response	**Meaning**
Active	The module is connected to the CPI bus and is making measurements according to the data logger program.
Offline	The module was present after startup but is no longer responding.
Unused	The module is or was connected and powered but is not included in the data logger program.
Wait Config	The module has not yet responded to a data logger's attempts to configure it.
Config Fail	The module could not be configured. A configuration error message is appended to this response.

12.2 COMM status LED

The COMM status LED indicates the current operation of the VOLT 100 series, as shown in the following table..

Table 12-2: COMM Status LED Activity		
Green	Flashing	Module has been configured by data logger and is receiving sync signals
Orange	Flashing	Device has not been configured by data logger
Red	Single-Flash	Device has been configured but is not receiving sync signals
	Double-Flash	Device has encountered a scan timeout
	Solid	Error

12.3 CPI port LEDs

Green and Orange LEDs on the CPI bus indicate the current operation of the CPI bus as shown in the following table.

Table 12-3: CPI port LED activity		
Green	Flashing	Frame sync
Orange	Flash	CPI activity
	Solid	CPI bus fault

12.4 Replacing a GRANITE Measurement Module

An existing VOLT 100 series or CDM-A100 series can be replaced with a new module using the same CPI address without requiring a change to the program.

Appendix A. Importing *Short Cut* code into *CRBasic Editor*

Short Cut creates a .DEF file that contains wiring information and a program file that can be imported into the *CRBasic Editor*. By default, these files reside in the C:\campbellsci\SCWin folder.

Import *Short Cut* program file and wiring information into *CRBasic Editor*:

1. Create the *Short Cut* program. After saving the *Short Cut* program, click the **Advanced** tab then the **CRBasic Editor** button. A program file with a generic name will open in CRBasic. Provide a meaningful name and save the CRBasic program. This program can now be edited for additional refinement.

   > **NOTE:**
   > Once the file is edited with *CRBasic Editor*, *Short Cut* can no longer be used to edit the program it created.

2. To add the *Short Cut* wiring information into the new CRBasic program, open the .DEF file located in the C:\campbellsci\SCWin folder, and copy the wiring information, which is at the beginning of the .DEF file.

3. Go into the CRBasic program and paste the wiring information into it.

4. In the CRBasic program, highlight the wiring information, right-click, and select **Comment Block**. This adds an apostrophe (') to the beginning of each of the highlighted lines, which instructs the data logger compiler to ignore those lines when compiling. The **Comment Block** feature is demonstrated at about 5:10 in the CRBasic | Features video ▶.

Appendix B. Analogue voltage measurement range and resolution

Table B-1: Analogue voltage measurement range and resolution					
fN1[1] (Hz)	Range[2] (mV)	Typical effective resolution[3]			
		Differential measurements with input reversal		Single-ended measurements or differential measurements without input reversal	
		RMS (µV)	bits	RMS (µV)	bits
30000	±5000	10.350	20.0	14.756	19.5
	±1000	2.239	19.9	3.148	19.4
	±200	0.799	19.0	1.121	18.5
15000	±5000	9.012	20.2	12.819	19.7
	±1000	1.948	20.1	2.809	19.5
	±200	0.700	19.2	1.030	18.7
7500	±5000	7.158	20.5	10.050	20.0
	±1000	1.544	20.4	2.266	19.8
	±200	0.553	19.5	0.817	19.0
3750	±5000	5.410	20.9	7.851	20.4
	±1000	1.166	20.8	1.689	20.3
	±200	0.410	20.0	0.627	19.4

Table B-1: Analogue voltage measurement range and resolution					
		Typical effective resolution[3]			
fN1[1] (Hz)	Range[2] (mV)	Differential measurements with input reversal		Single-ended measurements or differential measurements without input reversal	
		RMS (µV)	bits	RMS (µV)	bits
2000	±5000	4.047	21.3	5.806	20.8
	±1000	0.894	21.2	1.290	20.7
	±200	0.310	20.4	0.459	19.8
1000	±5000	2.838	21.9	4.359	21.2
	±1000	0.613	21.7	0.931	21.1
	±200	0.220	20.9	0.343	20.2
500	±5000	2.035	22.3	2.999	21.8
	±1000	0.445	22.2	0.659	21.6
	±200	0.157	21.4	0.248	20.7
100	±5000	0.950	23.4	1.388	22.9
	±1000	0.205	23.3	0.323	22.6
	±200	0.071	22.5	0.131	21.6
60	±5000	0.769	23.7	1.140	23.2
	±1000	0.162	23.6	0.261	23.0
	±200	0.056	22.9	0.113	21.8
50	±5000	0.732	23.8	1.112	23.2
	±1000	0.161	23.7	0.254	23.0
	±200	0.053	22.9	0.111	21.9
30	±5000	0.612	24.1	0.901	23.5
	±1000	0.131	24.0	0.217	23.2
	±200	0.042	23.3	0.099	22.0

| fN1[1] (Hz) | Range[2] (mV) | Typical effective resolution[3] | | | |
| | | Differential measurements with input reversal | | Single-ended measurements or differential measurements without input reversal | |
		RMS (µV)	bits	RMS (µV)	bits
25	±5000	0.580	24.1	0.858	23.6
	±1000	0.123	24.0	0.204	23.3
	±200	0.038	23.4	0.095	22.1
15	±5000	0.502	24.4	0.734	23.8
	±1000	0.107	24.2	0.177	23.5
	±200	0.031	23.7	0.088	22.2
10	±5000	0.499	24.4	0.683	23.9
	±1000	0.108	24.2	0.161	23.7
	±200	0.029	23.8	0.082	22.3
5	±5000	0.472	24.4	0.617	24.1
	±1000	0.102	24.3	0.151	23.7
	±200	0.024	24.1	0.082	22.3
2.5	±5000	0.447	24.5	0.564	24.2
	±1000	0.095	24.4	0.144	23.8
	±200	0.020	24.3	0.077	22.4

Table B-1: Analogue voltage measurement range and resolution

[1] First notch frequency

[2] Range overhead of ≈6% on all ranges guarantees that full-scale values will not cause overrange.

[3] Effective resolution (ER) in bits is computed from ratio of full-scale range to RMS noise.

Appendix C. Example programs

These programs were written for a GRANITE 6 data logger, except where noted. With slight modifications, they can be used with other Campbell Scientific data loggers.

> **NOTE:**
> For the GRANITE 10 and GRANITE 9 data loggers, the `CPIBusAddress` parameter must include the CPI bus when using bus B. Bus A is the default. For example, `CPI_BusB + 2` specifies CPI bus B and CPI address 2.

C.1 Configuring GRANITE Measurement Module with `CPIAddModule()`

The following program sets CPI addresses and device names on VOLT 108s with serial numbers 1234, 1235, and 1236 and makes a single-ended measurement on each module SE 1 channel.

CRBasic Example 4: Using CPIAddModule()

```
'GRANITE 6 Datalogger
'This program sets CPI addresses and device names on VOLT108s.
'It makes a single-ended measurement on each unit's SE 1 channel.
'Declare Variables and Units
Public SEVolt1
Public SEVolt2
Public SEVolt3
'Main Program
BeginProg
  'Set CPI Addresses
  CPIAddModule (VOLT108,1234,"A", 4)
  CPIAddModule (VOLT108,1235,"12345", 5)
  CPIAddModule (VOLT108,1236,"VOLT108 in Pump House", 6)
  'Main Scan
  Scan(5,Sec,3,0)
    'Single-ended voltage measurements on VOLT108s w/ CPI addresses 4, 5 and 6
    CDM_VoltSe(VOLT108,4,SEVolt1,1,mV5000,1,True,500,60,1,0)
    CDM_VoltSe(VOLT108,5,SEVolt2,1,mV5000,1,True,500,60,1,0)
    CDM_VoltSe(VOLT108,6,SEVolt3,1,mV5000,1,True,500,60,1,0)
  NextScan
EndProg
```

C.2 Measuring TEMP 120 and VOLT 108 at different speeds

The following program measures a full-bridge sensor on a VOLT 108 at 100 Hz in the main sequence, and 20 type-T thermocouples on a TEMP 120 module in a 5-second slow sequence.

CRBasic Example 5: Measuring TEMP 120 and VOLT 108

```
'GRANITE 6 Datalogger
'This program uses a VOLT 108 module to measure a full-bridge sensor
'at 100 Hz in the main sequence, and a TEMP 120 module to measure 20
'type-T thermocouples in a 5-second slow sequence.
'Declare Variables and Units
Public strain_raw : Units strain_raw = mVpV
Public TC(20)      : Units TC         = DegC
'Define Data Tables
DataTable(OneSec, TRUE, -1)
  DataInterval(0, 1, SEC, 10)
  Maximum(1, strain_raw, FP2, FALSE, TRUE)
EndTable
DataTable(Hourly, TRUE, -1)
  DataInterval(0, 60, MIN, 10)
  Average(20, TC(), FP2, FALSE)
EndTable
'Main Program
BeginProg
  'MainSequence
  Scan(10, MSEC, 20, 0)
    'Measure full-bridge sensor on VOLT 108 at CPI address 1
    CDM_BrFull(VOLT108, 1, strain_raw, 1, mV200, 1, X1, 1, 5000, _
    TRUE, TRUE, 1000, 1000, 1.0, 0.0)
    'Call 1-second data table to process and store data
    CallTable(OneSec)
  NextScan
  EndSequence
  SlowSequence
  Scan(5, SEC, 1, 0)
    'Measure 20 Type-T thermocouples on TEMP 120 with CPI address 2
    CDM_TCComp(TEMP120, 2, TC(), 20, 1, TYPET, 1, 0)
    'Call hourly data table to process and store data
    CallTable(Hourly)
  NextScan
  EndSequence
EndProg
```

C.3 Synchronized TEMP 120 and VOLT 108 measurements

The following program measures a full-bridge sensor on a VOLT 108 at 100 Hz, and 20 type-T thermocouples on a TEMP 120 module at 1 Hz. The measurements are synchronized by putting the faster measurements in a SubScan.

CRBasic Example 6: Synchronized TEMP 120 and VOLT 108 measurements

```
'GRANITE 6 Datalogger
'This program uses a TEMP 120 module to measure 20 type-T thermocouples at
'1 Hz and a VOLT 108 module to measure a full-bridge sensor at 100 Hz. A
'SubScan instruction is used to synchronize the full-bridge
'measurements with the thermocouple measurements.
'Declare Variables and Units
Public TC(20)      : Units TC        = DegC
Public strain_raw : Units strain_raw = mVpV
'Define Data Tables
DataTable(OneSec, TRUE, -1)
  DataInterval(0, 1, SEC, 10)
  Average(20, TC(), FP2, FALSE)
  Maximum(1, strain_raw, FP2, FALSE, TRUE)
EndTable
'Main Program
BeginProg
  Scan(1, SEC, 3, 0)
    'Measure 20 Type-T thermocouples on TEMP 120 with CPI address 1
    CDM_TCComp(TEMP120, 1, TC(), 20, 1, TYPET, 1, 0)
    SubScan(10, MSEC, 100)
      'Measure full-bridge sensor on VOLT 108 with CPI address 2
      CDM_BrFull(VOLT108, 2, strain_raw, 1, mV200, 1, X1, 1, _
      5000, TRUE, TRUE, 1000, 1000, 1.0, 0.0)
    NextSubScan
    'Call data table to process and store data
    CallTable(OneSec)
  NextScan
EndProg
```

C.4 Controlling an AM16/32B multiplexer

The following program makes 32 differential measurements through an AM16/32B multiplexer controlled by a VOLT 108 connected to a CR6 data logger. Programming and wiring for the GRANITE-series data loggers will be similar.

The CPI port on VOLT 100 series connects directly to the CPI port on the CR6. An SC-CPI device is required to connect to CR3000, CR1000X, and CR800-series data loggers. Connect the SC-CPI module to these dataloggers by wiring its 12V, G, C1, C2, and C3 terminals to the corresponding 12V, G, C1, C2, and C3 terminals of the data logger. Connect a CPI port on the VOLT 100 series to the CPI port on the SC-CPI.

Table C-1: Wiring for example B-3			
CR6	AM16/32B (2x32 mode)	VOLT 108	Sensor
	12V	12V	
	G	G	
	RES	SW5-2	
	CLK	SW5-1	
	COM ODD H	1H	
	COM ODD L	1L	
	COM (⏚)	⏚	Ground
	High channels 1H-24H		Signal high
	Low channels 1L – 24L		Signal low
CPI		CPI	

CRBasic Example 7: Controlling an AM16/32B multiplexer

```
'CR6 Datalogger
'This program sets CPI Address and Device Name on VOLT108 with serial number
'1234, and measures 32 differential voltages through an AM16/32B multiplexer
'controlled by a VOLT108
'**Set AM16/32B to 2x32 mode**
'Declare Variables
Dim LCount
Public MilliVolts(32)
DataTable(TenMin,True,-1)
  DataInterval(0,10,Min,10)
  Average(32,MilliVolts(),FP2,False)
EndTable
'Main Program
BeginProg
  'Set CPI Address to 1
  CPIAddModule (VOLT108,1234,"A",1)
  'Main Scan
  Scan(1,Min,3,0)
    'Turn AM16/32B Multiplexer on, and advance to first channel
    CDM_MuxSelect(VOLT108,1,1,2,20,1,1)
    LCount=0 'reset loop counter
    SubScan(0,uSec,32)
      LCount+=1 'increment loop counter
      'Differential measurement on the AM16/32B Multiplexer
      CDM_VoltDiff(VOLT108,1,MilliVolts(LCount),1,mV5000,1,True,5000,60,1.0,0)
      'Switch to next AM16/32B Multiplexer channel
      CDM_PulsePort(VOLT108,1,1,20000)
    NextSubScan
    'Turn AM16/32B Multiplexer Off
    CDM_SW5(VOLT108,1,2,0,0)
    Delay(0,150,mSec)
    'Call Data Tables and Store Data
    CallTable TenMin
  NextScan
EndProg
```

Appendix D. Calculating network restrictions

This section shows some common questions asked while designing networks with VOLT 100 series and how to calculate their answers. For all examples, the VOLT 108 or VOLT 116 is connected to a GRANITE 6 data logger.

D.1 Example 1

a. **How fast can a VOLT 116 make 32 single-ended measurements?**

The equation to calculate the time to make 32 single-ended measurements (which are measurements without input or excitation reversal) is copied from Table 10-1 (p. 33):

$$\textbf{Measurement Time} = \textbf{repetitions} \; \bullet \; \left(\textbf{T}_{\textbf{settle}} + \frac{10^6 \; \mu s/s}{f_{N1}} + 184 \; \mu s \right) + 31 \; \mu s$$

To make the fastest measurements possible, set f_{N1} to its maximum (30000 Hz) and T_{settle} to its minimum (100 µs). With these inputs and 32 repetitions, the fastest measurement time is calculated as **10186 µs**.

$$\textbf{Measurement Time} = 32 \; \bullet \; \left(100 \; \mu s + \frac{10^6 \; \mu s/s}{30000 \; Hz} + 184 \; \mu s \right) + 31 \; \mu s$$

$$= 10186 \; \mu s$$

The GRANITE 6 has a scan rate resolution of 1 ms, so the fastest scan rate possible in this example is 11 ms.

b. **Choosing a more practical scan rate of 20 ms, what is the longest cable that could be used between the VOLT 116 and the GRANITE 6 to make these 32 measurements?**

A scan rate of 20 ms (0.02 s) equals a measurement frequency of 50 Hz (1 ÷ 0.02 s). Using the equation found in CPI network bit rate (p. 35), the kilobits of data generated each second is

Kilobits per second = (number of measurements) × (measurement frequency) × (0.064 kilobits per measurement)

= (32 measurements) × (50 Hz) × (0.064 kilobits per measurement)
= 102.4 kbps

In this case, the `CPISpeed()` instruction could be used to change the bit rate from the 250 kbps default to 125 kbps, allowing a longer cable. Then, referring to the table: Network topology, bit rate, and cable length (p. 36), the longest cable length possible is **1200 ft** with the use of a termination plug, or **1000 ft** without.

c. What should the scan **BufferOption** be set to for this example?

The general rule is that the number of scan buffers should be enough to hold 2 seconds' worth of data. With a scan rate of 20 ms, the **BufferOption** should be 2 s ÷ 0.02 s = 100. The **CRBasic Scan()** instruction would be written this way:

```
Scan (20,msec,100,0)
```

d. If there were four other VOLT 116s on the network with this same configuration, what restraints would there be on the system?

Because the system can run in pipeline mode, each VOLT 116 can start its measurements at the same time, not requiring any change in the scan rate. The data generated (102.4 kbps) would be multiplied by a total of five VOLT 116s, giving 512 kbps total. In order to keep up with this data output, the CPI speed would need to be increased to **1000 kbps**. This reduces the total allowable cable length to **50 ft** with the use of a termination plug, or **1 ft** without (see Network topology, bit rate, and cable length (p. 36)).

D.2 Example 2

a. How many differential measurements can a VOLT 116 or VOLT A108 make at 5 ms (200Hz) if input reversal is used?

This example uses the measurement time equation for measurements with input reversal from Table 10-1 (p. 33):

$$\mathbf{Measurement\ Time} = \text{repetitions} \bullet \left[2 \bullet \left(\mathrm{T_{settle}} + \frac{10^6 \ \mu s/s}{f_{N1}} + 180 \ \mu s \right) + 5 \ \mu s \right] + 31 \ \mu s$$

The equation shows that making multiple measurements by using the **Repetitions** parameter within a measurement instruction is more efficient than using multiple measurement instructions. Solving the previous equation for repetitions gives the following:

$$\text{repetitions} = \frac{\text{measurement time} - 31 \ \mu s}{2 \left(\mathrm{T_{settle}} + \frac{10^6 \ \mu s/s}{f_{N1}} + 180 \ \mu s \right) + 5 \ \mu s}$$

With f_{N1} = 30000 Hz, $\mathrm{T_{settle}}$ = 100 µs, and measurement time = 5 ms (5000 µs), repetitions is calculated to be 7.866, so **7 repetitions**, or measurements, are possible at that scan rate.

$$\text{repetitions} = \frac{5000\ \mu\text{s} - 31\ \mu\text{s}}{2\left(100\ \mu\text{s} + \frac{10^6\ \mu\text{s/s}}{30000\ \text{Hz}} + 180\ \mu\text{s}\right) + 5\ \mu\text{s}} = 7.866$$

b. **At that measurement rate, what is the best attainable resolution for the measurements?**

Resolution increases as the f_{N1} decreases, but measurement time increases. Solving the equation for f_{N1} gives the following:

$$f_{N1} = \left(\frac{\frac{\text{measurement time} - 31\ \mu\text{s}}{\text{repetitions}} - 5\ \mu\text{s}}{2} - T_{\text{settle}} - 180\ \mu\text{s}\right)^{-1} \bullet 10^6\ \mu\text{s/s}$$

With a measurement time of 5 ms (5000 μs), settling time of 100 μs, and 7 repetitions, f_{N1} must be greater than 13807 Hz.

$$f_{N1} = \left(\frac{\frac{5000\ \mu\text{s} - 31\ \mu\text{s}}{7} - 5\ \mu\text{s}}{2} - 100\ \mu\text{s} - 180\ \mu\text{s}\right)^{-1} \bullet 10^6\ \mu\text{s/s} = 13807\ \text{Hz}$$

Thus, to improve measurement resolution, f_{N1} should be set to 15000. According to Analogue voltage measurement range and resolution (p. 42), this would improve the resolution to **9.012 μVRMS** for the largest voltage range, ±5000 mV.

D.3 Example 3

How fast can a VOLT 116 measure ten 3 kΩ full-bridge sensors using the default settling time (500 μs) and both excitation and input reversal, and achieve a resolution of less than 1 μV$_{RMS}$? For easier wiring, limit the sensors excited per excitation terminal to four.

The full-bridge measurement, `BrFull()`, makes a differential measurement. It is given that the measurement will use input reversal, so the resolution is given in the third column of Analogue voltage measurement range and resolution (p. 42). To achieve a resolution of less than 1 μV$_{RMS}$ within the ±5000 mV range, f_{N1} must be 100 Hz or better.

The measurement time is figured separately for each excitation channel used, where the repetitions are the number of sensors excited on that channel. In this setup, three excitation terminals are used, **X1 – X3**. The measurement times are given by the following equations:

$$\text{X1 measurement time} = \text{repetitions on X1} \bullet \left[4 \bullet \left(T_{\text{settle}} + \frac{10^6\ \mu\text{s/s}}{f_{N1}} + 180\ \mu\text{s}\right) + 8\ \mu\text{s}\right] + 46\ \mu\text{s} + 31\ \mu\text{s}$$

$$\text{X2 measurement time} = \text{repetitions on X2} \bullet \left[4 \bullet \left(T_{\text{settle}} + \frac{10^6\ \mu\text{s/s}}{f_{N1}} + 180\ \mu\text{s}\right) + 8\ \mu\text{s}\right] + 46\ \mu\text{s} + 31\ \mu\text{s}$$

$$\text{X3 measurement time} = \text{repetitions on X3} \bullet \left[4 \bullet \left(T_{\text{settle}} + \frac{10^6\ \mu\text{s/s}}{f_{N1}} + 180\ \mu\text{s}\right) + 8\ \mu\text{s}\right] + 46\ \mu\text{s} + 31\ \mu\text{s}$$

Because there are 10 measurements total, repetitions on **X1** will be 4, repetitions on **X2** will be 4, and repetitions on **X3** will be 2. Using the default settling time (500 µs) and the first notch frequency figured earlier (100 Hz), the sum of the above equations gives a total measurement time of **427511 µs** (427.511 ms). Therefore, a practical scan rate for this setup would be 500 ms.

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